2010

A Quantitative Analysis of the Urban Morphology of Southwestern Ontario Census Metropolitan Areas

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A Quantitative Analysis of the Urban Morphology of Southwestern Ontario Census Metropolitan Areas

(The morphology of SWOntario CMAs)

(Thesis format: Monograph)

by

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Graduate program in Geography

Submitted in partial fulfillment
of the requirements for the degree of
Master of Arts

School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

THE UNIVERSITY OF WESTERN ONTARIO

School of Graduate and Postdoctoral Studies

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entitled:

A Quantitative Analysis of the Urban Morphology of Southwestern Ontario Census Metropolitan Areas

is accepted in partial fulfillment of the

requirements for the degree of

Master of Arts

Date____________________ ____________________

Chair of the Thesis Examination Board

ABSTRACT

Patterns of urban development in North America have changed drastically over time: from dense urban cores to sprawling subdivisions. This study investigates changes in residential forms of Southwestern Ontario cities by characterizing numerous individual features which make up the built environment, and then evaluating spatial patterns and statistical relationships. Using high-quality data regarding the social and physical elements of Ontario cities within a geographic information system (GIS), this research provides improved methods to quantitatively characterize urban development forms at the micro level. Results show that the majority of morphological variables have systematic spatial patterns and are highly correlated. Most variables tend to either increase or decrease from the city centre outward, or have their extreme values in the oldest residential neighbourhoods. Results show that social and historical variables of a neighbourhood are highly correlated with morphology. This research has implications for planners, land developers, and other agents of urban change.

Keywords: urban form, urban morphology, GIS

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr Jason Gilliland, who supported and assisted with the formulization of the thesis topic, and assisted in the completion of this thesis. Thank you very much for allowing me to explore different avenues of research, and for taking the time to guide me though the early drafts of this thesis.

A special thanks to fellow graduate students Mat Novak, Martin Healy, Don Lafreniere, and Richard Sadler for assisting in thesis conceptualization as well as providing assistance in GIS. A specific thanks to Martin Healy, who painstakingly derived new and innovative ways to measure the large sets of data this thesis utilized.

Thank you to Dr. Godwin Arku for taking time out of your busy schedule to assist me in research, and allowing me to TA for your classes. A further thanks to Dr. Dianna Mok for her wisdom and guidance though my university experience.

I would like to send acknowledgement to the Department of Geography and the University of Western Ontario for the opportunity to complete my graduate work in a remarkable department. I also owe gratitude to the *Social Science and Humanities Research Council* for their financial contributions towards the completion of this research.

Thank you to my fiancée Nicole for her encouragement and motivation to continue with my studies. A special thank you to my friends for their ongoing encouragement and support. Finally, I would like to thank my parents and brother for their support throughout my post secondary career.

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CHAPTER 1
INTRODUCTION

Urban morphology, or the study of urban form, has recently received growing attention from geographers, planners, historians, and architects. When one thinks of a city, one is often thinking about an element of urban morphology: an iconic building, a public square, a transportation network, a monument, or a shopping centre. These individual features are a small portion of the total urban morphology of a city, which includes city blocks, lots, streets, and land use. This study quantifies levels of such variables, and attempts to statistically calculate the degree to which variables are correlated to each other, and to historical and economic variables.

1.1 Urban Morphology

Urban morphology can be described as the study of the physical form of cities created by human activity (Stanilov, 2003). Moudon (1997, P#3) simply describes urban morphology as "the study of the city as human habitat". Urban morphologists analyze the city's evolution from its formative years to its subsequent transformations, identifying its various components. Buildings, gardens, streets, blocks, lots, parks, and monuments are among the main elements of morphological analysis.

When discussing the history of urban morphology within the discipline of geography, two individuals must be acknowledged. The 'founding father' of geographical morphology is considered to be M. R. G. Conzen, a German geographer whose best known work is an inductive and empirical quantitative study on urban morphology of Alnwick (1960). The second major contributor, J. W. R. Whitehand, pushed the boundaries of urban morphology into urban economics, researching the relationships between the city, its habitats, and the dynamics of the building industry. These two individuals started a movement of study towards morphological research, one that would allow for further discourse in morphological analysis.

Today, with this increased discourse, it is accepted that morphological analysis is based on three principles (Moudon, 1997). The first principle is that urban form is defined by three fundamental physical elements: buildings and their related open spaces, lots, and streets. Secondly, urban form can be understood at different levels of resolution. Commonly, four are recognized: building/lot, street/block, city, and region. Thirdly,. Thus, form, resolution, and time constitute the three fundamental components of morphological research and analysis.

1.1.1 Increasing Need for Study

In North America over the past 100 years, human activity has created new morphologies of city designs and forms (Whitehand, 1992; Filion & Hammond, 2003). The most notable of these activities is urbanization, with the percentage of Canadians residing in urban areas shifting from 37 in 1900 to over 85 in 2005. (Statistics Canada, 2009). The combination of increasing population and decreasing household size significantly accelerated demand for new housing units. This shift has. Suburban development (also referred to as suburban sprawl) has raised public concern about the depletion of natural resources and the capacity of the planet to sustain such rates of growth. Natural features are removed to make way for development - wooded areas are cleared, streams are converted or channelized, wetlands are filled or fenced, and topography is levelled. It is projected that between the years 2000 and 2030, urban areas will cover an additional 100 million hectares of previously undeveloped land (Song & Knapp, 2007), with more than half of this growth taking place on arable land.

The physical forms and designs of urban development in North America underwent significant changes during the 20th Century (Southworth and Owens, 1993; Cervero and Gorham, 1995). Traditional urbanism in North America was built prior to the widespread use of automobiles; hence its characteristics reflect a greater reliance on pedestrian travel and public transit (Kunstler, 1996; Newman, 1996). These neighbourhoods utilize gridiron street patterns and were relatively compact. Eventually, they supported extensive streetcar networks, even in smaller cities, and often contained an element of mixed-use (Southworth and Owens, 1993; Christoforidis, 1994). Increased use of automobiles in the mid twentieth century created the sprawl or conventional suburban development pattern (Newman, 1996). Conventional suburban development is characterized by lower residential densities, wider streets, curvilinear street patterns, large lots and setbacks, and large, homogeneous areas of single family homes (Christoforidis, 1994; Newman, 1996; Johannsen, 2000). In response to these criticisms of the conventional suburban development pattern, the third form, new urbanism, emerged in the late 1980's mimicking traditional urbanism by reverting to gridiron street patterns, higher densities, mixed land uses, smaller building lots and setbacks, and an emphasis on alternative transportation modes (e.g. walking and public transit) (Duany, and Plater-Zyberk, 1992; Calthorpe, 1993; Christoforidis, 1994).

Analysis based on measures such as lots, buildings, and streets can reveal past trends in urban development, and contribute to predictions and planning for future development. Empirical measures of urban form can also effectively capture "on the ground" development effects of planning policies, such as industrial parks, new urbanism design, or transit-oriented development.

Geographic information systems (GIS), is a system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data. GIS have enabled and encouraged a renewal of interest in morphological analysis of development patterns, particularly by planners. For example, Galster *et al.* (2001) developed a complex and multi-faceted index to characterize sprawl in eight dimensions, while Ewing *et al.* (2003b) employed twenty-two variables combined into four sprawl factors using principal component analysis. More discussion on studies using GIS to measure performance indicators can be found in the literature review and methods sections.

A multitude of studies have been done on the form, evolution, and impacts of lots and buildings; however, streets (or the movement network) are often neglected (Carr, 2001; Filion & Hammond, 2003; Makse, Havlin & Stanley 1995). With new suburban developments highly characterized by their drastically different street and movement networks, it can be argued that studying the movement network is paramount in the continuing analysis of residential morphology.

1.1.1.1 Movement Networks

Movement networks are the primary ingredient of urban existence, compromising all roads, sidewalks, and paths in a city. Movement networks encompass all human movement through the city – from a super highway to interior halls. They provide the structure on which to weave the complex interactions of the architectural framework with human organization (Marshall, 2004). The unique character of streets, derived from "the urban process", creates social, political, technical, and artistic forces that generate a city's form (Jacobs, 1995).

Early neighbourhoods were comprised of a gridiron movement network, indicative of high connectivity and accessibility (Gallion, 1980). The mid nineteenth century period brought about streets that were curvilinear, and designed primarily for the automobile (Jiang, 2009). Typical suburban neighbourhoods of today feature poorly connected street networks and low accessibility (Stanilov, 2003). These poorly connected networks in turn influence peoples' travel choices and behaviour. Most recently, there has been a movement to build new suburban developments in high density, compact forms using more gridded street networks. These new types of developments are called 'new urbanist'. The range of movement network form and design over time in a Canadian city can be seen in Figure 1-1: Historical street network topologies in Toronto

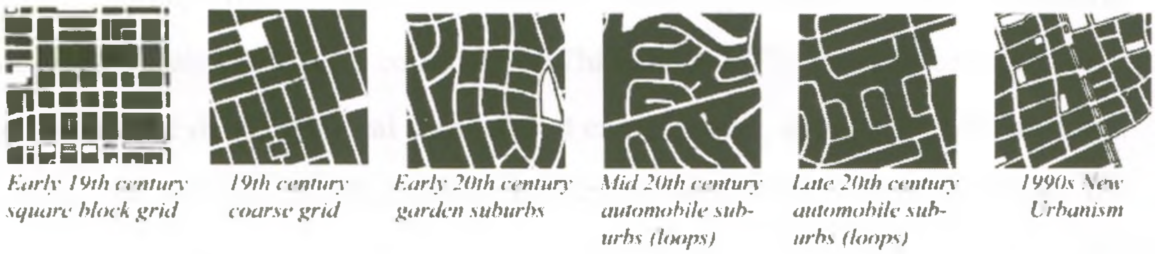


Figure 1-1: Historical street network topologies in Toronto
(Source: Wheeler, 2003)

In the pedestrian and streetcar eras (late 1800's and early 1900s), land in North American cities was typically intensively used, with high building densities and lot coverage, and high intermixture of land uses. With the advent of widespread automobile ownership, however, cities have greatly increased their spatial extent (Johnson, 2001), and have become less dense and more homogenous in land use and urban form (Heim, 2001). Although these changes have been much discussed, there have been few empirical studies of their objective impacts on urban form. A pioneering study by Borchert (1961) examined gross road densities and road junction densities, while Johnston (1976) measured street curvature and non-90-degree junctions. In an early statistical assessment of convergence and divergence in urban forms, Miliward (1975) used gross and net road density, road junction frequency, road connectivity, frequency of non-90-degree junctions, and road curvature, all measured for 500 m square quadrates sampled in 10 Canadian and 10 British cities. He reported that cities had become increasingly similar in their urban physical form (displaying "morphological homogenization") owing to shared innovations in transportation and site design.

1.1.2 Justification for Morphological Research

"Urban areas are the environment of the large majority of the population of economically advanced countries" (Whitehand, 1977). Production and maintenance of the physical form of that environment, especially the buildings, roads, and services, absorbs a large amount of wealth in the western world. In most western countries, home building alone absorbs about 20-25% of gross fixed investment (Needleman, 1965). Indeed, the importance of the physical form of towns and cities has major social, cultural and economic significance.

While it is clear that cities are growing by expanding their boundaries, the physical characteristics of these new urban areas remain unexplored. New urban extensions comprise the majority of the territory of large urban areas as more people establish their residence, work, shop, and spend their leisure time in these areas. As these spatial transformations are taking place, academics are slowly beginning to recognize this new spatial reality as well as the need for a detailed analysis of how its physical characteristics affect the lives of millions of people (Stanilov, 2003). The relative lack of studies analyzing the physical patterns of suburbanization could be explained by the young age of these environments (Moudon, 2002). The form of most traditional cities has evolved slowly over centuries with various layers of history, culture, and social memory deeply embedded in their social fabric (Fredland, 1975). Compared to the lifespan and long history of urban settlements, the postwar suburban extensions appear as infant creations, not fully developed and lacking articulation of their physical features. Urban morphology is important to study for three core reasons: quality of life, economics, and the environment.

1.1.2.1 Quality of Life

Morphology has a direct impact upon the health and safety of its residents. Neighbourhood factors that lead to high quality of life include walkability, proximity of recreational activities, air quality, and sustainability. In the past, quality of life and health consequences of suburban development were not adequately measured and documented (Samini, Mohammadian & Madenizadeh, 2009). However, as science, technology, and tools to measure these consequences have become more sophisticated, the adverse effects of suburban development on health and quality of life have begun to be explored (Frank et al., 2007). For example, many suburban dwellers spend much of their lives in cars; as distances and congestion increase, so does commuting time (Frank et al., 2007). As a result, overall human health has declined, as indicated by increased rates of obesity, heart disease, diabetes, and respiratory illness (Anderson & Butcher, 2006).

Health and quality of life factors in a neighbourhood also include the amount of criminal activity, motor vehicle collisions, exposure to pollution, and walkability (Anderson & Butcher, 2006). Walkability is one of the highest concerns, as it impacts both the health of its inhabitants and the quality of life of these inhabitants in terms of social interaction. Walkability also contributes to community building.

Scholars have found some disagreement between the "measured" quality of life a neighbourhood has and the "perceived" quality of life by its inhabitants. (Frank et al., 2007) Much debate has occurred over the significance of a neighbourhood with a high measured quality of life (but not perceived quality of life) and a high perceived quality of life (but not measured quality of life). The majority of scholars agree that both measures should be explored.

A link has been discovered between neighbourhood design and travel behaviour (Crepeau, 1998). Space syntax analysis shows that connectivity and integration positively affect walking (Baran et al, 2008), while low connectivity and sprawled urban form is correlated with obesity rates (Sui, 2003). Furthermore, urban design can allow for greater safety, including traffic safety (Rae, 2009).

1.1.2.2 Morphology and Economics / Land values

Morphology has a direct impact on the economy of an area. For example, neighbourhoods with gridiron streets offer better accessibility to retailers (and thus increased incomes), and looping suburbs with multiple culs-du-sac typically increase the value of residential land. Indeed, the layout of the street, the mix of uses, and the density of a neighbourhood all have direct impacts on land values.

Urban morphology has a direct link to residential property values (Tse & Love, 2000). Cortright (2009) found a direct link between walkability and housing price when the urban morphology allowed for walking destinations.

Further, site responsive design of streets and lot layout, taking into account natural topography and drainages, can minimize cost endured for storm water management (Cotton, 2008). Finally, Hillier (1996) discusses that a denser city is more economically successful.

1.1.2.3 Morphology and the Environment

Morphology has a direct impact upon the environment of an area. Morphological design and land use controls can allow for the preservation of environmentally sensitive areas, (while) street design can cut down on car emissions, and neighbourhood design can increase densities of land use (dwellings, retail pads, etc), preserving natural area. Space syntax analysis shows that a more connected street network creates more efficient trips for cars, reducing car emissions. Green neighbourhoods are important for the future sustainability of the environment (Garling, 1994). Compact urban forms preserve the environment, while increased green space allows for cleaner air (Garling, 1994).

1.2 Research Approach and Framework

A cross-sectional empirical study is conducted upon a multitude of morphological performance indicators across neighbourhoods in Southwestern Ontario Cities. The approach is quantitative in nature, and takes the form of an inductive analysis. The approach follows studies by other urban morphologist on other cities, positioning itself to be on the leading edge of urban morphology by using innovative GIS techniques examining a broad range of variables, and repeating the same analysis for multiple cities.

This research is divided into two distinct studies: 1) an in-depth study of the neighbourhood morphology of London, Ontario, and 2) a more general (larger breadth) study of neighbourhood morphology in six CMAs across Southwestern Ontario. The research is divided into these two separate studies mainly due to data availability: while a depth of data is available for London, only a small subset of that data is available for all cities in Southwestern Ontario. Therefore, the London study is an example of what can be done when multiple data sets are available; the Southwestern Ontario case study uses easily available data which can be replicated throughout the country. The information below was gathered from Statistics Canada.

1.2.1 Background on Study Areas

The Census Metropolitan Areas (CMAs) of London, Windsor, Sarnia, Brantford, Kitchener, and Guelph are the subject of the morphological analysis in this thesis. These cities were chosen primarily due to data availability, their median sizes, and their similar development time lines. London had the most data available, and therefore received more detailed analysis. Before conducting in-depth morphological analysis on these areas, it is important to briefly discuss the history, economy, and size of these cities.

1.2.1.1 London and London CMA (Source: Statistics Canada, 2006)

London was first settled in 1804, and became a village in 1826. London grew to be the largest city in Southwestern Ontario, with a 2006 population of 352,395 in the urban area, and a 2006 population of 457,720 in its CMA. London has a strong economic focus towards education, manufacturing, and health care. In the early 1990s London annexed hundreds of acres of land, doubling its size and making it one of Ontario's largest urban municipalities by land area at 420 square kilometres. This large land area gives London a relativity low population density at 838 persons per square kilometre. London's CMA area is 2,665 square kilometres, with 172 persons per square kilometre.

1.2.1.2 Windsor CMA (Source: Statistics Canada, 2006)

Windsor was first settled in 1749, and became the village of Sandwich in 1794. It was later renamed Windsor after the town in Berkshire, England. Windsor CMA grew to a population of 323,342 in the 2006 Canadian census. Windsor has a strong economic focus towards manufacturing, tourism, education, and government services. Windsor CMA has a land area of 395 square kilometres, with a population density of 780 persons per square kilometre.

1.2.1.3 Sarnia CMA (Source: Statistics Canada, 2006)

Sarnia was first settled in the 1830s as "The Rapids", became the town of Port Sarnia in 1856, and was later renamed Sarnia in 1857. Sarnia CMA grew to a population of 88,793 in the 2006 Canadian census. Sarnia has a strong economic focus towards education and government services. Sarnia CMA has a land area of 800 square kilometres, with a population density of 111 persons per square kilometre.

1.2.1.4 Brantford CMA (Source: Statistics Canada, 2006)

Brantford was first settled in the early 1800s as "Brant's ford", after Captain Joseph Brant crossed the Grand River, and became the town of Brantford in 1847. Brantford CMA grew to a population of 124,607 in the 2006 Canadian census. Brantford has a strong economic focus towards agriculture and manufacturing. Brantford CMA has a land area of 1,072.9 square kilometres, with a population density of 116 persons per square kilometre.

1.2.1.5 Kitchener CMA (Source: Statistics Canada, 2006)

Kitchener was first settled in the early 1800s as Berlin, after many German immigrants settled in the town, and became the city of Kitchener in 1916. Kitchener CMA includes 3 cities, Kitchener, Waterloo, and Cambridge, which form the regional municipality of Waterloo. Kitchener CMA grew to a population of 451,235 in the 2006 Canadian census. Kitchener CMA has a strong economic focus towards manufacturing, high tech, and research. Kitchener CMA has a land area of 827 square kilometres, with a population density of 546 persons per square kilometre.

1.2.1.6 Guelph CMA (Source: Statistics Canada, 2006)

Guelph was founded in 1827. Guelph CMA grew to a population of 127,009 in the 2006 Canadian census. Guelph has a strong economic focus towards agriculture and manufacturing. Guelph CMA has a land area of 378 square kilometres, with a population density of 336 persons per square kilometre.

1.3 Objective of Study

The Research Question

This study attempts to address one primary research question and three secondary questions.

Primary Question:

What are the similarities and differences in the urban morphology of Southwestern Ontario cities?

Secondary Questions:

1) How do the morphological characteristics of neighbourhoods within and among cities compare in relation to the historical timing of neighbourhood development?

2) How do the morphological characteristics of neighbourhoods within and among cities compare in relation to the incomes of neighbourhood residents?

3) How do the morphological characteristics of neighbourhoods within and among cities compare in relation to neighbourhood population density?

The main question of this research asks whether differences in the urban morphology of Southwestern Ontario cities exist, and if so, what their magnitude is. To accomplish this, a multitude of morphological 'performance indicators' are identified and quantified over Southwestern Ontario CMAs within a Geographic Information System. Values of each performance indicator are identified within defined neighbourhood boundaries, and are assessed by way of descriptive statistics, spatially over the CMAs, and by a spearman correlation.

The first sub question asks if morphological performance indictors vary over historical time period within and between cities in Southwestern Ontario. Each defined neighbourhood unit's major era of construction is identified and compared with the level of each performance indicator. Using a spearman correlation, it can be identified if levels of each performance indicator change in relation to the date they were constructed.

The second sub question asks if morphological performance indictors vary over neighbourhoods with different income levels within and between cities in Southwestern Ontario. Each defined neighbourhood unit's median household income is identified and compared with the level of each performance indicator. Using a spearman correlation, it can be identified if levels of each performance indicator change in relation to median household income.

The third sub question asks if morphological performance indictors vary over neighbourhoods with different population densities within and between cities in Southwestern Ontario. Each defined neighbourhood unit's population density is identified and compared with the level of each performance indicator. Using a spearman correlation, it can be identified if levels of each performance indicator change in relation to population density.

From these research questions, we can formulate three key hypothesis:

H1: Urban morphological characteristics of neighbourhoods will be correlated with median household income in the neighbourhood

H2:Ur ban morphological characteristics of neighbourhoods will be correlated with population density

H3: urban morphological characteristics of neighbourhoods will be correlated with era of development

Further, individual hypotheses could be made for each morphological performance indicator. For example, you could hypothesize that newer neighbourhoods will have lower building densities then older neighbourhoods, that neighbourhoods with higher incomes will have a higher number of culs-du-sacs, or that neighbourhoods with higher population densities will have smaller block sizes. While the results of the following study would allow one to test many hypothesis, this study focuses on quantifying the similarities and difference in the urban morphology of Southwestern Ontario cities.

1.4 Outline of Thesis

The following chapters discuss a detailed study on the urban morphology of London Ontario and Southwestern Ontario cities. Chapter 2 conducts a thorough study of the literature on the topics of urban morphology. Chapter 3 outlines all of the various methodology and sources used to produce the results in the following chapters. Chapter 4 outlines the results of London, while chapter 5 outlines the results of Southwestern Ontario Cities. Chapter 6 discusses the results presented in the presiding two chapters, and discusses limitation of the study, key findings, and calls for future research.

CHAPTER 2
URBAN MORPHOLOGY: A REVIEW OF THE LITERATURE

2.1 Introduction

This chapter provides a targeted review of existing literature in the field of urban morphology. It presents a background overview of the history and approaches to urban morphology, as well as a review of key studies that focus specifically on the key elements of streets, lots, buildings, and land use.

2.2 Defining Urban Morphology

In an early study on urban morphology, M. R. G. Conzen (1937) drew attention to three aspects of the physical fabric, viewed together as "townscape". First, he argued that the townscape has utility at the most basic level in providing orientation. Secondly, it has intellectual value by establishing a strong visual experience of the history of an area, helping people to place themselves within a wider evolving society, and stimulating historical thought. Finally, the townscape has aesthetic value, as the dominant features of an urban landscape stimulate our imaginations and provide emotional experiences. Early work by Conzen helped to develop methods for classifying urban elements, and decades of inductively driven "morphographic" case studies had serviced to identify the features common to cities, and the features which make cities distinctive.

Anne Vernez Moudon describes urban morphology as "the study of the city as human habitat" (1997, P#3), and argues that morphological analysis is based essentially on three principle elements: scale, resolution, and time. There is little agreement over what constitutes a morphological 'element', however, the urban design literature identifies morphological elements as streets, squares, parks, monuments, and street furniture, along with specific building types. In his description of elements, Whitehand, (1981) also include density, compactness, concentrations, dispersal, and mix of uses, all of which are properties of physical elements. Lynch (1960) uses cognitively based elements including paths, edges, districts, nodes, and landmarks to define urban form.

More focused classification systems have been devised for particular types of analysis. These single-purpose frameworks can inform a more universal classification scheme, but of themselves lack the generality or transferability for ordering urban form from 'room to region' (Osmond, 2010). It can be argued that this lack of a common vocabulary limits communication between researchers across spatial scales. In response, Kropf (1993), created an approach to define and subdivide urban form, based on the logical distinction between classes, relations, and properties of built form and a synthesis of established urban morphological perspectives. Kropf`s research allows for the definition of the urban structural unit, a morphological construct defined as areas with physiognomically homogeneous character which are marked in the built-up area by buildings and open spaces. (Wickop, 1998).

2.3 Approaches to Urban Morphology

As an organized body of knowledge, urban morphology has existed for over a century. In German-speaking countries, urban morphology grew with the advancement of the field of geography, while in English-speaking countries urban morphology has a shorter history. Further, outside of central Europe, its position has been peripheral to the mainstream of geography (Whitehand, 1977). Thus, there is a rarity of large scale studies outside of central Europe, save for a few works (e.g.: Vance, 1977).

Before 1970, urban morphology rarely appeared on the geographical research agenda of English speaking countries. This occurred for three reasons: 1) the lack of quantitative data; 2) a shift of attention to sociological and political questions; and 3) an increased concern with scales of analysis at which the structure of individual settlements was less important (Conzen, 1973). 'Placelessness' was a large focus of study at this time; Geographers were losing contact with their roots and frequently contributing as much to other disciplines as their own.

Since the mid-1990s there has been increasing interest in urban morphology among geographers and planners. An annual conference, the International Seminar on Urban Form (ISUF), was a catalyst for increased dialogues among the fragmented urban morphologists of the world. More importantly, as discussed in the introduction chapter, it was around this time that researchers began to analyze the links between morphology and population health and safety, the economy, and the environment.

There have recently been significant studies on urban morphology in Canada, being produced by researchers in a variety of disciplines, including architecture, planning, geography, and history. Gauthier and Gilliland (2006) use a novel classification scheme to identify and categorize significant works according to their particular epistemological perspective, and describe noteworthy contributions of various academic disciplines by key author and research themes. In a follow-up paper, Gilliland and Gauthier (2006) applied this 'epistemological mapping' to a review of urban morphology in Canada.

In these two papers, the authors propose a system to identify and interpret, or 'map', individual contributions to the study of urban form according to their respective theoretical or epistemological perspectives. In an effort to 'improve intelligibility' in urban morphology, they offer a two-tiered examination of prevailing approaches in the field. First, the authors distinguish between *cognitive* and *normative* approaches to urban form, and then a second distinction is made between what they term *internalist* and *externalist* contributions. They find that by using these basic criteria, it is possible to interpret and synthesize a multitude of contributions and map them using a simple Cartesian grid (Figure 2-1). The following review summarizes discussion from these two papers.

2.3.1 Cognitive versus normative contributions to urban morphology

The authors found that most studies on urban morphology are aimed at 1) providing explanations, or developing *explanatory* frameworks, or both (i.e. *cognitive* contributions); and 2) that most studies are aimed at determining the modalities according to which the city should be planned or built in the future (i.e. *normative* contributions). Moudon (1994) calls the categories *normative-prescriptive* and *substantive-descriptive*. Levy (2005) has suggested that the same distinction be made in the field of urban morphology, to distinguish between what he termed normative and cognitive approaches. The expression cognitive reflects the heuristic nature of an intellectual enterprise concerned with producing knowledge or developing theoretical means, methods, and techniques destined to produce such knowledge. The term normative denotes an intellectual exercise which aims at articulating a view of what the future should look like, or at exposing a doctrine or specific sets of norms and prescriptions that would serve such a view.

The authors term cognitive those contributions that aim to produce knowledge (e.g. Caniggia, 1963, 1994) or develop theoretical and analytical tools (e.g. Caniggia and Maffei, 1979; Maretto, 1984), and reserve the term normative for contributions explicitly aimed at articulating a vision of the future (e.g. Maretto, 2005), or at formulating an approach to planning practice (e.g. Caniggia and Marconi, 1986).

2.3.2 Internalist versus externalist approaches

Gauthier and Gilliland sort each contribution according to the epistemic status conferred to urban form. This is accomplished by distinguishing between contributions that consider urban form as a relatively independent system, and contributions in which urban form stands as a dependent variable, or passive product of various external determinants. An examination of the key research traditions in urban morphology, specifically the British, Italian and French schools, reveals that they hold in common the intent to capture in the empirical reality of the city and to study intricate details of such forms

To comprehend the urban fabric in terms of 'urban form', understood as a system of its own that is governed by *internal* sets of relations, necessitates two prerequisites: first, that the elements in the system are not discrete objects; and secondly, that the relations between elements are not contingent. In other words, there exists an 'internal' logic to this system. Such a perspective allows for the development of theoretical frameworks that find the primary explanation for morphogenesis in the constraints and potential for change present within the system itself. Gauthier and Gilliland propose to call these approaches that are primarily concerned with understanding the internal logic of the urban fabric *internalist* approaches to urban morphology.

Alternatively, Gauthier and Gilliland label as *externalist* those approaches that primarily see the urban form as the end product of processes driven by political (e.g. Çelik, 1997), anthropological (e.g. Rapoport, 1977, 1982; Rykwert, 1988), geographical and economic (e.g. Vance, 1977, 1990), historical (e.g. Benevolo, 1980), and perceptual (e.g. Lynch and Rodwin, 1958; Lynch, 1960) determinants. Historically, externalist contributions have been far more numerous than internalist ones. The authors posit that a common object of enquiry, i.e. the city as a spatial form, and a common conceptualization of the urban built environment as a dynamic system granted with relative autonomy, connects the contributions of the three aforementioned 'schools' and constitutes the primary core of the urban morphology research program, albeit this program is still in the process of becoming a paradigm. From an epistemological perspective, the commensurability of the cognitive-explanatory theoretical frameworks developed under the auspices of the three schools of urban morphology lies in their common internalist perspective.

Perhaps the most important contribution of urban morphology to the study of cities has been to show how the built environment can be understood as a system of relations submitted to rules of transformation. The conceptual possibility to capture some cultural occurrences in systemic terms has proven extremely fruitful in urban morphology, as it has in numerous other scientific fields and disciplines. This simple theoretical *a priori* allows us to better understand the complexity of the urban built environment, and in particular to better comprehend how the process of a city's physical formation has its own weight and inertia, that work to oppose social, economic and political factors, in the same way that it has been alternatively assumed that the physical development of the city is conditioned by these factors.

2.3.3 Mapping contributions to urban morphology

The usefulness of graphically mapping various contributions to the study of urban form on a grid should be seen at both a practical level for researchers interested in urban morphology, and at a more analytical and epistemological level, as it elicits new interpretations on the nature of contributions or groups of contributions that deal with urban form.

A look at the grid reveals that the internalist/cognitive quadrant includes various scientific studies concerned with the city as an artifact and spatial form, and which conceptualize its built environment as a system. Such a depiction best qualifies the work of M.R.G. Conzen (1960, 1962, 1968), for instance, as well as the scientific efforts of various proponents of 'process typology'. Whereas Muratori's philosophy and research methods broke the ground, the second generation process typologists such as Caniggia and Maffei (1979), Cataldi (1977), and Maretto (1984), have worked more attentively at developing a science of the built environment. The research tradition known as 'space syntax' (which will be explored later in this thesis) has also produced several important contributions to urban morphology that fall in this category, and is best represented by the work of Bill Hillier and Julienne Hanson from the Bartlett School of Planning at University College London (e.g. Hillier and Hanson, 1984; Hillier, 1996).

The externalist/cognitive quadrant re-groups the scientific contributions concerned with the forms and transformations of the urban built environment, but which rely predominantly on explanatory frameworks based on external conditions of development. The vast majority of scientific contributions dealing with urban form (especially from the Anglo-Saxon world) have adopted a common externalist perspective, even though they have come from a wide array of disciplinary perspectives (e.g. Benevolo, 1980; Lynch, 1960; Mumford, 1961; Rapoport, 1982; Vance, 1977). Most of the work that has been conducted in the so-called Conzenian tradition (most notably the contributions of geographer Jeremy Whitehand, 1972a, b, 1974, Whitehand and Whitehand, 1984) has been concerned with the impact of social or economic factors on the evolution of urban form. It therefore could be argued that although these more recent contributions draw upon Conzen's ideas, they are fundamentally different in that they adopt an externalist explanatory framework.

The studies categorized as internalist/ normative could be otherwise qualified as urban design normative contributions, as they aim at devising an urban form that has yet to be built. Many contributions from process typologists could be cited in this category (e.g. Cervallati *et al.*, 1981; Davoli and Zaffagnini, 1993; Maretto, 2005; Spigai, 1980). For further discussion of the influence of typo-morphological approaches on urban design, see Lane (1993) and Nigrelli (1999). Some of the ideas about heritage preservation that have been put forward by Conzenian researchers also belong in this category, such as Kropf's (1996) paper on typological zoning and Conzen's (1966, 1975) own work on the utility of town-plan analysis. This category of studies also includes the popular urban design doctrines that have come out of the United States in recent decades, such as New Urbanism (Duany *et al.*, 1999) and transit-oriented development (Calthorpe, 1993). In the externalist/normative quadrant group are studies that develop applied approaches to the processes dealing with the making of urban fabrics. Among the contributions to be found in this category are those arising from researchers who first developed externalist explanatory theoretical frameworks and then translated them into operational planning and design tools for the benefit of practitioners (e.g. Larkham, 1992, 1996; Lynch, 1981; Rapoport, 1977).

The present study can be classified as externalist in nature, as it views urban form as the end product of a number of processes, including historic an economic determinants. Further, this study is located between the cognitive and normative perspective. The study is primarily cognitive as it provides explanations for urban form and aims to produce knowledge and develop analytical tools, but at the same time it is normative as it aimed at determining the modalities according to which the city should be planned or built in the future. A red dot on Figure 2-1 displays the approximate location of this work as compared to others.

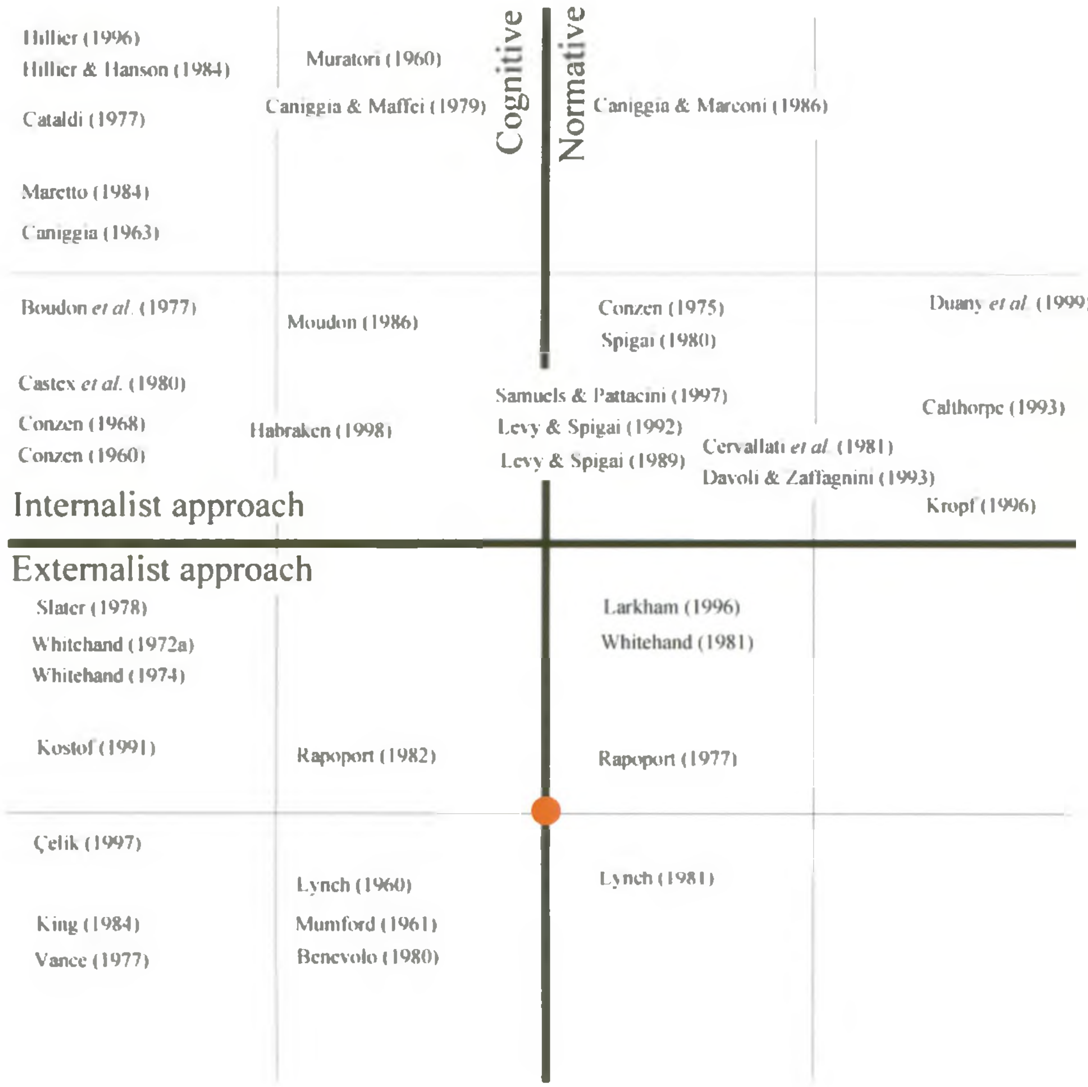


Figure 2-1: Mapping contributions to the study of urban form. (Gauthier and Gilliland, 2006)

2.3.4 Classical Theories of Urban Form

It is important to trace the development of the city over time in order to fully understand its form. The following summary of change in city form over time highlights in particular the changes in transportation technology that helped produce the different urban morphologies seen in most North American cities, including those in Southwestern Ontario.

The Early City

Over the past century, changes in transportation technology have lead to drastically different urban forms. In the pedestrian city, or mercantile city, transportation was primarily by foot or horse . The relationship between class and place of residence was that where the elite lived in the core of the city, and the working classes lived in the periphery.

In the early industrial city, new transportation technologies, such as the railroad, allowed for more rapid movement of people around the city. This essentially turned the city inside-out, with specialized industrial and commercial uses claiming most of the central area, and the wealthier classes moving to the periphery of the city.

Models of the Industrial City

In the industrial city, new transportation technologies powered by electricity helped increase the spatial extent of the city. Cities brought the logic of economies of scale, agglomeration economies, and the division of labour. As a result, the organization of the economy, of society, and of urban space was radically transformed. Users of land became spatially segregated by their ability to pay for the most attractive locations. Factories took the premium locations, and around these factories, speculators built homes for workers (as opposed to the factory building homes for their workers, which was previously the case in some cities). The networks of the streetcar lines were developed during the industrial era, and were a fundamental driver of urban change. Cities became 'machines' that could be rationally organized as a unitary system. This created the need for land use zoning laws, which regulated the locations of different uses over the city.

The Sector Model

In general, land use in cities in North America confirm to certain patterns. The classic study of land use in American cities was undertaken by Homer Hoyt (1939), who made a comparative study of patterns of rental values in 142 cities in the United States in the early 1900s. Hoyt developed a sector model of urban land use that was based on a number of generalizations derived from his study of patterns of rental values. In sum, these generalizations produced a model of urban land use. The main point of this model is the relative location of the different land use sectors. Hoyt argued that corridors of industry will always be surrounded on both sides by sectors of working class housing, while middle income housing will tend to act as a buffer between the industrial half of the city and the city's main sector of elite neighbourhoods. Each new generation of upper class would build or buy houses on the current edge of the city, as far away as possible from the lower class. This produced different zones of socioeconomic status.

The bid rent theory of urban land use

The idea that companies and households compete for space in a way that maximizes their utility is the basis for a neoclassical economic model of urban land use developed by William Alonso (1964). Given that general assumptions of the model are met, the model states that the most central areas of the city will be the most attractive as there are relatively few central sites in relation to the total space available. As a result, competition for these central sites will be intense, and the prices offered for them will be higher than less central sites. Different types of land users will place different financial evaluations on the utility of centrality, depending on their particular schedule of expected income and expenditures. It is logical, for example, to expect some offices, banks, hotels, and other commercial establishments to be able and willing to outbid households for central sites because the extra income accruing to a central location through increased trade is likely to outweigh the savings in commuting costs obtained at the same site by a household.

Each type of land user can thus be thought of as having a distinctive bid-rent curve that reflects the prices that a type is prepared to pay for sites at different distances to the core. Users with steeper curves capture more central sites, while those with shallower curves -residential users and manufacturing facilities – are left within the peripheral sites. This locational equilibrium is reflected in a simple pattern of concentric zones. In this way, commercial land use is located in the center of the city, and light manufacturing, residential, and heavy industry are located in concentric zones outward from the core.

The Post-Industrial City

The success of the motorized streetcar allowed for travel for up to 20 miles per hour, and opened the way for the streetcar suburb. So much new land became accessible that the price of land was kept down. The post-industrial city, or Fordist city, saw the rise of the automobile and the automobile suburb. As these automobile suburbs were laid out, the city changed back to a more symmetrical shape. A new model of urban form - the multiple-nuclei model - emerged as a schematic representation of the relative locations of the major categories of land use based on the evident proliferation of commercial and industrial nodes beyond the CBD. The model, created by Harris and Ullman (1945), argued that new automobile based suburban nodes of commercial and industrial activity were not arranged in any predictable fashion, except in relation to their souring land uses: they would all attract middle-income residential development.

During this time, the central city went through a decline in most North American cities. Not only had production facilities decentralized, but the structure of the economy was moving away from manufacturing industries that were often in central areas. The loss of jobs in the central city caused a shift in the employment base and population density, which resulted in radical changes in land use and morphology. New office blocks were built where abandoned factories were once located. White collar workers moved closer to the core, creating gentrified areas in the city centre.

2.4 Urban Taxonomy and Morphological Performance Indicators

Taxonomy is the branch of science concerned with a scheme of classification and originates from the Greek words taxis ('arrangement') and nomia ('distribution'). The evolutionary nature of an urban form is affected by certain long-lived taxonomy elements such as buildings and infrastructure, which may continue to influence the spatial configuration of new elements for decades and even centuries (Wegener, 1986). A particularly noteworthy study in urban taxonomy by Knaap and colleagues al. (2005) classified five urban scale-based approaches: metropolitan structure (regions); sub-metropolitan structure (sub-areas of regions); community design (neighbourhoods); urban design (blocks); and landscape ecology (patch structures in a landscape along a continuum) for measuring 'urban sprawl' using multi-disciplinary perspectives. A review by Knaap et al. (2005) showed that for studies at the metropolitan scale, urban sprawl measurements tend to focus on population/employment, shapes and job-housing balance etc, while at the sub-metropolitan scale, measures concentrate more on transport analysis and networks. Measures at the urban design scale are commonly based on subjective qualities (people's perceptions in experiencing space and design, e.g. coherence, safety, aesthetics) and objective measures (built form, building heights, solar access to buildings). Some of the urban design scale metrics of urban sprawl, such as transport infrastructure, building design, environmental context, accessibility and perceptions could provide information on improved standards for subdivision design and behavioural change towards sustainability (Knaap et al., 2005).

The present thesis utilizes numerous morphological performance indicators to empirically examine how urban form varies across neighbourhoods. Traditionally, performance indicators are variables which are commonly used to define and evaluate success. In this thesis, performance indicators are morphological variables, used to measure the success of individual neighbourhoods and entire cities. Performance indicators in this study range from street length to residential building proportion, and are extremely useful in comparing neighbourhoods within and across cities.

Early pioneering examples of the development and application of morphological performance indicators include a study by Borchert (1961), which examined gross road densities and road junction densities in Minneapolis and St. Paul, Minnesota. In an early quantitative assessment of convergence and divergence in urban forms, Millward (1975) used gross and net road density, road junction frequency, road connectivity, frequency of non-90-degree junctions, and road curvature, all measured for 500 m square quadrants sampled in 10 Canadian and 10 British cities. He reported that cities had become increasingly similar in their urban physical form, displaying "morphological homogenization" owing to shared innovations in transportation and site design.

Within the past two decades, several researchers have applied GIS to derive morphological measures as performance indicators related to the planning principles of smart growth (Duncan and Nelson, 1995, Daniels, 2001) and architectural principles of "new urbanism" (Katz 1993, Dutton, 2000). Morphological methods can directly measure aspects of urban physical form, and are thus highly useful for research on the localized impacts of recent planning and design strategies (Talen, 2002).

Key themes in this literature focused on "smart growth", "new urbanism", and "sustainability". For example, Bagley & Mokhtarian (2002) presented a method to assess neighbourhood types using several subjective and objective variables derived from new urbanism principles, while Burton (2002) developed a large set of indicators based on population density, built form density, and mix of uses, and used them to measure urban compactness in an investigation of sustainability. Grant (2006) compared "ideal" new urbanist forms to conventional post- 1945 suburbs using several measures of urban form and land use for 1,000 metre by 1,000 metre quadrants. The measures included land use dissimilarity and dispersion indices (measuring the variety and spatial clustering of land uses), measures of street density and connectivity, measures of the ratio of single to multiple housing units, and a measure of open space. Weston claimed that his results could help planners retrofit existing neighbourhoods to more closely adhere to new urbanism ideals.

Much of the debate on street pattern in terms of neighbourhood performance centres on new urbanism communities. For example, Grant (2006) assesses the benefits and costs of new urbanism developments across the United States. Grade finds that there is not much in the way of cost savings in new urbanism areas, although there is better design and less impact on the natural environment. Another example is Lund's (2003) paper which tests the claims of new urbanism, including pedestrian travel and neighbouring behaviours. Lund finds that residents walk more in new urbanism environments, although these walks were to get to a specific purpose (e.g. to get to work or shop), not for recreation or social interaction.

Another dominant theme in the recent literature is `walkability`. For example, Cervero and Kockelman (1997) considered a large number of neighbourhood variables, including proportion of blocks with sidewalk, block length, number of intersections, and retail store availability, to characterize walkable versus auto-dependent urban forms. Handy and Clifton (2000) identified factors that contribute to pedestrian accessibility at the neighbourhood level, while Krizek (2003) used housing density, neighbourhood retail employment (representing land use mix), and block size to compose an index of neighbourhood accessibility in relation to walkability.

The remainder of this literature review focuses on the morphological performance indicators used in the forthcoming analysis. The performance indicators are grouped into two categories: 1) Streets and Blocks, and 2) Lots, Buildings, and Land Use. The majority of previous work on morphological indicators has been in the realms of streets and blocks.

2.4.1 Streets and Blocks

The following section addresses literature which has a primarily focus on streets and blocks. First, streets will be discussed, including street networks and patterns, intersection density, connectivity, and space syntax. This will be followed by a blocks on blocks, including block size and block density.

There has been a considerable number of studies focussing on street and block patterns, often grouping a number of streets and blocks into neighbourhood or suburban units. For example, the volume *Twentieth-Century Suburbs* by Whitehand and Carr (2001) discusses, among other items, how street design has changed in suburbs over time, while *Streets and Patterns* by Marshall (2005) explores the different kinds of streets and patterns that might be used as the bases of urban design, and how these street patterns have changed over time.

2.4.1.1 Street Networks and Patterns

Numerous scholars have attempted to theoretically model street network morphology and usage, and the potential impacts of interventions. For example, Poulon (1982) created a model to discover the best pattern of residential streets based on the most desirable combination of environmental quality and service to traffic. Poulon models the street network based on total travel time, speed on different road types, delays from turning, and the spacing of roads. The results show that the best pattern of residential streets is deduced by removing through traffic on residential streets. Jiang, Zhao, and Yin (2008) also explored road configuration, suggesting that roads can be thought of as complex phenomena such as "ants/colonies and sand grins". Their results illustrate various emergent properties developed from roads and road network topology. Further, Snellen, Borgers, and Timmermans (2002) conducted a multilevel analysis on urban form, road network type, and mode choice for frequently conducted activities. They found that multilevel analysis is a very useful tool for exploring observations that are made at different levels of aggregation.

Penn et al (1998) used configurational modeling to analyze urban movement networks. They used a supply and demand model with routes and configuration on the demand side and width and traffic determines on the supply side. The underlying configurational logic is through a feedback 'multiplier effect'. The findings suggest the possibility of using urban design parameters, such as the plan configuration of the street grid, building height, and street width, to arrive at a better controlled relationship between vehicles and pedestrians in urban areas. Similarly, Jiang (2008) ranks spaces for predicting human movements in an urban environment. His study justifies how space syntax techniques can be used to predict human movement.

2.4.1.2 Intersection and Block Density and Connectivity

Measures of intersection and block density also reflect the level of 'connectivity' in the movement network. With the rise of concepts such as smart growth, new urbanism, and neo-traditional development, transportation and urban planners have put much attention on measures of street or network connectivity. Intersection density is measured by the number of intersections per square kilometre. A higher number would indicate more intersections and blocks and thus higher connectivity (Song & Knapp, 2007; Samimi et al, 2009; Millward & Xue, 2007). Song and Knapp (2007) calculated multiple measures for intersection density, according to the types of intersections, including cul-de-sacs. Similarly, Filion and Hammond (2002) used T and X intersections in their study of Kitchener-Waterloo neighbourhood form.

Intersection and block density and connectivity are commonly used by many scholars outside of geography (e.g., health researchers) when studying the built environment. For example, Dill (2004) used connectivity as a built environment measure when studying biking and walking in the Portland, Oregon region, and found that it was significant in influencing walking or biking. Similarly, Samimi, Mohammadian, & Madanizadeh (2009) found that increasing connectivity increases chances of walking, which results in a decrease in health-related problems like obesity.

The most popularly studied characteristic of street pattern and street design has been connectivity, defined as the "directness and availability of alternative routes from one point to another within a street network" (Transportation Research Board / Institute of Medicine, 2005). Within geographic research, connectivity is often used when attempting to measure urban form. For example, connectivity was used by Song and Knapp (2007) in their quantitative classification of neighbourhoods, and by Millward (1975) in his comparative examination of urban plans in Canada and Britain. Specific papers on connectivity include Peponis, Bafna, and Zhange (2006) in which they study, in great detail, the connectivity of streets in Atlanta, finding that levels of connectivity vary over different morphologies of the street network.

Some connectivity measures that have been used include the percent of gridded streets within a buffer distance around a person's home (Boarnet & Sarmiento, 1998; Boarnet & Greenwald, 2000), the number of intersections per square kilometre (Frank et al. 2005), percent of T-intersections and 4-way intersections (Handy, 1996), and the average block area (Krizek, 2000). Much of this previous research has identified a link between higher connectivity and higher levels of walking for purpose or leisure. Leslie et al (2007) use a connectivity measure in their study on walkable morphology, finding an association with increased transit and route options.

Many researchers have measured the street network based upon whether or not it has a grid layout. For example, Greenwald and Boarnet (2001) and Boarnet and Crane (2001) use the percentage of area in a one-quarter mile buffer zone that is covered by a grid street pattern, as measured by presence of four-way intersections. Boarnet and Crane chose this measure based upon research that showed that the number of four-way intersections was a good predictor of whether a neighbourhood reflected "neo-traditional" design elements. Other researchers have simply categorized a neighbourhood's street network as having a grid layout or not, or partially-gridded and used dummy variables (e.g. 1=grid, 0=not grid) for models. Snellen, Borgers, and Timmermans (2002) conducted a multilevel analysis on an array of street patterns including linear networks, radial networks, rings, grids, and shifted grids on cities in the Netherlands.

2.4.1.3 Space Syntax

The first notion of space syntax was written in the book *The Social Logic of Space* by Hillier and Hanson (1984). Over the subsequent years, Hillier would continue to refine his theories of space syntax, rooting them in graph theory and in urban morphology. Space syntax, as described in Hillier et al (1993), is a set of theories and techniques for the analysis of spatial configurations; in short, a tool for engineers, planners and architects to assess the social effects of the designs of urban movement networks. Space syntax aims at describing the relational properties of urban space, as it is through those relationships that meaning is conveyed to individuals using the space (Baran et al. 2008). Space syntax theory describes and measures quantitatively the relational properties of urban space. Such relational properties rest on assumptions that longer lines of sight, fewer turns, higher connectivity, and a high availably to reach points from every other point in space are desirable. The evidence has shown a positive relationship between the occurrence of activity and spaces that exhibit these desirable properties. Hillier et al. (1993), looked at natural movement or configuration and attraction in urban pedestrian movement. They found that land uses correlate with movement network configuration and space syntax results. Space syntax concepts and methodology is further refined in Space *is the Machine* (1996), where Hillier looks at outcomes of spatial configuration and outlines new techniques of implementing space syntax.

Space syntax outcome variables have been linked to land use, movement patterns, human culture, and even crime. Nubani and Wineman (2005) used space syntax to identify the relationship between space and crime. They found that how integrated a street was in the overall system of streets was positively correlated with crime rates on that street; in other words, poorly-integrated streets were safer then highly-integrated streets. Similarly, Hillier and Sahbaz

(2008) looked at crime, space syntax, and urban design, and found flats are the safest dwelling types, increased ground density is beneficial to safety, local movement is beneficial to safety, cul-de-sacs are safer than through streets, that there should be a good mix of uses for increased safety, and that there should be larger residential blocks for safety. Similarly, the book *Designing Out Crime* by Colduhoun (2004) talks about ways in which neighbourhoods can be designed and modified to decrease crime and increase quality of life. Density, street design, access to commercial land uses and proximity between job and house have all be tested using space syntax, however, street design and street layout have received less attention.

The ability of space syntax to describe global configuration properties of street design as well as relationships of part-to-whole quantitatively provides an important advantage over the existing methods of measuring street connectivity and syntactical accessibility. By attaching configurational measurements to each street segment in a study area, relationships between individual behaviours and those measurements can be examined. The evidence to date has focused mainly on the presence of activity on a street, finding that high integration streets have a higher number of pedestrians and car movements (Hillier & Hanson, 1984; Peponis et al., 2007; Hillier et al., 1993; Hillier, 1996; Penn et al., 1998; Read, 1999; Hillier, 2001; Raford & Ragland, 2006). In addition, the syntactical properties of space have been used in explaining crime occurrence (Hillier & Sahbaz, 2005; Nubani & Wineman, 2005; Baran et al., 2008; Long & Baran, 2006), pedestrian safety (Raford & Ragland, 2006), and spatial cognition (Kim, Y., 2001; Kim & Penn, 2004; Long & Baran, 2006). Overall, it is expected that people who live on well-integrated streets will show greater propensity to walk.

2.4.1.4 Blocks

An inverse function of streets, city blocks are essential elements of towns and cities, we know little about the comparative effects and performance of different block forms and sizes over time. Certainly, the evolution of blocks in many individual towns has been examined as part of wider town-plan analyses ever since M. R. G. Conzen's studies of Alnwick (1960) and Newcastle (1962). All these studies have increased our knowledge about the evolution of street, block and lot patterns in towns, but they mostly cover European towns of medieval origin that changed slowly over time.

Some have tackled towns of later periods that changed more quickly, for example Pietermaritzburg, South Africa (Haswell, 1990); Lodz, Poland (Koter, 1990). However, only a few have looked at towns or parts of cities that have experienced rapid, substantial changes since their inception. Baird's (1978) analysis of the North Jarvis neighbourhood in Toronto gave an early indication of the potential benefits of such studies. Moudon (1986) demonstrated this more fully in a comprehensive study of the Alamo Square neighbourhood in San Francisco, whose findings have given a detailed understanding of the processes involved in the evolution of block, lot and building patterns. While consideration of the effects of different block forms and sizes has not been their main concern, both studies provide valuable tools for such comparative analyses and for their extension beyond residential areas, say to city centers. Song & Knapp (2004) included block and lot depth, size, and density as a plot design and density measure in the quantification of urban form. They found that newer suburban neighbourhoods have smaller block and lot depth and size, as well as increased lot density.

2.4.1.4.1 Block Size

A handful of communities have adopted standards setting maximum block sizes, which capture two dimensions of the block, rather than the individual length of each side (Handy et al., 2003). This can be measured by the width and length, the area (e.g., acres), or the perimeter. For example, Fort Collins, Colorado specifies a maximum block size of 7 to 12 acres, depending on the zoning. Using block size measured by area or perimeter as a standard may be more flexible than block length for each side. Further, Song & Knapp (2004) used median block size as a street design measure in the quantification of urban form, and Ghosh & Vale (2009) used block size as a measure to describe New Zealand topology

2.4.1.4.2 Block Density

A few researchers have used block density as a proxy measure for connectivity. Frank et al. (2005) used the mean number of census blocks per square mile. The authors assert that census block density is a good proxy for street connectivity, since census blocks are typically defined as the smallest fully enclosed polygon bounded by features such as roads or streams on all sides. Cervero and Kockelman (1997) use blocks defined more traditionally – areas of land surrounded by streets. In either case, increased block density is thought to represent increased connectivity – more blocks means smaller blocks and more intersections. Further, Ghosh & Vale (2009) used block destiny as a measure to describe New Zealand topology.

2.4.2 Lots, Buildings, and Land Use

Lots and buildings in morphological research are almost always tide to their land use, and there is comparatively little research on these elements. For example, there is little research on the overall lot or building size of a neighbourhood; instead, lots and buildings size is divided into land uses, for example, single detached residential building size, multiple residential building size, commercial building size, and industrial building size (Kostof, 1991). Lot and Building form, size, and density is described in Vance's *The Continuing City* (1990), Kostof's "*The City Shaped* (1991), and Eisner's "*The Urban Pattern*" (1980). These works describe buildings in detail, yet do not quantify lot and building forms. This study is novel in quantifying lots and buildings both with and without land uses attached.

Song & Knapp (2004) included commercial land use, industrial land use, multifamily residential land use, and public land use measures in the quantification of urban form. Leslie et al (2007) use a dwelling density and retail area measure in their study on walkable morphology, finding an association between increased dwelling density with increased retail options. Ghosh & Vale (2009) used a general land use mix measure to describe New Zealand typology. Filion and Hammond (2003) used residential land use pattern in their study of Kitchener-Waterloo neighbourhood form and accessibility.

2.5 Conclusion

This chapter has provided a review of the recent literature pertaining to urban morphology which provides the foundation for this study. After reviewing the defining urban morphology and exploring its multiple historical and epistemological approaches, this review looked at recent literature concerning morphological performance indicators. Most previous studies have looked at only one or two morphological performance indicators and compared them with social or economic variables. This thesis attempts to improve upon these studies by creating a large set of morphological performance indicators and comparing these with social and economic variables.

CHAPTER 3
METHODS AND SOURCES

3.1 Introduction

The purpose of this chapter is to identify and outline the methods and data sources used in analysing morphology in the results chapters. This chapter begins with a discussion on aggregating morphology for analysis, which outlines the container approaches used in both the London and six CMA (census metropolitan area) studies. Limitations to this approach are discussed, followed by a discussion on map design and data display. GIS terms are then outlined, followed by a discussion on the methodology of creating individual performance indicators. These performance indicators are grouped into categories of streets, blocks, lots, buildings, and land-use performance indicators.

To assess various performance indicators over a given area, a "container approach" is adopted. This method allows for the comparison of various indicators within discrete geographical areas. Frequently, the average (mean) or maximum value of a performance indicator will be derived from a distribution of features within each container. The smaller and more numerous the containers are, the finer the resolution of the data analysis will be. It is important, however, to keep in mind the sample size of the data because containers that are too small will not have enough cases to make accurate statistical inferences.

In the London analysis, the container used is the "morphological unit", a specifically created geographical area that will be described later in this chapter. In the Southwestern Ontario analysis, the container is the 2006 Census Tract (CT), a geographical area created by Statistics Canada.

3.2 Aggregating Morphology for Analysis

3.2.1 Geographic Units of Analysis in London

A number of "container" units were considered for London, including planning districts, political wards, Census Tracts, and dissemination areas. Each of these units is discussed below.

3.2.1.1 City of London Neighbourhood Boundaries – Planning Districts and Wards

The City of London is divided into a number of neighbourhoods. Depending upon the source of data (e.g., the City of London, 3rd party maps, individual citizen opinion), the locations and names of these neighbourhoods change. The physical boundaries between neighbourhoods are often fuzzy.

The City of London divides its territory into 35 planning districts. These planning districts differ in characteristics, such as physical size, population density, housing stock, socioeconomic indicators, and era of development. Furthermore, more key morphological features, including street configuration, typical housing size, and socio-economic status, also vary significantly among planning districts. In reality, a number of distinct neighbourhoods typically exist within each planning district.

Accordingly, the planning district is too large of an area in which to conduct neighbourhood-level statistics. Unfortunately, London's 14 political wards are even larger than planning districts and also cannot be used for neighbourhood analysis. Some political wards, such as ward numbers 9, 12, and 14, are over 60 square kilometres in area, much larger than a typical neighbourhood.

3.2.1.2 City of London Census Tracts and Dissemination Areas

Census tracts (CTs) and dissemination areas (DAs) are also considered as geographic units for analysis of London data because they provide much smaller geographical units and allow for the linkage of various pertinent data from the Canadian census.

3.2.1.2.1 Census Tracts

Census tracts (CTs) are "small, relatively stable geographic areas that usually have a population of 2,500 to 8,000" (Statistics Canada, 2006). CTs are identified using six-character numeric 'names' (e.g., 0005.00) and are located in census metropolitan areas (CMAs) and larger census agglomerations (CAs).

Within the city limits of London, there are 82 CTs, as shown in Figure 3-1. Removing one large outlier in the south end of the city, the average census tract is 3.03 square kilometres, with a standard deviation of 4.9 square kilometres, indicating a large spread in areas. Like the planning districts, CTs are all different areas and vary greatly by socioeconomic and demographic composition. Since they are smaller than planning districts, they usually contain similar morphological features. However, there are some issues with using CTs as neighbourhood units. First, some CTs have major 4-lane roads running through them, which can be argued as being significant dividers of neighbourhoods. Secondly, some CTs have rail lines running through them, which also divide the neighbourhood. Thirdly, CTs do not always have consistent morphological features. For example, the same census tract might contain grid pattern streets with curvilinear streets, as well as morphologically inconsistent building forms developed in different eras. Thus, the census tract is not the best container to study morphological indicators in London.

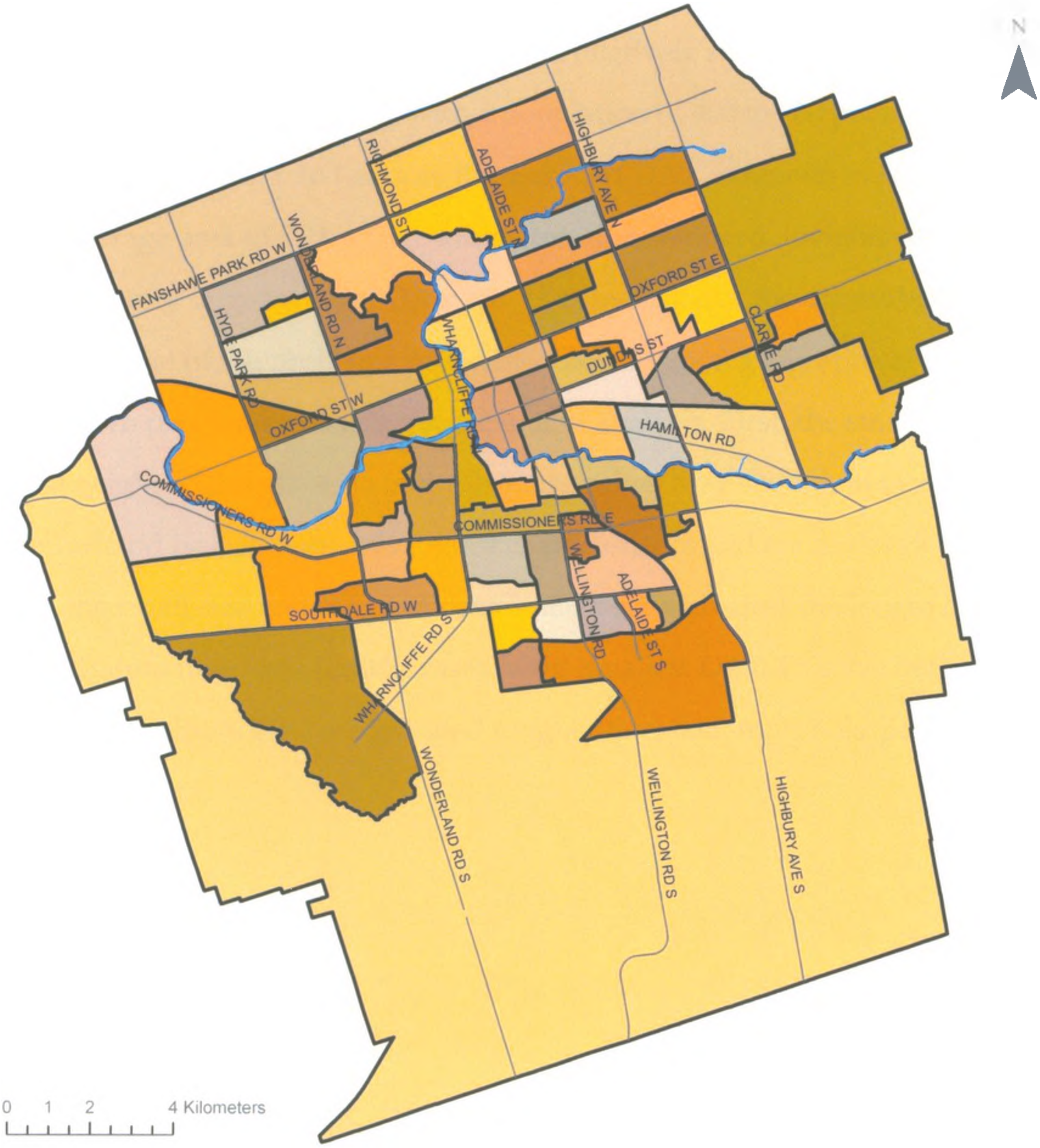


Figure 3-1: Census Tracts in London, Ontario

3.2.1.2.2 Dissemination Areas

A dissemination area (DA) is a "small, relatively stable geographic unit composed of one or more blocks, with a population of 400 to 700 persons" (Statistics Canada, 2006). In London, there are 541 DAs, as shown in Figure 3-2, with an average area of 0.78 square kilometres and standard deviation of 3.5, indicating a very large range of DA sizes. The small size of the dissemination area solves most of the problems posed by other common geographical units but raises its own problems as a geographic unit of analysis. First, the small size cuts "natural neighbourhoods" into multiple parts, when they should, in fact, be one neighbourhood based on morphological characteristics and era of development. Second, the small size and range of sizes could pose statistical challenges because some indicators may have limited cases in the smallest DAs. To solve both of these issues, multiple DAs are grouped tougher to create 'morphological units' as described below.

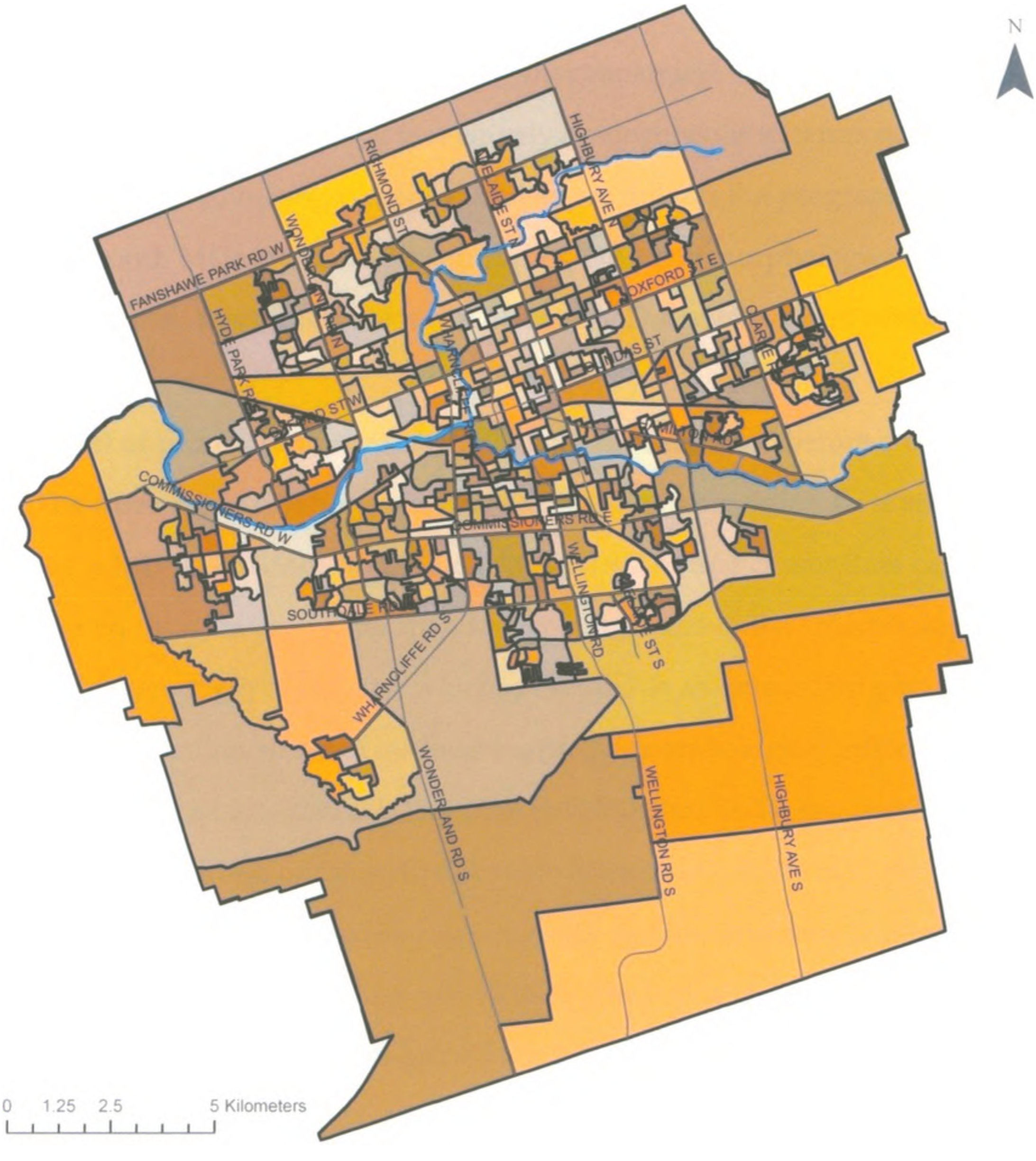


Figure 3-2: Dissemination Areas in London

3.2.1.3 The Morphological Unit

For the purpose of this research, a "morphological unit" (MU) is defined as a physical area of the city that is relatively homogeneous in terms of built form (e.g., street pattern, housing typology) and approximates the geographic size of a neighbourhood. MUs are created by grouping DAs into morphologically continuous units. Some MUs are made of a single DA, while others contain up to ten DAs.

A set of primary and secondary rules were established before creating the MUs. The three primary rules are applied in the following order. First and foremost, a MU must adhere to boundaries of DAs, so that census data can be incorporated into analysis. After that, MUs must adhere to the "morphological frame" (Conzen, 1969) of the city, which is defined as an antecedent plan feature, topographical outline, or set of outlines exerting a morphological influence on subsequent more or less conformable plan development and often passing its features on as inherited outlines. In this way, MUs must adhere to 1) rivers 2) rail lines, and 3) major roads. London has two major rail lines running through its core, and, while the southern line cuts all MUs, the northern line does not. This is due to the fact that the morphology on both sides of the line is consistent, and both sides are well connected by through streets. Therefore, this first rule does not apply in some of these areas. Second, the street configuration within the morphological unit must be consistent. This includes the basic street configuration (i.e., grid, non-grid), as well as street characteristics, such as intersection densities. Third, the age of development must be consistent. A morphological unit will have the majority of its structures completely developed within the same building boom. This measure is based upon the major era of development of the DA, as provided by Statistics Canada.

A second set of rules, or considerations, were also established. These considerations would only apply when not conflicting with one of the primary rules outlined above. In any order, the rules are as follows: morphological units should have similar dwelling-type mix, uniform street network, similar development densities, and a compact size.

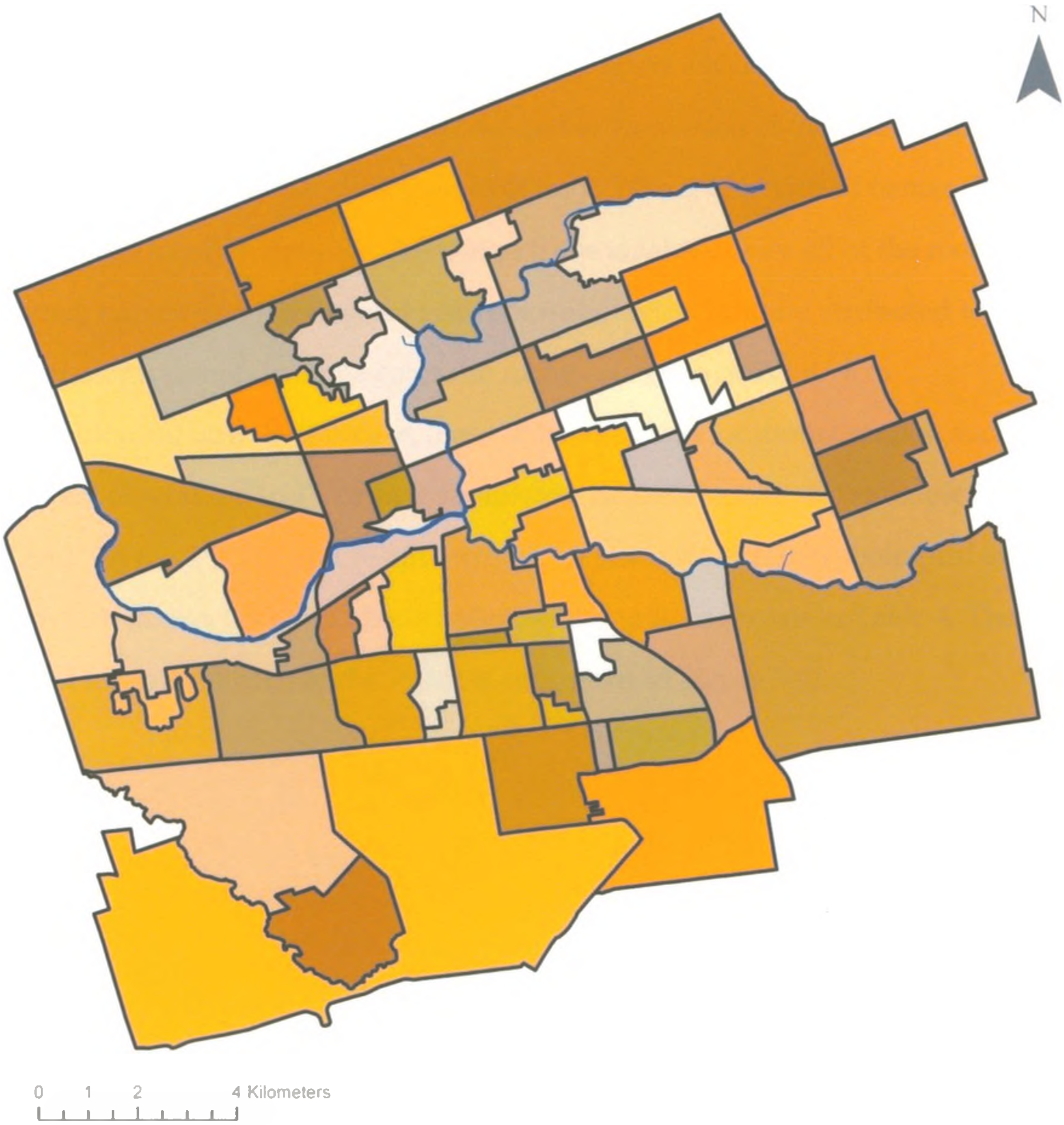


Figure 3-3: Morphological Units (MUs) in London

Using the above rules, 78 MUs were created (Figure 3-3). A unique ID is given to each morphological unit, along with a "popularized" neighbourhood name derived from local knowledge and a series of map sources (e.g., Rand McNally, Map Art, Fast Track, and City of London maps). Neighbourhood classification is subjective, and it would be impossible to properly name each morphological unit with a popularized name upon which everyone would agree. Nevertheless, all of the neighbourhood names from each of the three maps are plotted on top of the morphological unit map. Where locations of names differed, the average location between the two or three is taken. Once all of the names are plotted, names that fell closest to each morphological unit are attributed to that morphological unit. In some cases, no name existed to attribute to a morphological unit. In this case, these units are given locational names, such as to "west of wonderland", or neighbourhood names are split, for example, "Byron 1" and "Byron 2". The end result attributes a name to each morphological unit ID, which allows for easer identification of the unit, as shown in Table 4. The spatial location of each of the 78 MUs are shown in Figure 3-4.

Table 3-1: MUs IDs and Names

Morphological Units			
Unit ID	Unit Name	Unit ID	Unit Name
1	Argyle	40	Oakridge Park
2	Argyle Park	41	Oakridge Riverside
3	Baseline West	42	Old East
4	Baseline East	43	Old North
5	Berkshire Village	44	Orchard Park
6	Blackfriars	45	Oxford Park
7	Breughdale	46	Parkview
8	Byron	47	Peppertree Estates
9	Byron North	48	Pottersburg
10	Byron South	49	Pond Mills
11	Carling	50	Ridgeview Heights
12	Carling Heights	51	Riverbend
13	Chelsea Green	52	Rivervalley North
14	Cheardale	53	Sherwood Forest
15	Crumlin	54	Southcreek
16	Downtown	55	Southdale
17	Downtown North	56	South Winds
18	Downtown South	57	Springbank West
19	East of Old East	58	Springbank East
20	Fairmont	59	Stoneybrook Acres
21	Forward	60	Stoneybrook Meadows
22	Gainsborough Meadows	61	Summerside
23	Glencairn	62	Sunningdale
24	Glendale	63	The Gore
25	Hamilton Road	64	The Ponds
26	Hazelden	65	Trafalgar Heights
27	Huron Heights	66	University Heights
28	Hyde Park	67	Uplands Northcrest
29	Kensal Park	68	Wellingsbore
30	Knollwood Park	69	Wellington
31	Lambeth South	70	West of Wonderland
32	Lockwood Park	71	Westminster Park
33	London Junction	72	Westmount
34	Masonville	73	Whitehills
35	Medway Heights	74	Whiteoak
36	Melwin Heights	75	Wilton Grove
37	Nelson Park	76	Woodbank
38	North Park	77	Old South
39	Norton Estates	78	Lambeth North

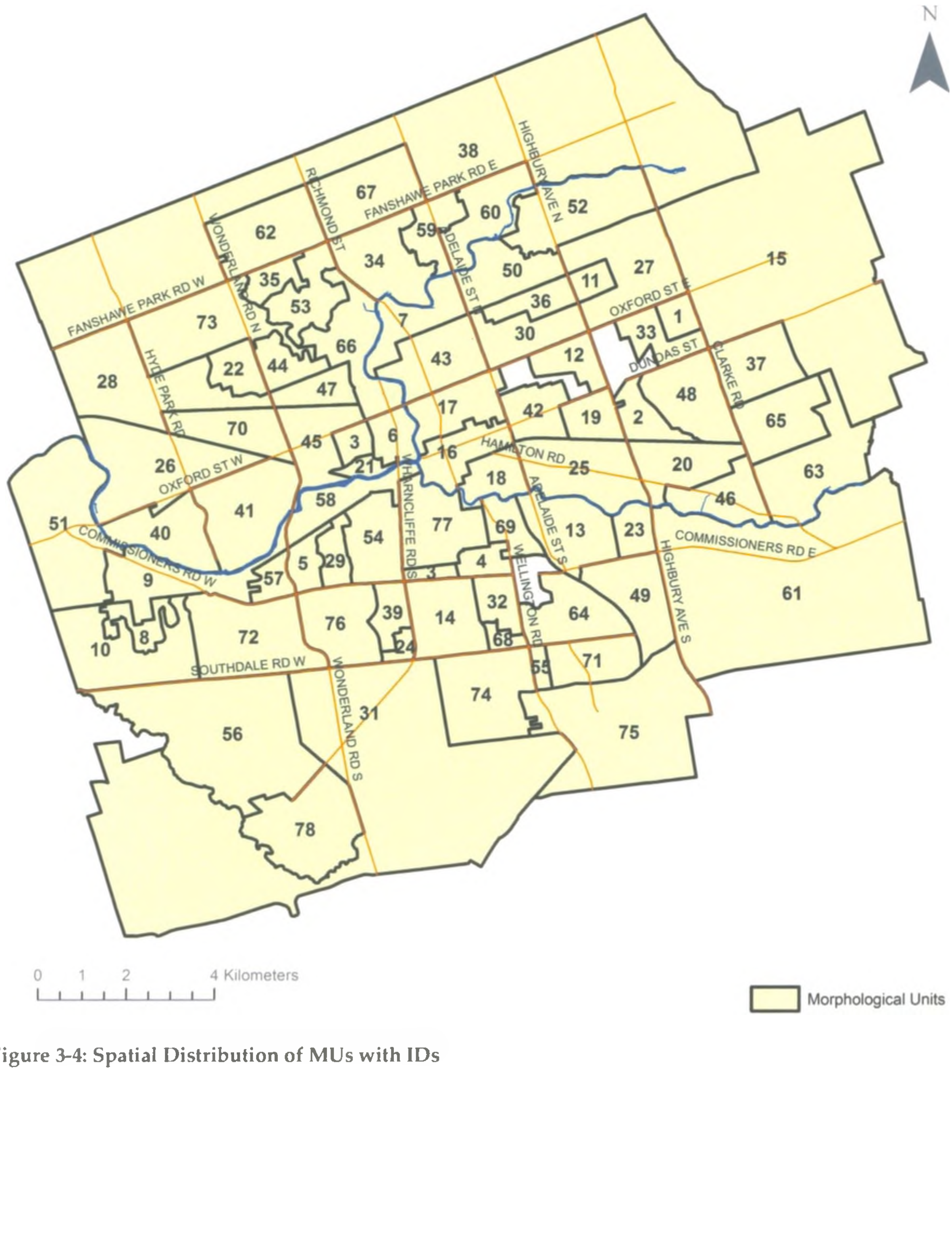


Figure 3-4: Spatial Distribution of MUs with IDs

3.2.2 Geographic Units of Analysis in Southwestern Ontario

Southwestern Ontario contains six CMAs: Windsor, Sarnia, London, Brantford, Kitchener-Waterloo, and Guelph. CTs were chosen as the geographic unit of measure in the Southwestern Ontario study due to a multitude of factors. First of all, no standardized boundaries exist for neighbourhoods in Southwestern Ontario, and data are not readably available for calculating morphological units, as was done for London. Dissemination areas are too small to be used as neighbourhood boundaries because they comprise a very small number of persons and do not complete neighbourhoods. Furthermore, as the methodology should be repeatable, CTs made sense to use because they are familiar to researchers and correspond to available census data. Not all census tracts are used in this analysis, however. Of the 350 CTs in the Southwestern Ontario CMAs, 35 CTs are removed because they were rural in nature. To determine if a CT is rural, the DMTI land-use file is laid over census tracts. CTs which had 0 residential, commercial, industrial, or institutional land uses in them (and thus 100% agricultural) are removed. This leaves 315 urban CTs to be analyzed.

3.2.3 Limitations and Considerations with the Container Approach

Using the container approach has many advantages and disadvantages over other approaches. While using the container approach is deemed the best methodology for this type of study due to its focus on neighbourhood morphology, it comes with its own set of limitations. When aggregating data to a given aerial unit, or a container, the precision of individual-level data is lost, and so is the ability to assess spatial and statistical trends found at that level. When aggregating a large number of data into a single aerial unit, any variation within that aerial unit is lost. While the standard deviation and distribution table gives an indication of this variation, its actual statistical and spatial relevance are lost.

Aggregating and reporting data by morphological units usually derives a mean or a maximum value. The mean is shown with its standard deviation. Smaller standard deviations indicate that the mean value is representative of the container. However, larger standard deviations indicate wide variation of data within the container, and, thus, much less confidence can be placed on the significance of the mean. In these cases, the container's boundaries could be adjusted to lower the standard deviation. No such action is taken in this thesis because one container may have very small standard deviations of one variable and large standard deviations of another variable.

3.2.4 Map Design and Data Display

The results of various analyses (shown in chapters 4 and 5) were obtained using ArcGIS 9.3 (ESRI). ArcGIS offers five statistical classification methods for displaying data: equal interval, quintile method, natural breaks, geometric interval, and standard deviation. Depending on the distribution of the data, one of two classification schemes is used. If the data are normally and evenly distributed over their range, the equal interval scheme is used because it is best suited for this type of data and will minimize any bias in the display. If the data are not normally and evenly distributed over their range, the geometric interval scheme is used because it will handle this type of distribution the best and produce a map that best shows the data distribution.

Equal interval divides the range of attribute values into equal-sized sub ranges, allowing the user to specify the number of intervals while ArcMap determines where the breaks should be. For example, if features have attribute values ranging from 0 to 300 and three classes are chosen, each class represents a range of 100 with class ranges of 0–100, 101–200, and 201–300. This method emphasizes the amount of an attribute value relative to other values, for example, to show that a store is part of the group of stores that made up the top one-third of all sales. It's best applied to familiar data ranges, such as percentages and temperatures.

The geometric interval is a classification scheme in which the class breaks are based on class intervals that have a geometrical series. The geometric coefficient in this classifier can change once (to its inverse) to optimize the class ranges. The algorithm creates these geometrical intervals by minimizing the Square sum of elements per class. This ensures that each class range has approximately the same number of values within each class and that the change between intervals is fairly consistent. This algorithm is specifically designed to accommodate continuous data. It produces a result that is visually appealing and cartographically comprehensive.

3.2.5 GIS Terms

Throughout the thesis, numerous GIS terms are used. Descriptions of these terms are provided below.

3.2.5.1 Spatial Join

The spatial join operation in ArcGIS is used to combine two or more datasets with respect to a spatial predicate. The predicate can be a combination of directional, distance, and topological spatial relations. In case of a non-spatial join, the joining attributes must be of the same type, but for a spatial join they can be of different types.

A join by location, or a spatial join, joins a point layer and a polygon layer in the attribute table. The join appends the attributes of the 1st point in the point layer that falls inside each polygon in the polygon layer.

An example of this is joining areas of water to a neighbourhood polygon. The areas of only those water areas that fell within the polygon would be attributed to the polygon. These areas could be summed to determine the total water area in the neighbourhood polygon. If a water area spanned across multiple polygons, it would first have to be cut across the polygon boundaries before being spatially joined.

3.2.5.1 Buffer

A buffer in ArcGIS is simply an area drawn around an existing line, point, or polygon as a user-defined distance. Unless otherwise stated, all buffers are drawn in a circular radius around a point or follow the contours of the polygon.

The remainder of the methods section discusses in detail the data requirements and methods used to create each performance indicator. This section is broken into street "performance indicators", block performance indicators, lot performance indicators, building performance indicators, and land-use performance indicators.

3.3 Street Performance Indicators

A street or road is a public thoroughfare for movement within an urban area. Streets are public parcels of land on which people may freely assemble, interact, and move about. Street performance indicators are calculated using a variety of data sources. In London, the 2009 City of London street centerline file, as shown in Figure 3-5, is used to calculate intersection density and street length. The 2009 street polygon file, as shown in Figure 3-6, is used to determine street density and street width. The 2006 DMTI road file, as shown in Figure 3-7, is used for the identification of arterial street proportion indicator. Furthermore, the City of London 2006 sidewalk centerline file (Figure 3-8) is used to determine the sidewalk-to-street ratio, and the City of London 2006 bike path file (Figure 3-9), is used to create the pathway-to-street ratio. These 2006 files are the latest available for the City of London.

A variety of measures based on the theories of space syntax (defined later in this chapter) are also conducted for London. These measures use "axial lines" (defined later in this chapter) as their input, which are created by using the 2008 aerial photograph and the 2008 street polygon file.

Street performance indicators for the six CMA study in chapter 5 were calculated using the DMTI street file for 2006 because it is the only street file that is available and consistent for the entire area. Therefore, a limited number of street measures are conducted in the six study cities in Southwestern Ontario, compared to London.

Figure 3-5: Sample of Single Line 2009 Layer
(Source: the City of London)

Figure 3-6: Sample of Road Polygon 2009 Layer
(Source: the City of London)

Figure 3-7: Sample of 2006 DMTI Road Layer
(Source: DMTI)

Figure 3-8: Sample of 2006 Sidewalk Layer
(Source: the City of London)

Figure 3-9: Sample of 2006 Multi Use Path and Bicycle Path Layer (Source: the City of London)

3.3.1 Intersection Density

The measure of intersection density was calculated using the DMTI road network file. The intersections were identified using a program (ArcScript) from ESRI, which was modified by Martin Healy to determine the number of streets that intersected, and the angles of intersection. Figure 3-10 shows an example of how these intersection points are displayed in ArcGIS in relation to the road network.

Figure 3-10: Identification Intersections

All intersection points are aggregated to the MU (London) or the CT (Southwestern Ontario) to derive the performance indicators for intersections.

Intersections are measured at the point at which three or more road segments meet (Figure 3-11). Endnodes (i.e., culs-de-sac) are not included in this measure. Intersections with four nodes are buffered by ten metres to correct for intersections where roads converged on an area, but did not perfectly align, and, thus, failed to be counted as a single intersection point (e.g. Figure 3-12).

Ten metre buffers are placed around each MU or CT to allow for intersections on the borders of two units to count for both. Finally, the intersections are spatially joined to the buffered containers. The number of intersections in each container is divided by the given container's area to calculate intersection density. A higher number indicates greater intersection density.

Figure 3-11: Sample of intersections with a valance of 2 or more

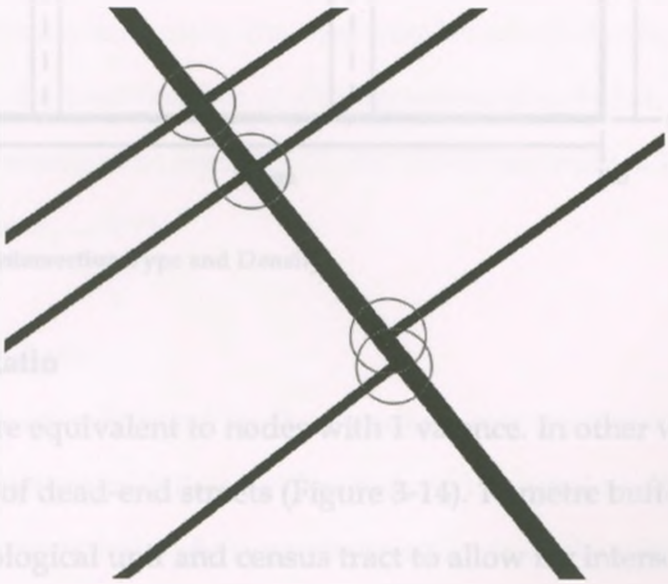


Figure 3-12: Buffering 4-node(X) intersections.
Ten metre radius buffers are placed around all 4-node(X) intersection. Intersections with intersecting buffers are counted as 1 X-intersections instead of 2 T-intersections (3-node intersection).

Intersection density is calculated as the number of >2-node intersections per square kilometre. The area of water bodies is excluded from the total area in these density calculations. For example, in Figure 3-13, the intersection density is 3 intersections per 100 square metres, or 0.03 intersections per square kilometre.

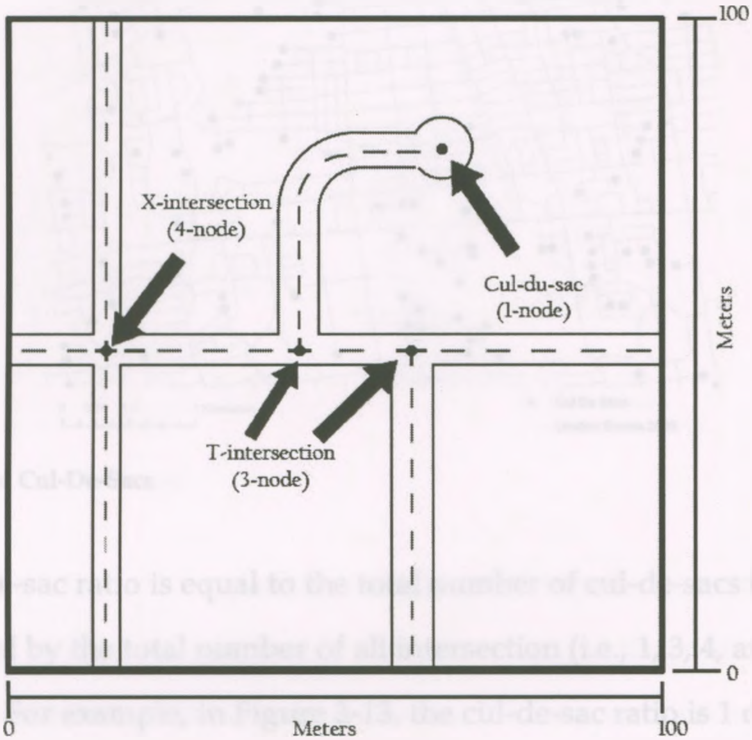


Figure 3-13: Schematic of Intersection Type and Density

3.3.1.2 Cul-De-Sac Ratio

Culs-de-sac are equivalent to nodes with 1 valence. In other words, these are nodes at the end of dead-end streets (Figure 3-14). 10 metre buffers are added around each morphological unit and census tract to allow for intersections bordering units to count in both. Finally, the culs-de-sac are spatially joined to the buffered containers. The number of culs-de-sac in each container is divided by the total number of intersections to calculate the cul-de-sac ratio.

Figure 3-14: Sample of Cul-De-Sacs

The cul-de-sac ratio is equal to the total number of cul-de-sacs in the given container divided by the total number of all intersection (i.e., 1, 3, 4, and 5–node) in the container. For example, in Figure 3-13, the cul-de-sac ratio is 1 cul-de-sac per every 4 intersections, or 25%

3.3.1.3 T-Intersection Ratio

T-intersections are calculated by three road segments intersecting (Figure 3-15). Ten metre buffers are added around each morphological unit and census tract to allow for intersections bordering units to count in both units. Finally, the three-node intersections are spatially joined to the buffered containers. The number of three-node intersections in each container is divided by the given container's total number of intersections to determine the T-intersection ratio.

Figure 3-15: Sample of T-intersections

The T-intersection ratio equals the number of T-intersections in the container divided by the total number of all intersections in the container. For example, in Figure 3-13, the T-intersection ratio is 2 T-intersections for every 4 intersections, or 50%.

3.3.1.4 X-Intersection Ratio

X-intersections are calculated by four road segments intersecting at a node (Figure 3-16). T-intersections are buffered by ten metres to correct for intersections that had roads that do not perfectly align and, thus, failed to be counted as a single X-intersection point. Furthermore, ten metre buffers are added around each morphological unit and census tract to allow for intersections bordering units to count in both. Finally, the four-node intersections are spatially joined to the buffered containers to allow for statistical analysis. The number of four-node intersections in each container is divided by the given morphological unit's total number of intersections to determine the X-intersection ratio.

Figure 3-16: Sample of X-intersections

The X-intersection ratio equals the number of X-intersections divided by the total number of all intersections. For example, in Figure 3-13, the X-intersection ratio is 1 X-intersection for every 4 intersections, or 25%.

3.3.2 Street Segment Length

Street segment length is calculated using the 2009 City of London road network file for London, and the DMTI road network file is used for the CMAs in Southwestern Ontario. The lengths of these street segments are calculated within ArcGIS and then aggregated to the morphological unit or the census tract to produce descriptive statistics.

3.3.3.1 Average Street Segment Length

Street segments are measured from node to node (i.e., end to end). The average street segment length is measured by calculating the length of each individual street segment in the given MUs (London) or CTs (Southwestern Ontario). Ten metre buffers are added around each container to allow for street segments bordering two units to count in both. The street segments are then spatially joined to the corresponding buffered container. The total length of street segments in each container is divided by the total number of street segments in that container to determine the average street segment length. For example, in Figure 3-17, the average street segment length is the sum of street segments A, B, C, D, E, F, G, and H divided by 8.

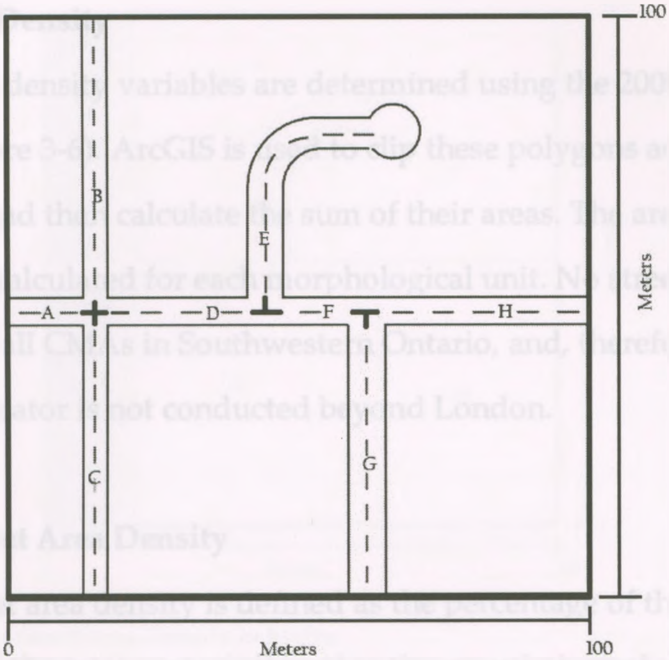


Figure 3-17: Schematic of Street Segment Length in Metres

3.3.3.2 Maximum Street Segment Length

Maximum street segment length reports the longest street segment in the given container. The maximum street segment length is measured by calculating the length of each individual street segment and then identifying the longest street segment in each MU (London) or CT (Southwestern Ontario CMAs). Ten metre buffers are added around each aerial unit to allow for street segments bordering units to count in both. For example, in Figure 3-17, the maximum street segment length is the maximum of street segments A, B, C, D, E, F, G, and H.

3.3.3 Street Area Density

Street area density variables are determined using the 2009 City of London polygon file (Figure 3-6). ArcGIS is used to clip these polygons according to the MU boundaries and then calculate the sum of their areas. The area of the street polygons is then calculated for each morphological unit. No street polygon file was available for all CMAs in Southwestern Ontario, and, therefore, this performance indicator is not conducted beyond London.

3.3.3.1 Gross Street Area Density

Gross street area density is defined as the percentage of the total area of paved streets and the total area of all land in the morphological unit. Gross street area density is measured by calculating the area of each individual street polygon and then aggregating all of the street polygons to the respective MUs. Ten metre buffers are added to each morphological unit to allow for street polygons bordering two units to count in both. Within ArcGIS, the street segments are spatially joined to the buffered MUs in order to calculate the gross street area density.

In Figure 3-18, the gross street area density is the sum of the areas of street segments A, B, C, D, E, F, G and H divided by the area of 100 m^2.

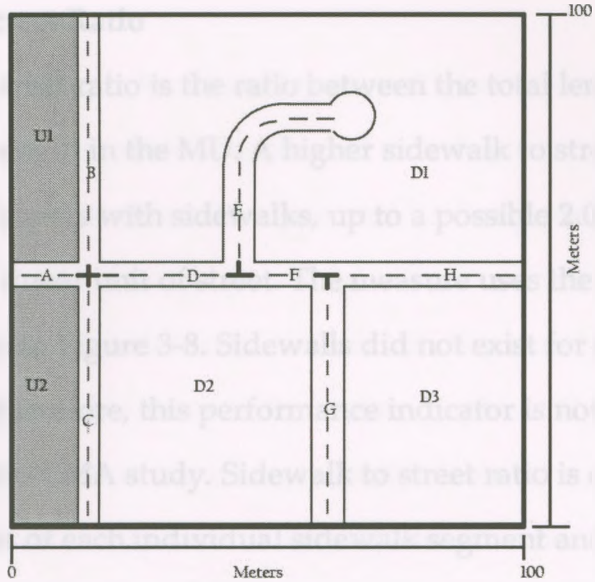


Figure 3-18: Diagram of Street Area Density in Metres

3.3.3.2 Net Street Area Density

Net street area density is defined as the percentage of the total area of paved streets and the developed area of all the land in the MU. Net street area density is measured by calculating the area of each individual street polygon and then aggregating all of the street polygons to the MUs. Ten metre buffers are added to each morphological unit to allow for street polygons bordering two units to count in both. Within ArcGIS, the street segments are spatially joined to the buffered MUs in order to calculate the net street area density. In Figure 3-18, the net street area density is the sum of the areas of street segments A, B, C, D, E, F, G and H divided by the area of 100 m² minus undevelopable areas of U1 and U3.

3.3.4 Sidewalk to Street Ratio

Sidewalk to street ratio is the ratio between the total length of sidewalks and the total street length in the MU. A higher sidewalk to street ratio indicates greater coverage of streets with sidewalks, up to a possible 2.00 linear units of sidewalks for every linear unit of street. The measure uses the 2006 sidewalk centerline file shown in Figure 3-8. Sidewalls did not exist for other Southwestern Ontario cities, and, therefore, this performance indicator is not in the Southwestern Ontario CMA study. Sidewalk to street ratio is calculated by summing the lengths of each individual sidewalk segment and street segment and then aggregating the sidewalk and street segments to the MUs. 10 metre buffers are added to each morphological unit to allow for sidewalks and streets bordering two units to count in both. The sidewalk and street segments are spatially joined to the buffered morphologic units. In Figure 3-19, the sidewalk to street ratio is the sum of sidewalk segment lengths a, b, c, d, and e divided by the street segment lengths A, B, C, D, E, F, G, and H.

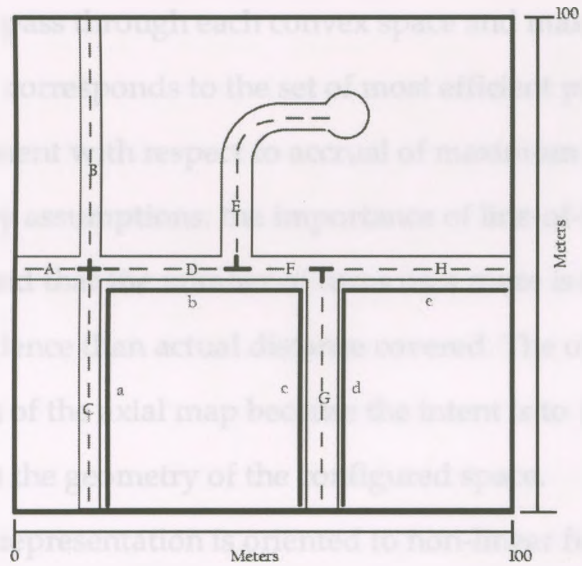


Figure 3-19: Diagram of Sidewalks (Grey) and Streets

3.3.5 Space Syntax

Space syntax methods are based on a topological representation of the "public," or "free", space in which people and vehicles circulate. As we move through a space, at most locations, the space can be comprehended as a "vista", which can be roughly represented by a straight line. An urban environment consists of two parts: spatial obstacles, such as buildings, and free space within which human beings are able to move from place to place. The notion of free space is defined as the parts of an urban space available for movement of people. Space syntax focuses on free space and decomposes an area of free space into small pieces of space, each of which can be perceived from a single vantage point. As such, this representation constitutes the cognitive modeling reference of the space syntax approach.

In space syntax, space is divided into two classes: two dimensional convex spaces and one-dimensional axial lines. The convex map decomposes open space into the least set of "fattest" convex spaces; the axial map comprises the least set of straight lines that pass through each convex space and makes all the axial links. The axial map corresponds to the set of most efficient potential paths through an environment with respect to accrual of maximum visual information and relies on two key assumptions: the importance of line-of-sight as an organizing device, and that the number of turns on a route is more crucial to human spatial experience than actual distance covered. The object of analysis is the abstracted graph of the axial map because the intent is to investigate the topology rather than the geometry of the configured space.

Space syntax representation is oriented to non-linear free space, with precise spatial representation. This representation is based on the notion of an isovist, which is defined as a visual field that is wholly visible from a single vantage point (Jiang et al., 2000).

An axial map of a circulation network is a representation that comprises the fewest longest lines of sight and movement, or visibility and permeability, which are necessary to cover the area of interest. The number and length of axial lines in the map are functions of the degree to which other parts of the system are directly accessible and visible from various points. Axial lines are straight because a straight line is the only path of movement that we are sure to see all at once from any point (Hillier & Hanson, 1984). Axial distance is not a metric distance but a topological distance. Two individuals standing at the end of an axial line will be able to see each other. The intent of measuring axial lines is that changes in direction and the presence of intervening streets are more likely to affect an individual's sense of orientations within a complex plan than sheer length of streets (Hillier & Hanson, 1984). The axial lines are used to calculate a set of measurements of syntactical properties of space (Hillier & Hanson, 1984). Each measure is assigned to each axial line on the map. Commonly calculated syntactical measures include connectivity, control, and integration, which are defined later in this section.

For urban morphological analysis, space syntax provides a range of spatial property parameters derived from a connectivity graph (Jiang, 2000). First, connectivity is the most apparent parameter for morphological analysis. Connectivity is defined as the number of nodes directly linked to each individual node in the connectivity graph. In the simplest sense, the connectivity of a line (roadway, alley, or trail) is the number of lines that are directly connected to it.

A modification of connectivity is control, which measures the degree to which a line controls access to its immediate neighbours-taking into account the number of alternative connections that each of these neighbours has (Klarqvist, 1993). Simply, the control value represents the degree to which a line is important for accessing neighbouring lines. A high control value indicates that the line is an important, almost necessary, link for neighbouring lines. Control is defined as a parameter that expresses the degree of choice each node represents for nodes directly linked to it. The control value (*crtl*) of a node (*i*) is determined according to the following calculation:

$$ctrl_i = \sum_{j=1}^{k} \frac{1}{C_j}$$

Equation 1: Control

Integration is an indicator of how easily one can reach a specific line of the axial map. Mathematically, integration is an algebraic function of the number of axial lines that must be traversed if one is to move from every line (street) to every other line (street) in the axial map. The higher the integration value of a line, the lower the number of axial lines needed to reach that line. For a given line, integration can be computed in terms of access from all other lines (called global integration), or in terms of those lines that are accessible up to a given number of lines away (called local integration). In syntactical analysis this is called the radii. If we limit the analysis to radius of 3, it means that the integration measure for a line will be calculated by considering only lines that are up to three turns away. Therefore, local integration can be a measure of local syntactical accessibility if the radii are small (Hillier, 1998), and global integration can be a measure of general syntactic accessibility if the radius considers all lines in the axial map (Peponis & Wineman, 2002). The axial line with the highest degree of global integration is the one that can be accessed with the least number of turns from all other axial lines. By contrast, an axial line that requires many turns to get to it from all other lines in the system is considered to have low syntactical accessibility and will have a low global integration value. Similarly, an axial line with the highest local integration value is a line that is accessible with the least number of connections from all other lines in its surrounding. This study uses a measure of local integration (radius 3) and global integration.

Figure 3-20 displays an example of an aerial map for a section of streets surrounding the forks of the Thames in London. In space syntax, the street segments, or axial lines, are treated as "nodes" or "vertices", and the intersections between the axial lines are treated as the elementary relations between spaces (Buckley & Haray, 1990). Because movement within a city can originate or terminate from any point along a street segment, it is reasonable to assume that the axial line or street segment itself should be the reference point for analysis. As Alexander (1979) noted, "the fewer the elements there are, the richer the relationships between them". The axial map is a simple picture that lets us grasp the whole of the network structure. It is this simplicity that has been the primary focus of criticism regarding space syntax analysis. It has been argued that by using a simple line representation of space, and then analyzing it topologically, space syntax ignores too much geometric and metric detail to be a credible measure of the accessibility of a specific location (Kropf, 1998). Further, Turner (2007) rejects the axial line altogether, instead using blocks as a basis of analysis. However, Hillier (1999) argues that "the 'line graph' internalizes axial lines into its structure of the graph and in doing so allows the graph analysis to pick up the nonlocal, or extrinsic properties of spaces that is critical to the movement dynamics through which a city evolves its essential structures". The "nonlocal" properties of an element are those that are defined by its relation to all others in the system. Because cities are essentially nonlocal systems, the method of space syntax offers an effective tool for understanding the underlying orderliness of urban space. Further, Penn (2008), in an attempt to question the use of the axial line, found that the movements of people in cities closely resemble the axial graph. Figure 3-21 displays an example of an axial map for the same area as Figure 3-20.

Figure 3-20: Sample of an Aerial Map showing Road Network

Figure 3-21: Sample of an Axial map

Space syntax techniques were not originally aimed at modeling urban circulation but at understanding the "spatial logic" of the urban grid (Hillier & Hanson, 1984). Nevertheless, numerous tests of the topological analysis with real-world observations have revealed that certain configurational properties of the street network are reliable predictors of patterns of pedestrian and vehicular movement. Based on a computation representation of the axial map as a graph, several useful measures of urban structure have been derived within space syntax. One of the most basic measures is how many other nodes are directly connected to each individual node.

The central concept of accessibility in space syntax is integration. Integration measures the relationship of each axial line to the network as a whole. The integration value of an axial line is a function of the minimum number of other axial lines that must be used in order to reach all other parts of the system from that axial line. Since integration is topological, not geometric, accessibility, the term depth (instead of distance) is typically used in space syntax studies to describe how far spaces lie from each other within a network. The depth of a node (axial line) is defined as the minimum number of steps required reaching all other axial lines, and is defined as:

$$\sum_{j=1}^{n} d_{ij}$$

Equation 2: Node Depth

in which *d(ij)* is the shortest path between two axial lines *i* and *j*. Alfonso Shimbel (1953), in his work on the structure of communication networks, called this measure dispersion *D*, and his "D-mark" is widely-used in communication and transportation applications of network analysis today (Wheeler & O'Kelly, 1999). In the context of special networks, Frank Harary (1959) referred to this measure as the status of a graph. Within space syntax, depth is calculated as mean depth (MD) for every axial line, as follows:

$$MD_i = \frac{\sum_{j=1}^{n} d_{ij}}{n - 1}$$

Equation 3: Mean Depth

in which *n* is the number of axial lines of the entire graph. According to Hillier and Hanson (1984), relations of depth involve "asymmetry" because a space is only deep from other spaces if it is necessary to pass through intervening spaces to reach them. In space syntax, a "normalization" procedure is used to remove the total depth calculation so as not to effect of the number of elements in the graph or the size of the city. This is done by comparing how deep the system is from a particular axial line with how deep or shallow it theoretically could be, by using the equation

$$RA_i = \frac{2(MD_i - 1)}{n - 2}$$

Equation 4: Relative Asymmetry

in which *RA* stands for the "relative asymmetry" of a line (Hillier & Hanson, 1983). This formula will give a value between 0 and 1, with high values indicating a space that is deep or segregated in the system, and low values representing a space that is shallow or integrated. When reporting results, it is common practice to use the reciprocal of this value, so that higher values correspond to higher integration, and lower values signify lower integration, which is arguably more intuitive. Relative asymmetry can, therefore, be thought of as a measure of integration: however, a further adjustment is made to allow for scale difference between axial maps:

$$RRA_i = \frac{RA_i}{D_n}$$

Equation 5: Real Relative Asymmetry

where *RRA* stands for real relative asymmetry, and *D* is the *RA* value for the root of a diamond-shaped system. Hillier and Hanson (1984) argue that this normalization procedure takes account of the fact that both buildings and settlements become relatively less deep as they grow, and, therefore, the D-value provides a standardized value for the integration parameter so that systems of different sizes can be compared. Figure 3-22 shows an example of the extent of the above computations on the axial lines sounding the forks of the Thames in London.

Figure 3-22: Sample of Space Syntax Output (Global Integration)

The axial map for the London, Ontario, 2008 road network is created using Axwomen, an extension for ArcView produced by Bin Jiang at the Centre for Advanced Spatial Analysis at University College London. To create a proper axial map, it is crucial that the original source map show accurate street locations and building footprints. Fortunately, the Human Environment Analysis Laboratory at the University of Western Ontario has access to parcel, block, and lot files, as well as high-resolution aerial photographs. These files are displayed in ArcGIS, and, using the Axwoman extension, axial lines are drawn over every street segment by hand.

The newest release of Axwomen by Jiang and Liu (2007) is based on the vector data structure of a GIS used to draw axial lines and compute space syntax. The structure of the space syntax implementation in GIS is shown in Figure 3-23, in which the main three functions are drawing, computation, and analysis.

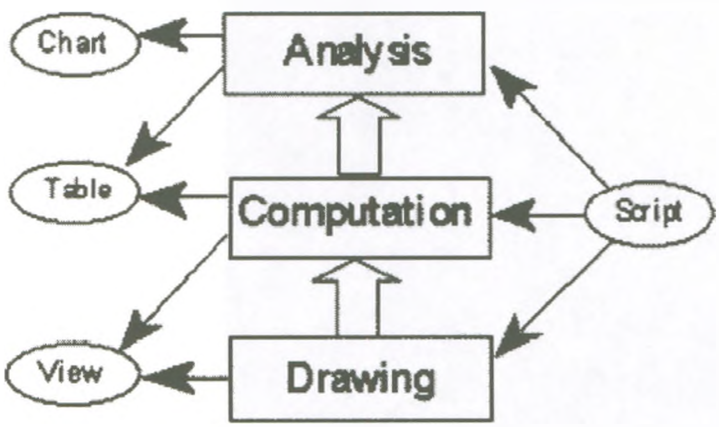


Figure 3-23: Structure of Axwomen
(Jiang and Liu, 2007)

Each axial line is drawn using the 2008 aerial photography coupled with the city's 2008 road file. In cases in which roads existed in the road file but are shown by the aerial photography to not yet be developed, axial lines are not drawn.

Ten metre buffers are added to each morphological unit to allow for axial lines between units to count in both. The space syntax axial lines are spatially joined to each buffered morphological unit, allowing for the median value in each to be derived.

3.3.5.1 Median Connectivity

The connectivity of an axial line measures the number of lines that directly intersect that given axial line. The connectivity of a single axial line must be a whole number greater than 1 because all roads must connect to at least one other road. A higher connectivity indicates greater density of streets and a higher likelihood of a grid street pattern. A sample map of connectivity lines can be viewed in Figure 3-24.

Figure 3-24: Sample of Connectivity Lines

In the example provided in Figure 3-25, the connectivity of axial line 1 is 4 because it intersects with 4 other axial lines. The median connectivity for the area is the middle number of the rank order of axial lines in each morphological unit.

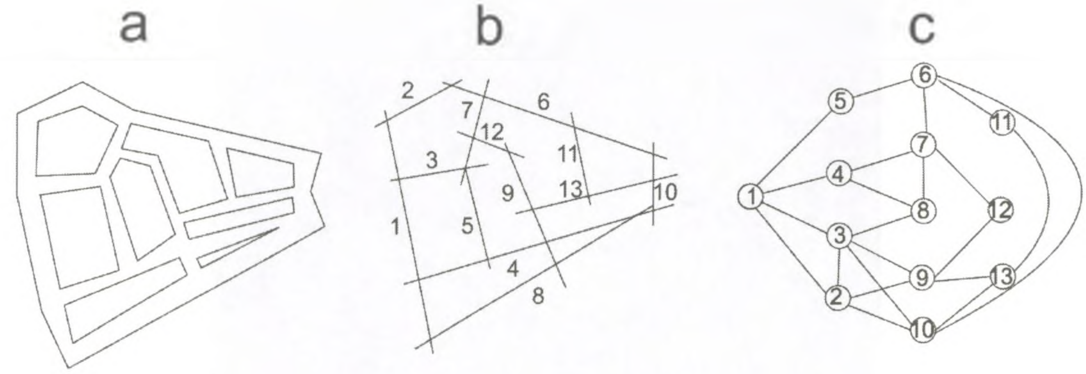


Figure 3-25: a) an urban system, (b) axial map, and (c) connectivity graph

3.3.5.2 Median Global Integration

Integration measures how many turns one has to make from a given street segment to reach all other street segments in the entire network, using the most direct route with the fewest possible turns. The global integration value of an axial line considers all neighbouring axial lines up to n (all) steps away. The first intersecting segment requires only one turn, the second two turns and so on. The street segment that requires the least amount of turns to reach all other streets is considered the most integrated. See Figure 3-26 for a sample of global integration lines.

Figure 3-26: Sample of Global Integration lines

3.3.53 Median Local Integration

The local integration value of an axial line considers all neighbouring axial lines up to three steps away. In this case, only three turns are counted departing from each street segment. If the amount of turns required for reaching three-segments away (valance of three) in the graph is analyzed, then the analysis are considered to measure iteration at a radius 'three'. See Figure 3-27 for a sample of local integration lines.

Figure 3-27: Sample of Local Integration lines

The local integration axial lines are spatially joined to each buffered morphological unit, allowing for the median value in each to be derived.

3.3.6 Average Street Width

The average street width for neighbourhoods in London was calculated using a two-step process. The first step was to use the 'lateral lines' ArcGIS extension to draw perpendicular lines from the 2009 London street network file to the front of each parcel (Figure 3-28). Once the lateral lines are drawn, they are cut to the road network, and then the average length of all the lines is calculated and attributed to the street segment. This average length is doubled and then spatially joined (through another lateral lines computation) to the DMTI street network to allow for further analysis. The results give a rough estimate of the average width of each road segment. Some segments, like those found in residential neighbourhoods, are extremely accurate due to their large amount of fronting parcels. Other street segments, like those found in industrial areas, are less accurate due to having low numbers of fronting parcels. This performance indicator is not conducted in the Southwestern Ontario study because a lot parcel file, which is used to make the lateral lines, is not available for all cities.

Figure 3-28: Lateral Lines

Depicting how lateral lines (red) are drawn outward from each road segment to the edge of the road. The length of these lines are averaged for each road segment, and then doubled to obtain a rough width of the road.

Ten metre buffers are added to each morphological unit to allow for streets between units to count in both, and street widths are spatially joined to the buffered morphologic units. The average street width is then derived by dividing the sum of all street segment widths by the total number of street segments in each morphological unit.

3.3.7 Proportion of irregular angled intersection

The average angular deviation at junctions is calculated by using a script provided by ESRI and modified by Martin Healy of the Human Environments Analysis Laboratory. The script counted how many streets intersected at each node and calculated the angles between them. All T (3-node), X (4-node), and 5-node intersections are included. For this study, intersections are considered irregular if they deviate from 90 degrees by 10 degrees or more.

3.3.8 Arterial Road Proportion

The DMTI street network includes a street classification system that categorizes streets into highways, arterial roads, and local roads. The highways are removed from this analysis, and the road classification system is used to determine the proportion of arterial roads to all roads (arterial roads and local roads combined) in a selected geographical unit.

Arterial road proportion is the ratio between the total number of arterial streets to the total number of streets within the MU of interest. Arterial proportion is measured by aggregating all of the street segments to the MU, with a 10 metre buffer around the MU to allow for street segments bordering units to count in both.

3.4 Block Performance Indicators

A city block, or urban block, is the smallest area surrounded on all sides by streets. City blocks are the space for buildings and open space within the street pattern of a city. They form the basic unit of a city's urban form. For the purpose of this thesis, major physical boundaries, such as rail lines and rivers, also help "frame" blocks.

All of the block performance indicators reported in this thesis use the 2006 Statistics Canada block file (Figure 3-29). The file is the latest file available and has a specific definition and creation rules.

It defines "a dissemination block" (DB) as an area bounded on all sides by roads and/or boundaries of standard geographic areas. The dissemination block is the smallest geographic area for which population and dwelling counts are disseminated. Dissemination blocks cover all the territory of Canada" (Statistics Canada, 2006).

To facilitate statistical analysis, the blocks are spatially joined to the MUs in the London study and the Census Tracts in the Southwestern Ontario study.

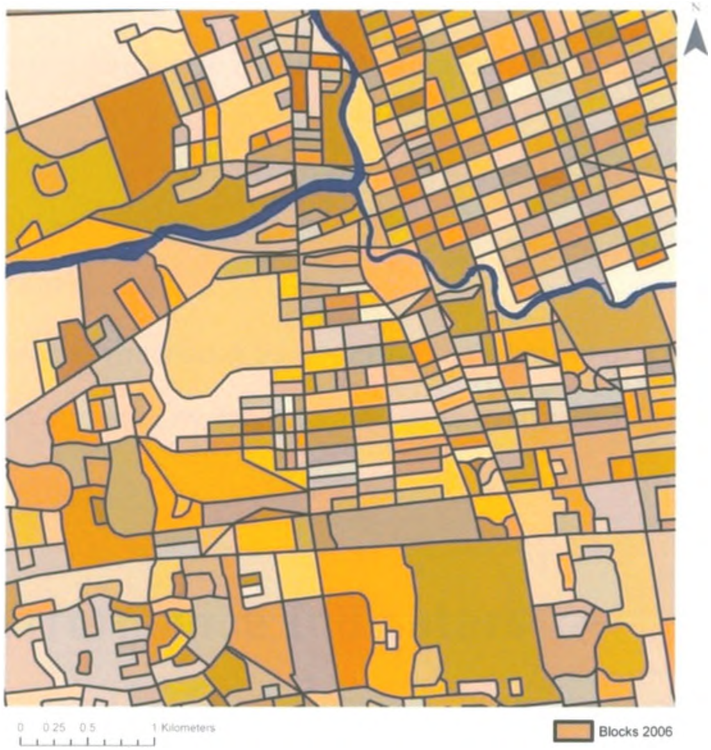


Figure 3-29: Example of Blocks
(Statistics Canada, 2006)

3.4.1 Block Size

Average and maximum block sizes are calculated using the 2006 DMTI block file for both London and other census cities in Southwestern Ontario.

3.4.1.1 Average Block Size

The average block size is determined by calculating the area of each individual block and then aggregating all of the blocks to the respective MUs (London) or CTs (Southwestern Ontario). The total area of blocks in each container is divided by the total number of blocks in that container to determine the average block size.

3.4.1.2 Maximum Block Size

The maximum block size is, simply, the area of the largest block in each container.

3.4.2 Block Density

Block Density is measured by counting the number of individual blocks in each MU and then dividing by the total MU area in square kilometres.

3.5 Lot Performance Indicators

A city lot, also referred to as a plot, tract, or parcel, is a piece of land owned or meant to be owned by a private citizen or a crown. A city block is divided into multiple lots. If two or more adjoining lots are owned by the same owner, the lots are amalgamated into one lot.

All of the lot performance indicators in London use the 2009 City of London parcel file (Figure 3-30). The file is the latest file available and was created by the City of London. A lot is not rateably available for cities outside of London, and, therefore, lot performance indicators are not calculated in the Southwestern Ontario study.

Figure 3-30: Example of Lots
(The City of London, 2009)

3.5.1 Lot Size

Average and maximum lot sizes are calculated using the 2009 block file for London.

3.5.1.1 Average Lot Size

The average lot size is generated by calculating the area of each individual lot and then aggregating all of the lots to the MU. The total area of lots in each MU is divided by the total number of lots in that MU to determine the average lot size.

3.5.1.2 Maximum Lot Size

The maximum lot size is, simply. the area of the largest lot identified in each MU following the procedures outlined above.

3.5.2 Average Lot Frontage

The average lot frontage is determined by measuring the street-facing side of each lot in the 2009 lot file. This is followed by joining this file to the MUs. The average lot frontage is calculated by dividing the total sum of lot frontages in each morphological unit by the total number of lots in that morphological unit.

3.5.3 Lot Density

Lot density is measured by calculating the number of individual lots in each MU and then dividing this number by the total area of the MU in square kilometres.

3.5.4 Lot to Block Ratio

The lot to block ratio is calculated by first joining the lots to the 2006 block file. This is followed by joining the block file to the MUs, and the total number of lots each MU is divided by the total number of blocks in that MU.

3.5.5 Proportion of Undeveloped Lots

The proportion of undeveloped lots is calculated by first joining the 2009 building file to the 2009 lot file to determine which lots have buildings (developed) and which lots do not (undeveloped), as shown in Figure 3-31. Those lots with buildings are removed from the lot layer, leaving only undeveloped lots. This is then followed by joining this undeveloped lot layer and the total lot layer to the MUs. The proportion of undeveloped lots is then calculated by dividing the number of undeveloped lots by the total lots in the morphological unit.

Figure 3-31: Example of Developed and Undeveloped Lots

3.6 Building Performance Indicators

A building is a human-made structure used or intended for supporting or sheltering a use. Buildings can take a multitude of uses, including residential, retail, office, and institutional. Buildings are usually contained by a single lot and usually do not span across blocks, roads, or rivers.

All of the building performance indicators use the 2009 structure file provided by the City of London (Figure 3-32). A building GIS is not available for cities outside of London, and, therefore, building performance indicators are not included in the Southwestern Ontario study.

Figure 3-32: Example of Buildings in London

3.6.1 Building Density

Building density is measured by calculating the number of individual buildings in an MU and then dividing by the total area of the MU in square kilometres.

3.6.2. Residential Buildings

To determine if a building is residential, the London's 2004 Land Use File (latest available to us) is joined to the building polygon layer (Figure 3-33). The residential buildings are then identified and spatially joined to the MU layer.

Figure 3-33: Sample of Residential Buildings

3.6.3.1 Residential Building Density

Residential building density is measured by calculating the number of individual residential buildings in a MU and then dividing by the area of the MU in square kilometres

3.6.3.1 Residential Building Proportion

Residential building proportion is determined by calculating the area of each individual residential building and dividing by the total area of all buildings in that MU.

3.6.3 Building Coverage Ratio (Building to Lot ratio)

The building coverage ratio is calculated by joining the buildings to the 2009 lot file. Lots with no buildings are removed. The total area of buildings in each morphological unit is divided by the total area of lots in that morphological unit to determine the building coverage ratio.

3.6.4 Size of Building Footprint

Building footprint measures are calculated using the 2009 structure file for London.

3.6.4.1 Average Building Footprint Size

The average building footprint size is calculated by calculating the area of each individual building footprint and then aggregating all of the building footprints to the MUs. The total area of building footprints in each morphological unit is divided by the total number of individual buildings in that morphological unit to determine the average building footprint size.

3.6.1.2 Maximum Building Footprint Size

The maximum building footprint size is single largest building footprint size in each MU.

3.6.5 Average Distance between Buildings

The average distance between buildings is calculated using a multi-stage process. First, the road is buffered with twenty flat-edge buffers for normal street segments or twenty circular buffers for dead-end streets. The buffers start at 14 meters away from the road, increasing by one-metre up to 34 metres. When these buffers intersected buildings, the areas within the buildings are removed. Left over are lines that stretch from the edge of one building to the edge of another. Depending on the distance of the buildings from the street and the size of the buildings, a set of buildings could have all twenty or a single buffer line between them. Furthermore, a single buffer line may pass through all of the buildings on the street or none at all. Of the twenty buffer lines, the line that passes through the most buildings is the buffer line used for each specific street segment.

3.6.6 Average Number of Buildings per Lot

The average number of buildings per lot is calculated by joining the buildings to the 2009 lot file and then dividing the total number of buildings in each morphological unit by the total number of lots in that morphological unit.

3.6.7 Average Number of Buildings per Block

The average number of buildings per block is measured by joining the buildings to the 2006 block file, and then dividing the total number of buildings in each morphological unit by the total number of blocks in that morphological unit.

3.6.8 Average Building Setback

The average building setback is calculated by extending lateral lines from the center of the street-facing lot line (using the 2009 lot file) to the front of the building. The length of these lines for each building is the building setback. Lots without buildings are excluded from this measure.

3.7 Land Use Performance Indicators

Land use, in its most basic sense, is the human modification of the natural environment into the built environment. In Canada, when this transformation occurs, the land is normally attributed a specific use based on the city's Official Plan and professional planners' advice. These specific uses are called zoning designations and come with their own list of approved uses that can legally operate on that parcel of land.

Every parcel in London has a specific land use designation, beginning with the general land use function (e.g., residential), and then subdividing this into multiple specific functions (e.g., multi-family residential).

All of the land-use performance indicators in the London study use the 2002 London Ontario land use file, as shown in Figure 3-34. The file is the latest file available to use and has been carefully checked for errors by researchers in the Human Environment Analysis Laboratory. For this research, specific land use codes are aggregated into general land use codes: residential, commercial, recreational, industrial, institutional, and agricultural. Other more specific codes have been used in this analysis, including retail, parks, and single family residential.

All of the land use performance indicators in the Southwestern Ontario study use the 2006 DMTI land use file. While this file is newer than the London file, it has many more errors in its classification of land use and, thus, is deemed inferior to the 2002 London land use file. As another land use file for cities outside of London is not readily available to use. The DMTI land use file is the only file that can be used for the Southwestern Ontario analysis. While the file does have some problems with its classification scheme and area boundaries, it should be assumed that these errors will be standard across all cities and, thus, will have little impact on comparisons among and between cities. The DMTI land use file attributes a land use code to polygons across the CMAs, with the following categories: (1) commercial, (2) government and institutional, (3) open area, (4) parks and recreational, (5) residential, (6) resource and industrial, and (7) water body.

Each of the above land use categories are summed and averaged within the MUs or Census Tracts.

Figure 3-34: Example of different land use mix in London
(Source: City of London, 2002)

3.7.1 Commercial Land Use

For the purpose of this research, two dimensions of commercial land use are considered: the proportion of commercial land use and the retail land use proportion.

3.7.1.1 Commercial Land Use Proportion

Commercial land use incorporates retailing, office, and service functions. The commercial land use proportion is determined by calculating the area of each individual commercial lot and then aggregating all of the commercial lots to the morphological unit or the census tract. The total area of commercial lots in each container is then divided by the total area of all land use lots in that container to determine the commercial land use proportion.

3.7.1.2 Retail Land Use Proportion

Retail land use is commercial land that incorporates retailing activates, such as shops and malls. Retail classifications are not included in the Southwestern Ontario study because the land use file did not include a distinct retail category. Retail land use proportion is determined by calculating the area of each individual retail lot and then aggregating all of the retail lots to the MUs. The total area of retail lots in each morphological unit is then divided by the total area of all lots in that morphological unit to determine the retail land use proportion.

3.7.2 Recreational Land Use

Two aspects of recreational land use are considered in this research: 1) the proportion of recreational land use, and 2) the proportion of land use dedicated to parks.

3.7.3.1 Recreational Land Use Proportion

Recreational land use incorporates activities such as sports and leisure facilities. Most recreational land is public space and is usually designed as parks or sports facilities. Recreational land use proportion is determined by calculating the area of each individual recreational lot, aggregating all of the recreational lots to the MUs, and then dividing the total area of recreational lots in each morphological unit by the total area of all land use lots in that MU.

3.7.3.2 Park Area Proportion

Park land use is always publicly owned and is often covered with vegetation (grass and trees). Park land use proportion is determined by calculating the area of each individual park lot and then aggregating all of the park lots to the MUs or CTs. The total area of park lots in each container is then divided by the total area of all land use lots in that container.

3.7.3 Urban Water Coverage Proportion

Urban water is always publicly owned and, in London's case, is largely dominated by the Thames River. Urban water coverage is measured first by cutting water lots along MU or CT boundaries, then by calculating the area of each individual urban water lot, and finally by aggregating all of the urban water lots to the MUs and CTs. The total area of urban water lots in each container is then divided by the total area of all land use lots in that container.

3.7.4 Industrial Land Use Proportion

Industrial land use deals with production, including factories, assembly plants, and warehouses. Industrial land use proportion is determined by calculating the area of each individual industrial lot and then aggregating all of the industrial lots to the MUs and CTs. The total area of industrial lots in each container is divided by the total area of all land use lots in that container.

3.7.5 Institutional Land Use Proportion

Institutional land use is land use designed to deal with public goods including schools, hospitals, and churches. Institutional land use proportion is determined by calculating the area of each individual institutional lot and then aggregating all of the institutional lots to the MUs and CTs. The total area of institutional lots in each container is divided by the total area of all land use lots in that container.

3.7.6 Residential Land Use

For the purposes of this research, two dimensions of residential land use are considered to be the proportion of residential land use and the proportion of single, detached, residential units.

3.7.6.1 Residential Land Use Proportion

Residential land use is land use designed to deal with the home/private lives of citizens. Residential land use proportion is determined by calculating the area of each individual residential lot and then aggregating all of the residential lots to the MUs or CT. The total area of residential lots in each container is divided by the total area of all land use lots in that container.

3.7.6.3 Proportion of Residential Land Use that is Single Family

The proportion of residential land use that is single family is determined by calculating the area of each individual single family residential lot and then aggregating all of the residential lots to the MUs. The total area of single family residential lots in each morphological unit is then divided by the total area of all residential use lots in that MU.

3.8 Statistical and Spatial Analysis

All morphological elements in both the London and Southwestern Ontario study are tested with Spearman's rank correlation. Spearman's correlation coefficient, r, is a non-parametric statistic and, so, can be used when data, like most data used in this study, have violated parametric assumptions, such as non-normally distributed data. Spearman's test works by first ranking the data and then applying Pearson's equation (the standard parametric correlation test) to those ranks. Pearson's correlation is the standard and most widely used parametric correlation test.

SPSS is used to calculate Spearman's correlation coefficient on all variables paired with every other variable. If the significance value for a correlation coefficient is less than 0.05 (95%), it can be concluded that there is a significant relationship between the two variables. This study takes this a step further by only accepting significance at the 0.01 (99%) level. The relationship can be positive in nature, in that an increase in one variable will increase the second, or negative in nature, in that an increase in one variable will decrease the second.

Although direct conclusions about causality cannot be made, the correlation coefficient can be squared to produce the coefficient of determination, or R^2. The coefficient of determination is a measure of the amount of variability in one variable that is explained by the other. It should be noted that although R^2 is an extremely useful measure of the substantive importance of an effect, it cannot be used to infer causal relationships.

The results chapters that follow examine each variable in detail. For each morphological performance indicator, an analysis of the significant Spearman's correlation for both independent and dependant variables is conducted. While the relationships with the independent variables are the most important, it is interesting to see which morphological variables significantly correlate with others. Significance in these cases is always at the $p<0.01$ level (99%), and significance in both the positive and negative directions will be addressed.

3.9 Conclusion

The purpose of this chapter was to identify and outline the methods and data sources used in analysing morphology in the upcoming results chapters. This chapter first began with a discussion on aggregating morphology for analysis, which outlined the container approaches used in both the London and six CMA study. Limitations to this approach were discussed, followed by a discussion on map design and data display. GIS terms were outlined, followed by a discussion on the methodology of creating individual performance indicators. These performance indicators were grouped into categories of streets, blocks, lots, buildings, and land use performance indicators. The following two chapters use this methodology and grouping system to quantify the urban morphology of South-western Ontario at the neighbourhood level.

CHAPTER 4 ASSESSING URBAN FORM IN LONDON, ONTARIO

4.1 Introduction

This chapter provides a detailed examination of the urban form of London, Ontario, using the quantitative methodology outlined in Chapter 3. To analyze the built form of individual neighbourhoods, the city of London is divided into 78 distinct morphological units (MUs). For each MU in London, a comprehensive set of performance indicators is derived to describe, analyze, and compare the morphological characteristics of streets, lots, blocks, buildings, and land uses. Findings regarding the similarities and differences in the morphology of neighbourhoods are identified by presenting the values for each performance indicator in a series of maps and descriptive statistics. Relationships among all variables are then evaluated using Spearman's rank correlation. In addition, findings are reported for any statistically significant relationships between a morphological variable and any key non-morphological variable of interest, including: historical timing of neighbourhood development; median household incomes of neighbourhood residents; and neighbourhood population density. The chapter concludes with a brief summary of findings; however, detailed discussion of the findings is reserved for Chapter 6.

4.2 Morphological Units

The 78 MUs in London total 296 square kilometres, which represents 70% of the total land area of London (422 square kilometres). The average size of a MU is 4.82 square kilometres, with a standard deviation of 6.09 square kilometres. The smallest morphological unit, Southdale (MU 55), is 0.37 square kilometres. The largest morphological unit, North Park (MU 38), is 34.0 square kilometres. Descriptive statistics regarding MU area is shown in Table 4-1.

Table 4-1: Descriptive Statistics: MU Area

Count	78
Minimum	4.05
Maximum	62.88
Mean	31.41
Standard Deviation	14.30

The spatial locations and boundaries of the 78 MUs are displayed in Figure 4-1. Table 4-2 displays each MUs ID, given name, area in square kilometres, average median household income, and predominate era of construction.

Table 4-2: Morphological Units

Unit ID	Unit Name	Area (Square Kilometres)	Average Median Household Income	Major Era of Construction
1	Argyle	0.72	$56,649.00	1950's
2	Argyle Park	1.29	$47,102.00	1920's
3	Baseline West	1.01	$51,996.33	1930's
4	Baseline East	0.79	$62,655.67	1930's
5	Berkshire Village	0.92	$46,532.80	1960's
6	Blackfriars	1.17	$45,327.60	1900's
7	Breughdale	2.14	$52,444.25	1940's
8	Byron	1.07	$94,701.13	1970's
9	Byron North	4.27	$59,940.88	1960's
10	Byron South	4.35	$113,256.33	1940's
11	Carling	0.65	$47,700.50	1960's
12	Carling Heights	1.35	$41,789.00	1940's
13	Chelsea Green	2.93	$41,646.50	1940's
14	Cheardale	2.79	$66,301.73	1970's
15	Crumlin	24.10	$67,734.00	1960's
16	Downtown	1.97	$34,668.25	1850's
17	Downtown North	2.27	$35,724.64	1850's
18	Downtown South	1.46	$29,149.50	1850's
19	East of Old East	1.28	$43,146.20	1900's
20	Fairmont	2.41	$56,329.71	1940's
21	Forward	0.44	$76,394.00	1900's
22	Gainsborough Meadows	1.21	$57,960.86	1970's
23	Glencairn	1.01	$54,878.50	1960's
24	Glendale	0.39	$54,668.00	1970's
25	Hamilton Road	4.71	$43,025.76	1900's
26	Hazelden	5.33	$94,494.27	1970's
27	Huron Heights	4.38	$54,378.69	1960's
28	Hyde Park	5.76	$76,415.14	1980's
29	Kensal Park	0.93	$45,781.60	1950's
30	Knollwood Park	2.17	$47,765.85	1960's
31	Lambeth South	31.27	$79,498.43	1900's
32	Lockwood Park	1.14	$65,965.57	1960's
33	London Junction	1.40	$41,491.50	1950's
34	Masonville	4.15	$91,788.25	1970's
35	Medway Heights	0.91	$104,788.67	1980's
36	Melwin Heights	1.19	$44,844.60	1950's
37	Nelson Park	2.62	$58,027.88	1970's
38	North Park	34.00	$74,656.20	2000's
39	Norton Estates	1.03	$51,517.20	1970's

40	Oakridge Park	2.68	$107,155.75	1960's
41	Oakridge Riverside	4.10	$75,370.92	1960's
42	Old East	1.63	$37,344.44	1860's
43	Old North	2.83	$70,364.08	1860's
44	Orchard Park	1.23	$100,126.00	1960's
45	Oxford Park	2.43	$35,127.60	1960's
46	Parkview	2.11	$59,964.40	1970's
47	Peppertree Estates	1.26	$62,285.80	1970's
48	Pottersburg	4.03	$47,284.09	1950's
49	Pond Mills	2.81	$56,245.89	1970's
50	Ridgeview Heights	2.49	$54,014.09	1950's
51	Riverbend	6.23	$107,598.75	1960's
52	Rivervally North	4.05	$79,721.50	1940's
53	Sherwood Forest	2.14	$139,168.83	1970's
54	Southcreek	2.37	$38,338.88	1920's
55	Southdale	0.37	$78,727.00	1960's
56	South Winds	9.62	$99,667.50	1970's
57	Springbank West	0.78	$87,120.00	1970's
58	Springbank East	1.92	$48,185.75	1900's
59	Stoneybrook Acres	1.53	$93,406.50	1960's
60	Stoneybrook Meadows	2.58	$90,024.80	1960's
61	Summerside	20.17	$83,742.17	1960's
62	Sunningdale	4.40	$99,325.33	1990's
63	The Gore	4.33	$54,314.00	1980's
64	The Ponds	2.73	$62,514.67	1960's
65	Trafalgar Heights	2.82	$67,267.85	1980's
66	University Heights	4.13	$32,789.20	1950's
67	Uplands Northcrest	4.42	$103,035.25	1990's
68	Wellingsbore	0.40	$58,244.50	1960's
69	Wellington	1.23	$54,738.17	1900's
70	West of Wonderland	2.31	$51,381.00	1980's
71	Westminster Park	2.03	$65,096.75	1970's
72	Westmount	4.62	$70,446.31	1970's
73	Whitehills	4.31	$67,536.18	1970's
74	Whiteoak	4.08	$63,619.56	1970's
75	Wilton Grove	8.83	$46,245.00	1960's
76	Woodbank	2.88	$67,887.60	1970's
77	Old South	4.09	$54,378.64	1870's
78	Lambeth North	4.41	$81,724.83	1900's

4.3 Median Household Income

To better interpret the spatial pattern of the following performance indicators, one must understand the spatial pattern of neighbourhood median household income. The median household income across all of London derived by averaging median household income in all DAs is $62,143, which is higher than the average for households reported by Statistics Canada: $53,684. Averaging the 78 MUs, the average median household income is $64,962, which is higher still. The discrepancies in these values are due to differences in the spatial grouping of data: Statistics Canada uses the response of the individual and therefore is the most accurate. The other two methods report the median household income in an aerial unit, and the average all of those units.

The MU with the maximum value of average median household income in Sherwood Forest (MU 53) with a value of $139,168, and the minimum value of $29,150 is found in downtown south (MU 14). Descriptive statistics can be found in Table 4-3. Neighbourhood level spatial variations in the median household income measure are shown in Figure 4-2.

Table 4-3: Descriptive Statistics: Median Household Income

Count	78
Minimum	$29,150
Maximum	$139,168
Mean	$64,932
Standard Deviation	$22,243

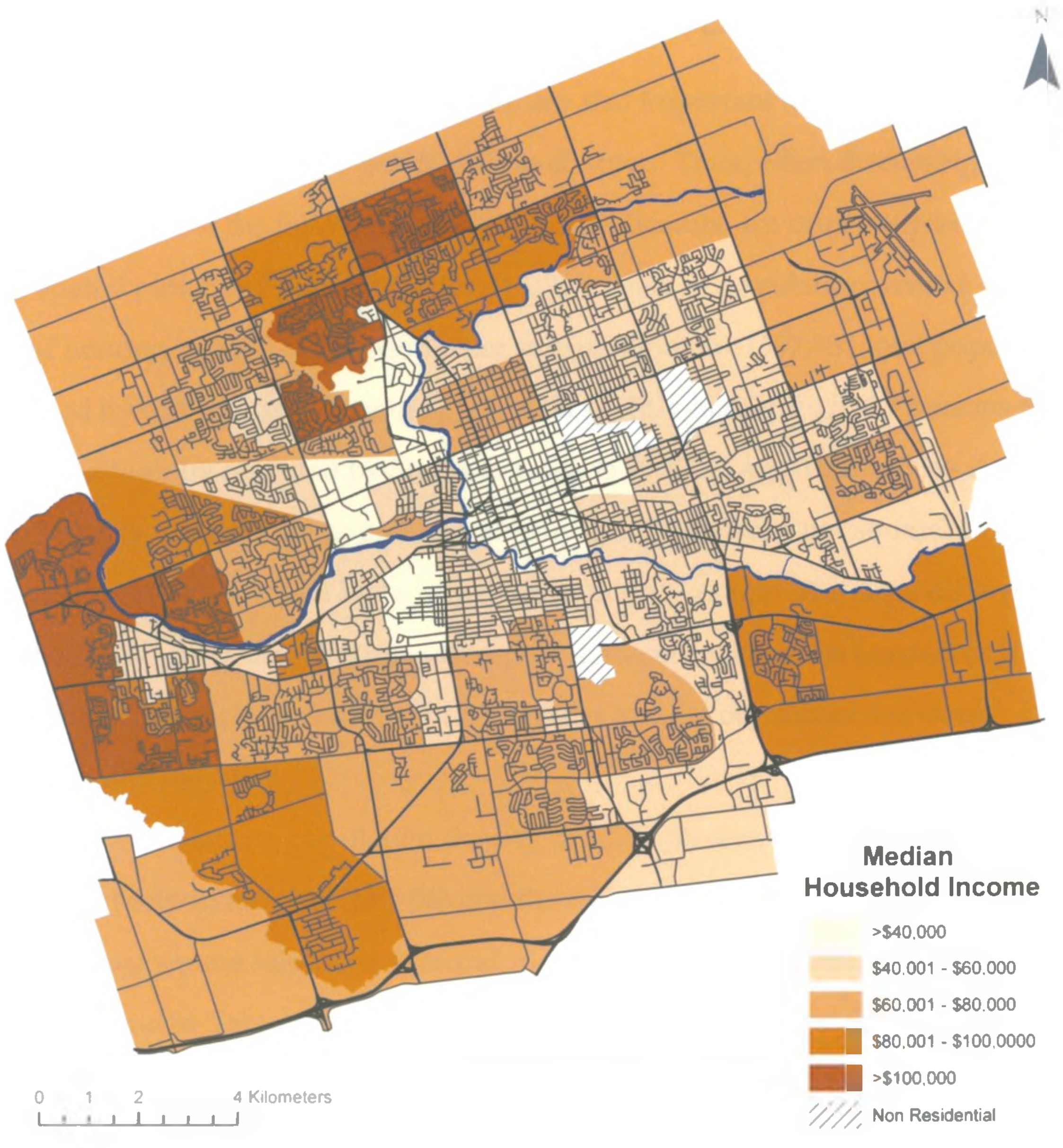


Figure 4-2: Median Household Income

4.4 Neighbourhood Population Density

The population densities of MUs are also important to note, as the values are inherently linked to the results in this chapter. Thus, when discussing the spatial pattern of the following performance indicators, we must keep in mind the spatial pattern of population density. The average population density across all of London in 2007 is 845 people per square kilometre (357,585 total population divided by 423 square kilometres), which is slightly higher than 837 persons per square kilometre reported by Statistics Canada in 2006. Aggregating this data to the 78 MUs, the average population density is 2,050 persons per square kilometre, which is much higher than the London average. The large differences in these values are due to large differences in the areas between London as a whole and the MUs, and the small differences in total population between London and the MUs.

The maximum population density of 4,270 persons per square kilometre is found in Melwin Heights (MU 36) and the minimum population density of 40 persons per square kilometre is found in Crumlin (MU 15). Descriptive statistics can be found in Table 4-4. Neighbourhood level spatial variations in the median household income measure are shown in Figure 4-3.

Table 4-4: Population Density per Square Kilometre

Count	78
Minimum	40
Maximum	4,270
Mean	2,050
Standard Deviation	1,121

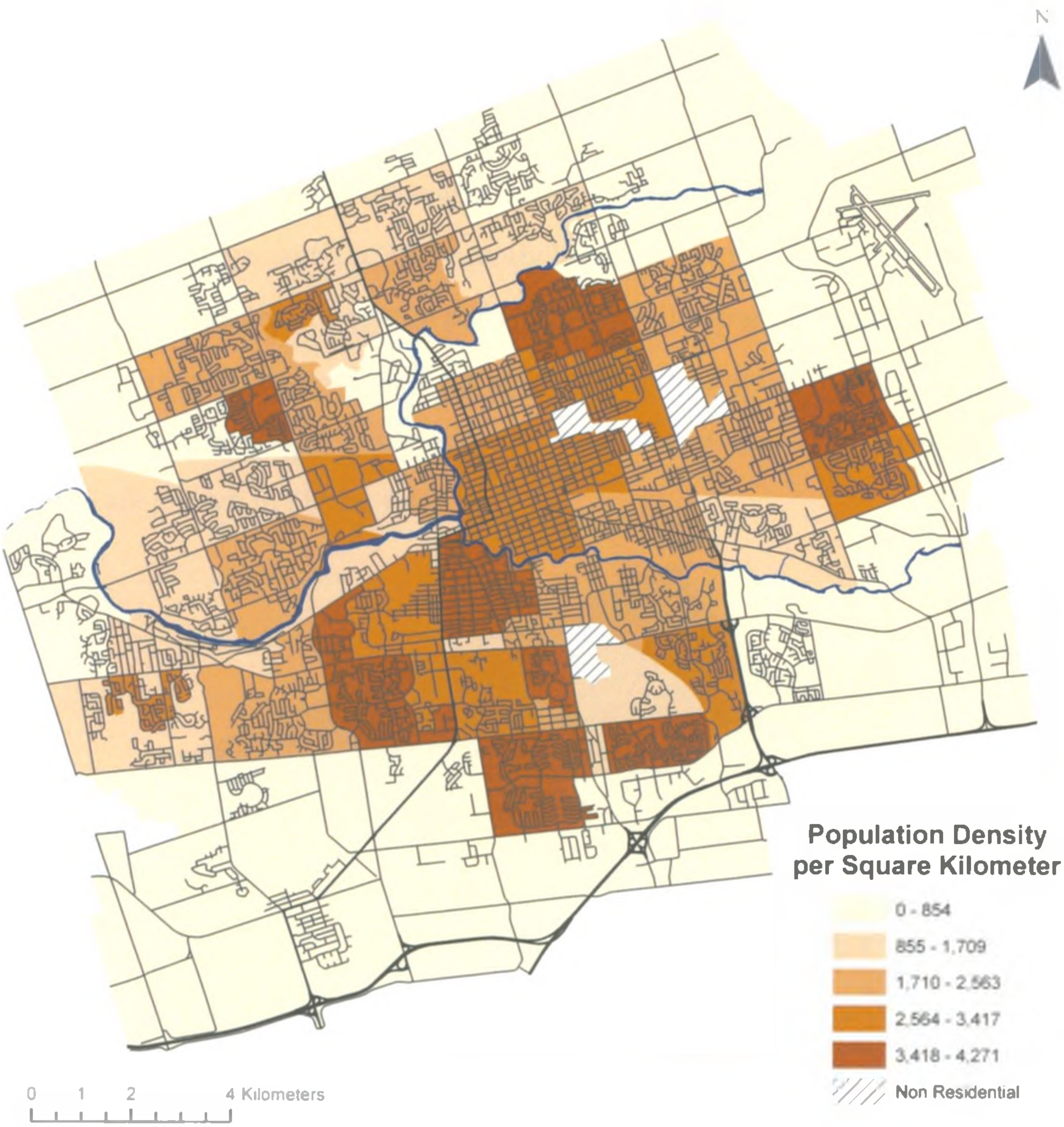


Figure 4-3: Population Density in London

4.5 Historical Timing of Neighbourhood Development

The historical timing of neighbourhood development is also important to note, as the development era is inherently linked to the results in this chapter. Thus, when discussing the spatial pattern of the following performance indicators, we must keep in mind the spatial pattern of era of development. Neighbourhood level spatial variations in the historical timing of development measure are shown in Figure 4-4.

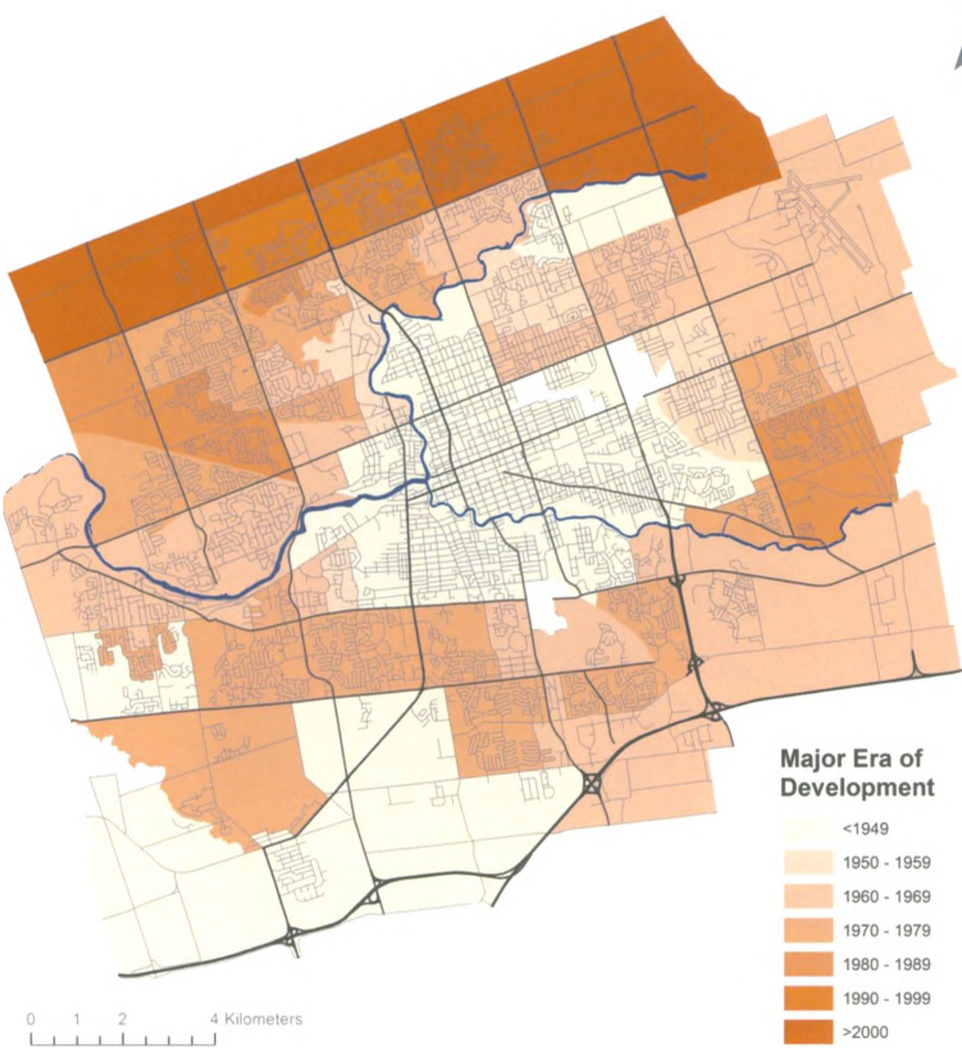


Figure 4-4: Major Era of Development in London, Ontario

4.6 Street Performance Indicators

4.6.1 Intersections

4.6.1.1 Intersection Density

There are 4,745 intersections with a valance of 3 or more in London, with an average density of 16.03 intersections per square kilometre (4,745 / 296 square kilometres). The 78 MUs have a mean intersection density of 31.41 intersections per square kilometre, with a standard deviation of 14.3 (note: 980 intersections are counted multiple times since they are on the edge two or more Morphological Units). The maximum density of 62.88 is found in Knollwood Park (MU 30) and the minimum density of 4.05 is found in Crumlin (MU 14). Neighbourhood level spatial variation in the intersection density measure is shown in Figure 4-5.

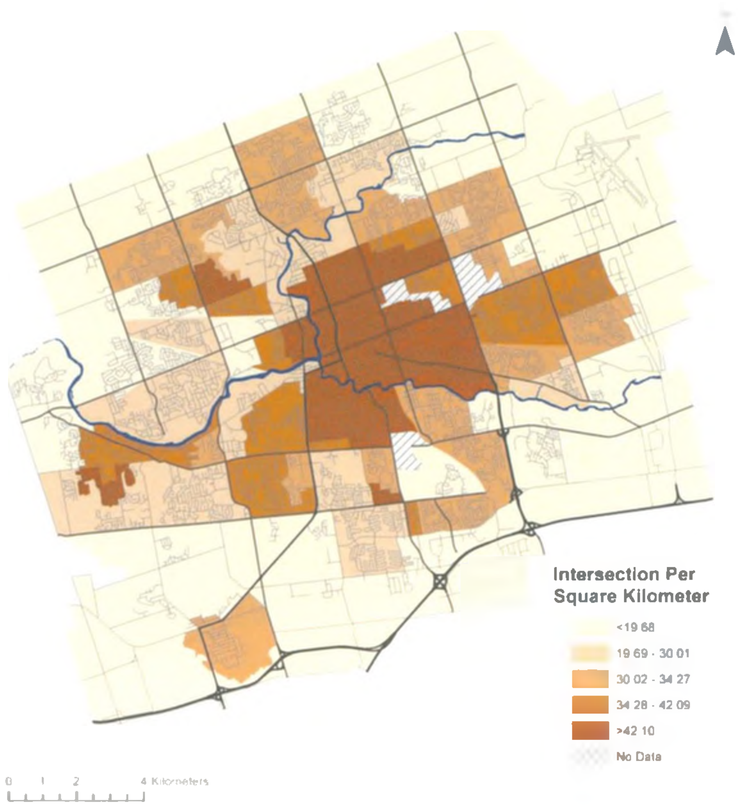


Figure 4-5- Intersection Density in London

4.6.1.2 Cul-De-Sac Proportion

There are 1,067 culs-du-sac in London, with an average cul-de-sac proportion of 16.4% (1,067 total culs-du-sac / 6,503 total intersections). The 78 MUs have a mean cul-de-sac proportion of 17.4%, with a standard deviation of 7% (note: 19 cul-de-sacs are counted multiple times since they are on the edge two or more Morphological Units). The maximum proportion of 37.5% is found in Springbank West (MU 57) and the minimum proportion (7%) in Downtown (MU 16). Neighbourhood level spatial variation in the cul-de-sac proportion measure is shown in Figure 4-6.

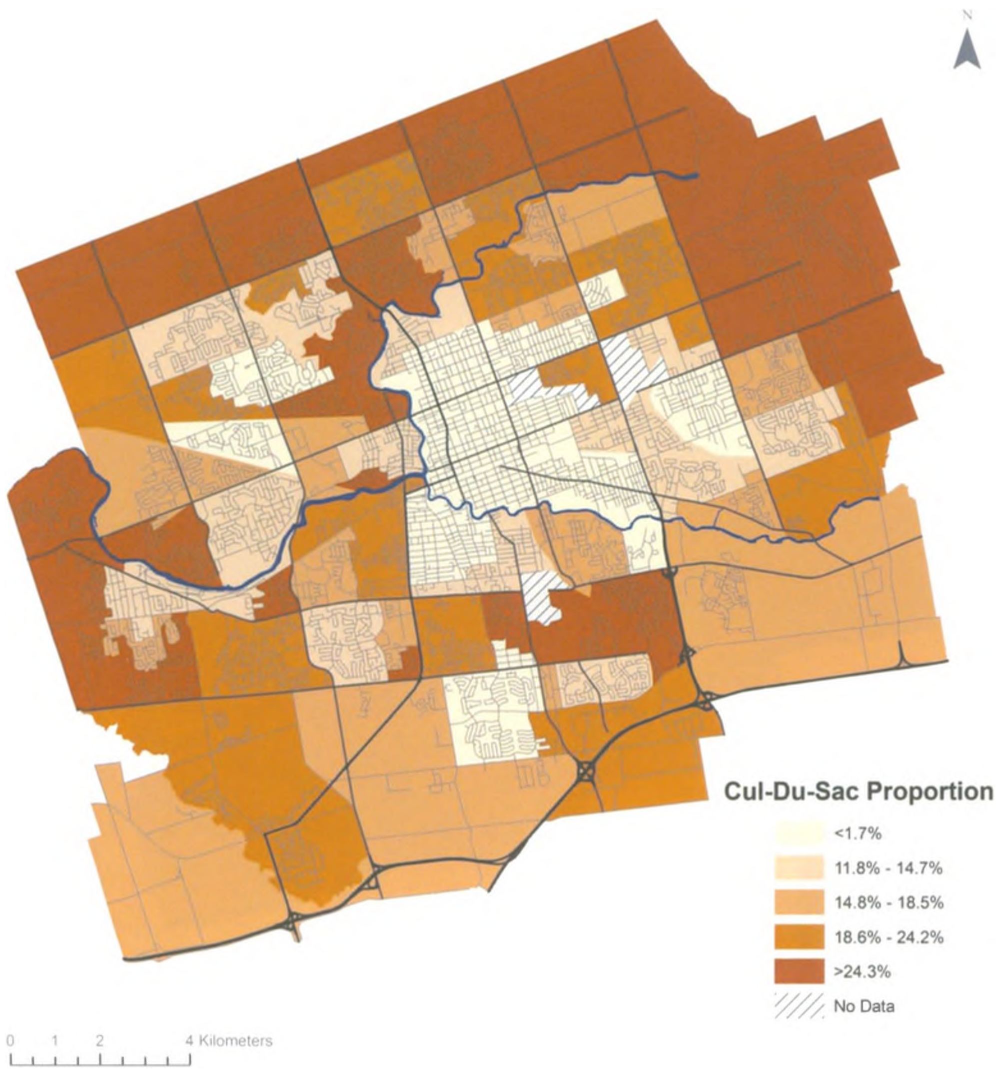


Figure 4-6: Cul-Du-Sac Proportion in London

4.6.1.3 T-Intersection Proportion

There are 3,991 T-intersections in London, with an average T-intersection proportion of 61.4% (3,991 total T-intersections / 6,503 total intersections). The 78 MUs have a mean T-intersection proportion of 79%, with a standard deviation of 11%. The maximum proportion (94%) can be found in Orchard Park (MU 44) and the minimum proportion (37%) in Downtown (MU 16). Neighbourhood level spatial variation in the T-intersection proportion measure is shown in Figure 4-7.

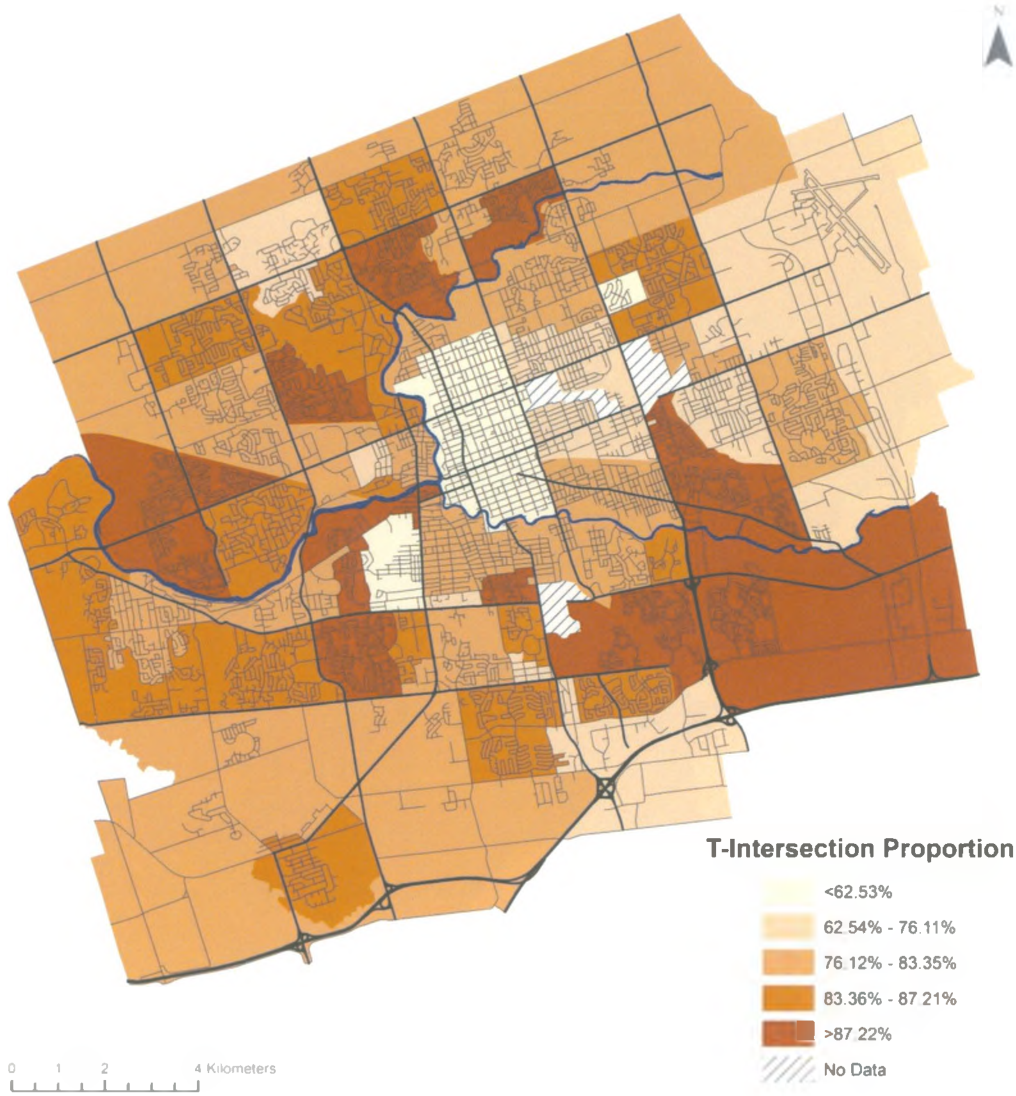


Figure 4-7: T-Intersection Proportion in London

4.6.1.4 X-Intersection Proportion

There are 941 X-intersections in London, with an average X-intersection proportion of 14.5% (941 total X-intersections / 6,503 total intersections). The 78 MUs have a mean X-intersection proportion of 20%, with a standard deviation of 10%. The maximum proportion of 62% is found Downtown (MU 16) and the minimum proportion of 4% in Fairmont (MU 20). Figure 4-8 shows neighbourhood level spatial variation in the X-intersection proportion measure.

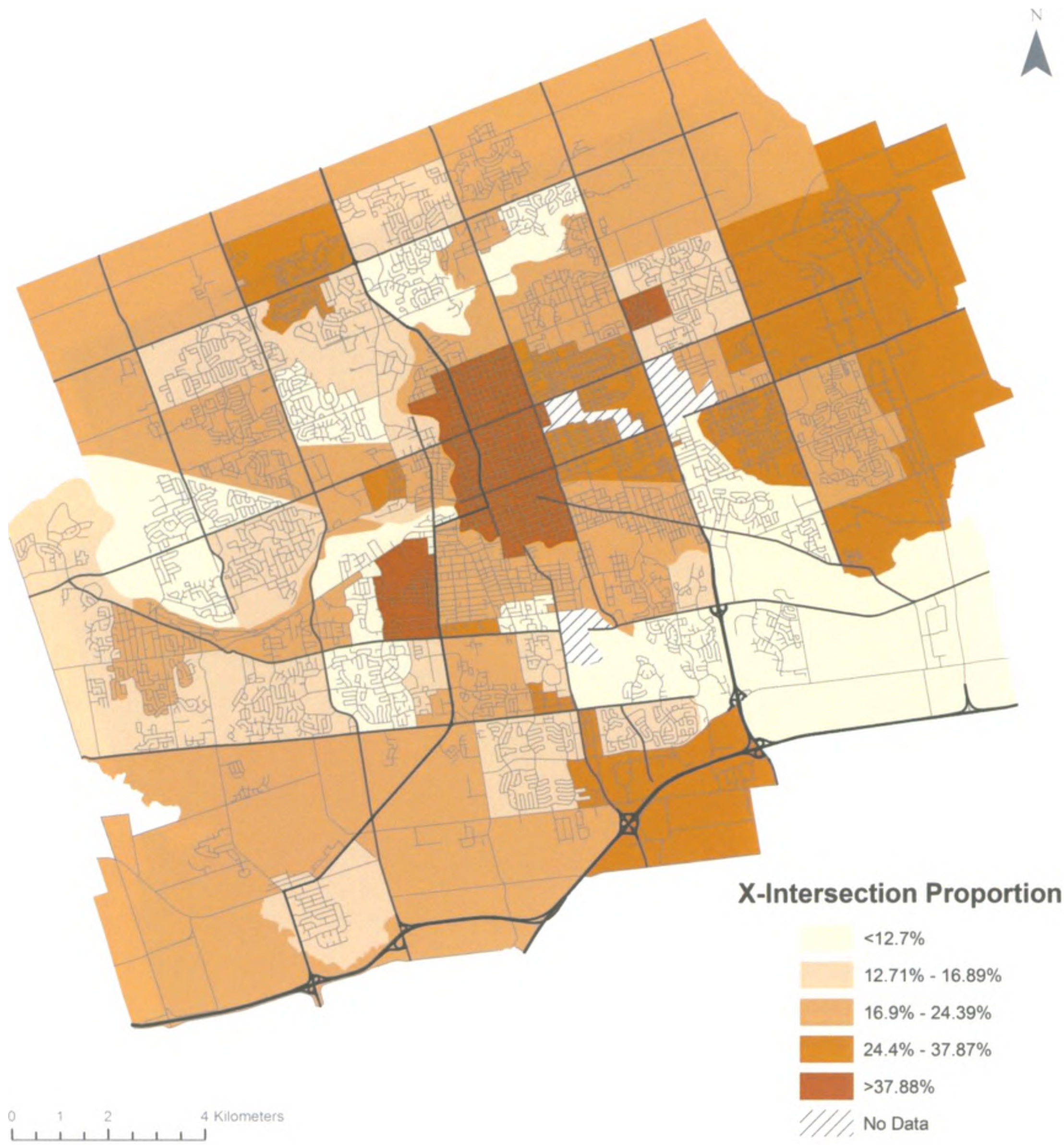


Figure 4-8: X-Intersection Proportion in London

4.6.2 Street Segment Length

4.6.2.1 Average Street Segment Length

There are 8,882 street segments in London, with an average length of 207 metres. The 78 MUs have an overall average street segment length of 205 metres with a standard deviation of 57 metres. The maximum average segment length (439 metres) is found in Crumlin (MU 15) and the minimum (121 metres) in Blackfriars (MU 6). Neighbourhood level spatial variation in the average street segment length measure is shown in Figure 4-9.

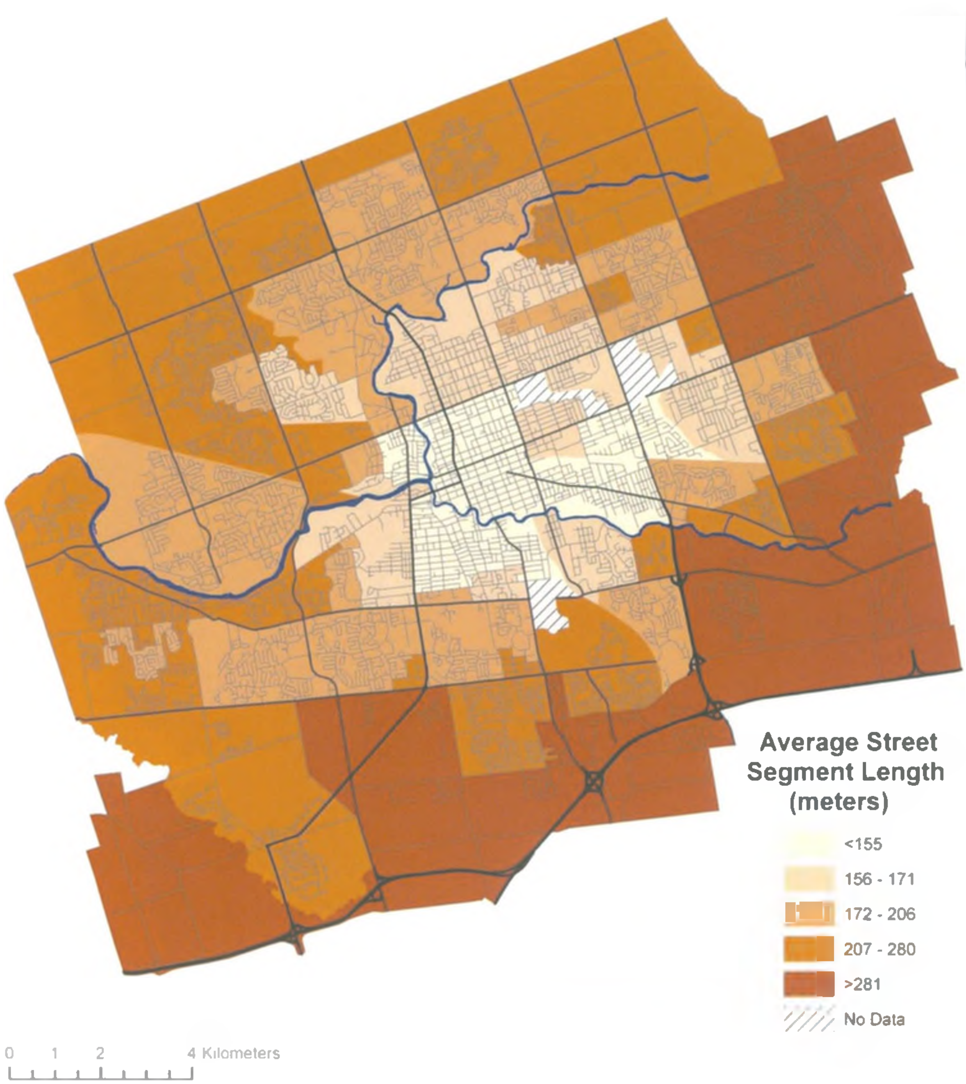


Figure 4-9: Average Street Segment Length in London

4.6.2.2 Maximum Street Segment Length

There are 8,882 street segments in London, with a maximum length of 9,785 metres. The 78 MUs have an average maximum street segment length of 1,166 metres with a standard deviation of 1,172 metres. The maximum maximum segment length (of 786) metres is found in London Junction (MU 33) and the minimum maximum segment length (of 373) is found in Downtown South (MU 18). Figure 4-10shows neighbourhood level spatial vacation of the maximum street segment length measure.

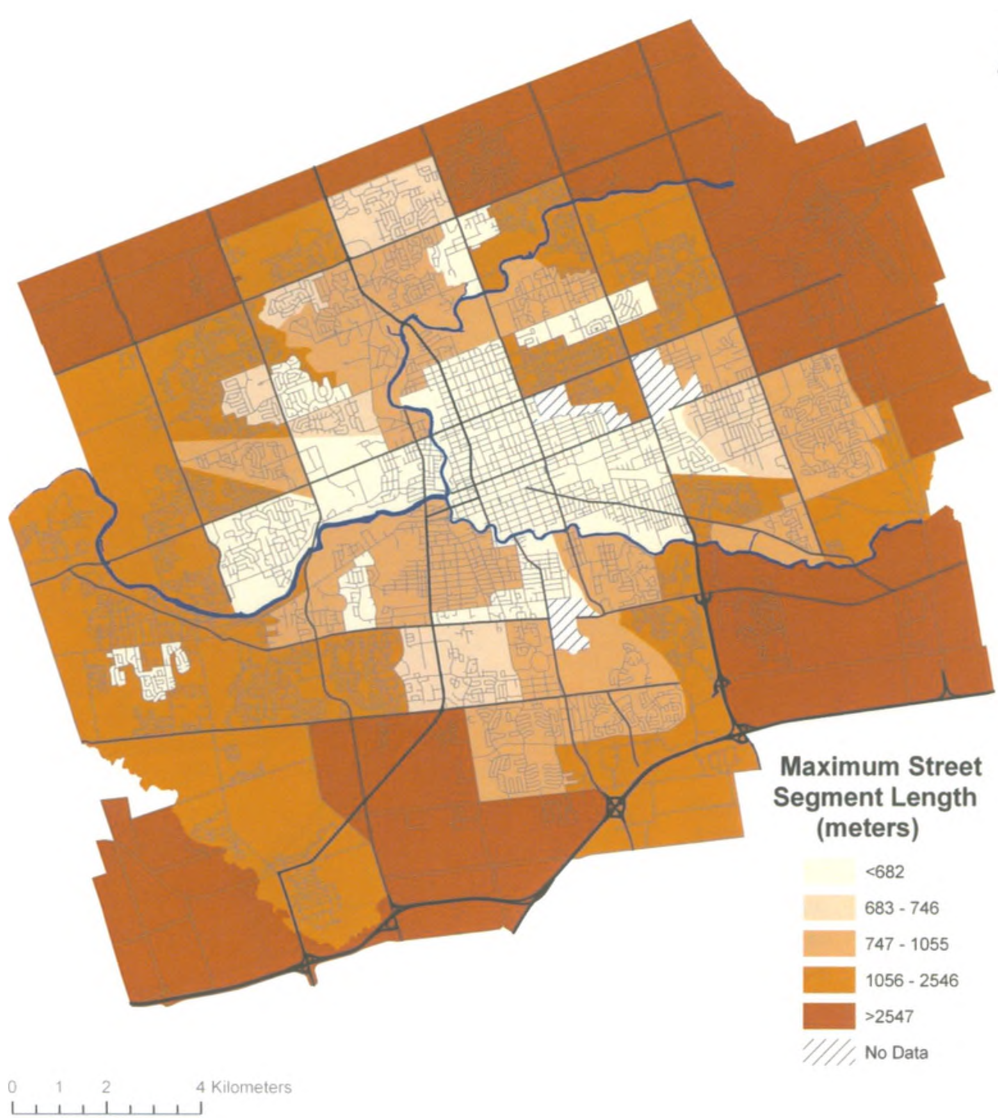


Figure 4-10: Maximum Street Segment Length in London

4.6.3 Street Area Density

4.6.3.1 Gross Street Area Density

There is a paved street area of 16,922,370 square metres in London, with an average gross street density of 6% (16,922,370 square metres paved area / 294,375,707 square metres total area). The 78 MUs have a mean gross street area density of 12%, with a standard deviation of 5%. The maximum proportion of 25% can be found in Wellingsbore (MU 68) and the minimum proportion of 2% in North Park (MU 38). Neighbourhood level spatial variation in the gross street area density measure is shown in Figure 4-11.

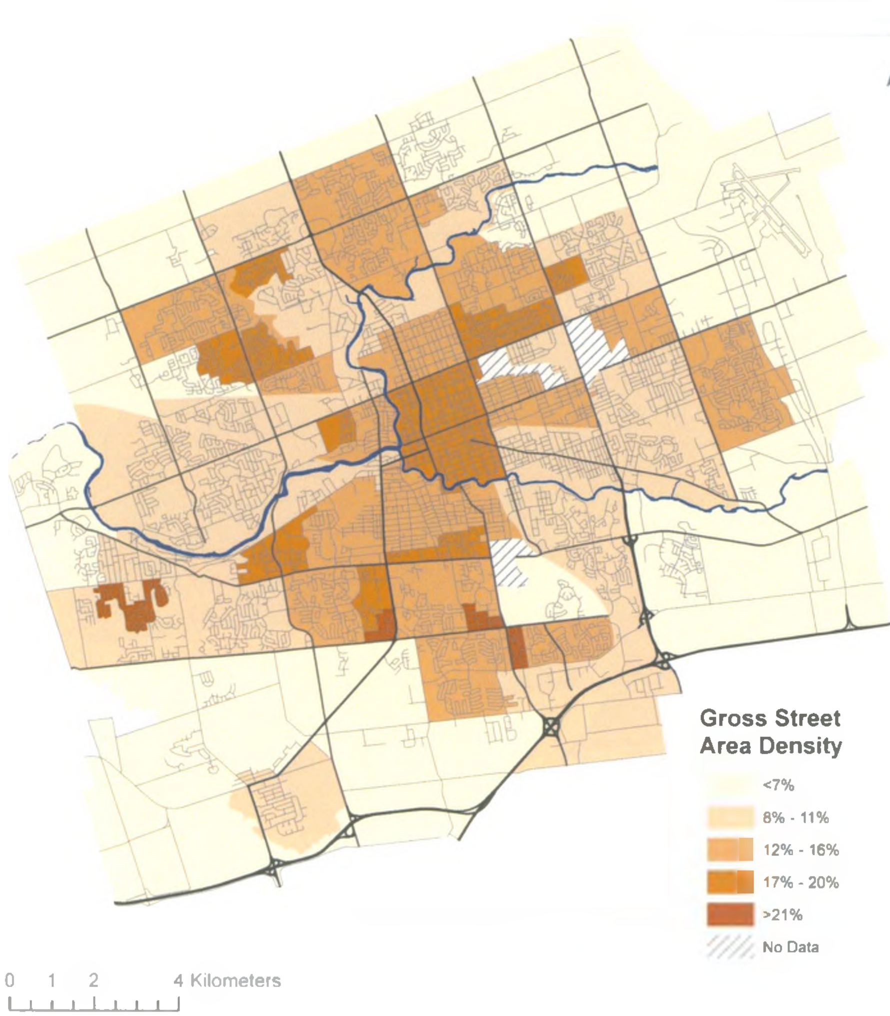


Figure 4-11–Gross Street Area Density in London

4.6.3.2 Net Street Area Density

There is a paved street area of 16,922,370 square metres in London, with an average net street density of 6% (16,922,370 square metres paved area / 275,414,349 square metres area without water or park). The 78 MUs have a mean net street area density of 13%, with a standard deviation of 5%. The maximum proportion (24%) can be found in Southdale (MU 55) and the minimum proportion (3%) in North Park (MU 38). Figure 4-12 shows neighbourhood level spatial vacation of the net street area density variable.

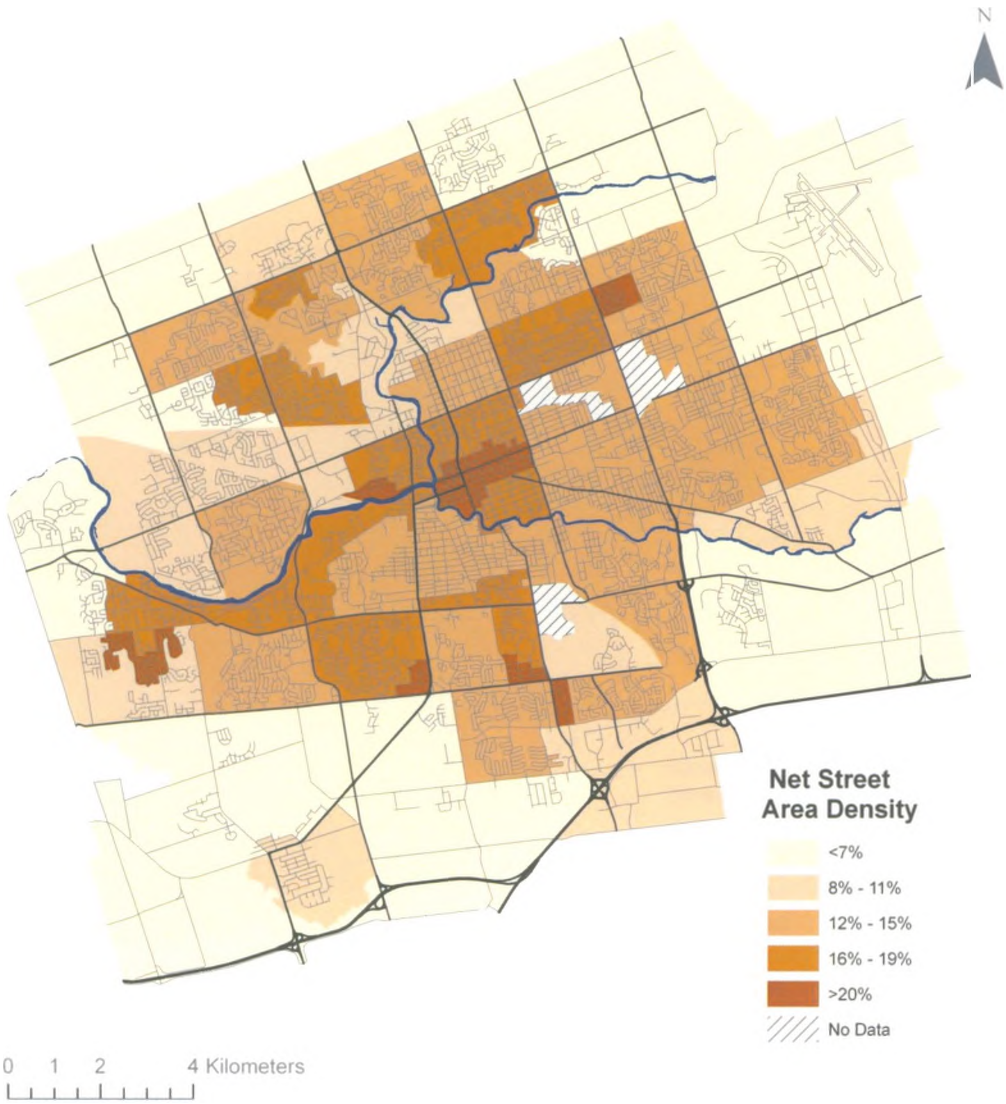


Figure 4-12: Net Street Area Density in London

4.6.4 Pathways

4.6.4.1 Sidewalk to Street Proportion

There are 1,344,397 metres of sidewalk in London and 1,842,430 metres of street in London, creating an average sidewalk to street proportion of 0.72 or, expressed as a ratio, 0.7:1 out of a possible 2:1. The 78 MUs have a mean sidewalk to street proportion of 0.82, or 0.8:1, with a standard deviation of 0.40. The maximum proportion of 1.66 (1.6:1) is in Old East (MU 42) and the minimum proportion of 0.05 (0.05:1) in Crumlin (MU 15). Neighbourhood level spatial variation in the pathway to street proportion measure is shown in Figure 4-13.

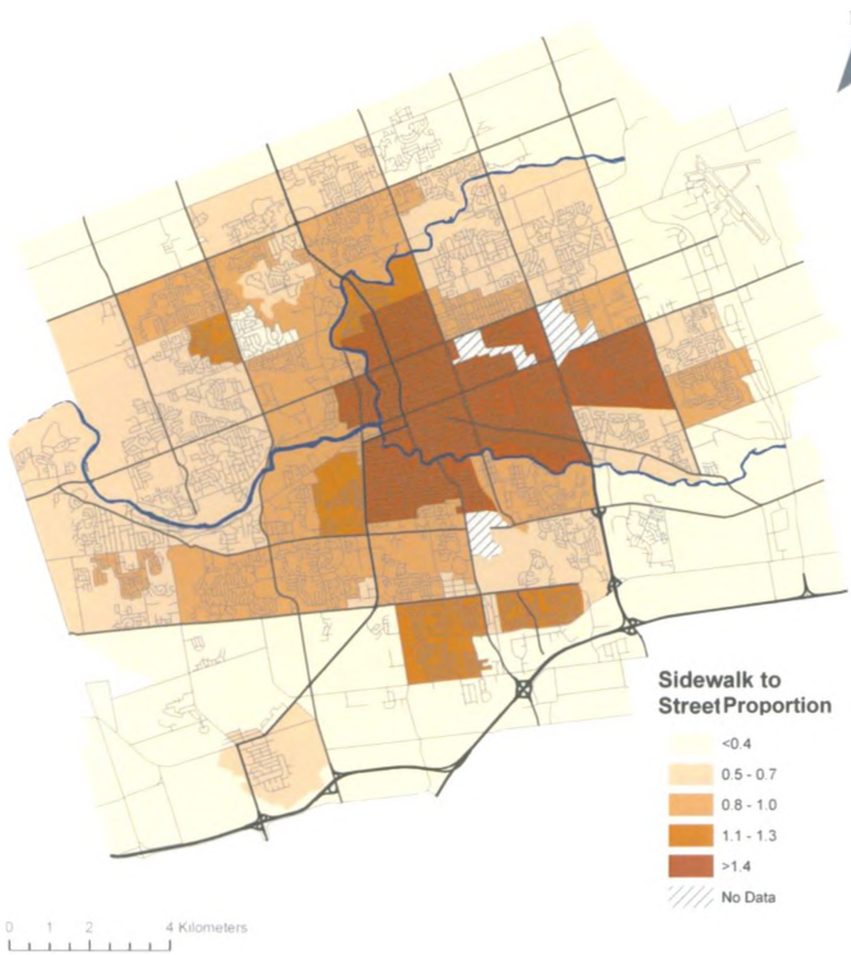


Figure 4-13: Sidewalk to Street Proportion in London

4.6.4.2 Pathway to Street Proportion

There are 228,110 metres of pathway in London and 1,842,430 metres of street in London, creating an average path to street ratio of 0.12:1, or 12%. The 78 MUs have a mean pathway to street ratio of 0.26:1, or 26%, with a standard deviation of 16%. The large difference between the proportions is due to the fact that London has a large amount of street length in non-developed areas, decreasing the overall pathway to street proportion. In the MUs, the maximum proportion of 0.68:1 or 68% is found in Springbank East (MU 57) and the minimum proportion of 0:1 or 0% in Riverbend (MU 51) and Crumlin (MU 15). Figure 4-13 shows neighbourhood level spatial vacation of the net street area density variable.

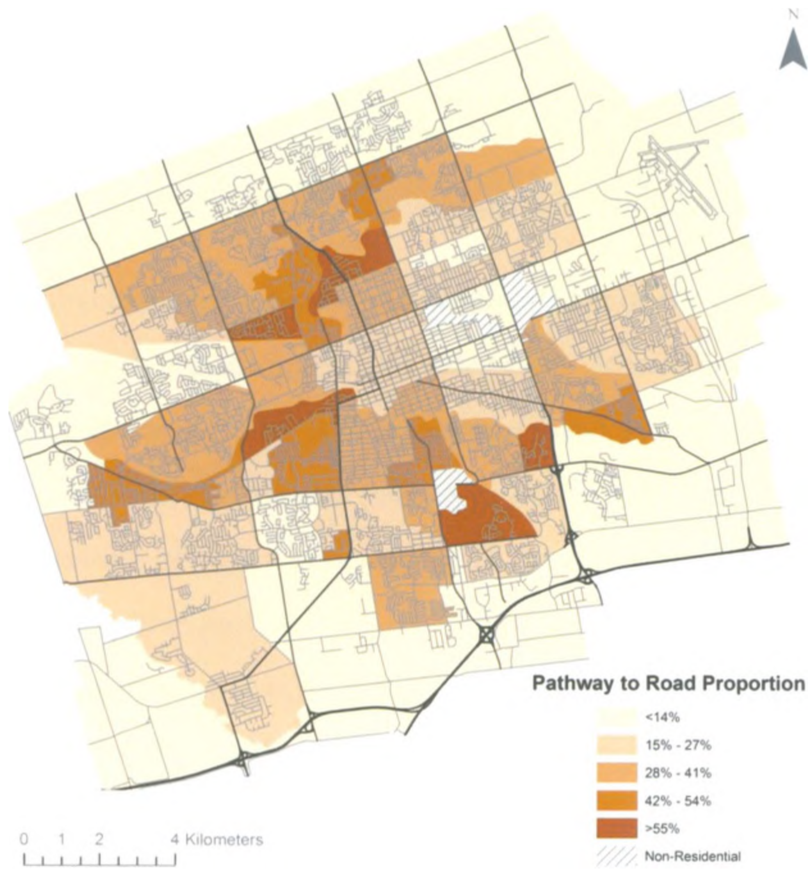


Figure 4-14: Sidewalk to Street Proportion in London

4.6.5 Space Syntax

Space Syntax, as displayed in detail in the methods chapter, outputs the connectivity and integration of the street network. In London, there are a total of 5,661 axial lines drawn to create the space syntax output. The average axial line was 305 metres long, with each line intersecting 2.8 other axial lines on average. A summary of the space syntax output for all of London is shown in Table 4-5.

Table 4-5: Summary of Space Syntax Output

Number of Axial Lines	5661
Total Length of Axial Lines	
Min	31m
Mean	305.2141m
Max	9094m
Number of Intersections	16020
Intersections / Axial Lines	2.829889
Median Global Integration (radius n)	1.021043
Median Depth (to n steps)	62978.51
Median Depth to three steps	24.85091
Median Local Integration (radius 3)	1.574896

Mean connectivity (number of intersections/ number of axial lines) is measured at 2.8, which is a comparatively low value. Most cities in Europe, for example, have mean connectivity values between 6 and 8. This shows that it is difficult to get across the city without making a large number of street changes. There is a clear pattern of higher connectivity in the core over the suburbs and the fringe, as one might expect.

The most highly connected street segments in London are some of the longest and most centrally-located axial lines in the network. The most highly connected street, Oxford street, links the old core with the suburbs, following the trajectory of growth of the city itself, and spans completely across the city east-west. A point of interest is the average global integration, which is just over 1.04.

This is relatively low in comparison to some European cities, as Greek cities had average global integrations of 1.39 (Peponis et all, 1989), while London England has a mean global integration of 1.70 (Hiller, 1996). On the other hand, London, Ontario's global integration is high compared to 0.966 for other English cities and 0.482 for Iranian cities (Karimi, 1997).

As a street network grows, it naturally becomes "deeper". This fact is reflected in the static for depth, which measures the total number of steps required to get from one node to all other nodes in the system. Depth increases with every addition axial line drawn in the system. In London, the average depth value is 62,979.

An examination of local integration maps and statistics reveal that various street segments differ with regard to the extent of their catchments; that is, some streets, such as Viscount Road, are highly locally integrated, but not highly globally integrated, while others, such as William Street, have high integrations for both local and global measures. In general, maps of local integration tend to resemble connectivity maps. This finding is understandable, as connectivity is merely integration to one step away, or to a radius of one, whereas local integration is integration to three steps away. London's mean local integration value is 1.7, substantially higher than its global integration value. This means that local places are more connected then places far away. Compared to London, England's average local integration of 2.43 (Hillier, 1996), other English cities average local integration of 2.03, and Iranian cities average local integration of 1.6 (Karimi, 1997), London, Ontario's average local integration is relatively low.

A space is said to be integrated if all the other spaces can be reached after traversing a small number of intervening spaces. This concept is measured by global integration. Similarly, connectivity and local integration measure the degree of integration at the local level. Therefore, there is a correlation between these local and global parameters (Figure 4-15)

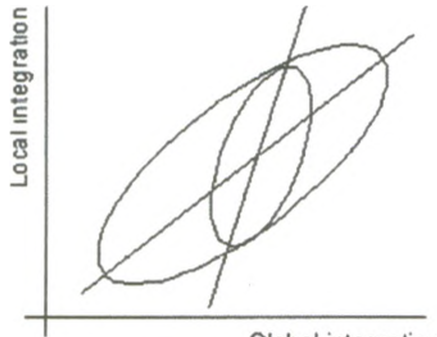


Figure 4-15: Normal Correlation between Global and Local Integration (Source: Jiang et al., 2000)

Comparing local integration to global integration, a loose relationship between the two can be seen (Figure 4-16). It is interesting to see that up until a specific point (about 1.3 global integration and 4.0 local integration), integration values appear to be randomly distributed, whereas after this specific point, integration values in both local and global integration increase congruently; that is, there are no highly global integrated streets that are not highly local integrated streets, and vice versa.

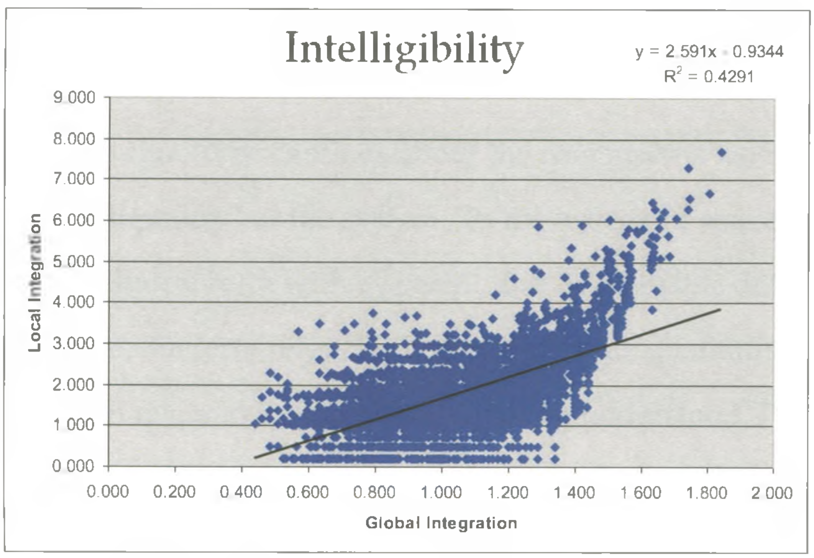


Figure 4-16: London's Intelligibility between Local and Global Integration

In space syntax terminology, the correlation between connectivity and global integration is referred to as the "intelligibility" of the system, since it is a measure of the degree to which the global properties of the network are discernible from the highly local properties. It has been suggested by Hiller (1996) that an R^2 value of greater than 0.45 represents an "intelligible" system. Using this guideline, we can see that system intelligibility of street network of London has a value of 0.1142, much lower than the threshold of 0.45 (Figure 4-17). Even by adjusting the trend line to be logarithmic, the R^2 value sill remains around 0.12. Thus, London's street network is not an intelligible system.

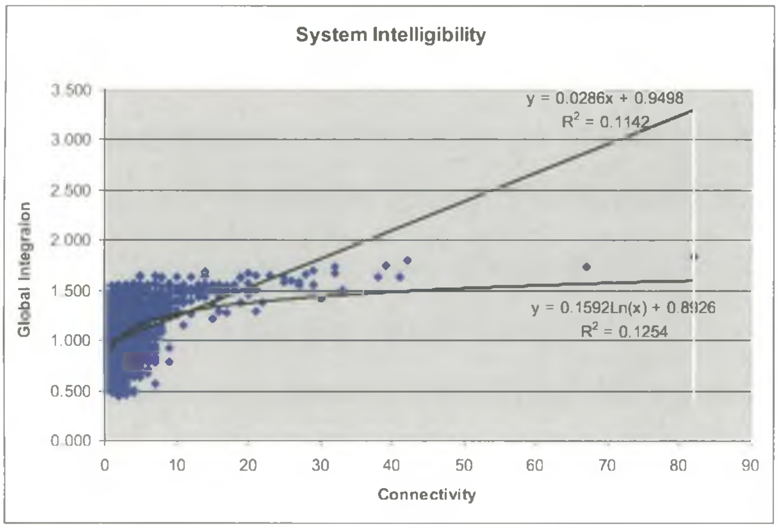


Figure 4-17: System Intelligibility

However, we should be cautious about the conclusions we make regarding the "intelligibility" of the system. In the lexicon of space syntax, intelligibility is a technical term with a specific and quantifiable definition, whereas in lay usage, the term refers to the more general, qualitative characteristics which relate to the capability of being understood. Furthermore, in the field of urban design, Kevin Lynch (1990) has introduced the concepts of "legibility" and "imageability" to describe and analyze the perceptual characteristics of urban spaces which he argues is necessary for "good city form". Besides the local street pattern, there are many physical elements which enhance intelligibility, or the way that we perceive urban spaces, including natural landmarks such as a mountain or a coastline, or monumental human constructions such as church steeples, skyscrapers, or public statues. Ultimately, the lack of intelligibility of the global structure in a commercial or industrial city has to be compensated by a relative accessibility to the core.

The space syntax parameter of connectivity is a highly localized measure of accessibility, as it only takes into consideration other axial lines at topological depths of just one step away (radius-1). On the other hand, integration is a "global" measure since it considers relations between a given axial line and all other axial lines in the system as a whole (radius-n), and for this reason, it us usually described as global integration. Research has revealed that another useful measure of accessibility is integration calculated within a few steps (usually three) from each line in every direction (radius-3). This can be thought of as local integration because it reveals the local properties of a network. Empirical studies have suggested that pedestrian movements are more strongly correlated with local, rather than global measures of integration: the reverse is true for vehicular movement (Hillier, 1996).

It is true that London sits in the transportation framework on Southwestern Ontario (and to a larger extent, Ontario, Canada, and North America), but space syntax modeling is specifically calibrated for urbanized, high dense areas. In this sense, we can ignore all areas outside of the urban growth boundary, and assume London's urban areas exist in a bubble. The entire city can be looked at from a global integration measure, whereas if we wanted to apply space syntax models to specific neighbourhoods, it may be more appropriate to look at the local integration of the axial lines.

4.6.5.1 Connectivity

Connectivity expresses the number of axial lines that directly intersect a given axial line. Thus, the connectivity of a street must be a whole number. In London, the median connectivity for an axial line is 2, with a standard deviation of 2.75. The 78 MUs have an average median connectivity of 2.46 with a standard deviation of 0.84. The maximum median connectivity of 7 is found in Downtown South (MU 18) and the minimum of 2 is found Riverbend (MU 51). Neighbourhood level spatial variation in the connectivity measure is shown in Figure 4-18.

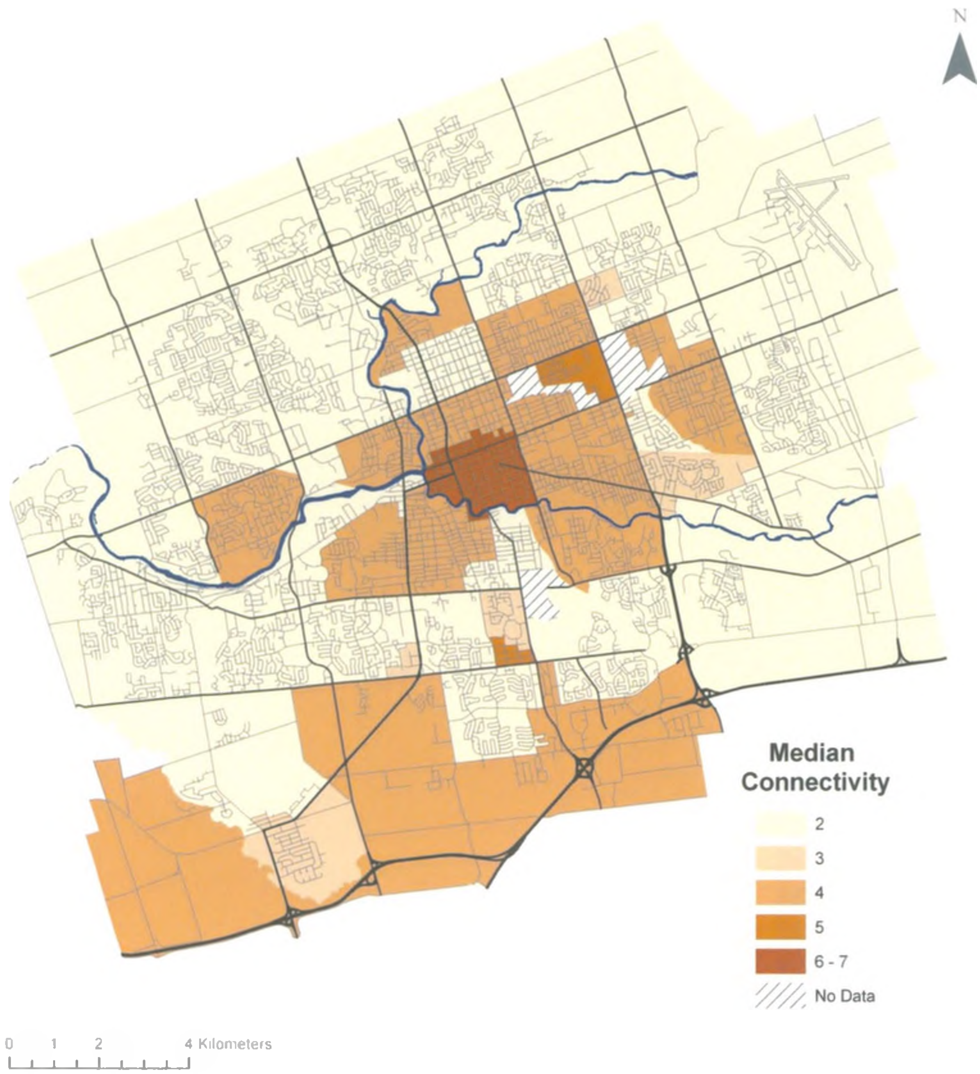


Figure 4-18: Median Connectivity in London

4.6.5.3 Global Integration

The global integration of an axial line shows the degree to which each axial line integrated or segregated from the entire street system network. In London as a whole, the median global integration is 1.02, with a standard deviation of 0.23. The 78 MUs have a median global integration of 1.14. The maximum global integration value of 1.56 can be found in Carling Heights (MU 12) and the minimum value of 0.75 in Whiteoak (MU 74). Figure 4-19 shows neighbourhood level spatial vacation of the global integration measure. Note that the most easterly MU has high integration values due to the airport.

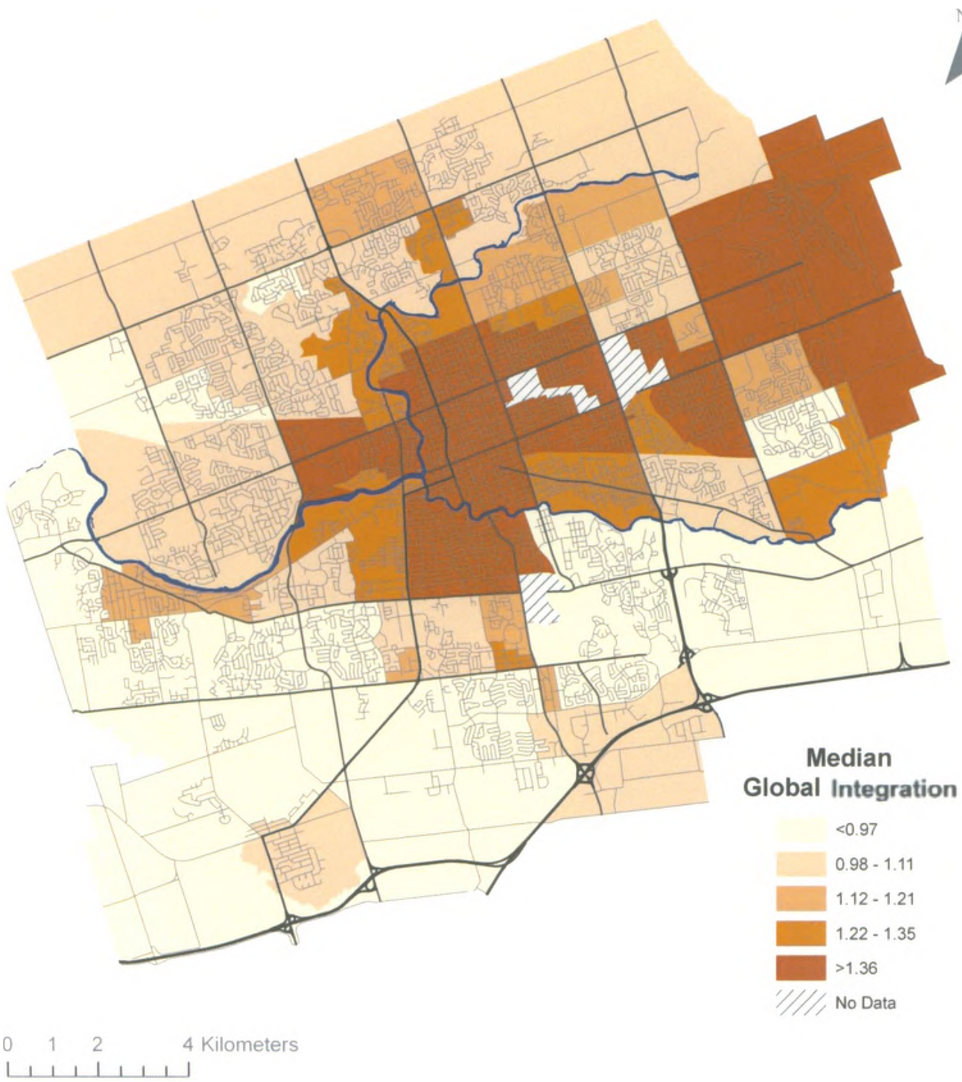


Figure 4-19: Median Global Integration in London

4.6.5.4 Local Integration

The local integration of an axial line shows the degree to which each axial line integrated or segregated from the street system network within 3 turns. Local integration is measured by the median local integration value in each Morphological unit. In London, the average median local integration is 1.57, with a standard deviation of 0.94. The 78 MUs have an average median local integration of 2.02. The maximum median global integration value of 4.08 is found in Carling Heights (MU 16) and the minimum median global integration value of 1.16 is found in Westminster Park (MU 71). Neighbourhood level spatial variation in the local integration measure is shown in Figure 4-20.

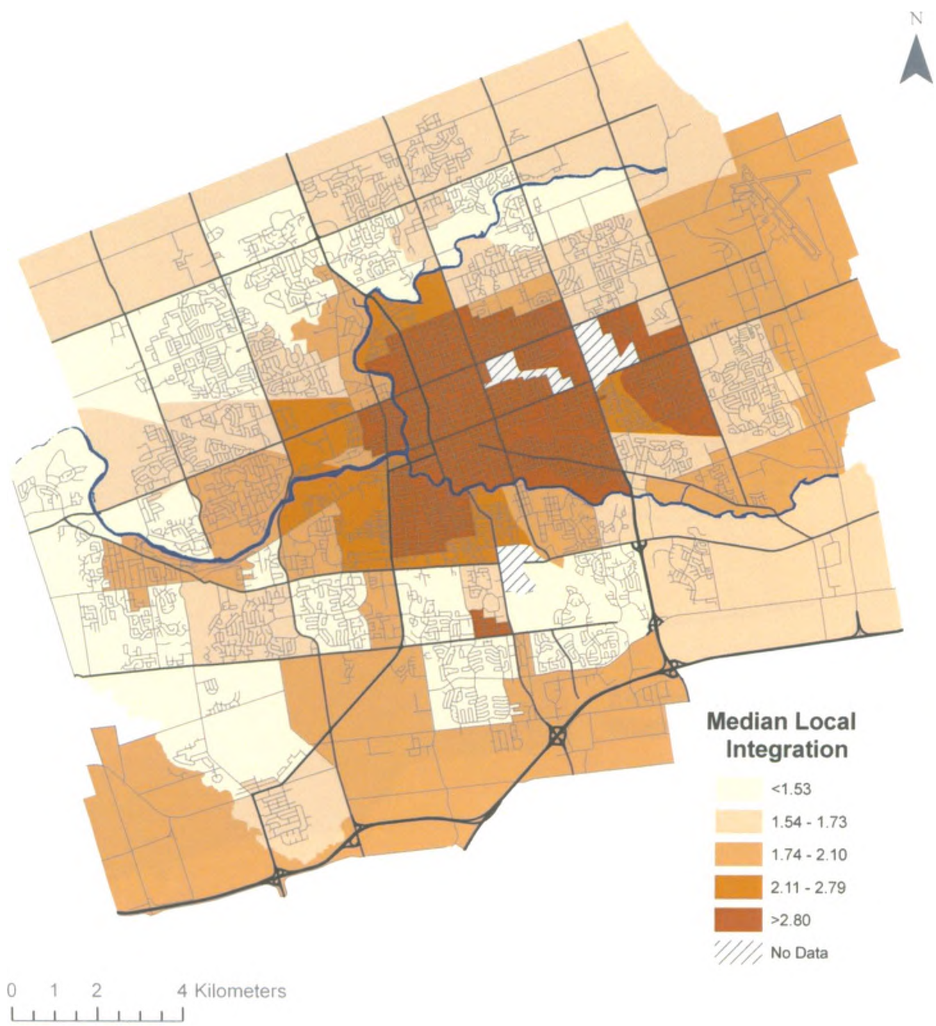


Figure 4-20: Average Local Integration in London

4.6.6 Average Street Segment Width

There are 8,882 street segments in London, with an average segment width of 9.91 metres and a standard deviation of 4.65 metres. The 78 MUs have an overall average street segment length of 10 metres with a standard deviation of 0.9 metres. The maximum average segment length of 12 metres is found in Lockwood Park (MU 23) and the minimum average segment length of 7.5 in Southdale (MU 55). Neighbourhood level spatial variation in the average street segment width measure is shown in Figure 4-21: Average Street Segment Width in London.

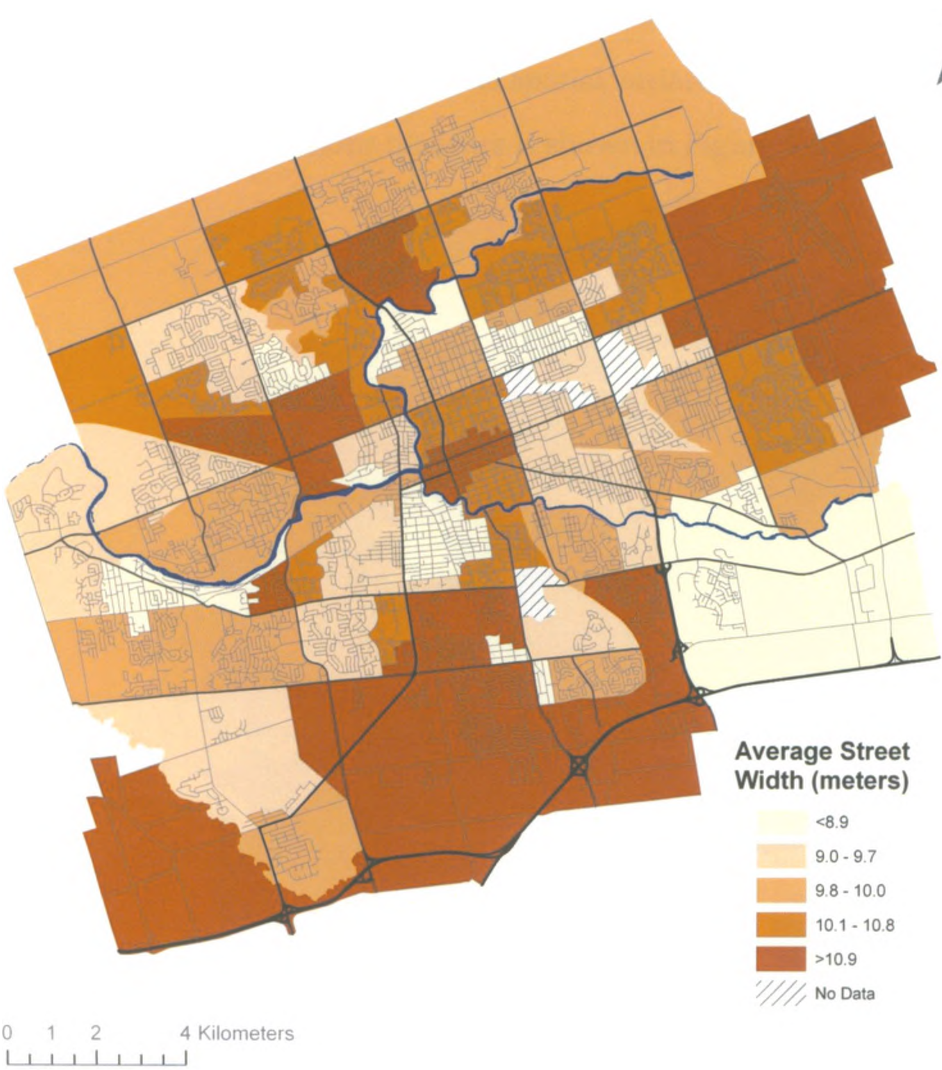


Figure 4-21: Average Street Segment Width in London

4.6.7 Proportion of Irregular Angled Intersections

Irregular intersections are defined by those intersections with angles greater than 100 degrees and less than 90 degrees. There are 599 of these intersections in London, with an average proportion of irregular angled intersections of 13% (599 irregular angled intersections / 4656 total T, X and irregular intersections). The 78 MUs have an overall proportion of irregular angled intersections of 13% with a standard deviation of 10%. The maximum proportion of irregular angled intersections of 50% can be found in Old South (MU 77) and the minimum proportion of 0% in Argyle, Byron, Byron South, Glencarin, Oxford Park, Riverbend, and The Ponds (MUs 1, 8, 10, 23, 45, 51, and 64 respectively). Neighbourhood level spatial variation in the proportion of irregular angled intersections measure is shown in Figure 4-22.

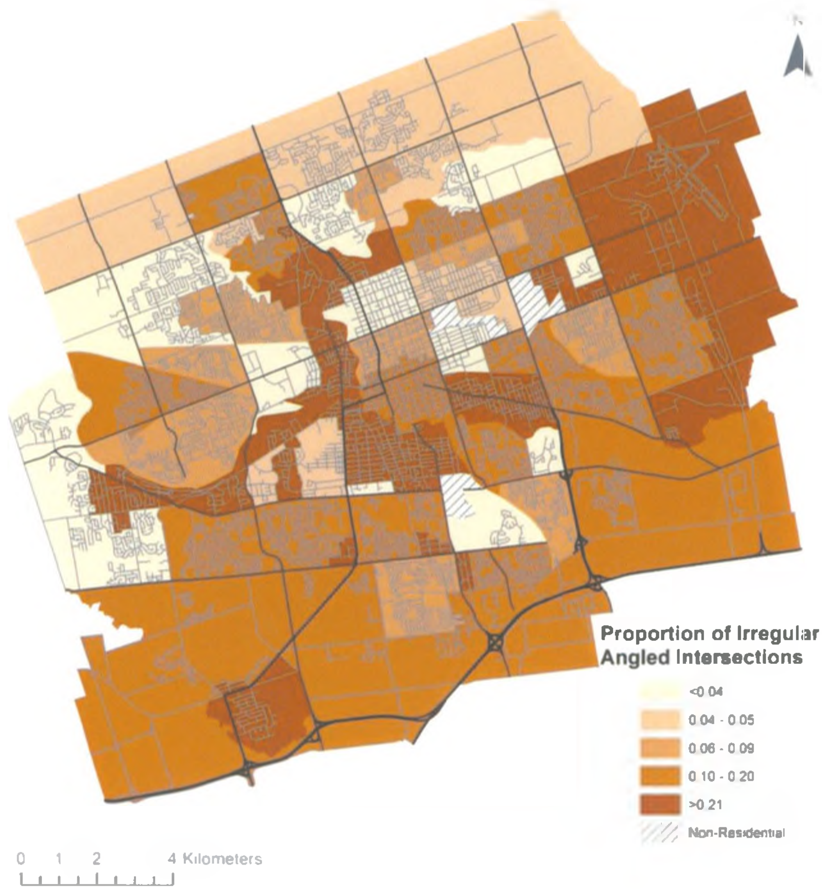


Figure 4-22: Proportion of Irregular Angled Intersections in London

4.6.8 Proportion of Arterial Streets

Streets are classified as either *arterial* or *local/collator* using the DMTI street file as further described in the methods. Calculating both performance indicators would be redundant, as one would be the direct opposite of the other. Thus, only the proportion of arterial streets has been calculated.

There are 12,036 street segments in London using DMTI street data, with an average proportion of 18% (2,160 arterial street segments / 120,36 street segments). The 78 MUs have an overall arterial street segment proportion of 20% with a standard deviation of 12%. The maximum arterial proportion of 67% is found in Lambeth South (MU 31) and the minimum of 3% in Byron (MU 8). Neighbourhood level spatial variation in the proportion of arterial streets measure is shown in Figure 4-23.

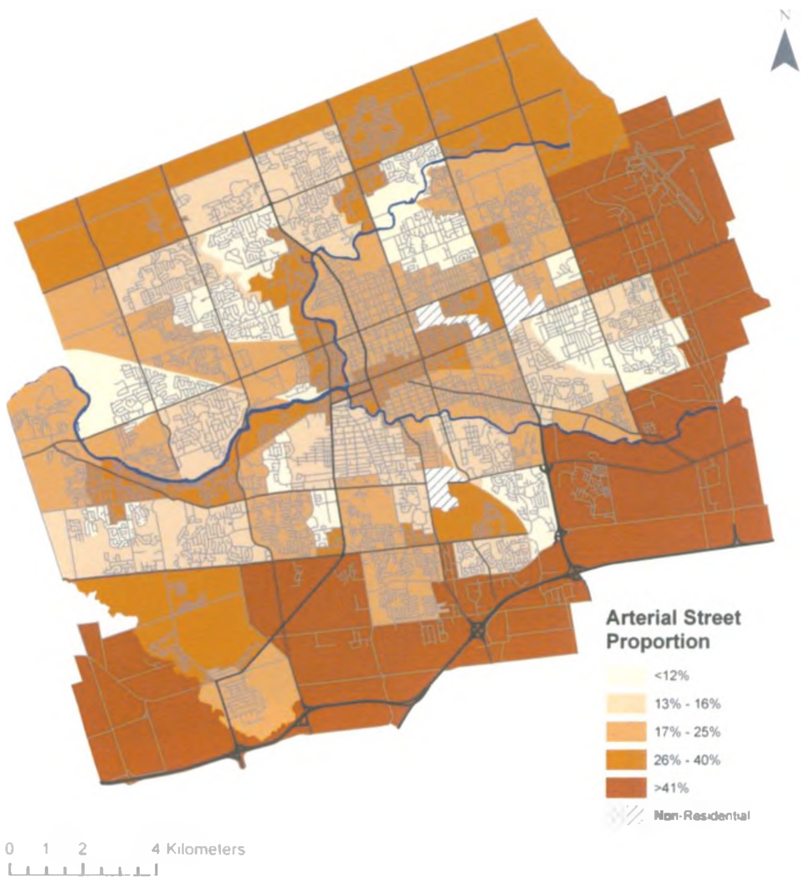


Figure 4-23: Proportions of Arterial Streets in London

4.7 Block Performance Indicators

4.7.1 Block Size

4.7.1.1 Average Block Size

There are 3,807 blocks in London with an average block size of 0.17 square kilometres. There are 3,594 blocks in the 78 MUs in London, with an overall average block size of 0.23 square kilometres and a standard deviation of 0.19 kilometres. The maximum average block size (0.91 square kilometres) is found in South Winds (MU 56) and the minimum (0.03) in Downtown (MU 16). Figure 4-24 Figure 4-13 shows neighbourhood level spatial vacation of the average block size measure.

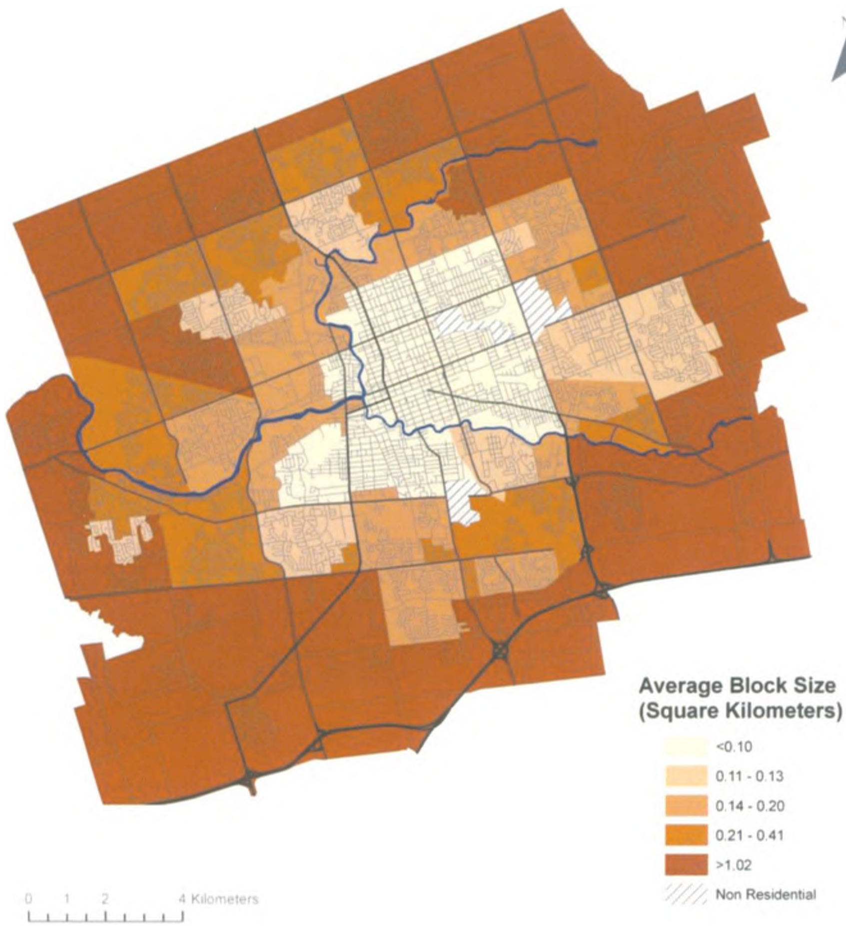


Figure 4-24: Average Block Size in London

4.7.1.12 Maximum Block Size

There are 3,807 blocks in London with a maximum block size of 7.84 square kilometres. There are 3,594 blocks in the 78 MUs in London, with an overall average maximum block size of 1.84 square kilometres and a standard deviation of 0.19 kilometres. The maximum maximum block size of 7.85 square kilometres can be found in Crumlin (MU 15) and the minimum maximum block size of 0.17 can be found in Downtown (MU 16). Neighbourhood level spatial variation in the maximum block size measure is shown in Figure 4-23

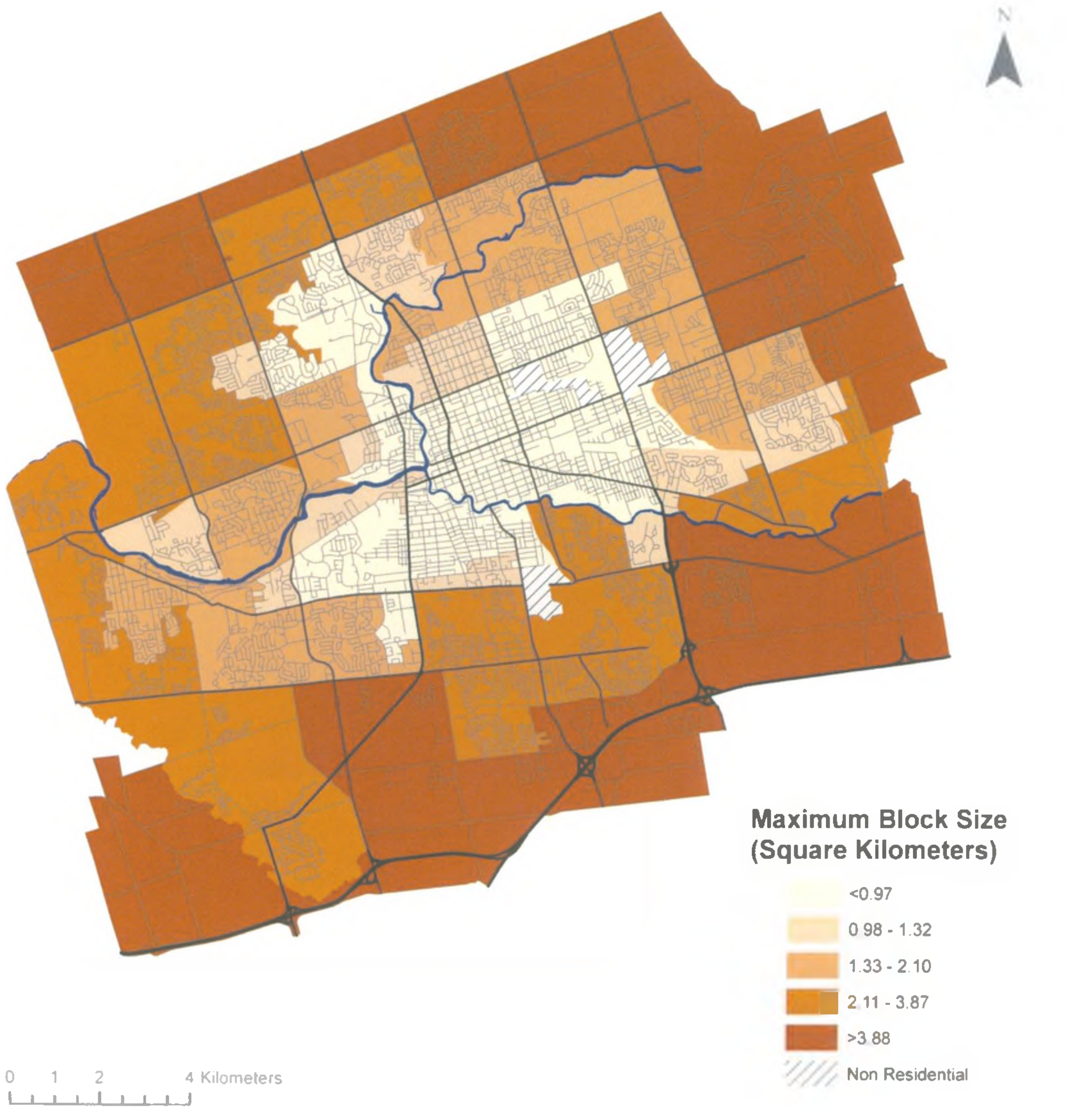


Figure 4-25: Maximum Block Size in London

4.7.2 Block Density

There are 3,807 blocks in London, with an average block density of 4.7 blocks per square kilometres (3,807 blocks / 425 square kilometres). There are 3,594 blocks in the 78 MUs in London, with an overall average block density of 22 blocks per square kilometre and a standard deviation of 12.6 blocks per square kilometre. The MU average is much higher than the London average because it removes the very large blocks to the south end of the city. The maximum block density of 54.4 blocks per square kilometre is found Downtown (MU 16) and the minimum block density of 2.03 is found in Summerside (MU 61). Neighbourhood level spatial variation in the block density measure is shown in Figure 4-26.

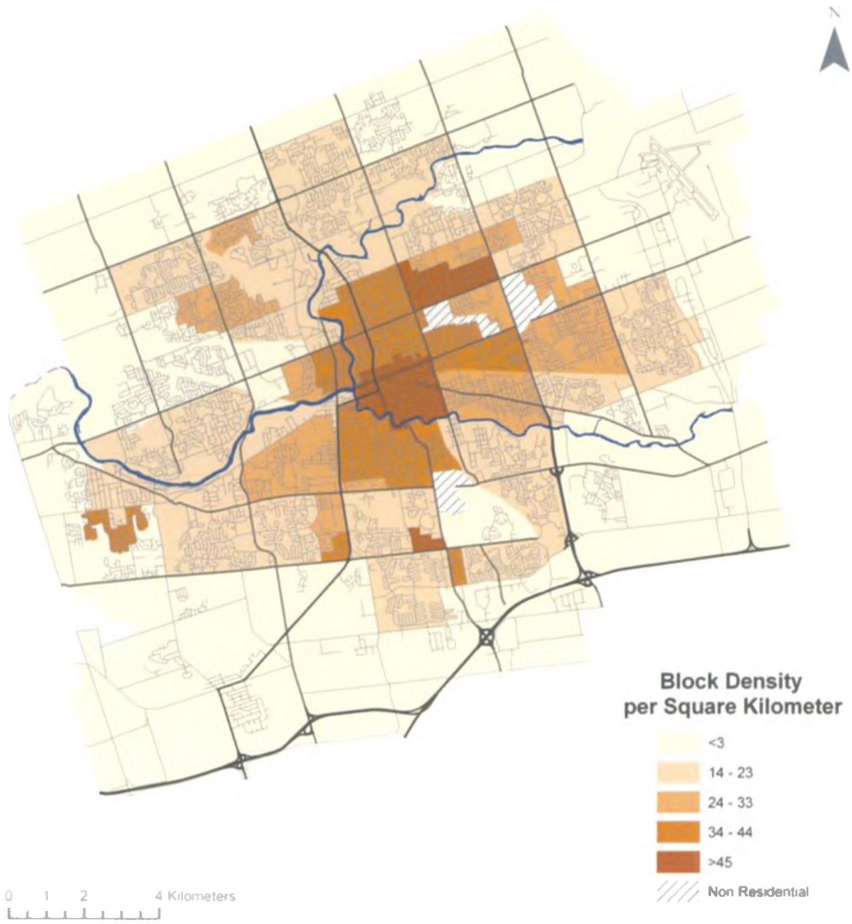


Figure 4-26: Block Density per Square Kilometre

4.8 Lot Performance Indicators

4.8.1 Lot Size

4.8.1.1 Average Lot Size

There are 100,875 lots in London, with an average lot size of 3,743 square metres. There are 99,916 lots in the 78 MUs in London, with an average lot size of 3,215 square metres a standard deviation of 5,194 square metres. The maximum lot size of 33,618 square metres is found in Crumlin (MU 15) and the minimum of 656 is found in Old South (MU 77). Neighbourhood level spatial variation in the average block lot measure is shown in Figure 4-27.

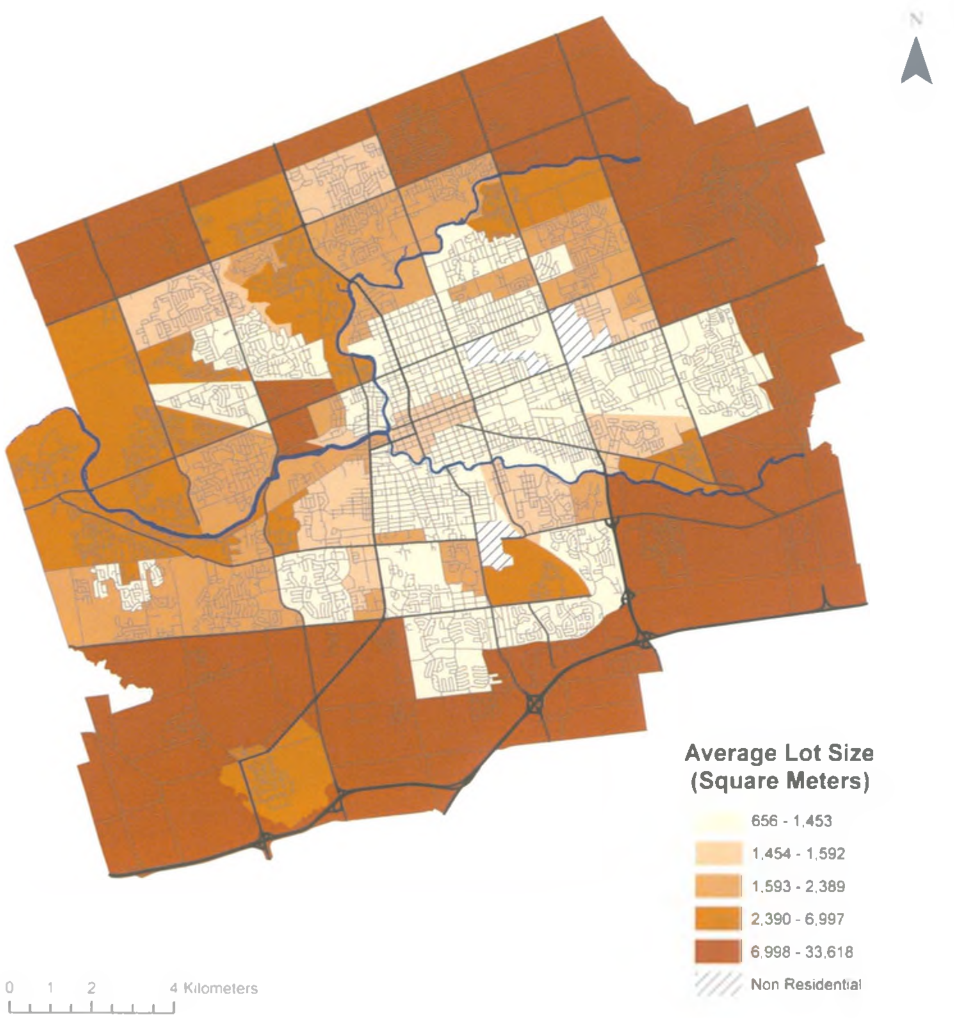


Figure 4-27: Average Lot Size

4.8.1.2 Maximum Lot Size

There are 100,875 lots in London, with a maximum lot size of 4,641,015 square metres (4.6 square kilometres). There are 99,916 lots in the 78 MUs in London, with an average maximum lot size of 3,215 square metres a standard deviation of 5,194 square metres. The maximum maximum lot size of 4,641,015 square metres is found in Crumlin (MU 15) and the minimum maximum lot size of 728,031 square metres is found in Southdale (MU 77). Figure 4-28 shows neighbourhood level spatial vacation of the maximum lot size measure.

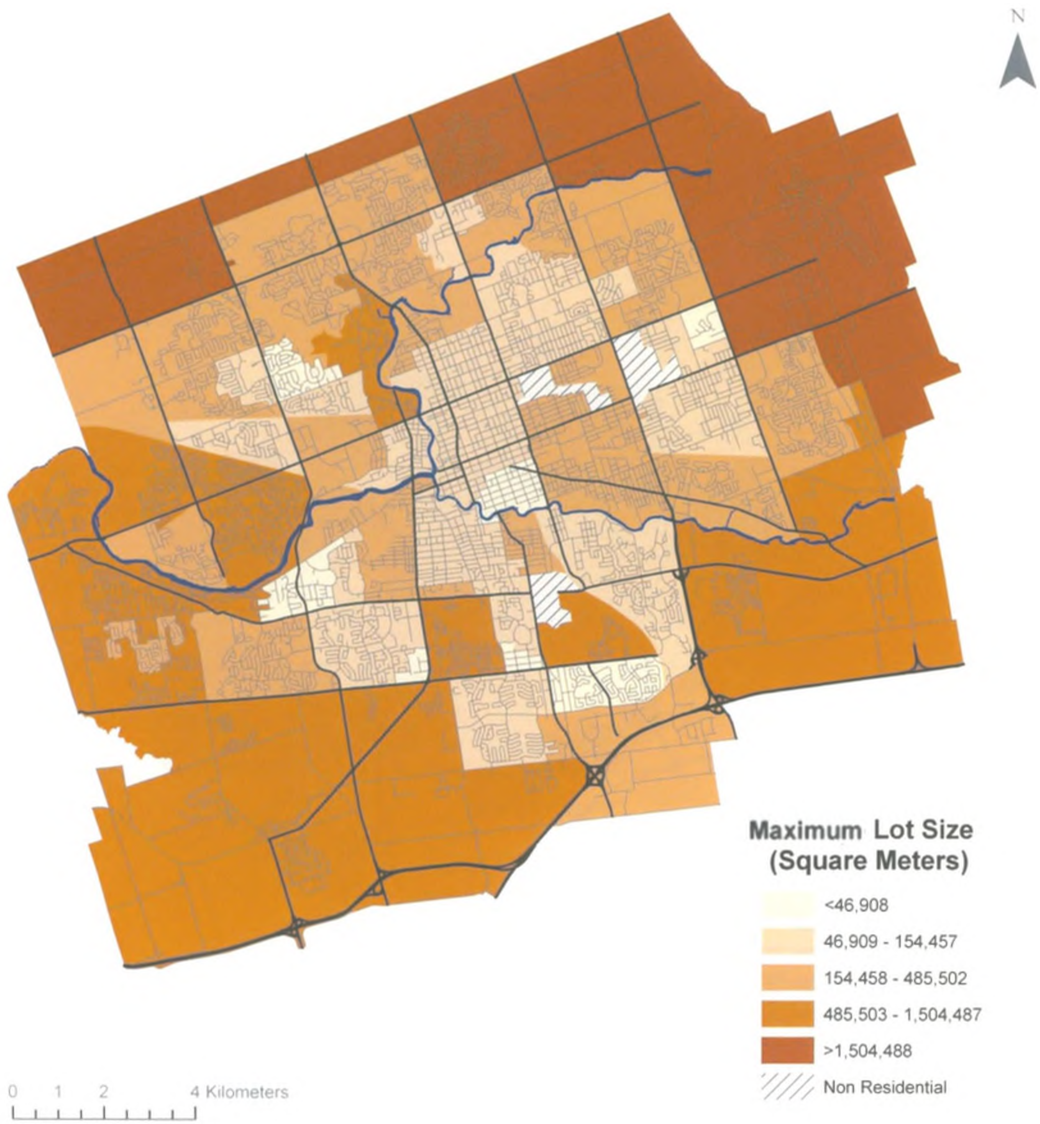


Figure 4-28: Maximum Lot Size

4.8.2 Lot Density

There are 100,875 lots in London, with an average lot density of 237 lots per square kilometre (100,875 lots divided by 425 square kilometres). There are 99,916 lots in the 78 MUs in London, with an overall average lot density of 546 lots per square kilometre and a standard deviation of 266 lots per square kilometre. The MU average is much higher than the London average because it removes the very large lots to the south end of the city. The maximum lot density of 1,178 lots per square kilometre is found in Old South (MU 77) and the minimum lot density of 30 lots per square kilometre occurs is found in Crumlin (MU 15). Figure 4-29 shows neighbourhood level spatial vacation of the lot density measure.

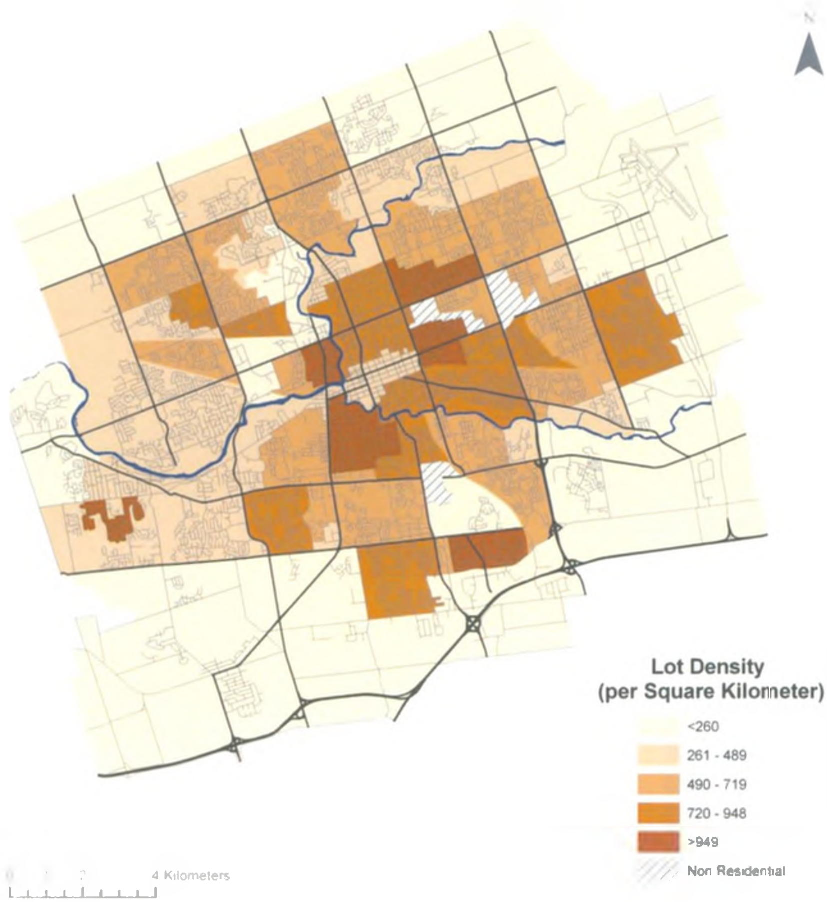


Figure 4-29: Lot Density per Square Kilometre

4.8.3 Lots per Block

There are 100,875 lots in London, with an average lot to block proportion of 26.5 lots per block (100,875 lots / 3,807 blocks). There are 99,916 lots in the 78 MUs in London, with an overall lot to block proportion of 27.8 lots per block and a standard deviation of 11 lots per block. The maximum lot to block proportion of 55.1 lots per block is found in West of Wonderland (MU 67) and the minimum lot density of 8.6 lots per block is found in Downtown (MU 16). Neighbourhood level spatial variation in the lots per block measure is shown in Figure 4-30.

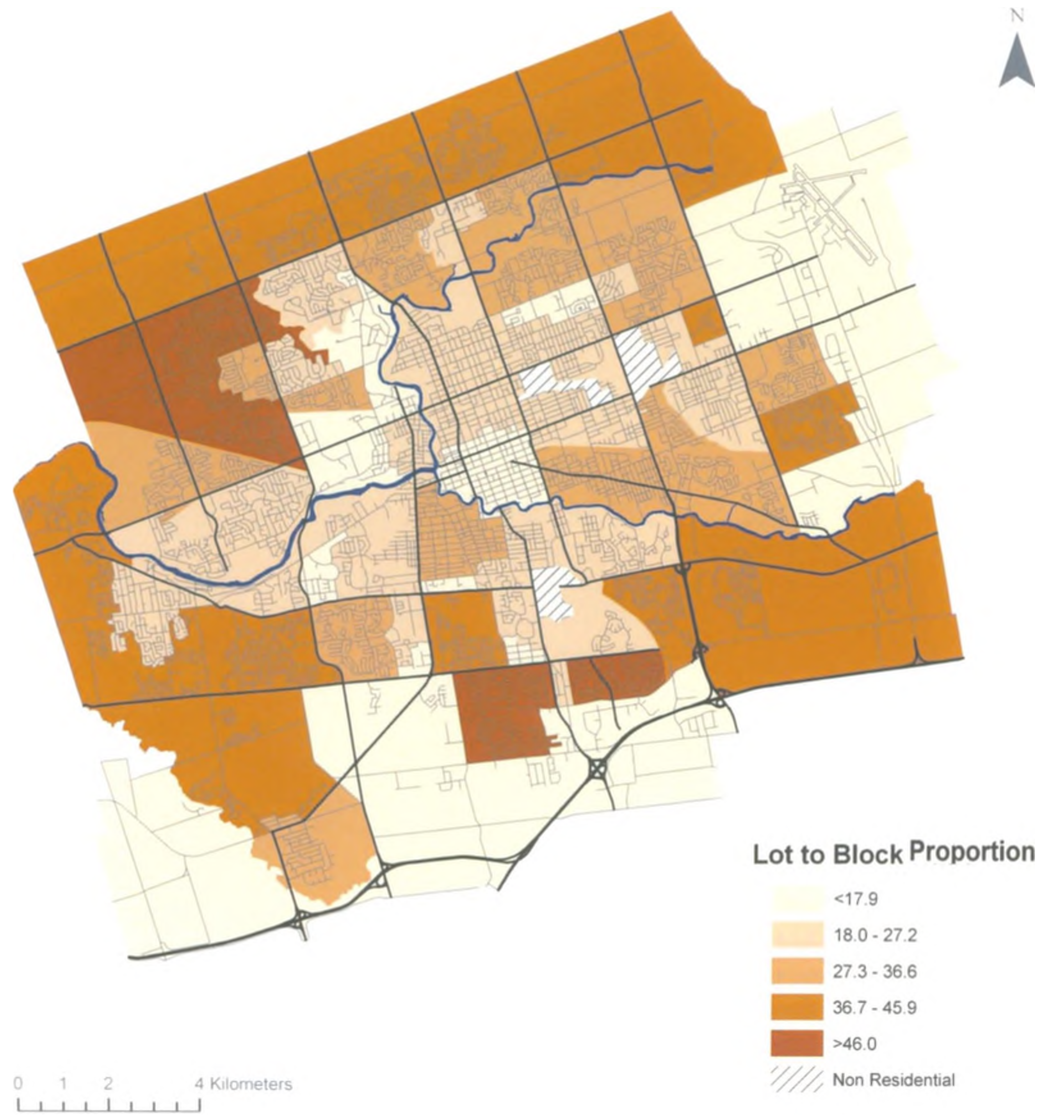


Figure 4-30: Lot to Block Proportion

4.8.4 Proportion of Undeveloped Lots

There are 100,875 lots in London, with an average proportion of undeveloped lots of 13% (13,522 undeveloped lots / 100,875 total lots). There are 99,916 lots in the 78 MUs in London, with an overall proportion of undeveloped lots of 12% and standard deviation of 18%. The maximum proportion of undeveloped lots (69%) is found in West of Wonderland (MU 67) and the minimum proportion (1%) is found in Kensal Park (MU 29). Neighbourhood level spatial variation in the proportion of undeveloped lots measure is shown in Figure 4-31.

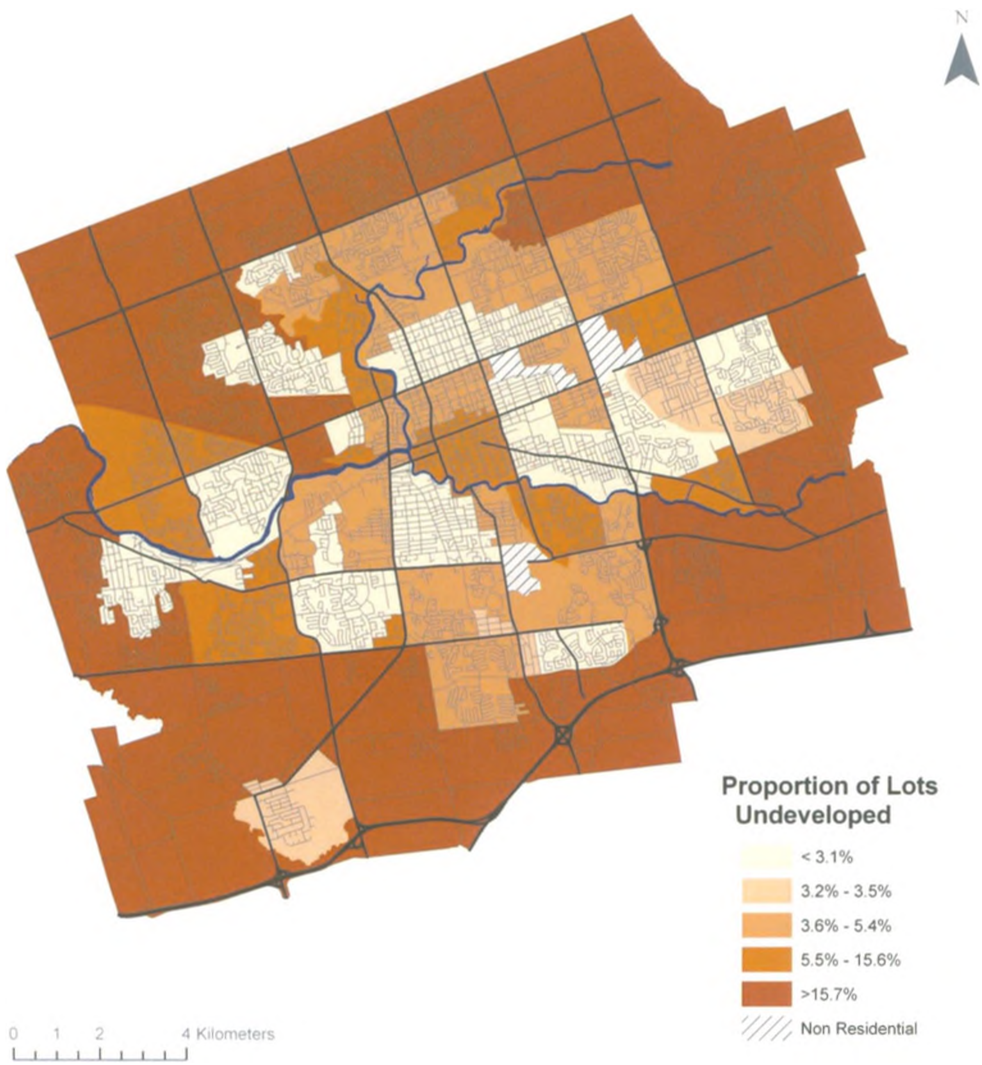


Figure 4-31: Proportion of Undeveloped Lots in London

4.8.5 Lot Frontage

There are 100,875 lots in London, with an average lot frontage of 33 metres (3,311,917 metres total frontage divided by 100,875 total lots). There are 99,916 lots in the 78 MUs in London, with an overall lot frontage of 34 metres and standard deviation of 23 metres. The maximum lot frontage of 141 metres is found in Crumlin (MU 15) and the minimum of 18 metres is found in Old South (MU 77). Neighbourhood level spatial variation in the proportion of undeveloped lots measure is shown in Figure 4-32.

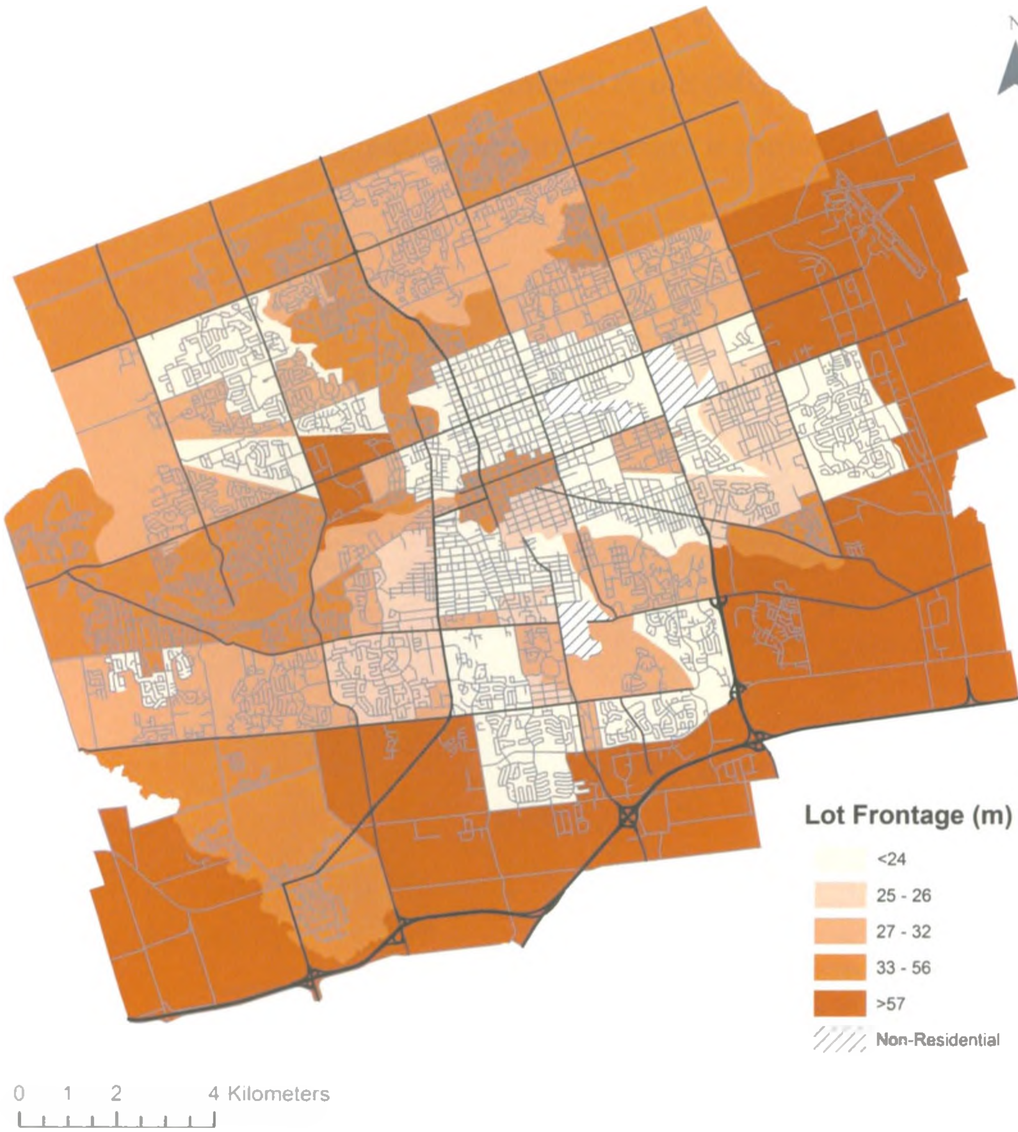


Figure 4-32: Lot Frontage in London

4.9 Building Performance Indicators

4.9.1 Building Density

There are 131,046 buildings in London, with an average building density of 553 buildings per square kilometre (131,046 buildings divided by 425 square kilometres). There are 128,280 buildings in the 78 MUs in London, with an overall average building density of 748 buildings per square kilometre and a standard deviation of 457 buildings per square kilometre. The maximum building density of 2,084 can be found in Old South (MU 77) and the minimum building density of 30 can be found in Lambeth South (MU 31). Neighbourhood level spatial variation in the building density measure is shown in Figure 4-33.

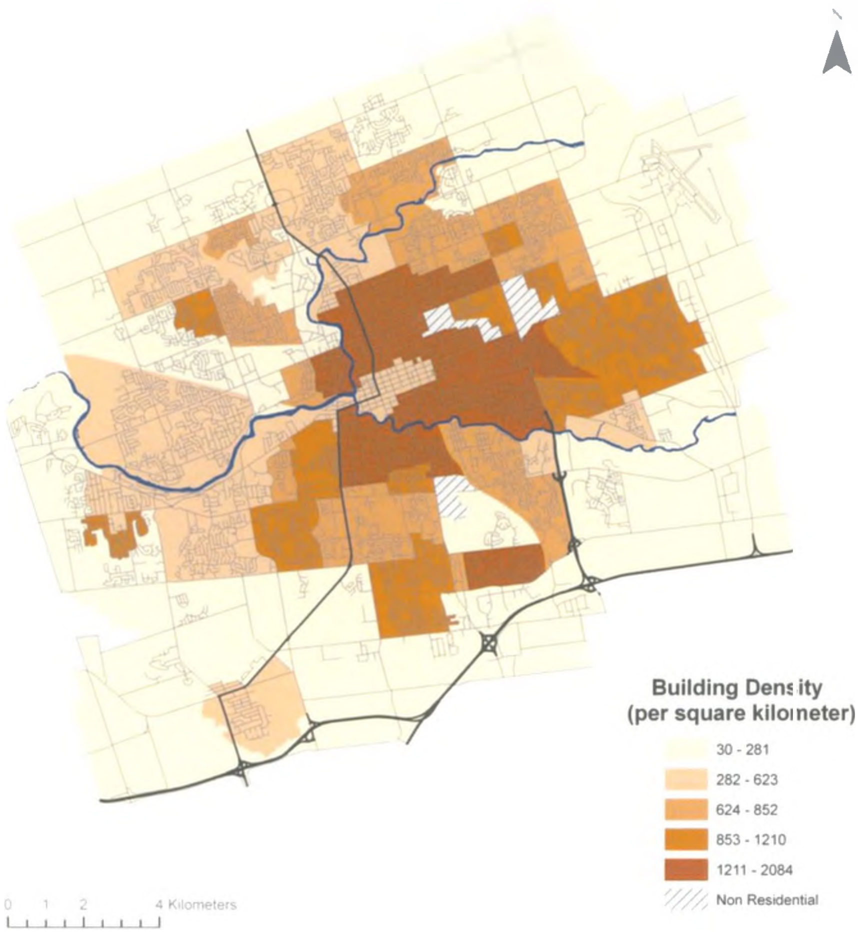


Figure 4-33: Building Density per Square Kilometre

4.9.2 Residential Building

4.9.2.1 Residential Building Density

There are 118,942 residential buildings in London, with an average residential building density of 280 residential buildings per square kilometre (118,942 residential buildings divided by 425 square kilometres). There are 118,061 residential buildings in the 78 MUs in London, with an overall average residential building density of 701 residential buildings per square kilometre and a standard deviation of 437 residential buildings per square kilometre. The maximum residential building density of 2,004 is found in Old South (MU 77) and the minimum residential building density of 9 is found in Lambeth South (MU 31). Neighbourhood level spatial variation in the residential building density measure is shown in Figure 4-33.

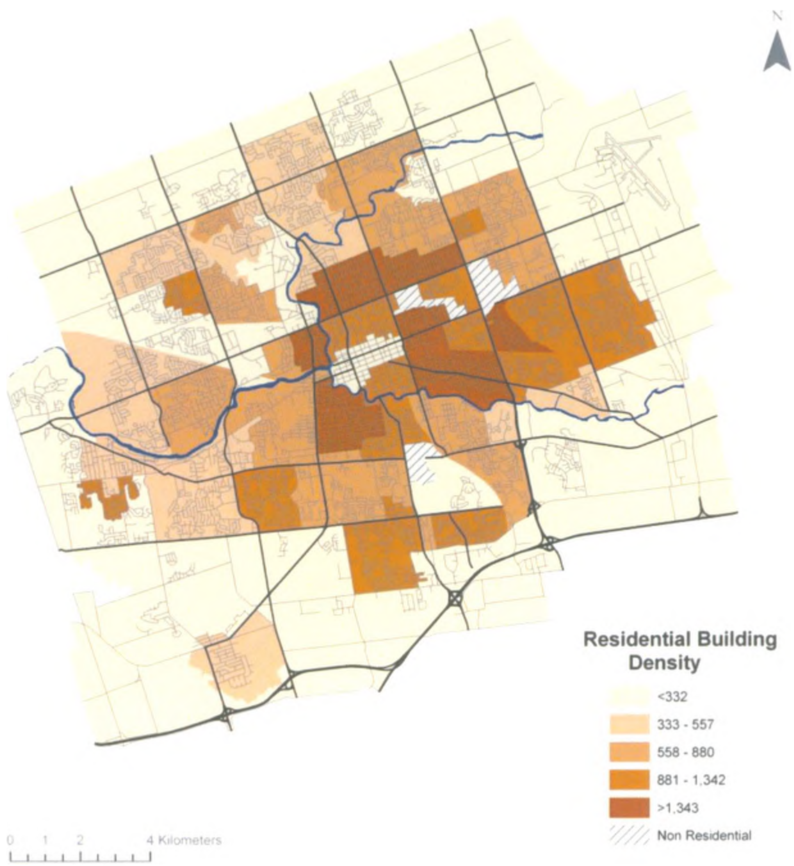


Figure 4-34: Residential Building Density per Square Kilometre

4.9.2.2 Residential Building Proportion

There are 118,942 residential buildings in London, with an average residential building proportion of 91% (118,942 residential buildings divided by 131,046 total buildings). There are 118,061 residential buildings in the 78 MUs in London, with an overall average residential building proportion of 90% and a standard deviation of 14%. The maximum residential building proportion of 100% is found in Byron (MU 8) and the minimum residential building proportion of 32% is found in Lambeth South (MU 31). Neighbourhood level spatial variation in the residential building proportion measure is shown in Figure 4-35.

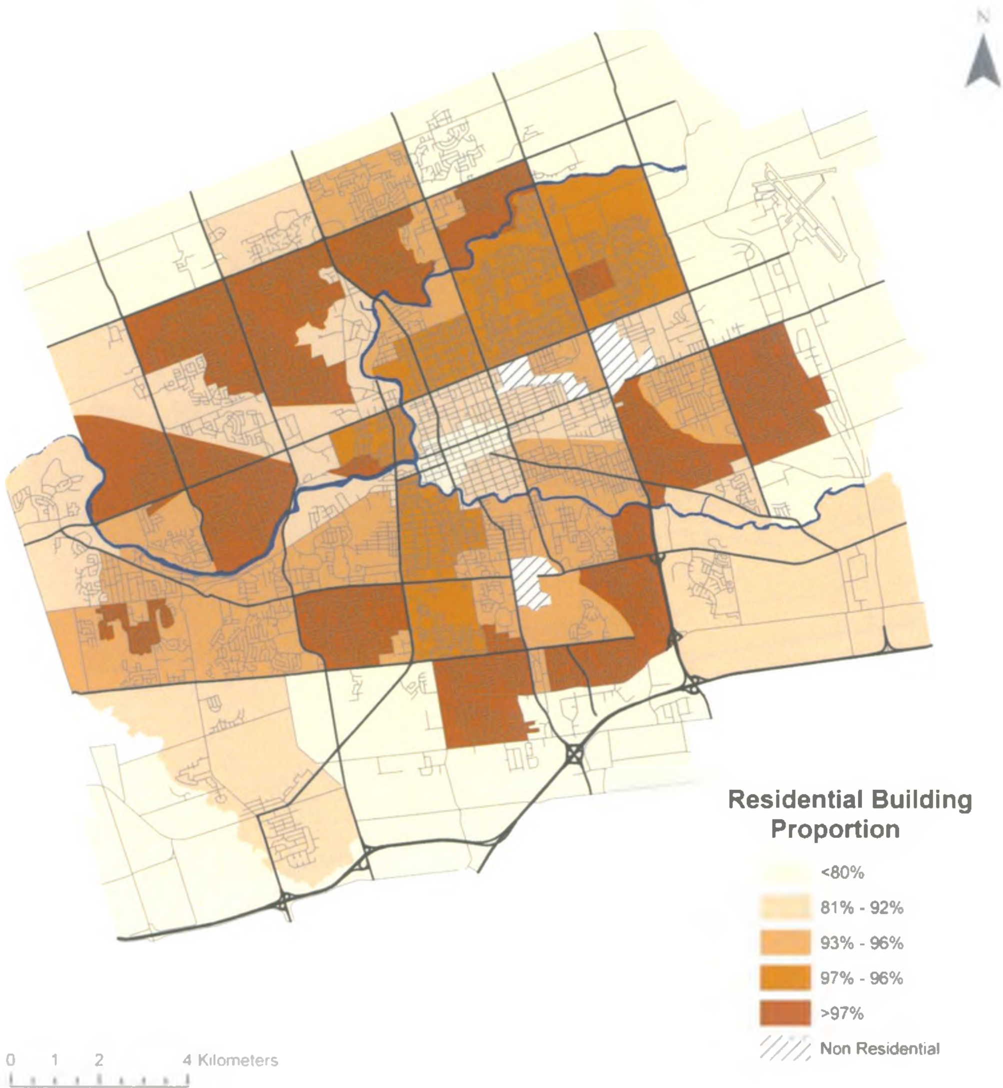


Figure 4-35: Residential Building Proportion in London

4.9.3 Building Coverage Proportion

There are 131,046 buildings in London, with an average building coverage proportion of 8% (22,931,670 total building area divided by 288,417,260 total lot area with buildings). There are 128,280 buildings in the 78 MUs in London, with a building coverage proportion of 16% and a standard deviation of 7%. The maximum building coverage proportion of 43% is found in Downtown (MU 16) and the minimum building coverage proportion of 1% is found in the North Park (MU 38). Neighbourhood level spatial variation in the building coverage proportion measure is shown in Figure 4-36.

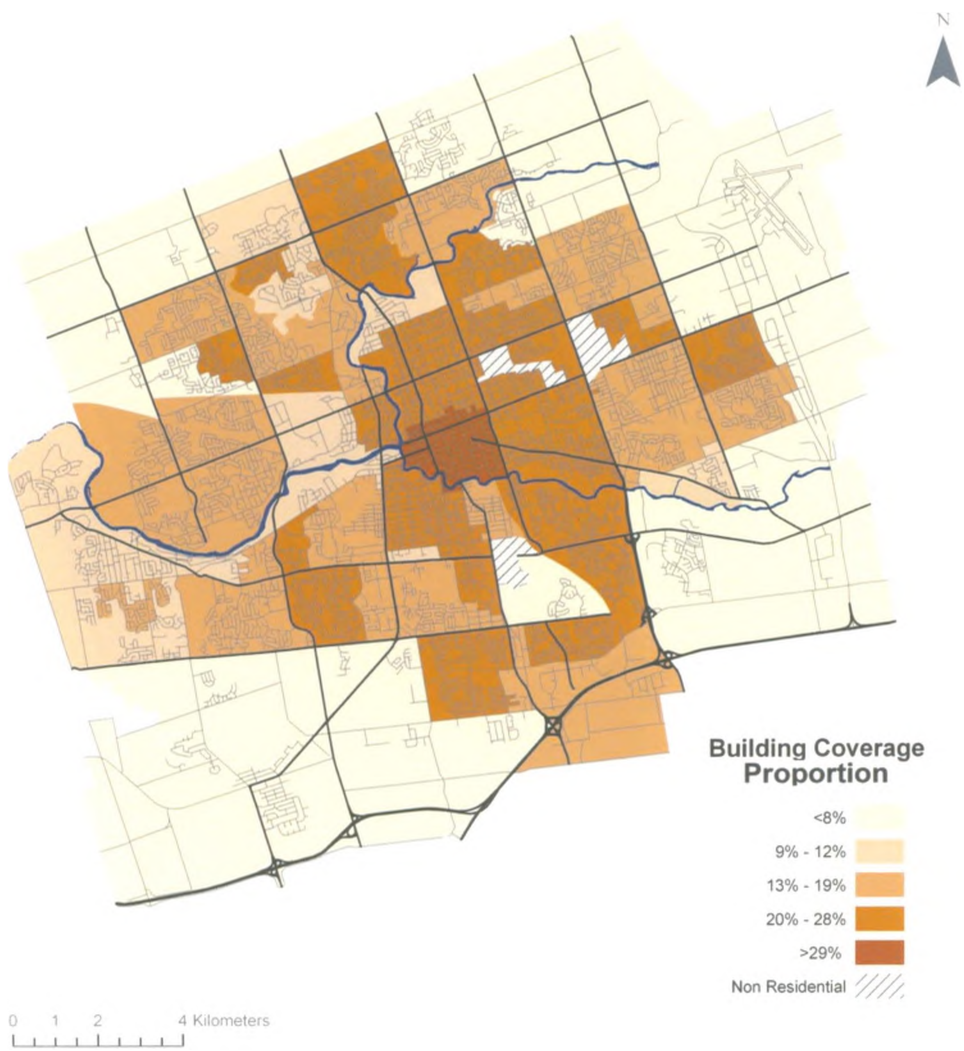


Figure 4-36–Building Coverage Proportion in London

4.9.4 Building Footprint Size

4.9.4.1 Average Building Footprint Size

There are 131,046 buildings in London, with an average building footprint size of 192 square metres. There are 128,280 buildings in the 78 MUs in London, with an average building footprint size of 210 square metres and a standard deviation of 182 square metres. The maximum building footprint size of 1,545 square metres is found in the industrial area Wilton Grove (MU 75) and the minimum building footprint size of 80 square metres is found in the residential neighbourhood of Forward (MU 21). Figure 4-37 displays the neighbourhood level spatial variation in the average building footprint size measure.

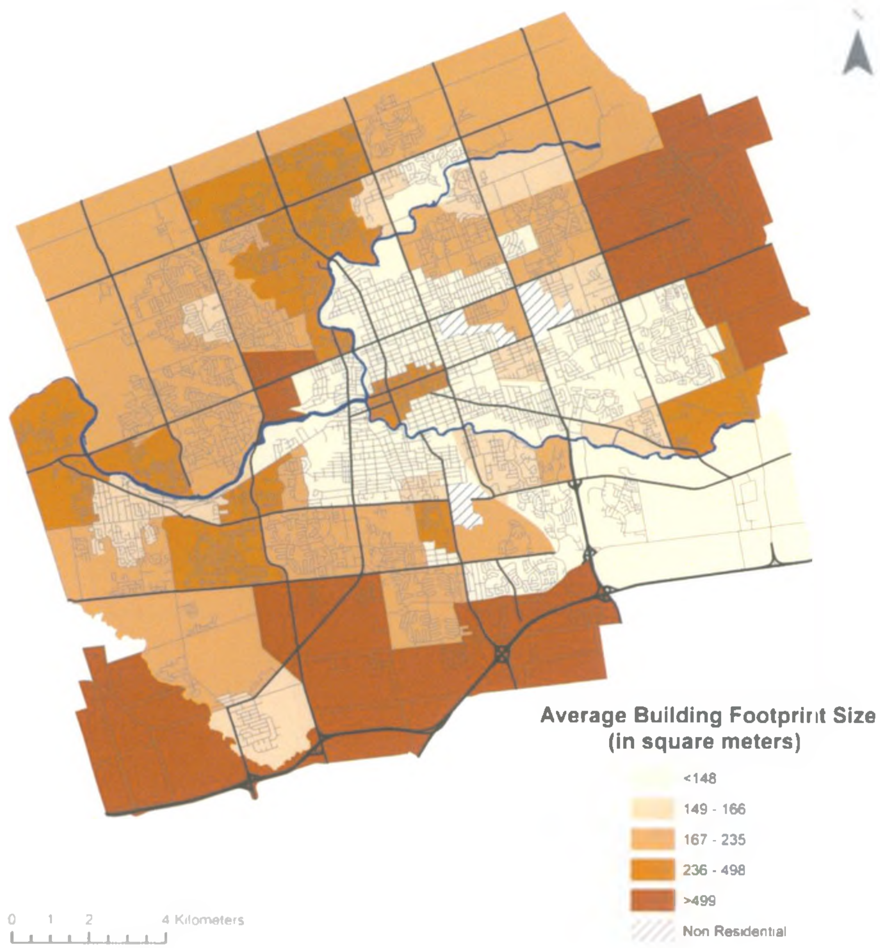


Figure 4-37: Average Building Footprint Size in London

4.9.4.2 Maximum Building Footprint Size

There are 131,046 buildings in London, with a maximum building footprint size of 67,416 square metres. There are 128,280 buildings in the 78 MUs in London, with an average maximum building footprint size of 12,842 square metres and a standard deviation of 13,486 square metres. The maximum maximum building footprint size of 67,416 can be found in the industrial area Wilton Grove (MU 75) and the minimum maximum building footprint size of 342 can be found in the neighbourhood of Forward (MU 21). Neighbourhood level spatial variation in the maximum building footprint size measure is shown in Figure 4-38.

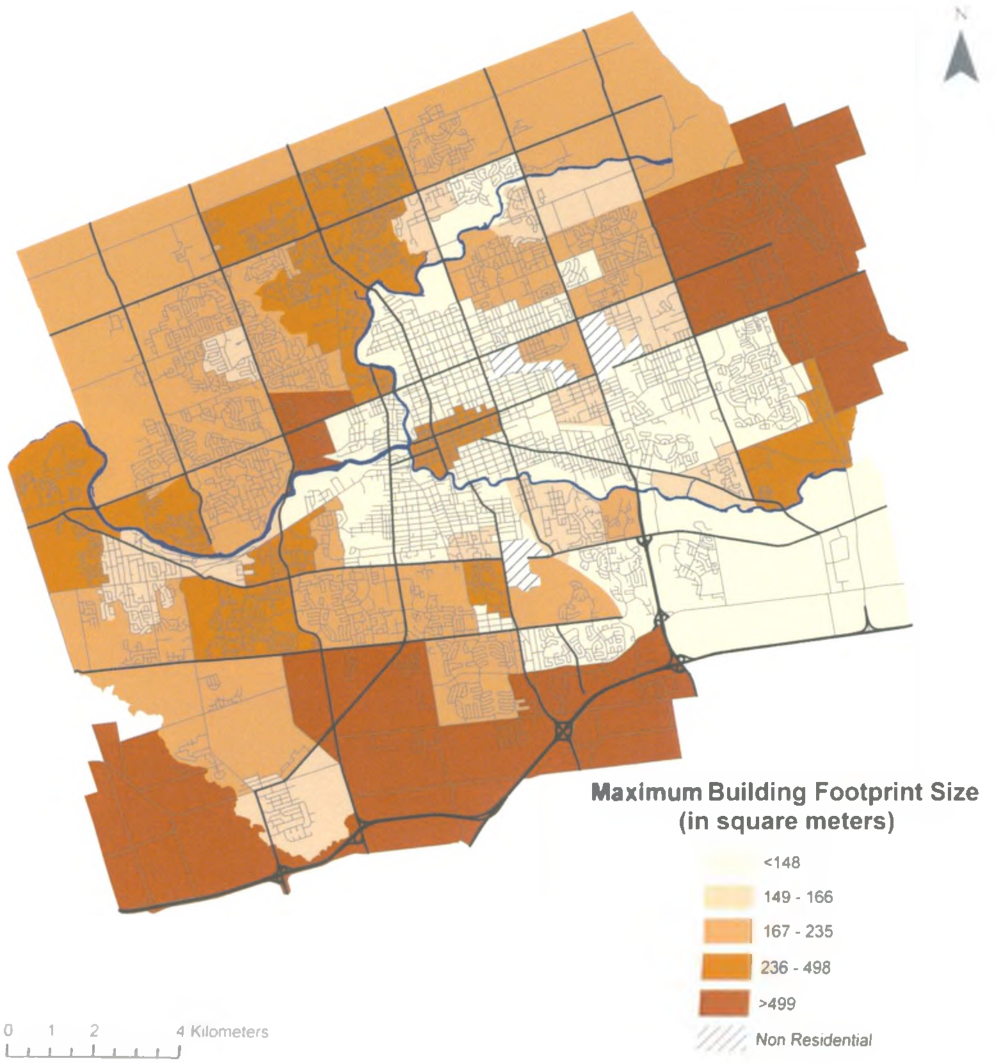


Figure 4-38–Maximum Building Footprint Size in London

4.9.5 Distance between Buildings

There are 131,046 buildings in London, with an average distance between buildings of 11.14 metres. There are 128,280 buildings in the 78 MUs in London, with an average distance between buildings of 10.36 metres and a standard deviation of 5.31 metres. The maximum distance between buildings of 33.84 metres is found in Crumlin (MU 15) and the minimum distance between buildings of 5.29 is found is found in Old North (MU 43). Neighbourhood level spatial variation in the distance between buildings measure is shown in Figure 4-39.

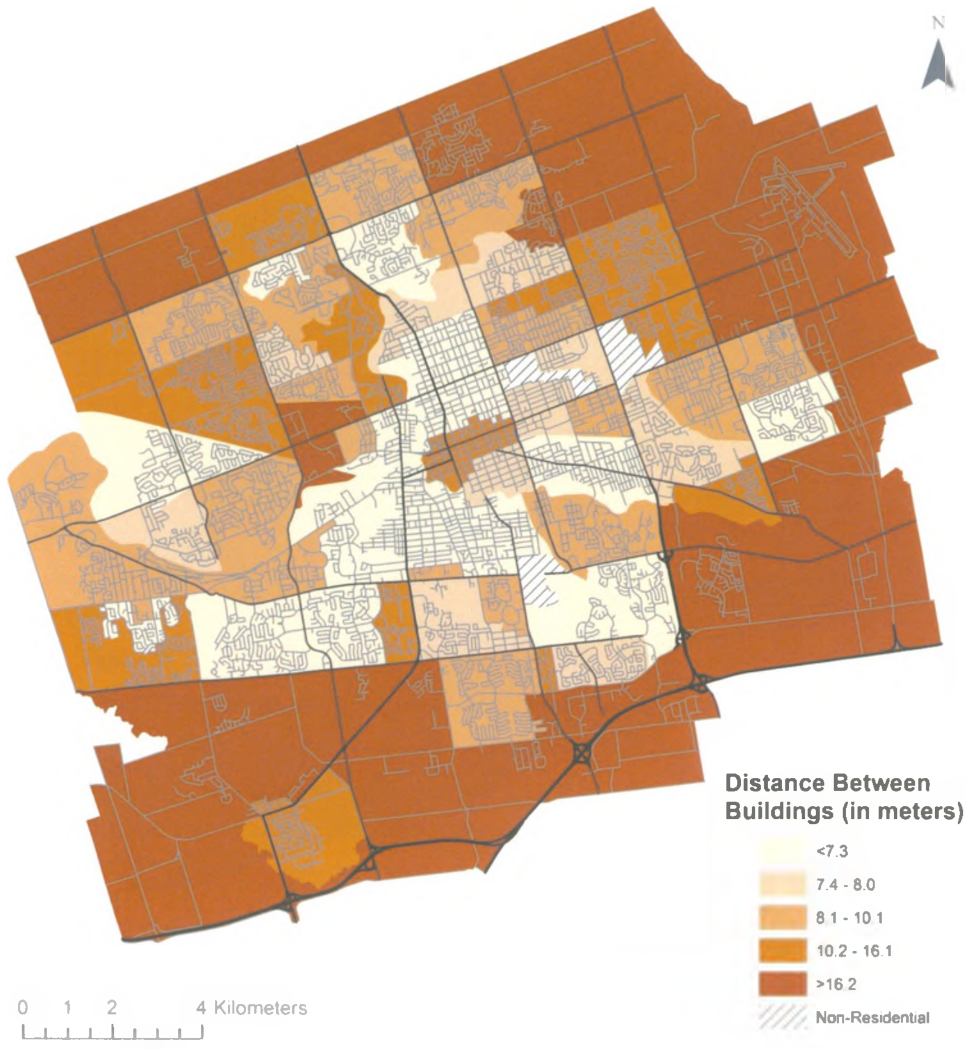


Figure 4-39: Distance between Buildings

4.9.6 Average Number of Buildings per Lot

There are 131,046 buildings in London, with an average building to lot proportion of 1.3 buildings per lot (131,046 buildings / 100,875 lots). There are 128,280 buildings in the 78 MUs in London, with an average building to lot proportion of 1.3 buildings per lot and a standard deviation of 0.32 buildings per lot. The maximum building to lot proportion of 1.94 is found in Hamilton Road (MU 25) and the minimum building to lot proportion of 0.41 is found in West of Wonderland (MU 70). Figure 4-40 displays the neighbourhood level spatial variation in the average number of buildings per lot measure.

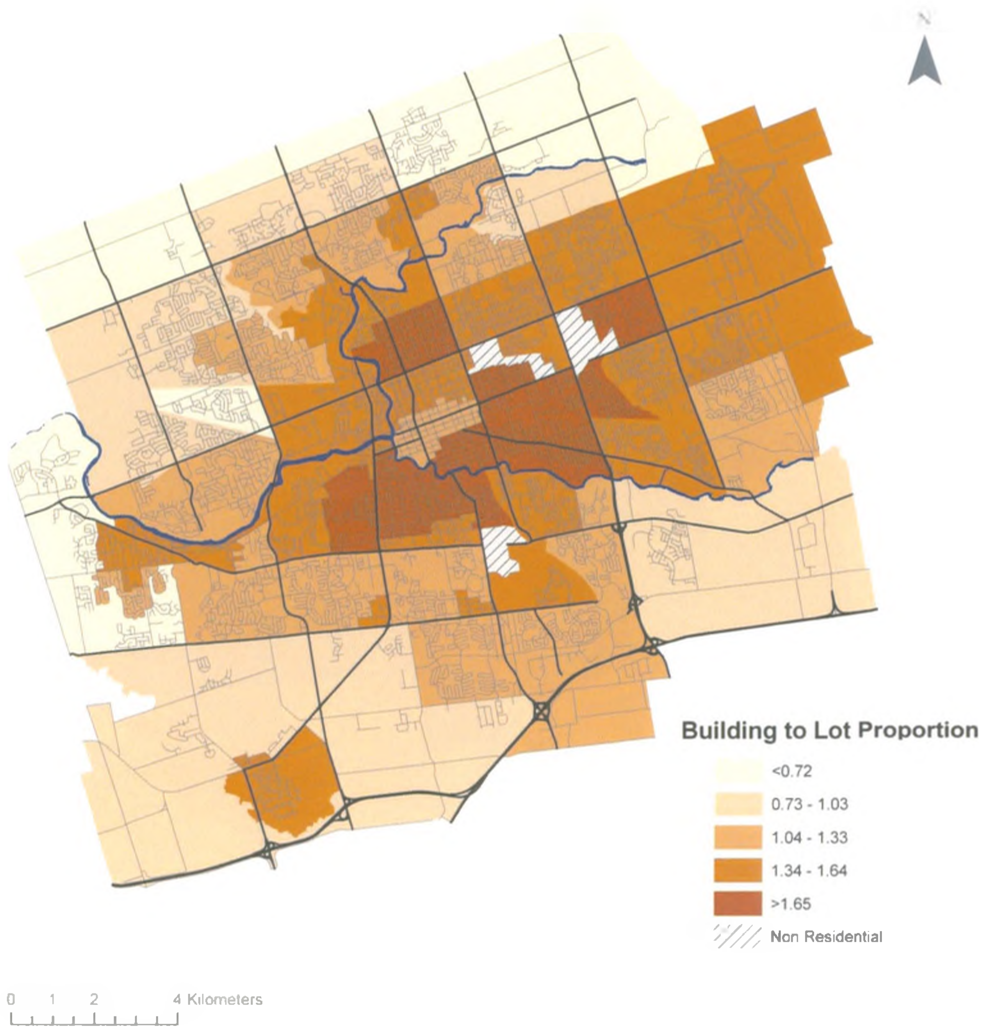


Figure 4-40: Building to Lot Proportion in London

4.9.7 Average Number of Buildings per Block

There are 131,046 buildings in London, with an average building to block proportion of 34 buildings per block (131,046 buildings / 3,807 blocks). There are 128,280 buildings in the 78 MUs in London, with an average building to block proportion of 34 buildings per block and a standard deviation of 12 buildings per block. The maximum building to block proportion of 77 buildings per block is found in Argyle (MU 1) and the minimum building to block proportion size of 11 buildings per block can be seen in the Downtown (MU 16). Neighbourhood level spatial variation in the distance between buildings measure is shown in Figure 4-41.

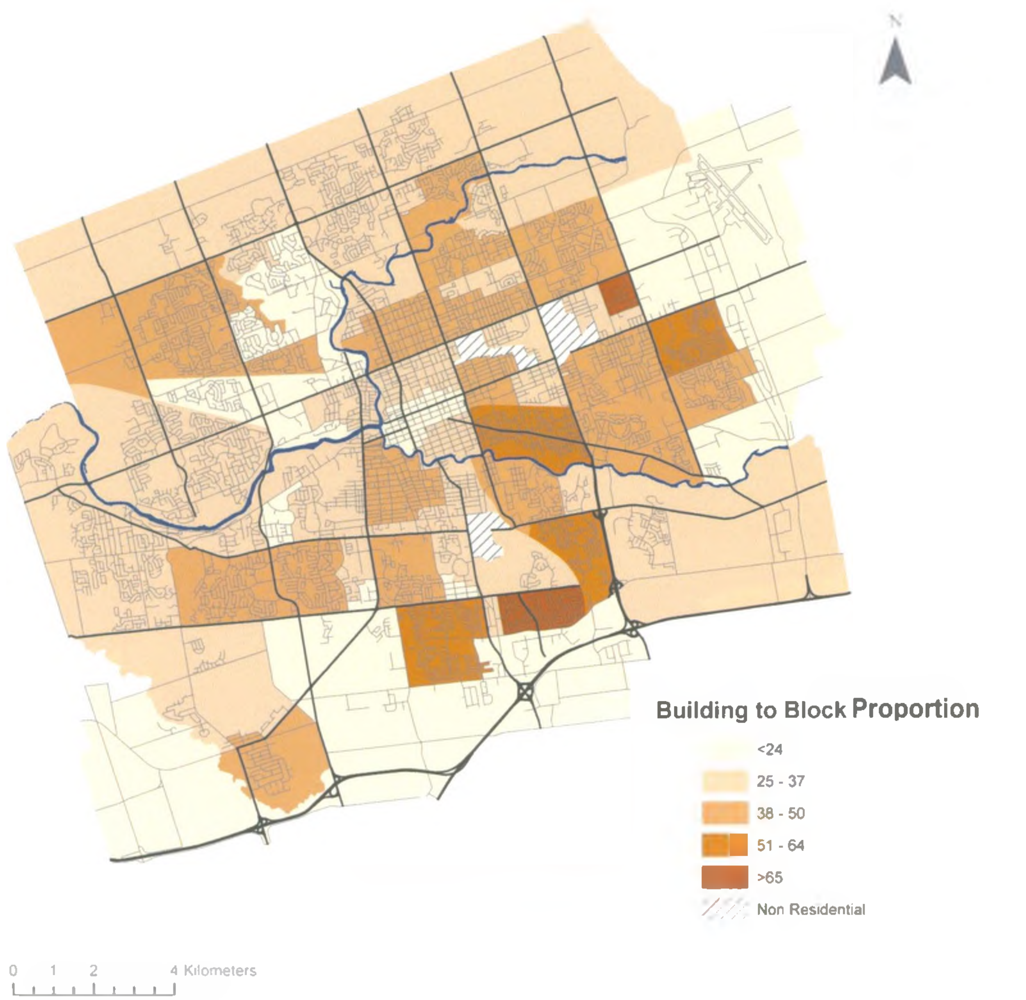


Figure 4-41- Building to Block Proportion in London

4.9.8 Building Setback

There are 131,046 buildings in London, with an average building setback of 6 metres (796,203 metres total setback / 131,046 buildings). There are 128,280 buildings in the 78 MUs in London, with an average building setback of 8.6 metres and a standard deviation of 3.8 buildings metres. The maximum building setback of 25.6 metres is found in Lambeth South (MU 31) and the minimum setback (3.1 metres) in the Old North (MU 43). Neighbourhood level spatial variation in the building setback measure is shown in Figure 4-42.

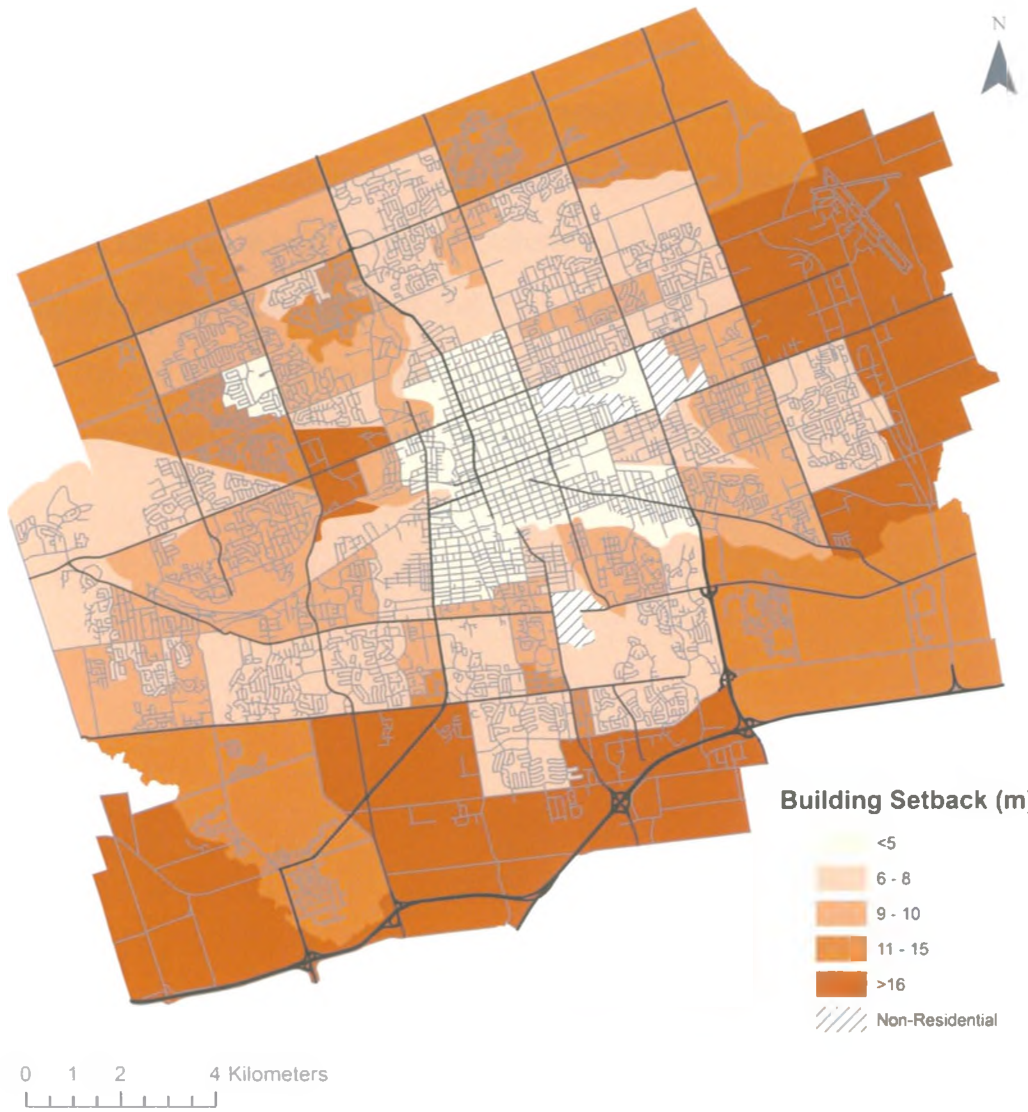


Figure 4-42: Building Setbacks in London

4.10 Land Use Performance Indicators

The land use file, provided by the City of London for the year 2002, totals 375 square kilometres in area. The file attributes a land use code to each parcel of land in the city, with these codes following into one of the following categories: (1) Land, (2) Farm, (3) Residential, (4) Commercial, (5) Industrial, (6) Institutional, (7) Special Purpose, and (8) Government. Each of these major categories is broken down into a multitude of sub categories. For example, an automotive dealership has a code 422, with the 400 representing Commercial, and the 22 representing the 22^{nd} land use within commercial. For the purposes of this thesis, land use in London has been grouped into 6 main categories: Residential (92.4 square kilometres), Commercial (16.9 square kilometres), Recreational (28 square kilometres), Institutional (14.5 square kilometres), Industrial (41.7 square kilometres) and Agricultural (183 square kilometres). Note that the 183 square kilometres of agricultural land use is not used as a performance indicator as this area shrinks to 8 square kilometres within the MUs.

4.10.1 Commercial Land Use

There are 131,046 commercial lots in London totalling 16.9 square kilometres, with an average commercial land use proportion of 4.5% (16.9 square kilometres commercial lots / 375 square kilometres total land use area). There are 16.2 square kilometres of commercial land use in the 78 MUs in London, with an average commercial proportion of 7.9% and a standard deviation of 8.5%. The maximum proportion of 57% is found in the Downtown (MU 16) and the minimum proportion (0%) in Orchard Park (MU 44). Figure 4-43 displays the neighbourhood level spatial variation in the commercial land use measure.

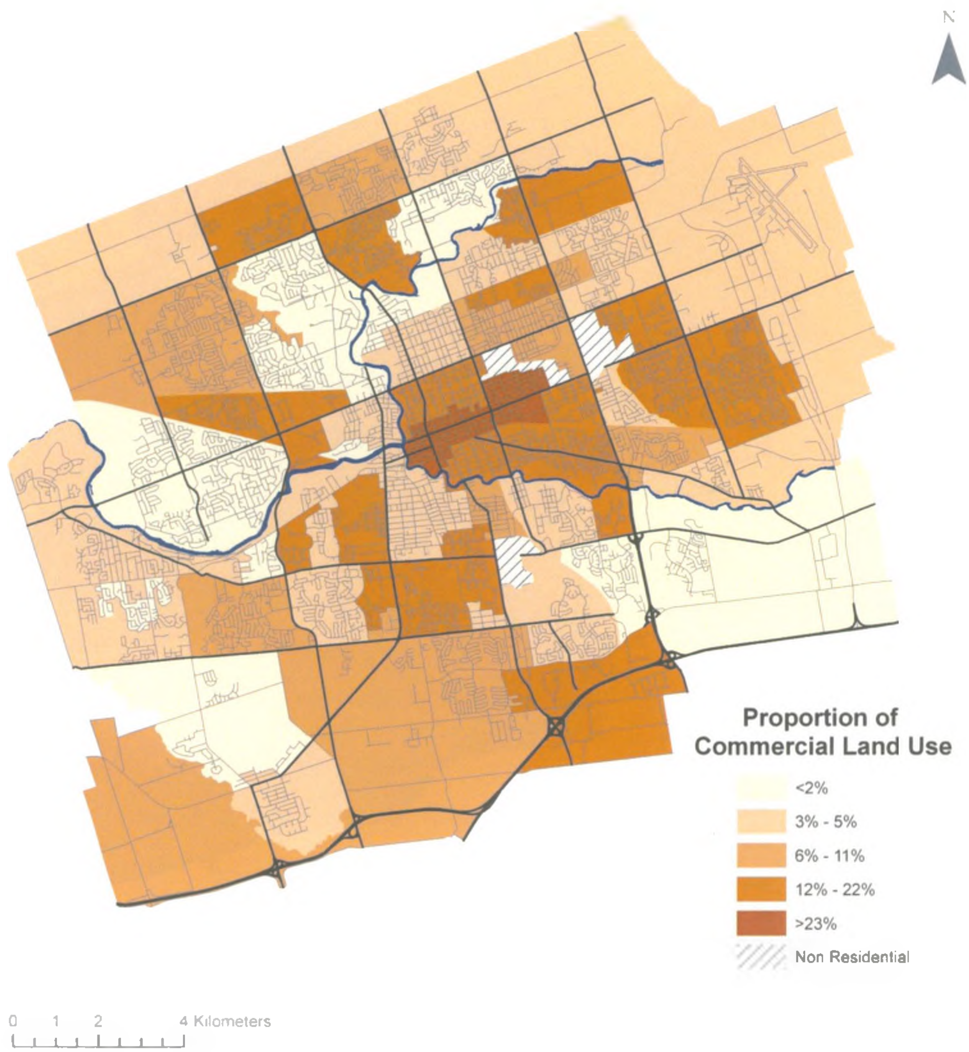


Figure 4-43: Proportion of Commercial Land Use in London

4.10.1.1 Retail Land Use

There are 10.2 square kilometres of retail land use, with an average retail land use proportion of 2.7% (10.2 square kilometres retail lots divided by 375 square kilometres total land use area). There are 7 square kilometres of retail land use in the 78 MUs in London, with an average retail proportion of 4.7% and a standard deviation of 4.9%. The maximum proportion of 15% can be found in Downtown (MU 16) and the minimum proportion of 0% in 9 MUs (8, 10, 21, 35, 40, 41, 44, 51 and 68). Neighbourhood level spatial variation in the retail land use is shown in Figure 4-44.

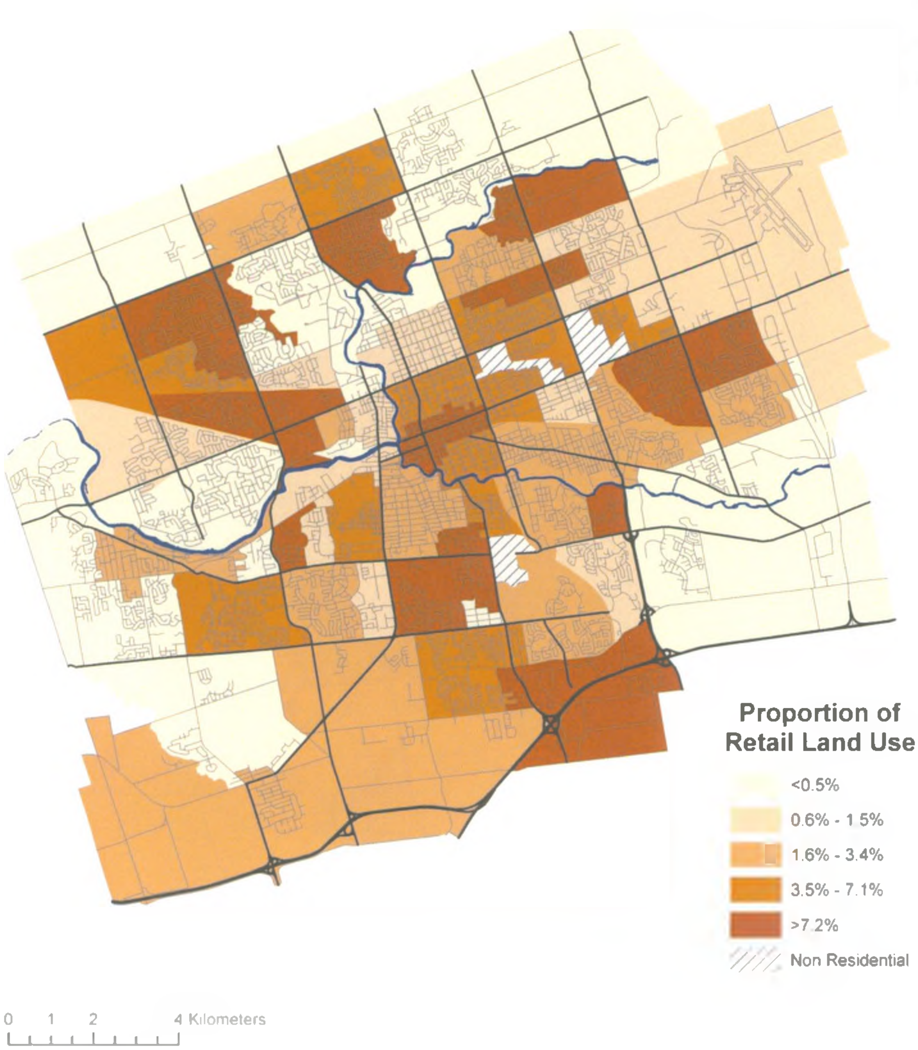


Figure 4-44: Proportion of Retail Land Use in London

4.10.2. Recreational Land Use Proportion

There are 785 recreational lots in London totalling 28 square kilometres, with an average recreational land use proportion of 7.5% (28 square kilometres recreational lots divided by 375 square kilometres total land use area). There are 23 square kilometres of recreational land use in the 78 MUs in London, with an average recreational proportion of 14% and a standard deviation of 11%. The maximum recreational land use proportion of 47% is found in Stoneybrook Meadows (MU 60) and the minimum recreational land use proportion of 0% can be found in Baseline (MU 4). Neighbourhood level spatial variation in the recreational land use is shown in Figure 4-45.

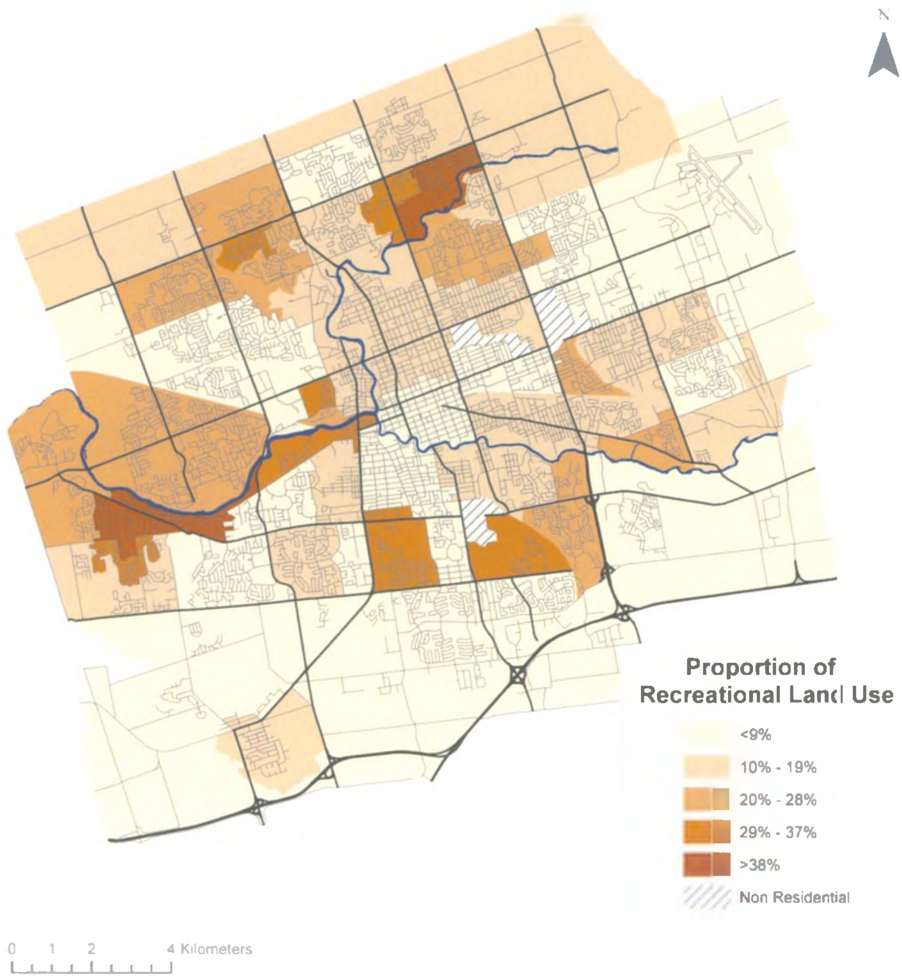


Figure 4-45: Proportion of Recreational Land Use in London

4.10.3 Park Area

There are 375 park lots in London totalling 18.6 square kilometres, with an average parks land use proportion of 5% (18.6 square kilometres parks lots divided by 375 square kilometres total land use area). There are 18.6 square kilometres of parks land use in the 78 MUs in London, with an average parks proportion of 9% and a standard deviation of 10%. The maximum parks land use proportion of 48% can be found in Oakridge Park (MU 40) and the minimum parks land use proportion of 0% in 3 MUs (3, 4, and 62). Neighbourhood level spatial variation in the park area land use is shown in Figure 4-46.

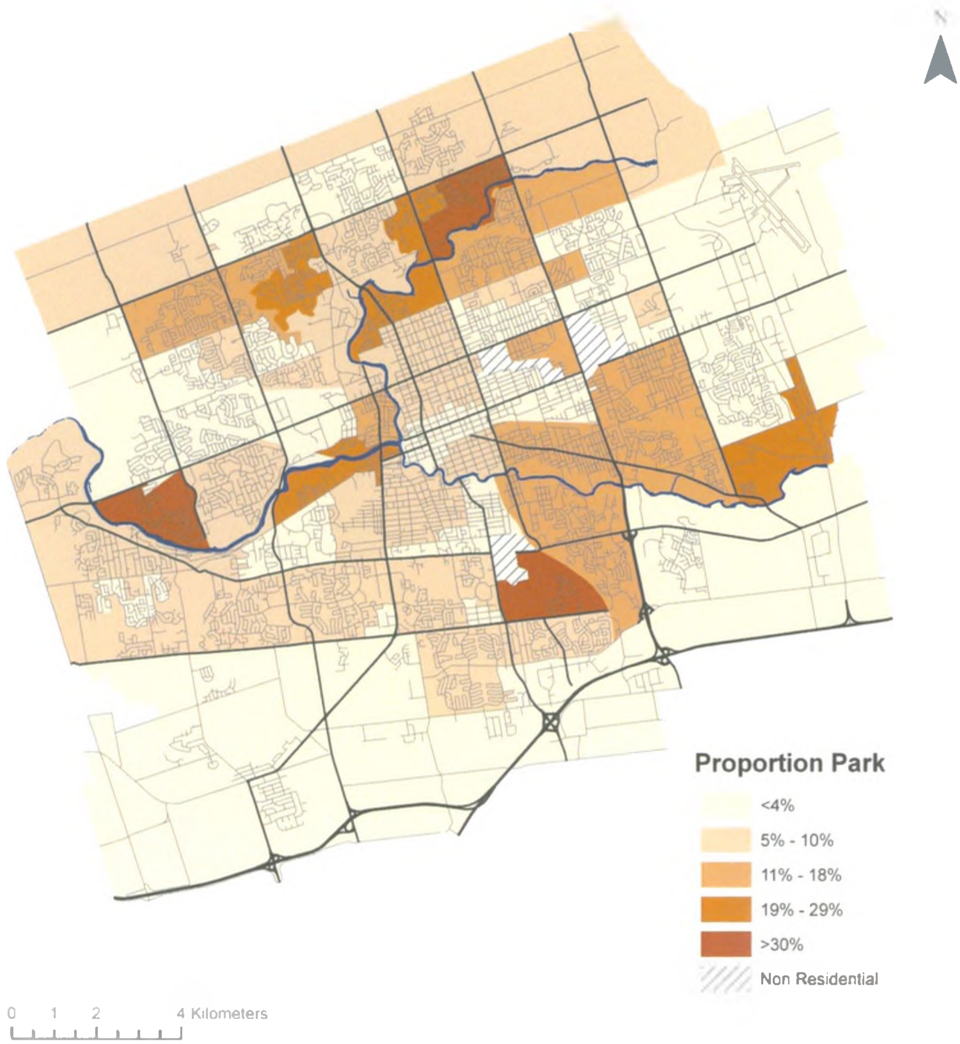


Figure 4-46: Proportion of Parks Land Use in London

4.10.4 Urban Water Coverage

There are 6.8 kilometres of water in London, with an average water coverage of 1.6% (6.8 square kilometres industrial lots / 422 square kilometres total London area). There are 5.9 square kilometres of urban water in the 78 MUs in London, with an average water coverage of 3% and a standard deviation of 4%. The maximum industrial land use proportion of 20% is found in Forward (MU 21) and the minimum industrial land use proportion of 0% is found in 20 MUs (2, 3, 7, 10, 18, 21, 23, 28, 29, 33, 34, 36, 39, 41, 44, 54, 65, 68, 73, 77). Neighbourhood level spatial variation in the urban water is shown in Figure 4-47.

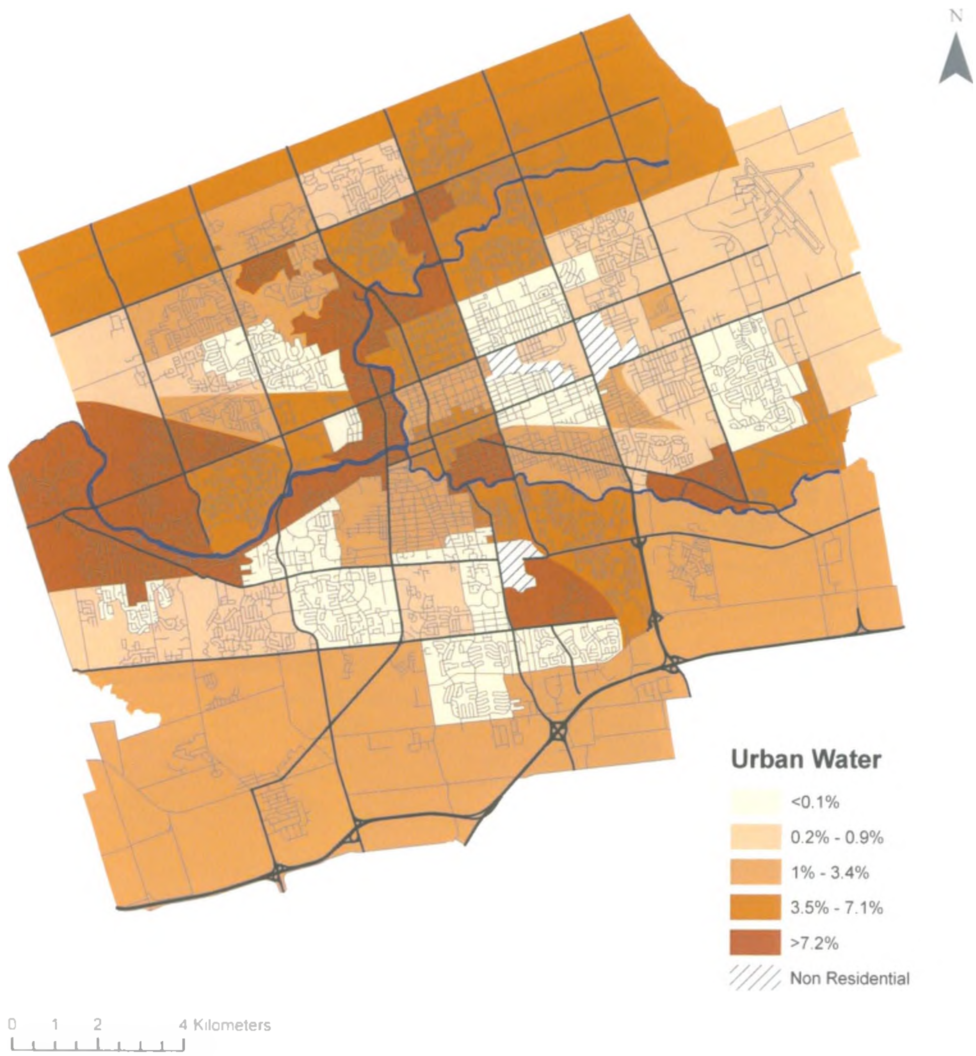


Figure 4-47: Proportion of Urban Water in London

4.10.5 Industrial Land Use

There are 1,741 industrial lots in London totalling 41.7 square kilometres, with an average industrial land use proportion of 11% (41.7 square kilometres industrial lots / 375 square kilometres total land use area). There are 39 square kilometres of industrial land use in the 78 MUs in London, with an average industrial proportion of 9% and a standard deviation of 13%. The maximum industrial land use proportion of 66% is found in Wilton Grove (MU 75) and the minimum industrial land use proportion of 0% in 14 MUs (5, 11, 22, 32, 35, 36, 39, 51, 55, 57, 60, 62, 67, and 73). Figure 4-48 displays the neighbourhood level spatial variation in the industrial land use measure.

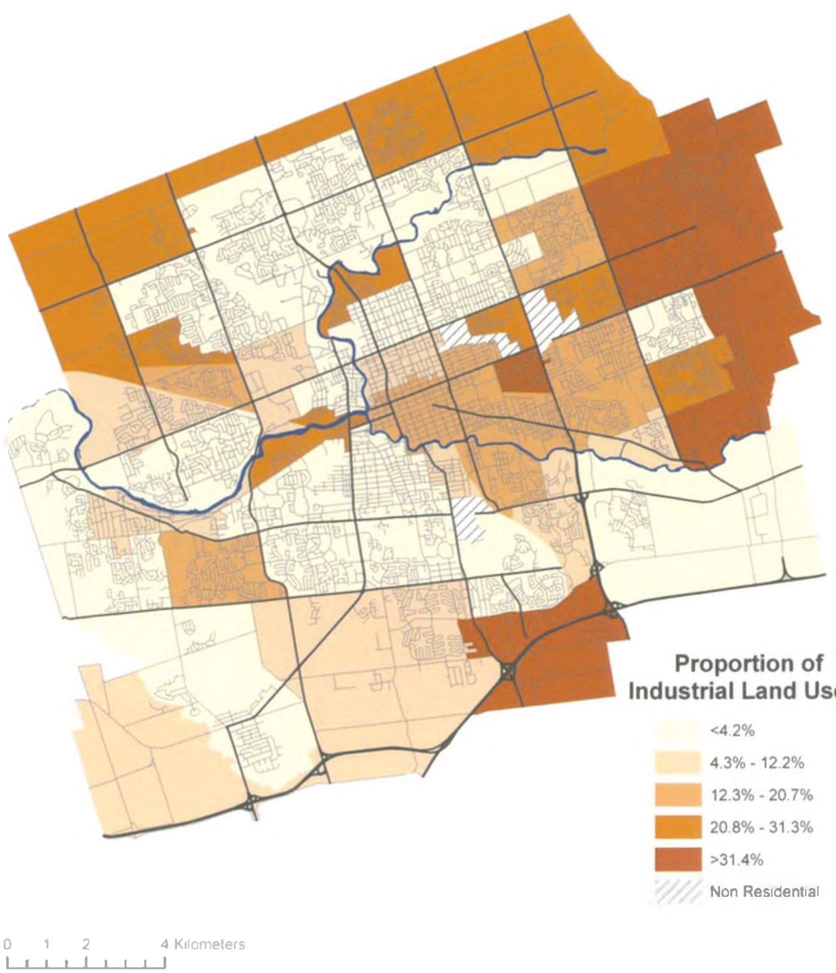


Figure 4-48: Proportion of Industrial Land Use in London

4.10.6 Institutional Land Use

There are 488 institutional lots in London totalling 14.5 square kilometres, with an average institutional land use proportion of 4.6% (14.5 square kilometres institutional lots divided by 375 square kilometres total land use area). There are 12 square kilometres of institutional land use in the 78 MUs in London, with an average institutional proportion of 7% and a standard deviation of 9%. The maximum proportion of 55% is found in University Heights (MU 66) and the minimum proportion (0%) in 7 MUs (8, 21, 35, 52, 57, 63, 68). Figure 4-49 displays the neighbourhood level spatial variation in the industrial land use measure.

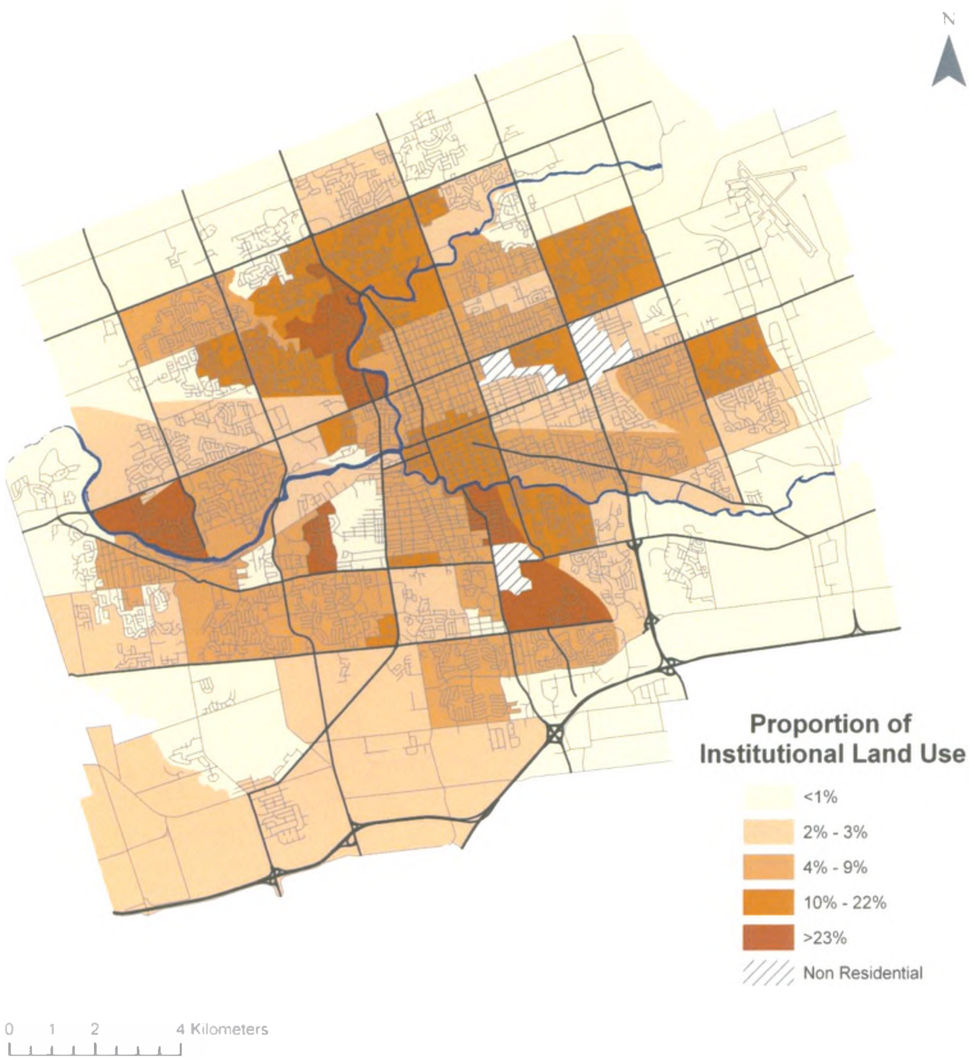


Figure 4-49: Proportion of Institutional Land Use in London

4.10.7 Residential Land Use

There are 84,083 residential lots in London totalling 92.4 square kilometres, with an average residential land use proportion of 25% (92.4 square kilometres residential lots / 375 square kilometres total land use area). There are 89 square kilometres of residential land use in the 78 MUs in London, with an average residential proportion of 52% and a standard deviation of 20%. The maximum residential land use proportion of 96% is found in Wellingsbore (MU 68) and the minimum residential land use proportion of 7% is found in Crumlin (MU 15). Figure 4-50displays the neighbourhood level spatial variation in the residential land use measure.

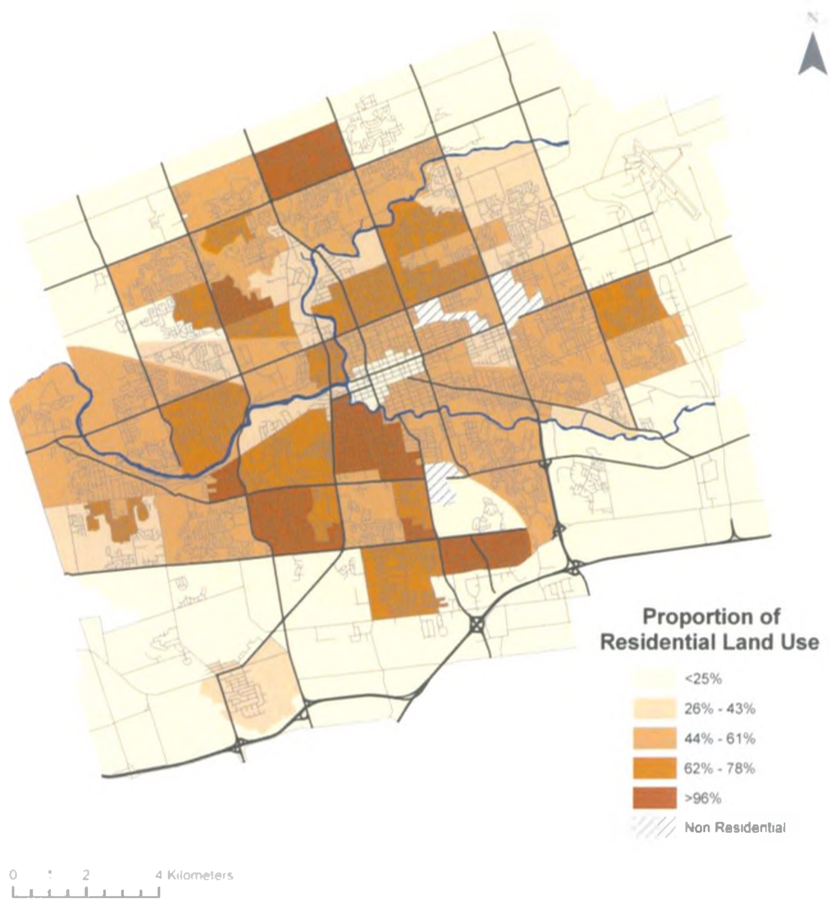


Figure 4-50: Proportion of Residential Land Use in London

4.10.7.1 Proportion of Single Family Residential Land Use

There are 72,202 single family residential lots in London totalling 63 square kilometres, with an average single family residential land use to all residential land use proportion of 68% (62 square kilometres of single family residential lots / 92 square kilometres total residential land use lots). There are 59 square kilometres of single family residential land use in the 78 MUs in London, with an average single family residential to total residential proportion of 67% and a standard deviation of 18%. The maximum proportion of 99% is found in Orchard Park (MU 44) and the minimum proportion of 13% is found in West of Wonderland (MU 70). Figure 4-51 displays the neighbourhood level spatial variation in the single family residential land use measure.

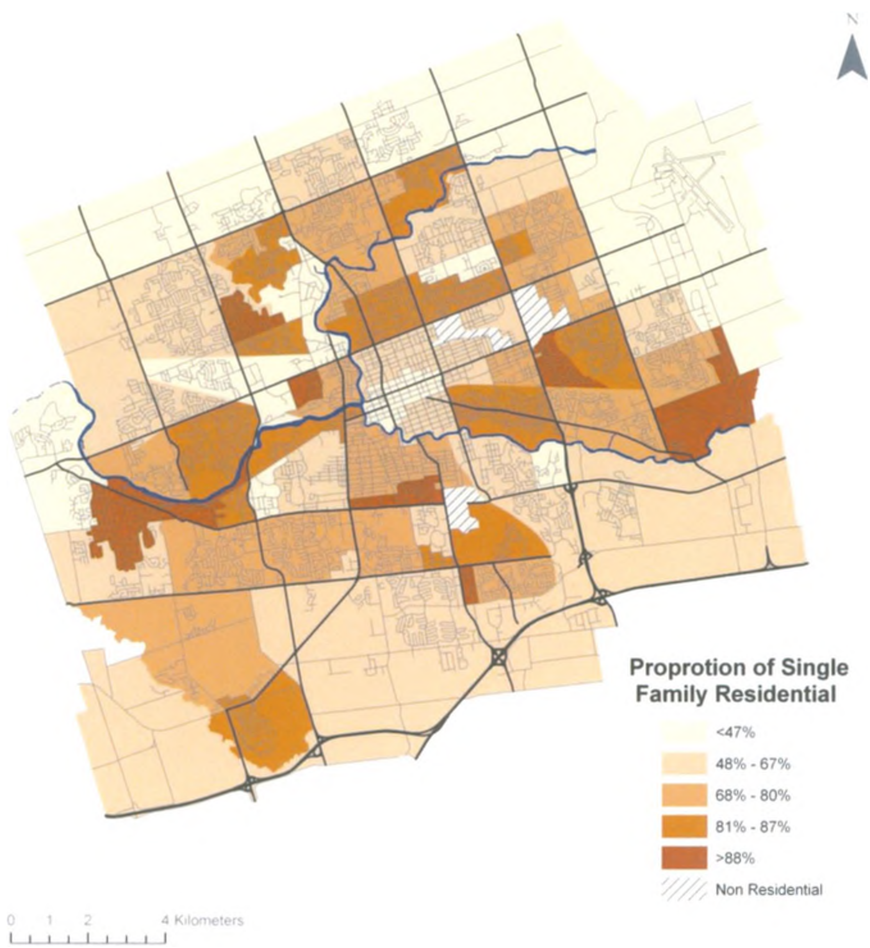


Figure 4-51: Proportion of Single Family Residential Land Use in London

4.11 London Statistical Analysis

A spearman's rank correlation coefficient was conducted on all variables in the London analysis. The mechanics of this statistical analysis are described in detail in the methodology section.

4.11.1 Spearman's rank correlation coefficient

The spearman's rank correlation coefficient is a non-parametric measure of statistical dependence between two variables. It assesses how well the relationship between two variables can be described using a monotonic function. A perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other.

At the end of each performance indicators report above, significant positive and negative correlations are presented. These correlations are spearman's rank correlation coefficients which are significant at the 0.01 confidence interval. The full table of correlations can be found in Appendix A. The three independent variables of this study, population density, median household income, and era of development, are found to be significantly correlated with many performance indicators. The following table (Table 4-6) shows how independent variable ranked agents each performance indicator

Table 4-6: Spearman's correlation coefficients

		Median Household Income	Population Density	Major Era of Construction
Median Household Income	Significant Correlation Coefficient		-.376**	.466**
	Non-Significant Correlation Coefficient	1.000		
	Significance (2-tailed)	.	0.001	0.000
	N	78	78	78
Population Density	Significant Correlation Coefficient	-.376**		
	Non-Significant Correlation Coefficient		1.000	0.003
	Significance (2-tailed)	0.001	.	0.981
	N	78	78	78
Major Era of Construction	Significant Correlation Coefficient	.466**		
	Non-Significant Correlation Coefficient		0.003	1.000
	Significance (2-tailed)	0	1	.
	N	78	78	78
Intersection Density	Significant Correlation Coefficient	-.335**	.628**	-.331**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.003	0	0.003
	N	78	78	78
Cul-Du-Sac Proportion	Significant Correlation Coefficient	.388**	-.338**	.279*
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0	0	0
	N	78.00	78.00	78.00
T-Intersection Proportion	Significant Correlation Coefficient	.353**		
	Non-Significant Correlation Coefficient		-0.04	0.207
	Significance (2-tailed)	0.002	0.729	0.068
	N	78	78	78
X-Intersection Proportion	Significant Correlation Coefficient	-.380**		-
	Non-Significant Correlation Coefficient		0.07	0.17
	Significance (2-tailed)	0.001	0.559	0.139
	N	78	78	78
Average Street Segment Length	Significant Correlation Coefficient	.389**	-.336**	.550**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0	0.003	0
	N	78	78	78
Maximum Street Segment Length	Significant Correlation Coefficient	.376**	-.470**	.353**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.001	0	0.002
	N	78	78	78

		Median Household Income	Population Density	Major Era of Construction
Gross Street Area Density	Significant Correlation Coefficient	-.224*	.691**	
	Non-Significant Correlation Coefficient			-0.07
	Significance (2-tailed)	0.048	0	0.558
	N	78	78	78
Net Street Area Density	Significant Correlation Coefficient		.578**	
	Non-Significant Correlation Coefficient	-0.17		-0.12
	Significance (2-tailed)	0.142	0	0.3
	N	78	78	78
Sidewalk to Street Proportion	Significant Correlation Coefficient	-.525**	.613**	-.398**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0	0	0
	N	78	78	78
Path to Road Proportion	Significant Correlation Coefficient			
	Non-Significant Correlation Coefficient	-0.11	0.17	-0.22
	Significance (2-tailed)	0.325	0.141	0.051
	N	78	78	78
Median Connectivity	Significant Correlation Coefficient	-.559**		-.554**
	Non-Significant Correlation Coefficient		0.14	
	Significance (2-tailed)	0	0.207	0
	N	78	78	78
Median Global Integration	Significant Correlation Coefficient	-.583**		-.555**
	Non-Significant Correlation Coefficient		0.10	
	Significance (2-tailed)	0	0.363	0
	N	78	78	78
Median Local Interaction	Significant Correlation Coefficient	-.725**		-.648**
	Non-Significant Correlation Coefficient		0.13	
	Significance (2-tailed)	0	0.261	0
	N	78	78	78
Street Width	Significant Correlation Coefficient			
	Non-Significant Correlation Coefficient	-0.034	0.146	0.193
	Significance (2-tailed)	0.769	0.202	0.090
	N	78	78	78
Proportion of Irregular Intersection Angles	Significant Correlation Coefficient			
	Non-Significant Correlation Coefficient	-0.04	-0.22	-0.07
	Significance (2-tailed)	0.741	0.058	0.523
	N	78	78	78

		Median Household Income	Population Density	Major Era of Construction
Proportion of Arterial Streets	Significant Correlation Coefficient		-.438**	
	Non-Significant Correlation Coefficient	-0.15		-0.11
	Significance (2-tailed)	0.178	0	0.34
	N	78	78	78
Average Block Size	Significant Correlation Coefficient	.599**	-.645**	.477**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0	0	0
	N	78	78	78
Maximum Block Size	Significant Correlation Coefficient	.636**	-.524**	.498**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.000	0.000	0.000
	N	78	78	78
Block Density	Significant Correlation Coefficient	-.468**	.617**	-.426**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.000	0.000	0.000
	N	78	78	78
Average Lot Size	Significant Correlation Coefficient	.296**	-.689**	
	Non-Significant Correlation Coefficient			0.170
	Significance (2-tailed)	0.008	0.000	0.136
	N	78	78	78
Maximum Lot Size	Significant Correlation Coefficient	.323**	-.621**	
	Non-Significant Correlation Coefficient			0.156
	Significance (2-tailed)	0.004	0.000	0.174
	N	78	78	78
Lot Density	Significant Correlation Coefficient	-.258*	.677**	
	Non-Significant Correlation Coefficient			-0.140
	Significance (2-tailed)	0.022	0.000	0.223
	N	78	78	78
Lots Per Block	Significant Correlation Coefficient	.484**		.461**
	Non-Significant Correlation Coefficient		-0.039	
	Significance (2-tailed)	0.000	0.734	0.000
	N	78	78	-.612**
Proportion of Undeveloped Lots	Significant Correlation Coefficient		-.612**	
	Non-Significant Correlation Coefficient	0.187		0.162
	Significance (2-tailed)	0.102	0.000	0.157
	N	78	78	78

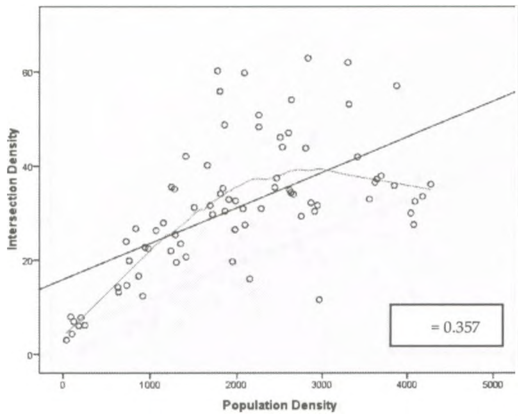
		Median Household Income	Population Density	Major Era of Construction
Lot Frontage	Significant Correlation Coefficient			
	Non-Significant Correlation Coefficient	0.041	-0.066	-0.055
	Significance (2-tailed)	0.721	0.565	0.630
	N	78	78	78
Building Density	Significant Correlation Coefficient	-.428**	.671**	-.363**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.000	0.000	0.001
	N	78	78	78
Residential Building Density	Significant Correlation Coefficient	-.374**	.660**	-.325**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.001	0.000	0.004
	N	78	.285*	78
Residential Building Proportion	Significant Correlation Coefficient	.285*	.450**	.225*
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.011	0.000	0.047
	N	78	78	78
Building Coverage Proportion	Significant Correlation Coefficient	-.328**	.724**	
	Non-Significant Correlation Coefficient			-0.072
	Significance (2-tailed)	0.003	0.000	0.532
	N	78	78	78
Average Building Footprint Area	Significant Correlation Coefficient	.275*		.471**
	Non-Significant Correlation Coefficient		-0.203	
	Significance (2-tailed)	0.015	0.075	0.000
	N	78	78	78
Maximum Building Footprint Area	Significant Correlation Coefficient	-.315**		
	Non-Significant Correlation Coefficient		0.063	0.011
	Significance (2-tailed)	0.005	0.581	0.927
	N	78	78	78
Building to Lot Proportion	Significant Correlation Coefficient	-.689**	.339**	-.645**
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.000	0.002	0.000
	N	78	78	78
Building to Block Proportion	Significant Correlation Coefficient		.309**	
	Non-Significant Correlation Coefficient	-0.017		0.012
	Significance (2-tailed)	0.882	0.006	0.916
	N	78	78	78

		Median Household Income	Population Density	Major Era of Construction
Space Between Buildings	Significant Correlation Coefficient			
	Non-Significant Correlation Coefficient	0.040	0.013	-0.104
	Significance (2-tailed)	0.730	0.913	0.363
	N	78	78.	78
Building Setback	Significant Correlation Coefficient	.226*		
	Non-Significant Correlation Coefficient		-0.110	0.045
	Significance (2-tailed)	0.046	0.337	0.698
	N	78	78	78
Commercial Proportion	Significant Correlation Coefficient	-.514**	.348**	
	Non-Significant Correlation Coefficient			-0.172
	Significance (2-tailed)	0.000	0.002	0.133
	N	78	78	78
Residential Proportion	Significant Correlation Coefficient		.669**	
	Non-Significant Correlation Coefficient	0.050		0.107
	Significance (2-tailed)	0.665	0.000	0.351
	N	78	78	78
Industrial Proportion	Significant Correlation Coefficient	-.339**	-.294**	-.243*
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.002	0.009	0.032
	N	78	78	78
Institutional Proportion	Significant Correlation Coefficient	-.293**	.303**	
	Non-Significant Correlation Coefficient			-0.195
	Significance (2-tailed)	0.009	0.007	0.087
	N	78	78	78
Recreational Proportion	Significant Correlation Coefficient	.226*		
	Non-Significant Correlation Coefficient		-0.118	0.013
	Significance (2-tailed)	0.046	0.303	0.912
	N	78	78	78
Agricultural Proportion	Significant Correlation Coefficient	.368**	-.592**	.259*
	Non-Significant Correlation Coefficient			
	Significance (2-tailed)	0.001	0.000	0.022
	N	78	78	78
Retail Proportion	Significant Correlation Coefficient	-.455**	.385**	
	Non-Significant Correlation Coefficient			-0.121
	Significance (2-tailed)	0.000	0.000	0.290
	N	78	78	78

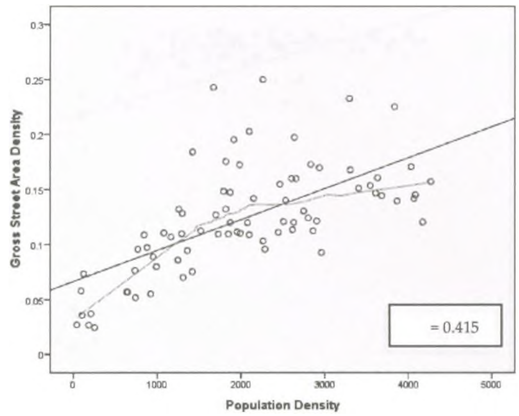
		Median Household Income	Population Density	Major Era of Construction
Park Proportion	Significant Correlation Coefficient			
	Non-Significant Correlation Coefficient	-0.013	-0.010	-0.093
	Significance (2-tailed)	0.913	0.932	0.419
	N	78	78	78
Urban Water Proportion	Significant Correlation Coefficient		-.454**	
	Non-Significant Correlation Coefficient	0.069		-0.159
	Significance (2-tailed)	0.549	0.000	0.165
	N	78	78	78
Single Family Proportion	Significant Correlation Coefficient	.248*		
	Non-Significant Correlation Coefficient		-0.112	-0.090
	Significance (2-tailed)	0.029	0.330	0.432
	N	78	78	78

4.11.1 Population Density

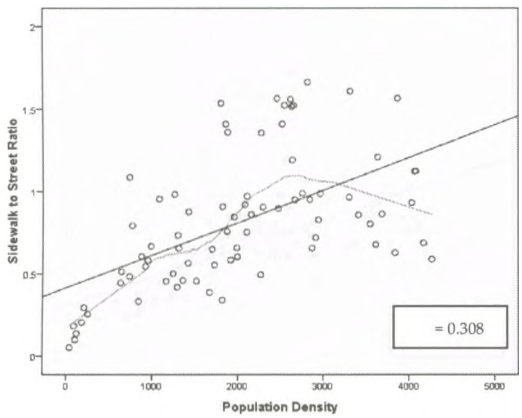
Population Density is significantly positively correlated with the variables intersection density (0.628), gross and net street area density (0.691, 0.578), sidewalk to street proportion (0.613), block density (0.617), lot density (0.677), building density (0.671), residential building density (0.660), residential building proportion (0.450), building coverage proportion (0.724), building to lot proportion (0.339), building to block proportion (0.309), residential land use proportion (0.669), commercial land use proportion (0.348), institutional land use proportion (0.303), and retail land use proportion (0.385). Scatter plots of these positive correlations are shown in Figure 4-52.


Intersection Density
Population Density
= 0.357

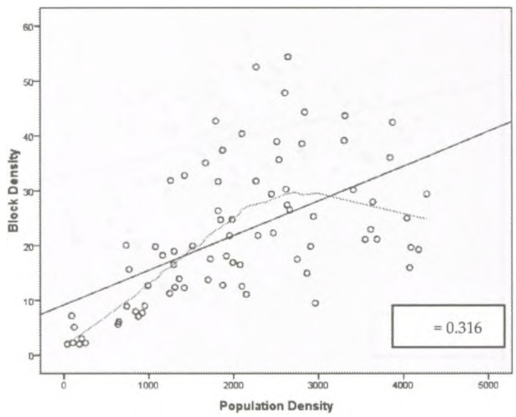
(a)


Gross Street Area Density
Population Density
= 0.415

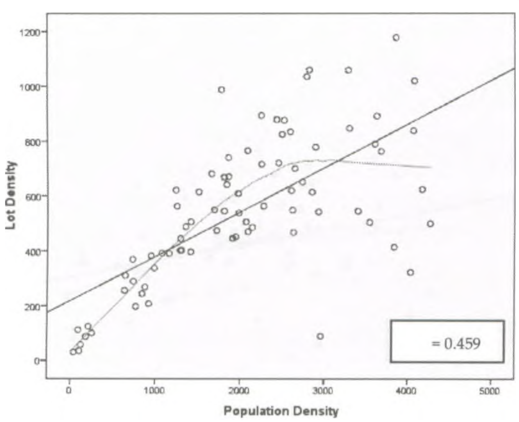
(b)


Sidewalk to Street Ratio
Population Density
= 0.308

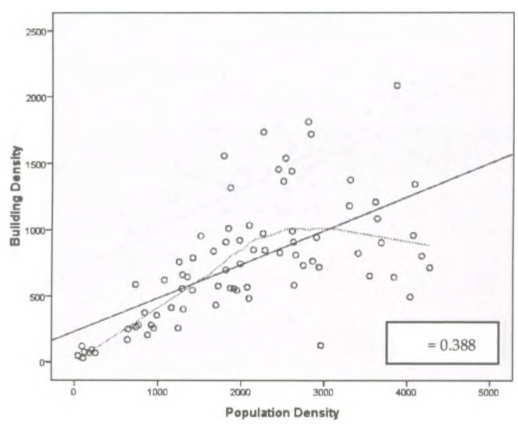
(c)


Block Density
Population Density
= 0.316

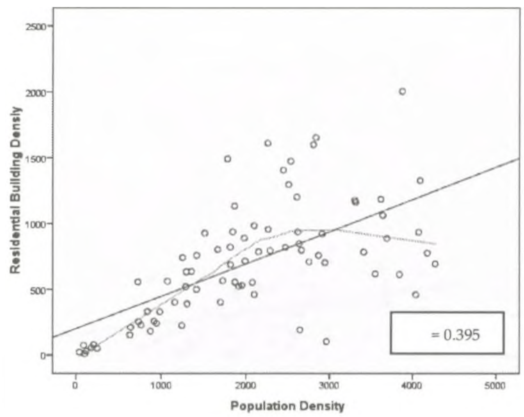
(d)


Lot Density
Population Density
= 0.459

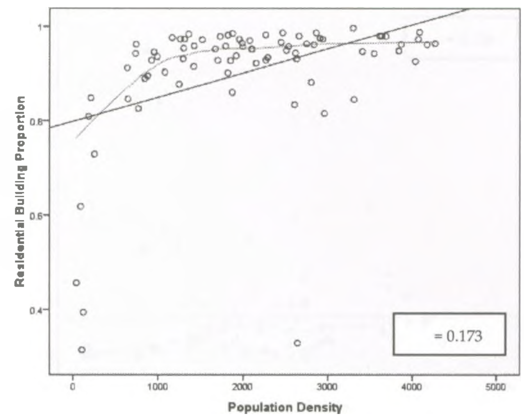
(e)


Building Density
Population Density
= 0.388

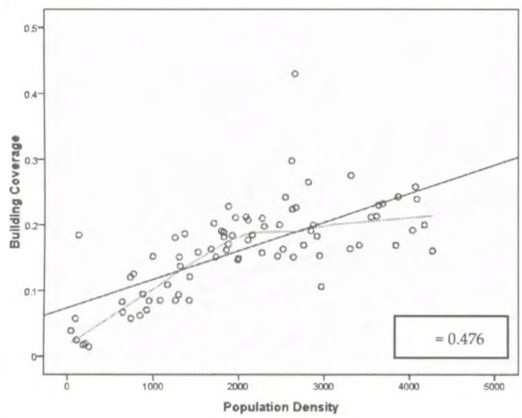
(f)


Residential Building Densiy
Population Density
= 0.395

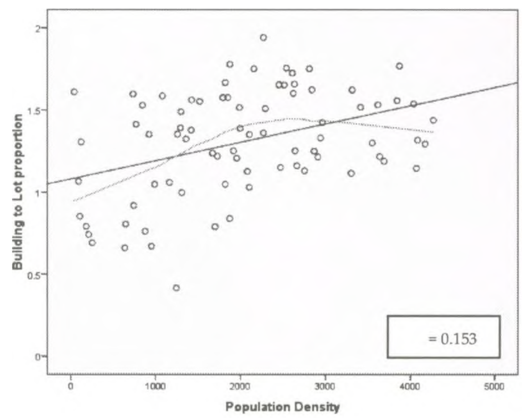
(g)


Residential Building Proportion
Population Density
= 0.173

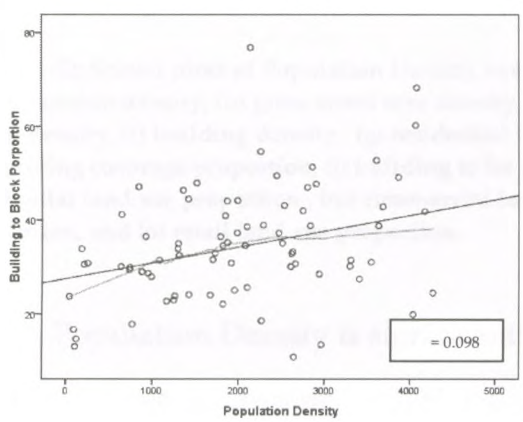
(h)


Building Coverage
Population Density
= 0.476

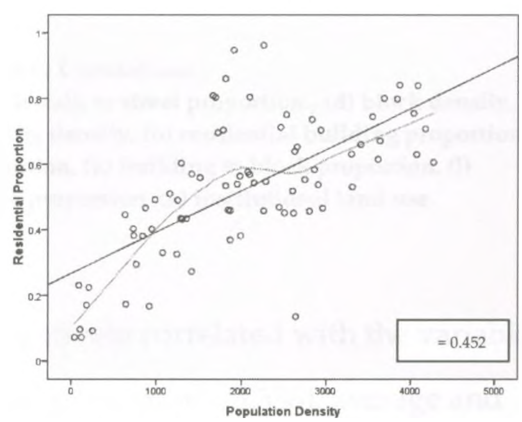
(i)


Building to Lot proportion
Population Density
= 0.153

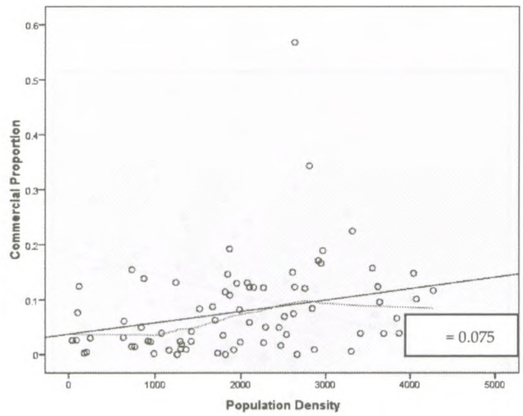
(j)


Building to Block Porportion
Population Density
= 0.098

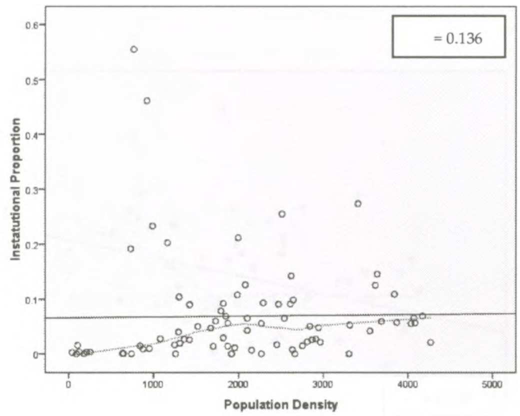
(k)


Residential Proportion
Population Density
= 0.452

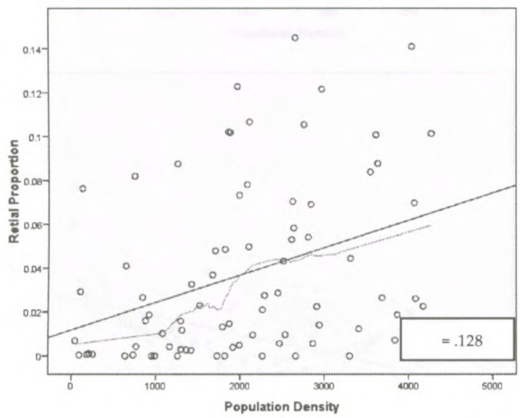
(l)



(m)



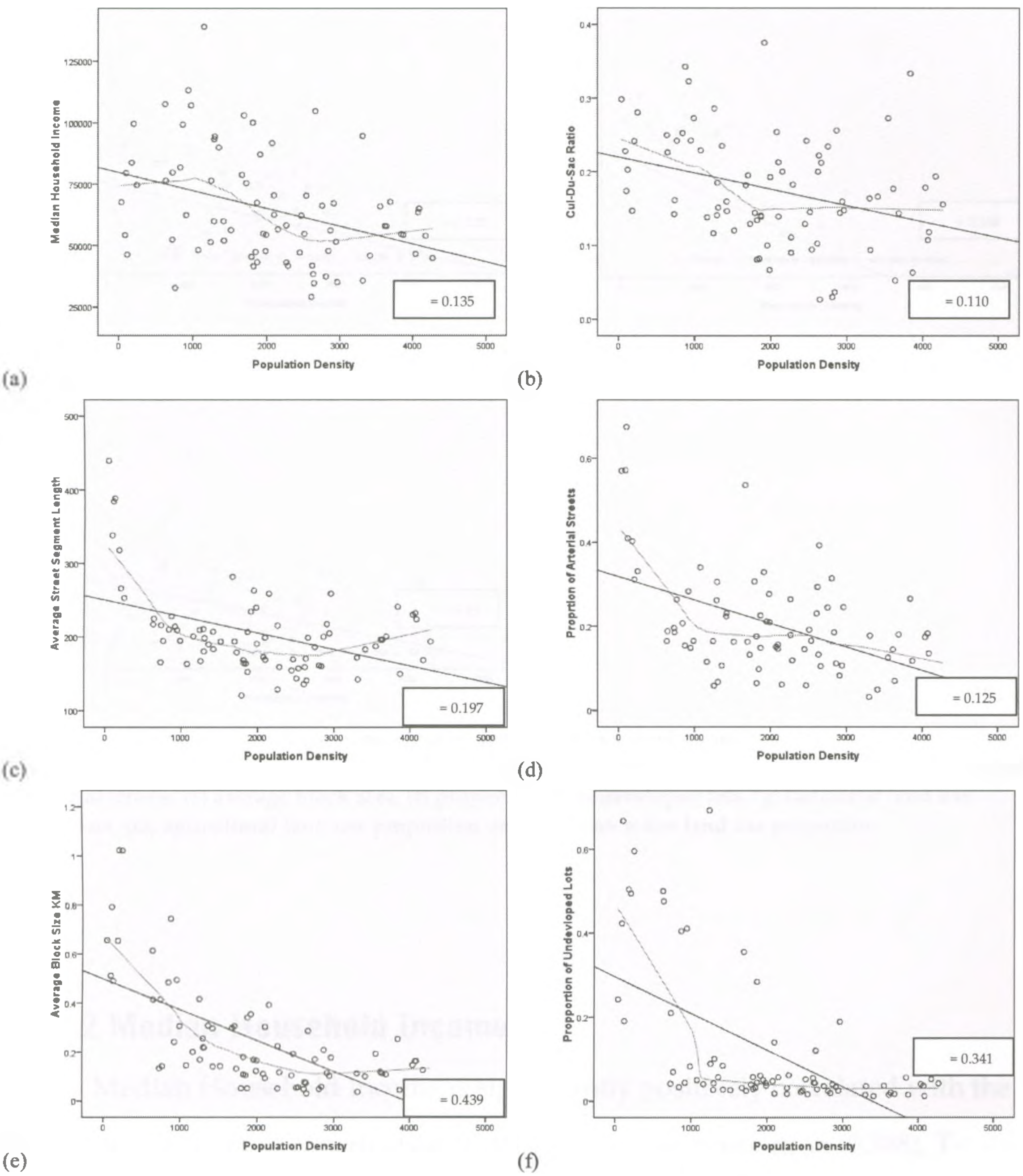
(n)



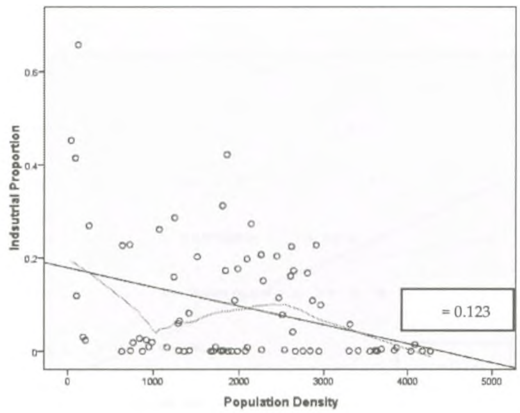
(o)

Figure 4-52: Scatter plots of Population Density and Positive Correlations
(a)intersection density, (b) gross street area density, (c)sidewalk to street proportion , (d) block density, (e) lot density, (f) building density, (g) residential building density, (h) residential building proportion, (i) building coverage proportion, (j) building to lot proportion, (k) building to block proportion, (l) residential land use proportion , (m) commercial land use proportion, (n) institutional land use proportion, and (o) retail land use proportion.

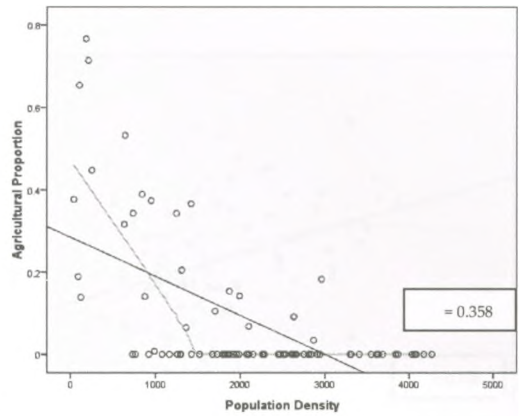
Population Density is significantly negatively correlated with the variables median household income (-0.376), cul-de-sac proportion (-0.338), average and maximum street segment length (-0.336, -0.470), proportion of arterial streets (-0.438), average and maximum block area (-0.689, -0.21), proportion of undeveloped lots (-0.612), industrial land use proportion (-0.294), agricultural land use proportion (-0.592), and urban water land use proportion (-0.454). Scatter plots of these negative correlations are shown in Figure 4-53.



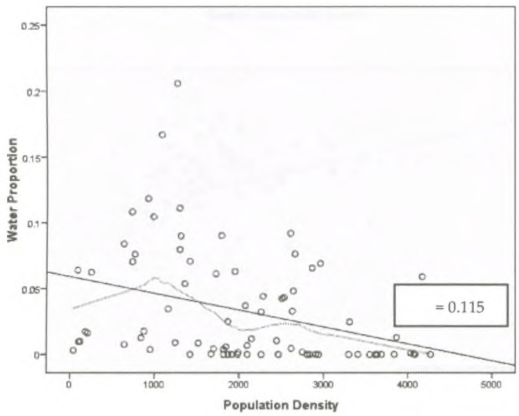
Median Household Income
Population Density
= 0.135
(a)
Cul-Du-Sac Ratio
Population Density
= 0.110
(b)
Average Street Segment Length
Population Density
= 0.197
(c)
Proprtion of Arterial Streets
Population Density
= 0.125
(d)
Average Block Size KM
Population Density
= 0.439
(e)
Propportion of Undeveloped Lots
Population Density
= 0.341
(f)



(g)



(h)

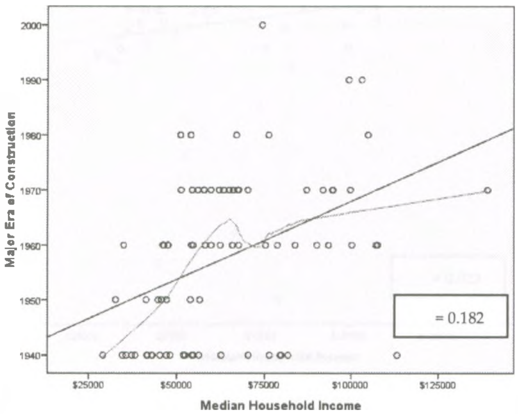


(i)

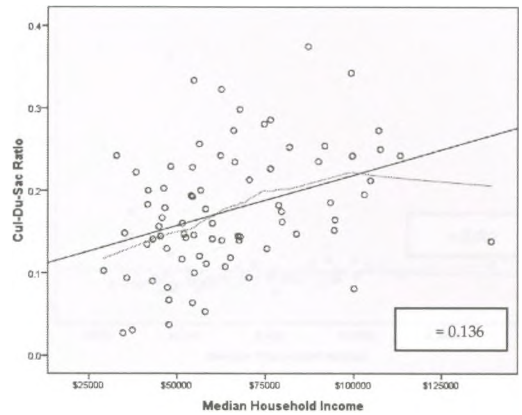
Figure 4-53: Scatter plots of Population Density and Negative Correlations
(a) median household income, (b) cul-de-sac proportion, (c)average street segment length, (d) proportion of arterial streets, (e) average block area, (f) proportion of undeveloped lots, (g) industrial land use proportion, (h), agricultural land use proportion, and (i) urban water land use proportion.

4.11.2 Median Household Income

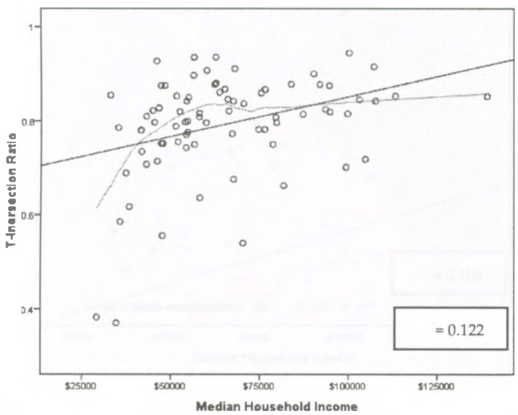
Median Household Income is significantly positively correlated with the variables major era of construction (0.466), cul-du-sac proportion (0.388), T-intersection proportion (0.353), average and maximum street segment length (0.389, 0.376), average and maximum block area (0.599, 0.463), lots per block (0.484), residential building proportion (0.285), average and maximum building footprint area (0.275, 0.315), and agricultural land use proportion (0.368). Scatter plots of these positive correlations are shown in Figure 4-54.


Major Era of Construction
Median Household Income
= 0.182

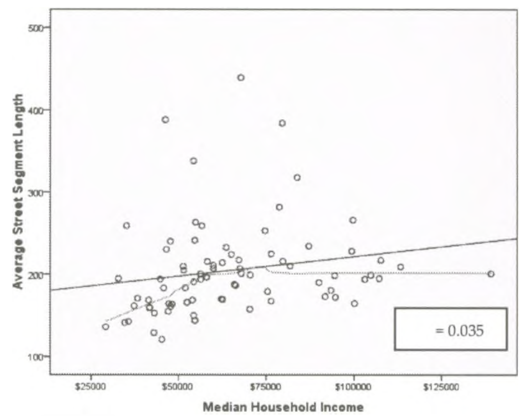
(a)


Cul-Du-Sac Ratio
Median Household Income
= 0.136

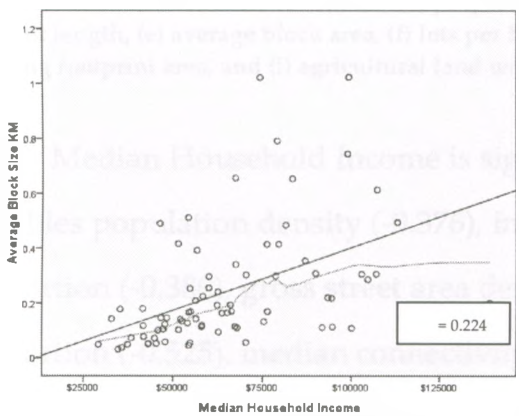
(b)


T-Inersection Ratio
Median Household Income
= 0.122

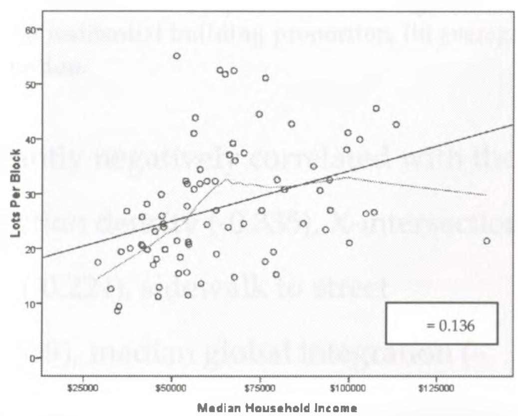
(c)


Average Street Segment Length
Median Household Income
= 0.035

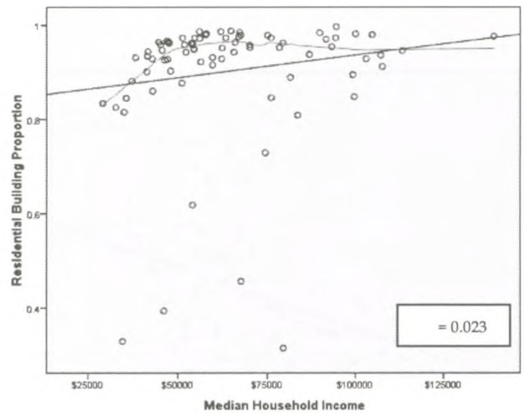
(d)


Average Block Size KM
Median Household Income
= 0.224

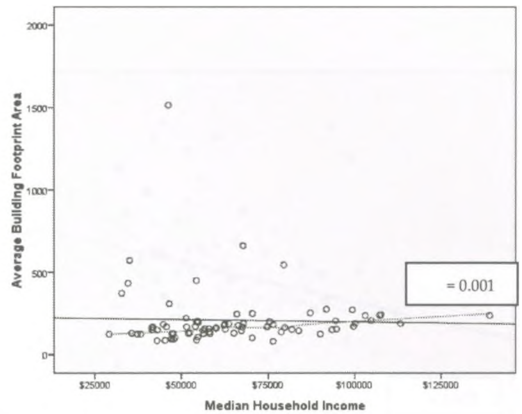
(e)


Lots Per Block
Median Household Income
= 0.136

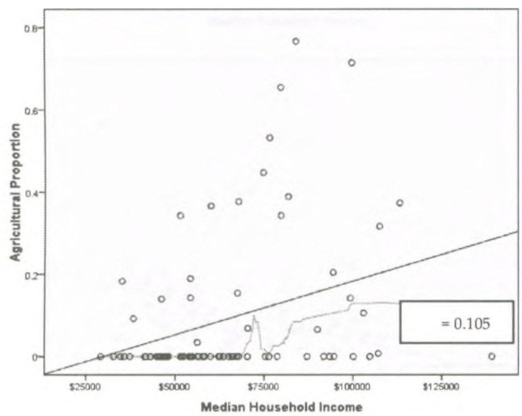
(f)



(g)



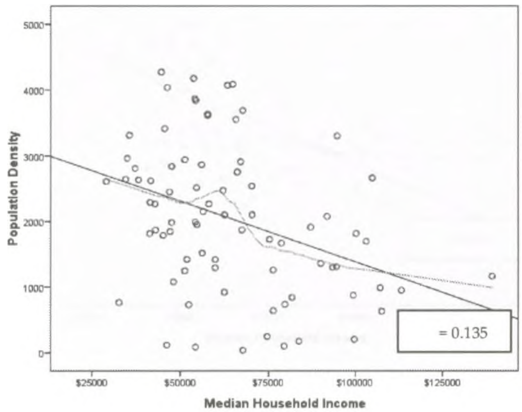
(h)



(i)

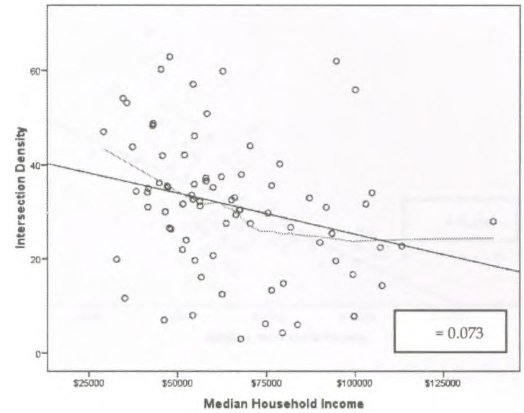
Figure 4-54: Scatter plots of Household Income and Positive Correlations
(a) major era of construction, (b) cul-du-sac proportion, (c) T-intersection proportion, (d) average street segment length, (e) average block area, (f) lots per block, (g) residential building proportion, (h) average building footprint area, and (i) agricultural land use proportion.

Median Household Income is significantly negatively correlated with the variables population density (-0.376), intersection density (-0.335), X-intersection proportion (-0.380), gross street area density (-0.224), sidewalk to street proportion (-0.525), median connectivity (-0.559), median global integration (-0.583), median local integration (-0.725), block density (-0.468), building density (-0.428), residential building density (-0.374), building coverage proportion (-0.328), building to lot proportion (-0.689), commercial land use proportion (-0.514), government and institutional land use proportion (0.293), industrial land use proportion (-0.339), and retail land use proportion (0.455). Scatter plots of these negative correlations are shown in Figure 4-55.



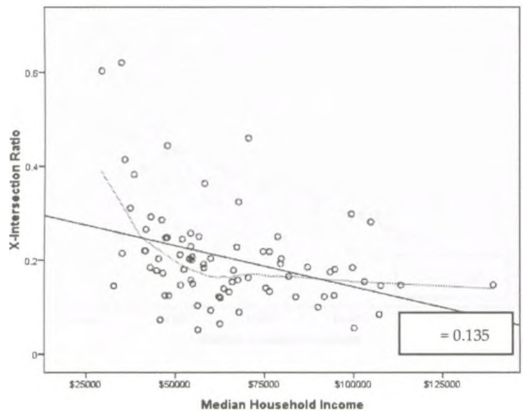
Population Density
0
1000
2000
3000
4000
5000
= 0.135
$25000
$50000
$75000
$100000
$125000
Median Household Income

(a)



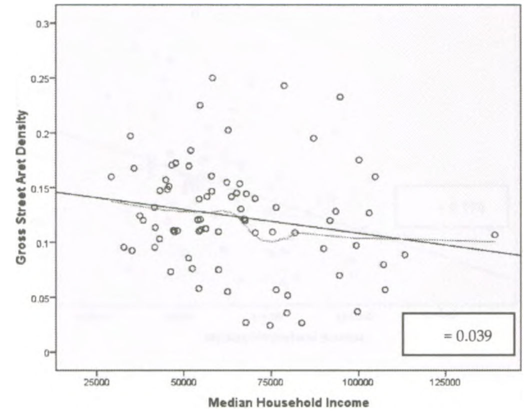
Intersection Density
0
20
40
60
= 0.073
$25000
$50000
$75000
$100000
$125000
Median Household Income

(b)



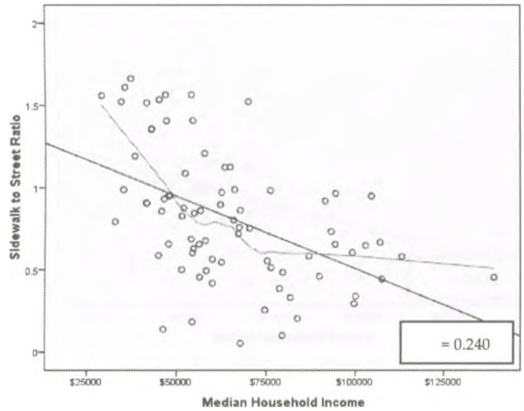
X-Intersection Ratio
0
0.2
0.4
0.6
= 0.135
$25000
$50000
$75000
$100000
$125000
Median Household Income

(c)



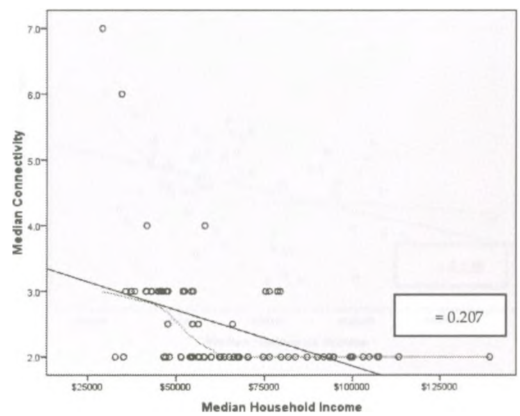
Gross Street Aret Density
0
0.05
0.1
0.15
0.2
0.25
0.3
= 0.039
25000
50000
75000
100000
125000
Median Household Income

(d)



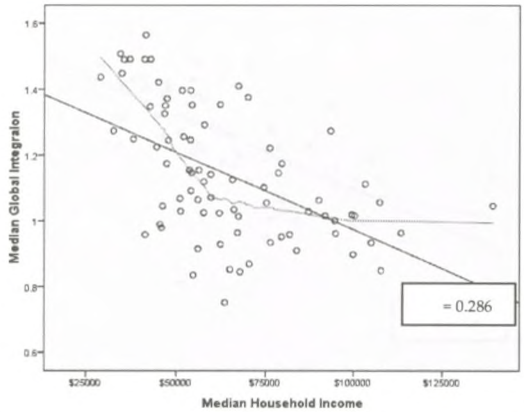
Sidewalk to Street Ratio
0
0.5
1
1.5
2
= 0.240
$25000
$50000
$75000
$100000
$125000
Median Household Income

(e)

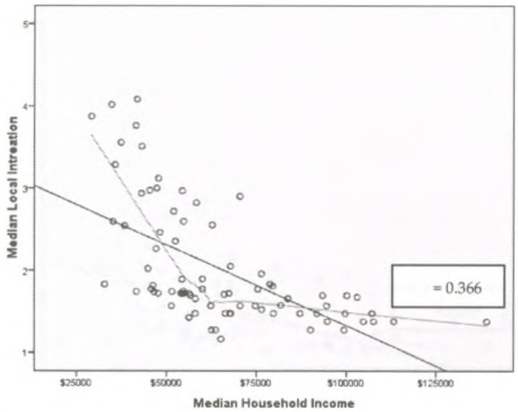


Median Connectivity
2.0
3.0
4.0
5.0
6.0
7.0
= 0.207
$25000
$50000
$75000
$100000
$125000
Median Household Income

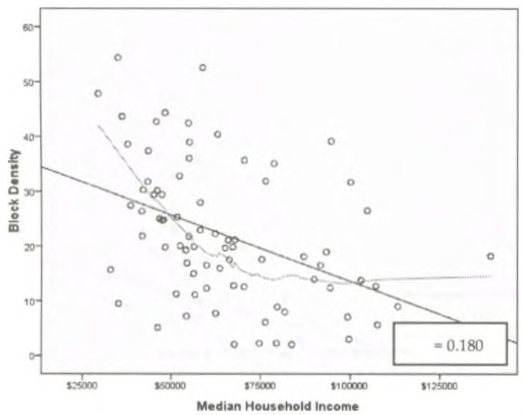
(f)


Median Global Integraion
1.6
1.4
1.2
1
0.8
0.6
= 0.286
$25000
$50000
$75000
$100000
$125000
Median Household Income

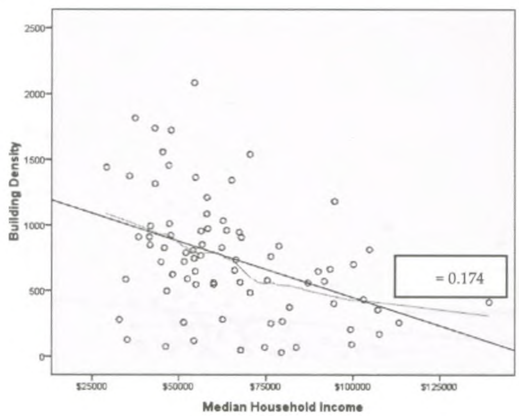
(g)


Median Local Intreation
5
4
3
2
1
= 0.366
$25000
$50000
$75000
$100000
$125000
Median Household Income

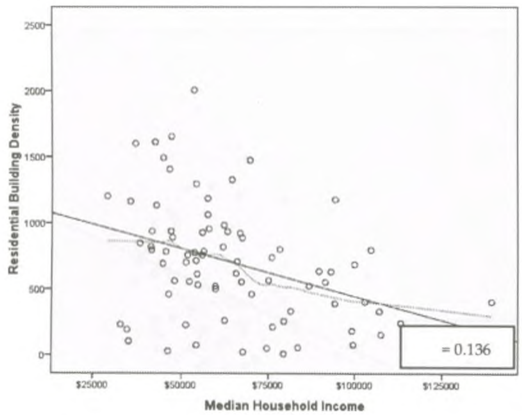
(h)


Block Density
60
50
40
30
20
10
0
= 0.180
$25000
$50000
$75000
$100000
$125000
Median Household Income

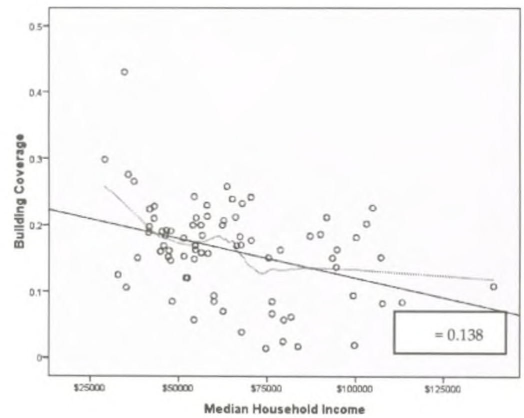
(i)


Building Density
2500
2000
1500
1000
500
0
= 0.174
$25000
$50000
$75000
$100000
$125000
Median Household Income

(j)


Residential Building Density
2500
2000
1500
1000
500
0
= 0.136
$25000
$50000
$75000
$100000
$125000
Median Household Income

(k)


Building Coverage
0.5
0.4
0.3
0.2
0.1
0
= 0.138
$25000
$50000
$75000
$100000
$125000
Median Household Income

(l)

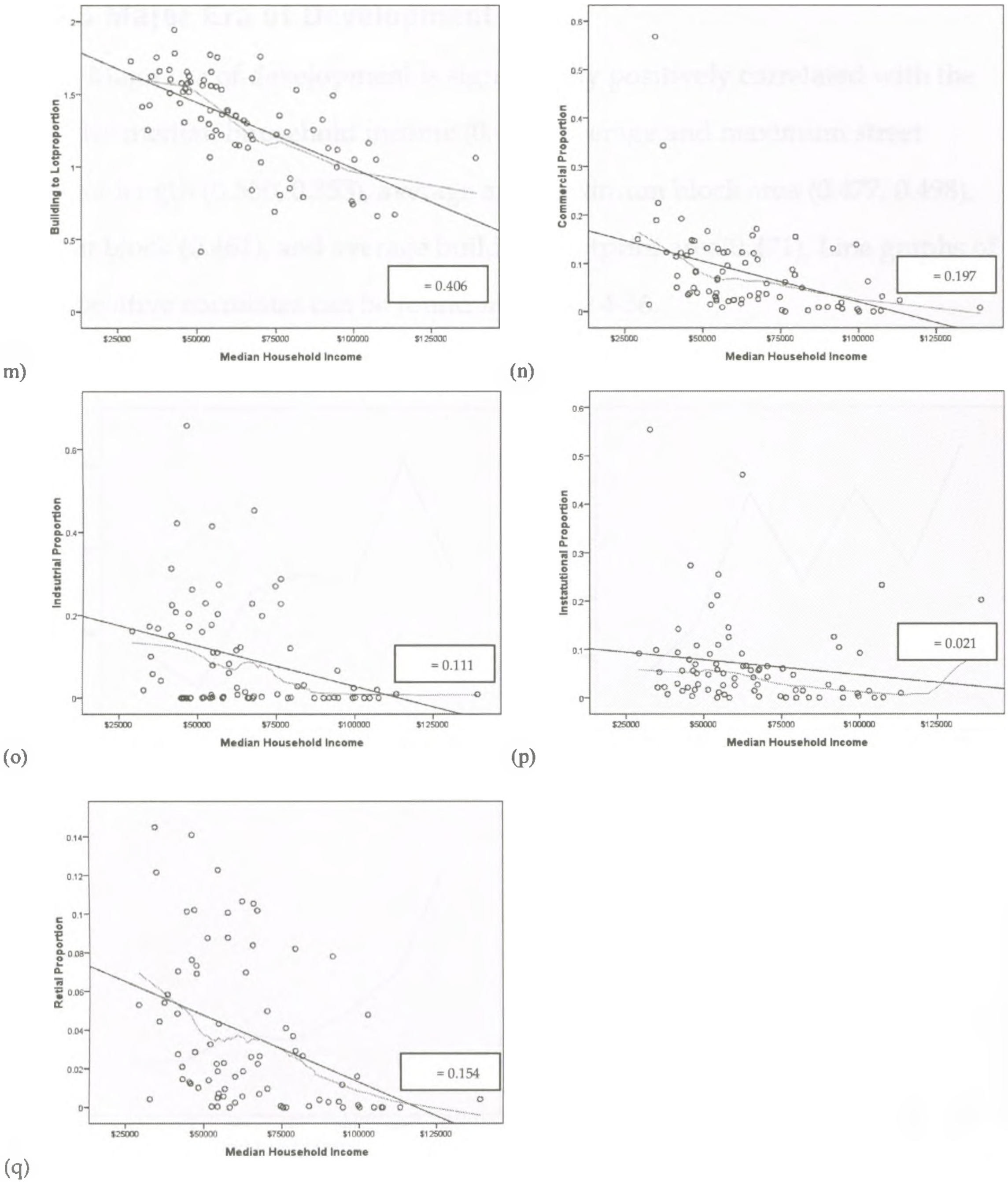
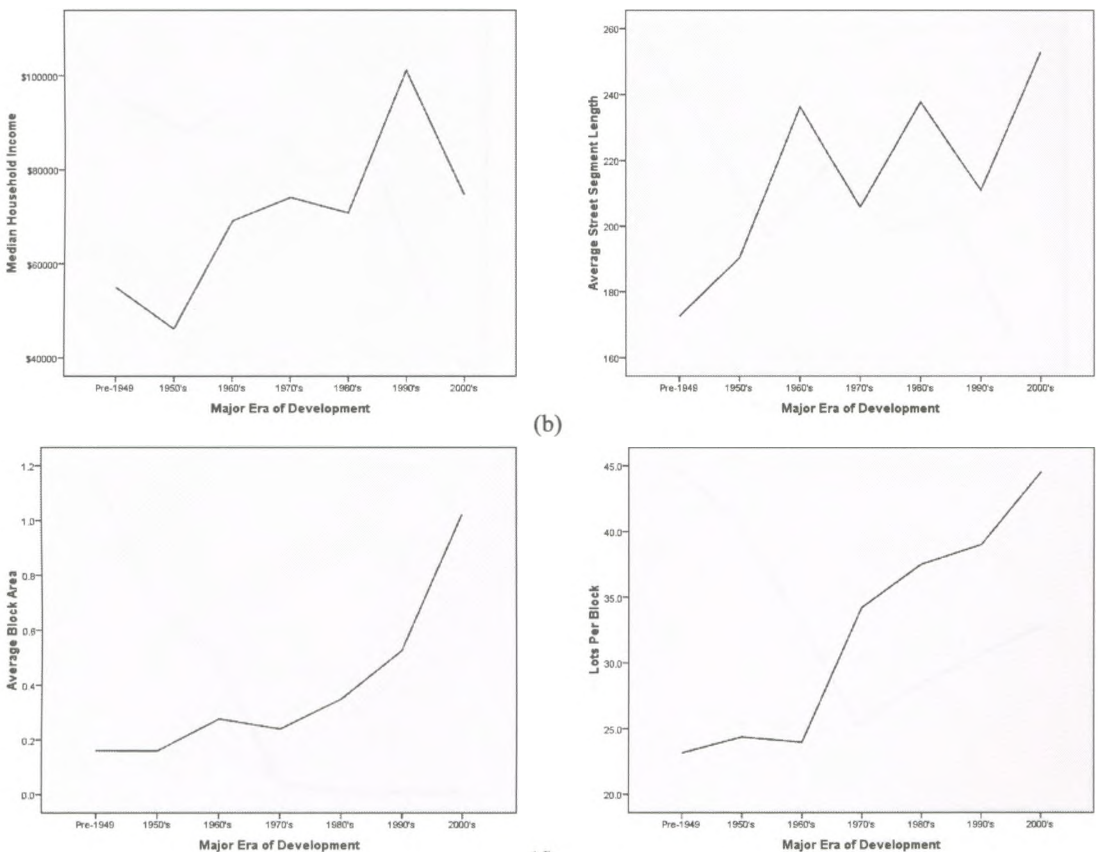


Figure 4-55: Scatter plots of Household Income and Negative Correlations
(a) population density, (b) intersection density, (c) X-intersection proportion, (d) gross street area density, (e) sidewalk to street proportion, (f) median connectivity,(g) median global integration, (h) median local integration, (i) block density, (j) building density, (k) residential building density, (l) building coverage proportion, (m) building to lot proportion, (n) commercial land use proportion, (o) government and institutional land use proportion, (p) industrial land use proportion, and (q) retail land use proportion.

4.11.3 Major Era of Development

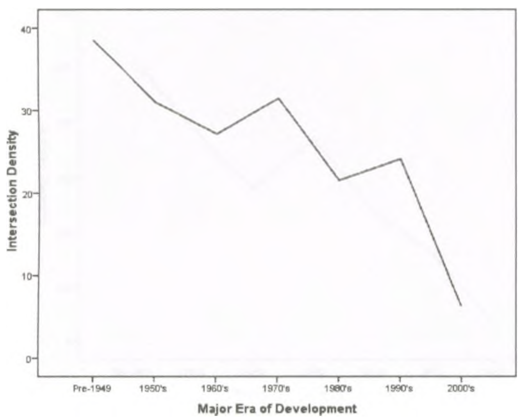
Major era of development is significantly positively correlated with the variables median household income (0.466), average and maximum street segment length (0.550, 0.353), average and maximum block area (0.477, 0.498), lots per block (0.461), and average building footprint area(0.471). Line graphs of these positive correlates can be found in Figure 4-56.



(a) (b) (c) (d)

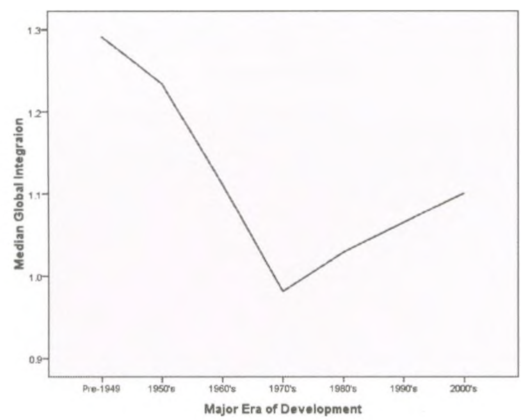
Figure 4-56: Line graphs of Era of Development and Positive Correlations
(a) median household income, (b) average street segment length, (c) average block area, and (d) lots per block.

Major era of development is significantly negatively correlated with the variables intersection density (-0.331), sidewalk to street ratio (-0.398), median connectivity (-0.554), median global integration (-0.555), median local integration (-0.648), block density (-0.426), building density (-0.363), residential building density (-0.325), and building to lot proportion (-0.645). Line graphs of these negative correlates can be found in Figure 4-57.



(b)

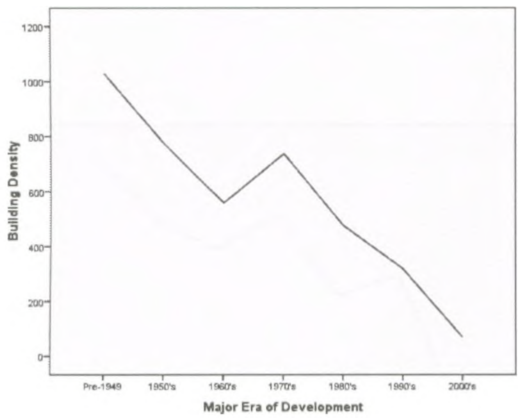
(c)



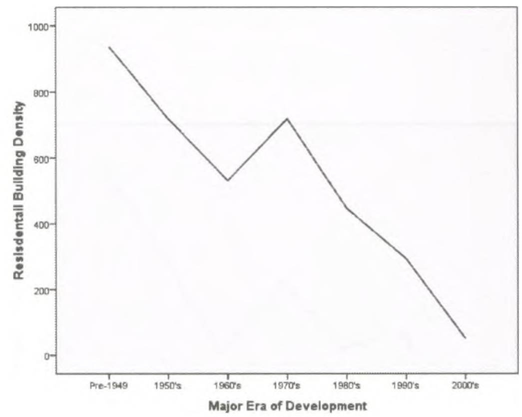
(d)

(e)

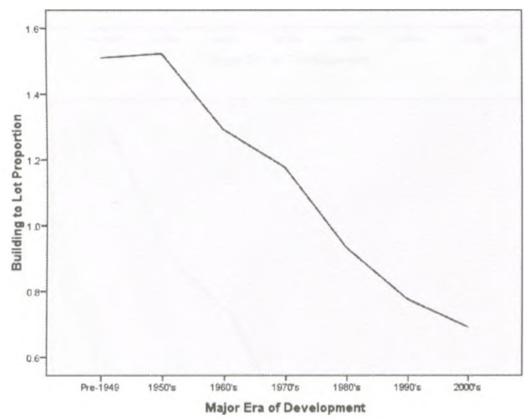
(f)



(g)



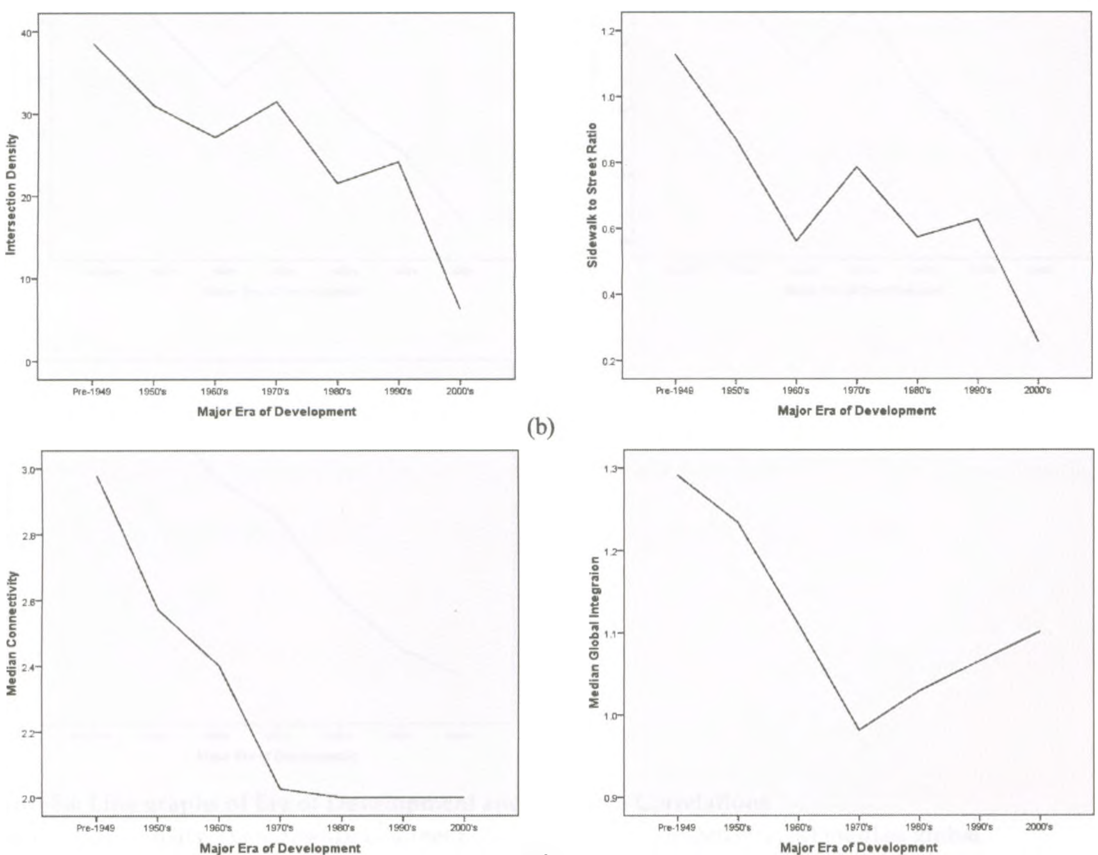
(h)



(i)

Figure 4-57 - Line graph of Major Era of Development and (a) intersection density, (b) sidewalk to street ratio, (c) median connectivity, (d) median global integration, (e) median local integration, (f) block density, (g) building density, (h) residential building density, and (i) building to lot proportion.

Variables that are not significantly statistically linearly correlated to era of development can still be non-linearly correlated with era of development. For example, all land use are not significantly correlated with major era of development. This is because some of these variables have low proportions pre 1950, have higher proportions in the mid-range years (1970-1980), and then have lower proportions in most recent years (1990s-2000s), or reverse (high-low-high). All variables that display this type of pattern are shown in Figure 4-58.



(a) (b)

(c) (d)

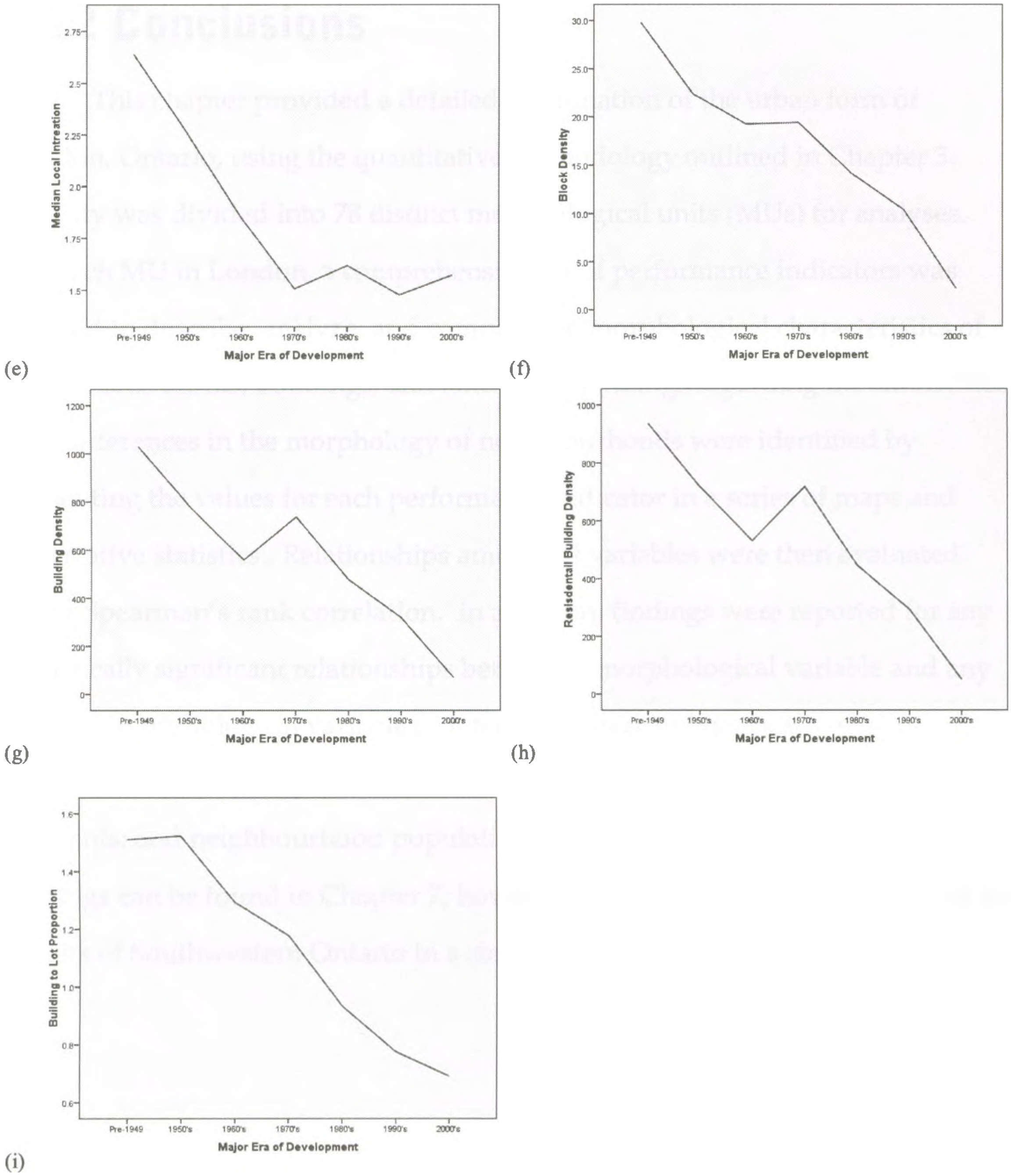


Figure 4-58: Line graphs of Era of Development and Negative Correlations
(a) intersection density, (b) sidewalk to street ratio, (c) median connectivity, (d) median global integration, (e) median local integration, (f) block density, (g) building density, (h) residential building density, and (i) building to lot proportion.

4.12 Conclusions

This chapter provided a detailed examination of the urban form of London, Ontario, using the quantitative methodology outlined in Chapter 3. The city was divided into 78 distinct morphological units (MUs) for analyses. For each MU in London, a comprehensive set of performance indicators was derived to describe, analyze, and compare the morphological characteristics of streets, lots, blocks, buildings, and land uses. Findings regarding the similarities and differences in the morphology of neighbourhoods were identified by presenting the values for each performance indicator in a series of maps and descriptive statistics. Relationships among all variables were then evaluated using Spearman's rank correlation. In addition, findings were reported for any statistically significant relationships between a morphological variable and any key non-morphological variable of interest, including: historical timing of neighbourhood development; median household incomes of neighbourhood residents; and neighbourhood population density. Detailed discussion of these findings can be found in Chapter 7; however, the upcoming chapter discusses the results of Southwestern Ontario in a similar fashion to this chapter.

CHAPTER 5
ASSESSING URBAN FORM IN SOUTHWESTERN ONTARIO CENSUS METROPOLITAN AREAS

5.1 Introduction

This chapter provides a detailed examination of the urban form of Southwestern Ontario Census Metropolitan Areas (CMAs), using the quantitative methodology outlined in Chapter 3. To analyze the built form of individual neighbourhoods, the CMAs are divided into 315 Census Tracts (CTs). For each CT, a comprehensive set of performance indicators is derived to describe, analyze, and compare the morphological characteristics of streets, blocks, and land uses. Findings regarding the similarities and differences in the morphology of neighbourhoods within and between cities are identified by presenting the values for each performance indicator in a series of maps and descriptive statistics. Relationships among all variables are then evaluated using Spearman's rank correlation. In addition, findings are reported for any statistically significant relationships between a morphological variable and any key non-morphological variable of interest, including: historical timing of neighbourhood development; median household incomes of neighbourhood residents; and neighbourhood population density. The chapter concludes with a brief summary of findings; however, detailed discussion of the findings is reserved for Chapter 6.

5.2 Census Tracks

Southwestern Ontario has a total of 350 census tracts within 6 CMAs: Windsor, Sarnia, London, Brantford, Kitchener, and Guelph. These CTs have a total area of 6,841 square kilometres. There are 315 urban CTs used in this analysis, with a total area of 1,128 square kilometres. These will be the CTs discussed in the remainder of the analysis. The average size of a census tract is 3.58 square kilometres, with a standard deviation of 4.54 square kilometres. The smallest census tract, CT# 268, is 0.42 square kilometres. The largest census tract, CT#86, is 38 square kilometres. Descriptive statistics can be found in Table 5-1.

Table 5-1: Descriptive Statistics: Census Tract Area

Count	315
Minimum	0.42
Maximum	37.97
Mean	3.58
Standard Deviation	4.54

Like the morphological units, each CT has been uniquely numbered 1-315. Further, the population, median household income, major era of development and area in square kilometres is shown in Table 5-2 by way of introduction. Unlike the morphological units, CTs are not given popularized names. Instead, the CMA and city name where each census tract resides is shown. Average median household income, population density, and major era of development will be explained in more detail in the pages following the chart.

Table 5-2 : Census Tract Data						
ID	CMA	City Name	Area (Square Kilometres)	Population	Median Household Income	Major Era of Development
1	Kitchener	Kitchener-Waterloo-Cambridge	4.85	5,923	$58,908	1970's
2	Kitchener	Kitchener-Waterloo-Cambridge	9.88	8,902	$96,430	2000's
3	Kitchener	Kitchener-Waterloo-Cambridge	5.46	2,316	$44,612	1960's
4	Kitchener	Kitchener-Waterloo-Cambridge	1.92	6,026	$52,621	1970's
5	Kitchener	Kitchener-Waterloo-Cambridge	1.07	2,897	$55,880	1970's
6	Kitchener	Kitchener-Waterloo-Cambridge	1.03	4,183	$62,192	1970's
7	Kitchener	Kitchener-Waterloo-Cambridge	0.87	3,060	$55,397	1980's
8	Kitchener	Kitchener-Waterloo-Cambridge	2.04	6,744	$81,448	1980's
9	Kitchener	Kitchener-Waterloo-Cambridge	30.65	14,430	$79,935	2000's
10	Kitchener	Kitchener-Waterloo-Cambridge	6.41	3,989	$50,302	2000's
11	Kitchener	Kitchener-Waterloo-Cambridge	3.49	5,812	$64,635	1970's
12	Kitchener	Kitchener-Waterloo-Cambridge	2.86	7,282	$53,605	1960's
13	Kitchener	Kitchener-Waterloo-Cambridge	1.46	7,379	$41,401	1970's
14	Kitchener	Kitchener-Waterloo-Cambridge	1.19	1,183	$46,288	1950's
15	Kitchener	Kitchener-Waterloo-Cambridge	2.40	7,195	$42,967	1950's
16	Kitchener	Kitchener-Waterloo-Cambridge	2.24	5,321	$68,945	1960's
17	Kitchener	Kitchener-Waterloo-Cambridge	1.23	3,439	$71,822	1970's
18	Kitchener	Kitchener-Waterloo-Cambridge	1.75	4,600	$91,335	1980's
19	Kitchener	Kitchener-Waterloo-Cambridge	0.90	3,637	$81,448	1980's
20	Kitchener	Kitchener-Waterloo-Cambridge	1.06	3,813	$78,411	1970's
21	Kitchener	Kitchener-Waterloo-Cambridge	1.42	6,442	$47,473	1970's
22	Kitchener	Kitchener-Waterloo-Cambridge	1.27	6,505	$43,581	1970's
23	Kitchener	Kitchener-Waterloo-Cambridge	5.31	9,374	$83,878	1990's
24	Kitchener	Kitchener-Waterloo-Cambridge	1.51	5,242	$44,169	Pre 1940's
25	Kitchener	Kitchener-Waterloo-Cambridge	1.71	4,509	$40,247	Pre 1940's
26	Kitchener	Kitchener-Waterloo-Cambridge	0.78	2,128	$43,853	Pre 1940's
27	Kitchener	Kitchener-Waterloo-Cambridge	1.47	3,325	$58,743	1950's
28	Kitchener	Kitchener-Waterloo-Cambridge	1.62	4,597	$55,422	1960's
29	Kitchener	Kitchener-Waterloo-Cambridge	4.10	7,471	$67,811	1970's
30	Kitchener	Kitchener-Waterloo-Cambridge	1.53	3,578	$47,277	1960's
31	Kitchener	Kitchener-Waterloo-Cambridge	6.06	6,902	$88,892	1980's
32	Kitchener	Kitchener-Waterloo-Cambridge	2.03	5,181	$54,204	1950's
33	Kitchener	Kitchener-Waterloo-Cambridge	1.44	5,634	$45,995	Pre 1940's
34	Kitchener	Kitchener-Waterloo-Cambridge	0.66	1,866	$29,101	Pre 1940's
35	Kitchener	Kitchener-Waterloo-Cambridge	1.11	2,281	$40,558	Pre 1940's
36	Kitchener	Kitchener-Waterloo-Cambridge	1.76	3,854	$52,019	1950's
37	Kitchener	Kitchener-Waterloo-Cambridge	0.83	2,548	$51,720	Pre 1940's
38	Kitchener	Kitchener-Waterloo-Cambridge	1.49	4,426	$45,148	Pre 1940's
39	Kitchener	Kitchener-Waterloo-Cambridge	4.86	1,051	$42,058	1950's
40	Kitchener	Kitchener-Waterloo-Cambridge	1.34	3,415	$49,423	1950's
41	Kitchener	Kitchener-Waterloo-Cambridge	6.09	4,196	$71,082	2000's
42	Kitchener	Kitchener-Waterloo-Cambridge	7.26	2,012	$122,360	2000's
43	Kitchener	Kitchener-Waterloo-Cambridge	2.47	5,372	$72,337	1950's
44	Kitchener	Kitchener-Waterloo-Cambridge	1.52	3,830	$44,066	1970's
45	Kitchener	Kitchener-Waterloo-Cambridge	3.98	0	$0	
46	Kitchener	Kitchener-Waterloo-Cambridge	1.86	6,210	$58,548	1970's
47	Kitchener	Kitchener-Waterloo-Cambridge	1.68	3,733	$112,628	1970's
48	Kitchener	Kitchener-Waterloo-Cambridge	1.16	2,658	$49,464	Pre 1940's
49	Kitchener	Kitchener-Waterloo-Cambridge	1.39	3,634	$56,190	1950's
50	Kitchener	Kitchener-Waterloo-Cambridge	2.62	6,514	$58,551	1960's
51	Kitchener	Kitchener-Waterloo-Cambridge	0.66	1,265	$39,395	1950's

Table 5-2 : Census Tract Data						
ID	CMA	City Name	Area (Square Kilometres)	Population	Median Household Income	Major Era of Development
52	Kitchener	Kitchener-Waterloo-Cambridge	1.57	1,874	$17,446	1950's
53	Kitchener	Kitchener-Waterloo-Cambridge	1.70	3,619	$41,550	1960's
54	Kitchener	Kitchener-Waterloo-Cambridge	2.95	0	$0	
55	Kitchener	Kitchener-Waterloo-Cambridge	2.07	4,806	$76,257	1970's
56	Kitchener	Kitchener-Waterloo-Cambridge	4.07	5,765	$54,175	1970's
57	Kitchener	Kitchener-Waterloo-Cambridge	8.43	7,639	$93,100	2000's
58	Kitchener	Kitchener-Waterloo-Cambridge	3.00	6,340	$90,026	1990's
59	Kitchener	Kitchener-Waterloo-Cambridge	1.73	5,900	$82,307	1980's
60	Kitchener	Kitchener-Waterloo-Cambridge	1.90	6,427	$88,731	1980's
61	Kitchener	Kitchener-Waterloo-Cambridge	17.66	13,389	$93,966	2000's
62	Kitchener	Kitchener-Waterloo-Cambridge	2.72	7,375	$92,432	1980's
63	Kitchener	Elmira	16.59	6,329	$77,486	1970's
64	Kitchener	Elmira	19.76	2,718	$61,484	Pre 1940's
65	Kitchener	Kitchener-Waterloo-Cambridge	3.01	7,119	$72,791	2000's
66	Kitchener	Kitchener-Waterloo-Cambridge	1.90	7,301	$64,285	1970's
67	Kitchener	Kitchener-Waterloo-Cambridge	2.60	4,992	$46,026	1950's
68	Kitchener	Kitchener-Waterloo-Cambridge	2.61	6,104	$61,072	Pre 1940's
69	Kitchener	Kitchener-Waterloo-Cambridge	1.31	4,803	$62,595	1970's
70	Kitchener	Kitchener-Waterloo-Cambridge	3.17	4,704	$64,948	Pre 1940's
71	Kitchener	Kitchener-Waterloo-Cambridge	2.50	2,962	$84,244	1970's
72	Kitchener	Kitchener-Waterloo-Cambridge	1.26	2,646	$40,557	Pre 1940's
73	Kitchener	Kitchener-Waterloo-Cambridge	9.79	5,670	$49,127	Pre 1940's
74	Kitchener	Kitchener-Waterloo-Cambridge	3.60	3,652	$52,703	Pre 1940's
75	Kitchener	Kitchener-Waterloo-Cambridge	1.38	4,275	$52,928	1970's
76	Kitchener	Kitchener-Waterloo-Cambridge	5.38	779	$70,708	1970's
77	Kitchener	Kitchener-Waterloo-Cambridge	4.84	7,681	$100,494	1980's
78	Kitchener	Kitchener-Waterloo-Cambridge	6.93	6,636	$90,546	2000's
79	Kitchener	Kitchener-Waterloo-Cambridge	1.13	4,700	$65,916	1970's
80	Kitchener	Kitchener-Waterloo-Cambridge	0.88	3,295	$58,588	1970's
81	Kitchener	Kitchener-Waterloo-Cambridge	2.33	5,874	$68,772	1960's
82	Kitchener	Kitchener-Waterloo-Cambridge	4.23	4,284	$56,682	Pre 1940's
83	Kitchener	Kitchener-Waterloo-Cambridge	0.53	1,930	$41,280	Pre 1940's
84	Kitchener	Kitchener-Waterloo-Cambridge	7.68	3,669	$62,151	1970's
85	Kitchener	Kitchener-Waterloo-Cambridge	2.04	4,055	$59,047	Pre 1940's
86	Kitchener	Kitchener-Waterloo-Cambridge	37.97	5,204	$78,056	1970's
87	Kitchener	Kitchener-Waterloo-Cambridge	3.40	3,861	$48,780	Pre 1940's
88	Kitchener	Kitchener-Waterloo-Cambridge	2.12	5,783	$84,837	1980's
89	Kitchener	Kitchener-Waterloo-Cambridge	3.01	8,392	$88,226	1990's
90	Kitchener	Ayr	14.42	4,290	$84,556	1990's
91	Brantford	Brantford	8.27	7,125	$43,177	Pre 1940's
92	Brantford	Brantford	14.85	11,255	$61,638	2000's
93	Brantford	Brantford	3.84	4,697	$56,874	Pre 1940's
94	Brantford	Brantford	11.15	948	$124,337	1950's
95	Brantford	Brantford	1.58	3,960	$34,118	Pre 1940's
96	Brantford	Brantford	0.51	1,356	$21,741	Pre 1940's
97	Brantford	Brantford	0.76	3,210	$41,355	Pre 1940's
98	Brantford	Brantford	1.57	2,954	$33,578	Pre 1940's
99	Brantford	Brantford	2.73	5,315	$46,703	1950's
100	Brantford	Brantford	1.59	4,503	$45,923	1950's
101	Brantford	Brantford	7.30	1,406	$39,692	1990's
102	Brantford	Brantford	4.41	4,256	$53,427	1980's

Table 5-2 : Census Tract Data						
ID	CMA	City Name	Area (Square Kilometres)	Population	Median Household Income	Major Era of Development
103	Brantford	Brantford	1.46	4,980	$75,650	1980's
104	Brantford	Brantford	2.57	6,218	$44,425	1950's
105	Brantford	Brantford	2.48	4,769	$67,563	1950's
106	Brantford	Brantford	2.92	5,824	$72,464	1960's
107	Brantford	Brantford	3.31	7,023	$59,713	1960's
108	Brantford	Brantford	1.70	5,964	$50,851	1970's
109	Brantford	Brantford	1.49	4,429	$76,452	1970's
110	Brantford	Paris	6.09	6,461	$64,128	Pre 1940's
111	Brantford	Paris	8.97	4,716	$60,961	Pre 1940's
112	Guelph	Guelph	6.70	7,063	$92,154	1970's
113	Guelph	Guelph	5.09	3,143	$43,706	1970's
114	Guelph	Guelph	1.88	4,349	$69,620	1980's
115	Guelph	Guelph	11.01	6,330	$81,906	2000's
116	Guelph	Guelph	1.36	3,275	$89,179	1970's
117	Guelph	Guelph	4.25	3,432	$97,570	1990's
118	Guelph	Guelph	7.29	5,866	$100,952	2000's
119	Guelph	Guelph	2.37	4,158	$73,422	1950's
120	Guelph	Guelph	2.01	3,788	$45,366	Pre 1940's
121	Guelph	Guelph	2.21	1,163	$71,823	1960's
122	Guelph	Guelph	2.21	6,137	$69,640	1990's
123	Guelph	Guelph	7.69	3,581	$76,510	2000's
124	Guelph	Guelph	2.05	5,009	$57,592	1950's
125	Guelph	Guelph	0.61	1,504	$26,187	Pre 1940's
126	Guelph	Guelph	1.35	4,339	$51,469	Pre 1940's
127	Guelph	Guelph	1.52	3,052	$46,418	Pre 1940's
128	Guelph	Guelph	1.77	3,526	$86,118	2000's
129	Guelph	Guelph	1.85	6,225	$66,887	1970's
130	Guelph	Guelph	2.11	5,359	$82,299	1980's
131	Guelph	Guelph	1.77	4,465	$82,106	2000's
132	Guelph	Guelph	0.99	4,842	$45,556	1970's
133	Guelph	Guelph	1.07	2,465	$48,957	1970's
134	Guelph	Guelph	2.10	5,848	$54,305	Pre 1940's
135	Guelph	Guelph	1.90	4,096	$52,316	1950's
136	Guelph	Guelph	1.67	3,159	$63,794	1950's
137	Guelph	Guelph	3.56	4,956	$66,661	1970's
138	Guelph	Guelph	9.18	3,813	$47,028	1970's
139	London	London	9.65	4,415	$53,539	1970's
140	London	London	1.02	4,075	$60,785	1970's
141	London	London	1.08	4,185	$55,770	1970's
142	London	London	1.15	4,997	$48,336	1970's
143	London	London	1.82	4,363	$62,659	1970's
144	London	London	1.27	3,663	$52,762	1990's
145	London	London	0.76	3,642	$60,239	1970's
146	London	London	1.08	2,800	$68,248	1970's
147	London	London	2.73	2,516	$62,190	1960's
148	London	London	0.56	2,487	$70,441	1970's
149	London	London	0.86	737	$44,780	1980's
150	London	London	1.54	4,937	$55,957	1970's
151	London	London	1.80	3,676	$62,903	1980's
152	London	London	1.00	4,015	$57,470	1970's
153	London	London	1.92	5,887	$51,830	1960's

Table 5-2 : Census Tract Data						
ID	CMA	City Name	Area (Square Kilometres)	Population	Median Household Income	Major Era of Development
154	London	London	1.03	3,730	$53,655	1970's
155	London	London	1.35	5,530	$57,153	1980's
156	London	London	1.04	3,863	$49,902	1970's
157	London	London	3.58	5,835	$80,722	1970's
158	London	London	5.66	8,104	$99,137	1970's
159	London	London	7.33	6,178	$81,160	1950's
160	London	London	2.72	3,076	$62,235	1950's
161	London	London	6.71	5,530	$108,872	1960's
162	London	London	1.34	4,099	$87,746	1960's
163	London	London	4.10	7,082	$71,382	1950's
164	London	London	0.84	2,755	$42,878	1960's
165	London	London	2.24	5,147	$42,653	1970's
166	London	London	1.70	5,410	$34,107	1970's
167	London	London	2.05	5,317	$52,911	1950's
168	London	London	2.14	4,173	$42,964	1950's
169	London	London	1.52	4,525	$35,225	1950's
170	London	London	0.85	1,683	$54,840	Pre 1940's
171	London	London	0.64	2,360	$67,093	Pre 1940's
172	London	London	0.80	4,288	$35,364	Pre 1940's
173	London	London	1.59	5,103	$45,917	Pre 1940's
174	London	London	1.02	1,128	$40,016	Pre 1940's
175	London	London	1.76	5,195	$38,345	1970's
176	London	London	3.61	6,991	$35,305	1970's
177	London	London	2.15	4,516	$33,198	Pre 1940's
178	London	London	1.98	4,849	$31,008	Pre 1940's
179	London	London	1.18	2,695	$34,153	Pre 1940's
180	London	London	1.68	3,806	$38,184	Pre 1940's
181	London	London	2.04	4,607	$47,981	Pre 1940's
182	London	London	4.52	6,661	$58,540	1950's
183	London	London	7.18	8,603	$63,349	1990's
184	London	London	1.10	3,775	$54,770	1970's
185	London	London	1.14	5,106	$56,890	1960's
186	London	London	23.81	1,506	$47,691	1990's
187	London	London	1.75	2,513	$50,459	1950's
188	London	London	1.29	3,094	$42,821	1950's
189	London	London	1.52	4,115	$44,130	1950's
190	London	London	1.51	1,366	$35,586	Pre 1940's
191	London	London	0.97	4,107	$37,732	Pre 1940's
192	London	London	1.09	4,695	$32,835	Pre 1940's
193	London	London	1.35	3,801	$37,194	Pre 1940's
194	London	London	0.84	0	$0	
195	London	London	2.81	4,268	$38,673	1950's
196	London	London	2.13	4,106	$47,983	1950's
197	London	London	3.38	4,307	$54,039	1960's
198	London	London	1.32	4,966	$37,899	1960's
199	London	London	0.88	2,660	$44,773	1950's
200	London	London	1.15	3,603	$39,102	1950's
201	London	London	1.35	3,965	$65,631	Pre 1940's
202	London	London	1.82	3,604	$58,569	Pre 1940's
203	London	London	3.45	3,805	$41,357	1970's
204	London	London	2.16	3,441	$91,164	1960's

Table 5-2 : Census Tract Data

ID	CMA	City Name	Area (Square Kilometres)	Population	Median Household Income	Major Era of Development
205	London	London	3.08	7,809	$60,250	1970's
206	London	London	0.54	2,471	$58,260	1970's
207	London	London	2.84	4,387	$78,590	1970's
208	London	London	1.80	1,179	$24,818	1950's
209	London	London	1.50	5,897	$40,262	1960's
210	London	London	1.64	5,691	$50,144	1960's
211	London	London	1.62	5,938	$48,130	1960's
212	London	London	6.53	5,972	$82,189	1960's
213	London	London	3.41	6,906	$58,661	2000's
214	London	London	3.42	5,809	$98,074	2000's
215	London	London	2.42	4,117	$100,176	1970's
216	London	London	1.74	3,512	$77,256	1980's
217	London	London	3.44	5,419	$118,536	1990's
218	London	London	14.04	4,843	$88,847	1950's
219	London	St. Thomas	11.36	6,371	$67,520	1970's
220	London	St. Thomas	1.56	2,563	$53,093	1950's
221	London	St. Thomas	1.27	2,453	$53,051	Pre 1940's
222	London	St. Thomas	1.45	3,529	$53,455	Pre 1940's
223	London	St. Thomas	2.80	4,269	$50,805	1960's
224	London	St. Thomas	3.42	5,259	$63,498	1990's
225	London	St. Thomas	1.16	3,008	$45,629	Pre 1940's
226	London	St. Thomas	4.62	2,954	$32,347	Pre 1940's
227	London	St. Thomas	8.29	5,704	$63,400	1970's
228	London	Stratroy	9.15	5,593	$61,451	1990's
229	London	Stratroy	4.16	5,244	$53,416	1960's
230	London	Stratroy	2.62	2,549	$54,923	1970's
231	Windsor	Windsor	4.37	5,749	$71,207	1950's
232	Windsor	Windsor	4.31	6,158	$84,131	2000's
233	Windsor	Windsor	2.64	6,115	$91,162	1990's
234	Windsor	Windsor	4.41	6,688	$70,648	1990's
235	Windsor	Windsor	4.23	2,744	$62,217	1950's
236	Windsor	Windsor	3.45	7,284	$83,834	1950's
237	Windsor	Windsor	2.22	4,152	$71,865	1950's
238	Windsor	Windsor	1.99	4,620	$80,510	1950's
239	Windsor	Windsor	3.80	1,506	$64,932	1990's
240	Windsor	Windsor	8.83	288	$59,928	Pre 1940's
241	Windsor	Windsor	4.09	6,204	$24,297	1970's
242	Windsor	Windsor	4.73	6,053	$48,037	1950's
243	Windsor	Windsor	5.18	8,433	$66,906	2000's
244	Windsor	Windsor	2.89	194	$0	1950's
245	Windsor	Windsor	1.08	3,297	$38,336	Pre 1940's
246	Windsor	Windsor	1.02	2,772	$46,793	1950's
247	Windsor	Windsor	2.72	5,546	$56,000	1950's
248	Windsor	Windsor	2.28	3,679	$76,969	1950's
249	Windsor	Windsor	3.26	4,888	$58,717	1950's
250	Windsor	Windsor	4.72	5,331	$35,150	1970's
251	Windsor	Windsor	1.48	3,731	$46,183	1960's
252	Windsor	Windsor	2.36	4,056	$46,719	1970's
253	Windsor	Windsor	1.87	4,938	$65,706	1970's
254	Windsor	Windsor	4.16	8,213	$59,428	2000's
255	Windsor	Windsor	2.11	3,869	$73,224	1970's

Table 5-2 : Census Tract Data

ID	CMA	City Name	Area (Square Kilometres)	Population	Median Household Income	Major Era of Development
256	Windsor	Windsor	1.82	3,920	$93,650	1970's
257	Windsor	Windsor	2.95	5,338	$44,859	1950's
258	Windsor	Windsor	1.56	4,642	$53,207	1950's
259	Windsor	Windsor	1.18	2,747	$53,202	1950's
260	Windsor	Windsor	1.27	2,415	$55,010	Pre 1940's
261	Windsor	Windsor	1.04	4,011	$42,605	Pre 1940's
262	Windsor	Windsor	1.11	2,264	$30,178	Pre 1940's
263	Windsor	Windsor	0.99	4,096	$41,874	Pre 1940's
264	Windsor	Windsor	0.85	1,100	$43,148	Pre 1940's
265	Windsor	Windsor	1.75	4,174	$39,548	1950's
266	Windsor	Windsor	1.19	2,503	$30,163	Pre 1940's
267	Windsor	Windsor	0.86	3,400	$30,306	Pre 1940's
268	Windsor	Windsor	0.42	1,503	$33,032	Pre 1940's
269	Windsor	Windsor	0.84	4,699	$27,642	Pre 1940's
270	Windsor	Windsor	0.98	4,974	$19,660	1970's
271	Windsor	Windsor	0.82	4,357	$35,500	Pre 1940's
272	Windsor	Windsor	1.00	3,859	$23,149	1960's
273	Windsor	Windsor	0.63	2,376	$37,132	Pre 1940's
274	Windsor	Windsor	1.04	3,398	$55,568	Pre 1940's
275	Windsor	Windsor	1.00	1,552	$30,323	Pre 1940's
276	Windsor	Windsor	1.68	3,356	$48,592	1950's
277	Windsor	Windsor	1.20	5,167	$40,158	1970's
278	Windsor	Windsor	2.80	6,814	$62,696	1950's
279	Windsor	Windsor	2.48	6,104	$64,395	1950's
280	Windsor	Windsor	1.47	5,140	$47,443	1960's
281	Windsor	Windsor	4.01	5,304	$85,289	1990's
282	Windsor	Windsor	4.46	4,359	$99,177	1990's
283	Windsor	Windsor	3.61	6,145	$84,630	1990's
284	Windsor	Windsor	3.07	3,993	$86,556	1980's
285	Windsor	Windsor	9.64	7,690	$92,397	1990's
286	Windsor	Windsor	3.15	7,484	$96,140	1980's
287	Windsor	Windsor	3.37	3,675	$103,964	1970's
288	Windsor	Windsor	2.78	6,407	$74,892	1990's
289	Windsor	Windsor	12.16	8,071	$87,000	2000's
290	Windsor	Windsor	15.87	6,027	$103,628	2000's
291	Windsor	Windsor	3.23	4,873	$78,859	1970's
292	Windsor	Amherstburg	7.97	4,776	$79,486	1970's
293	Windsor	Amherstburg	2.98	5,898	$48,189	1970's
294	Sarnia	Sarnia	30.57	856	$0	Pre 1940's
295	Sarnia	Sarnia	1.08	2,779	$36,280	Pre 1940's
296	Sarnia	Sarnia	2.34	5,114	$43,107	1950's
297	Sarnia	Sarnia	1.47	3,187	$59,848	1950's
298	Sarnia	Sarnia	1.34	2,827	$39,018	1950's
299	Sarnia	Sarnia	1.08	3,592	$36,850	Pre 1940's
300	Sarnia	Sarnia	1.12	2,045	$31,840	1970's
301	Sarnia	Sarnia	0.89	3,330	$33,412	Pre 1940's
302	Sarnia	Sarnia	1.96	5,173	$41,097	1950's
303	Sarnia	Sarnia	1.88	3,545	$74,212	1960's
304	Sarnia	Sarnia	1.83	3,168	$53,375	1950's
305	Sarnia	Sarnia	1.50	3,022	$73,930	1950's
306	Sarnia	Sarnia	3.08	4,777	$66,001	1950's

Table 5-2 : Census Tract Data						
ID	CMA	City Name	Area (Square Kilometres)	Population	Median Household Income	Major Era of Development
307	Sarnia	Sarnia	3.71	2,019	$56,626	1950's
308	Sarnia	Sarnia	3.71	4,631	$109,883	1970's
309	Sarnia	Sarnia	11.47	2,403	$110,873	1950's
310	Sarnia	Sarnia	11.07	5,086	$93,405	1980's
311	Sarnia	Sarnia	2.55	2,414	$92,107	1970's
312	Sarnia	Sarnia	3.68	4,675	$52,674	1970's
313	Sarnia	Sarnia	2.04	6,561	$59,756	1970's
314	Sarnia	Sarnia	18.16	6,574	$76,328	1970's
315	Sarnia	Sarnia	20.19	1,667	$74,348	Pre 1940's

Looking at the above table, 3 CTs (45, 54, and 194) have no population or income values. This is because these CTs are non-residential CTs (they are used for institutional purposes).

The 6 CMAs span across a wide area of Southwestern Ontario. Thus, it is impossible to show a meaningful map of every single CT. Therefore, one map is produced for each CMA, showing the locations and boundaries of the CTs in its major city. While a vast majority of the 315 CTs are shown on this map, some CTs, like those found in small towns such as St. Thomas, are not shown (but used in the analysis). An introduction to this map is shown in Figure 5-1, below.

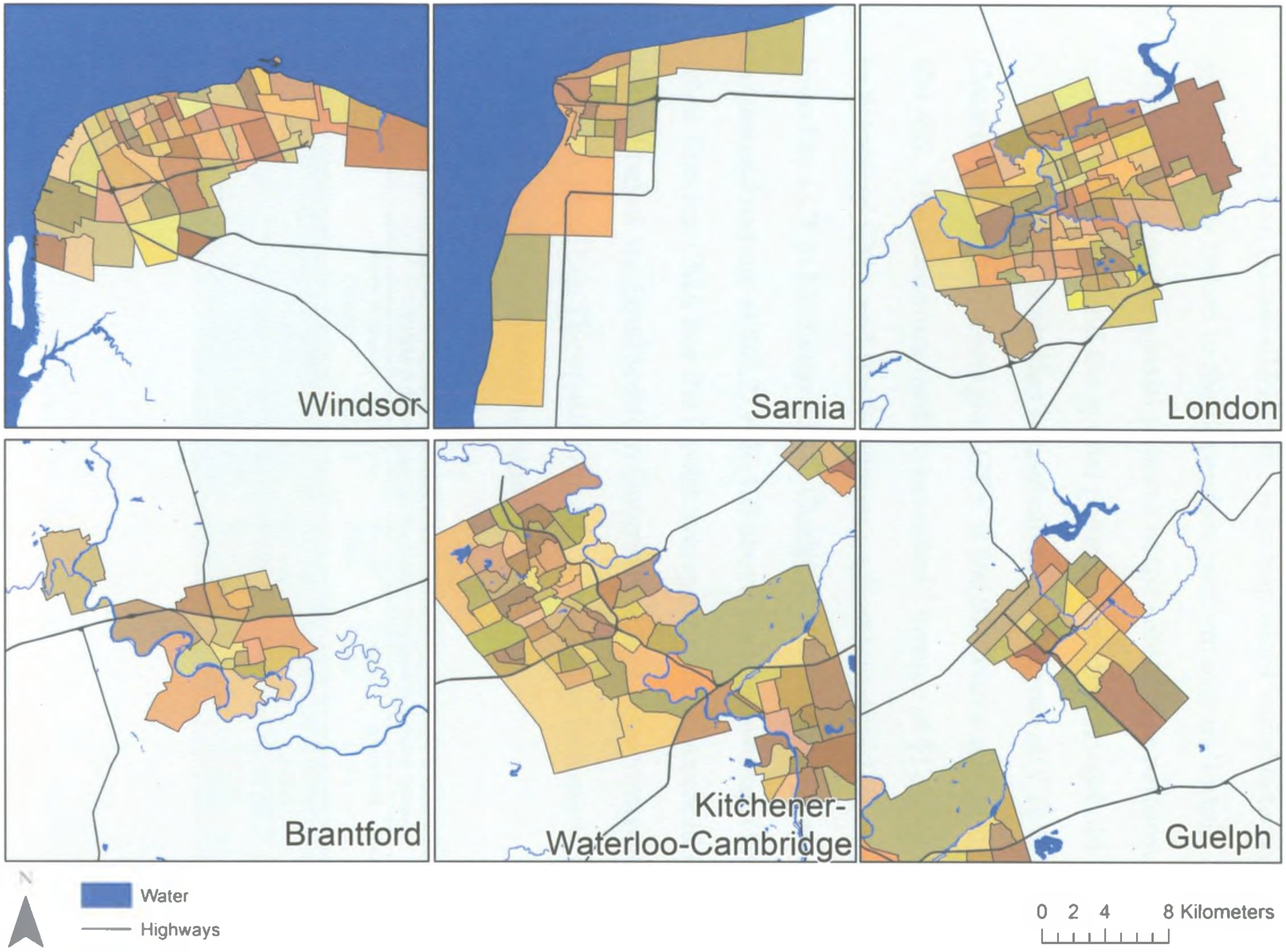


Figure 5-1: Sample of Cities in Southwestern Ontario

5.3 Median Household Income

Median household income is an important variable to note, as the values are inherently linked to the dependent performance indicators. In other words, when discussing the spatial patterns of the subsequent performance indicators, we must keep in mind the spatial pattern of median household income.

The average median household income across all CTs in Southwestern Ontario, derived by averaging CT's, is $60,094 with a standard deviation of $20,405. The maximum median household income of $124,337 is found in a CT in Brantford CMA and the minimum median household income of $17,446 is found in a CT in Kitchener CMA. Guelph CMA has the highest average median household income at $66,279 ($6,195 above the Southwestern Ontario average), while London CMA has the lowest average median household income at $55,933 ($4,161 below the Southwestern Ontario average). Descriptive statistics can be found in Table 5-3. The spatial variations in median household income within and among CMAs be seen in Figure 5-2.

Table 5-3: Descriptive Statistics: Median Household Income

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	312	63	22	91	21	88	27
Minimum	$17,446	$19,660	$31,840	$ 24,818	$21,741	$17,446	$26,187
Maximum	$124,337	$103,964	$110,873	$ 118,536	$124,337	$122,360	$100,952
Mean	$60,094	$58,510	$59,771	$55,933	$55,941	$63,337	$66,279
Standard Deviation	$20,405	$23,397	$26,558	$18,322	$20,898	$19,396	$18,676

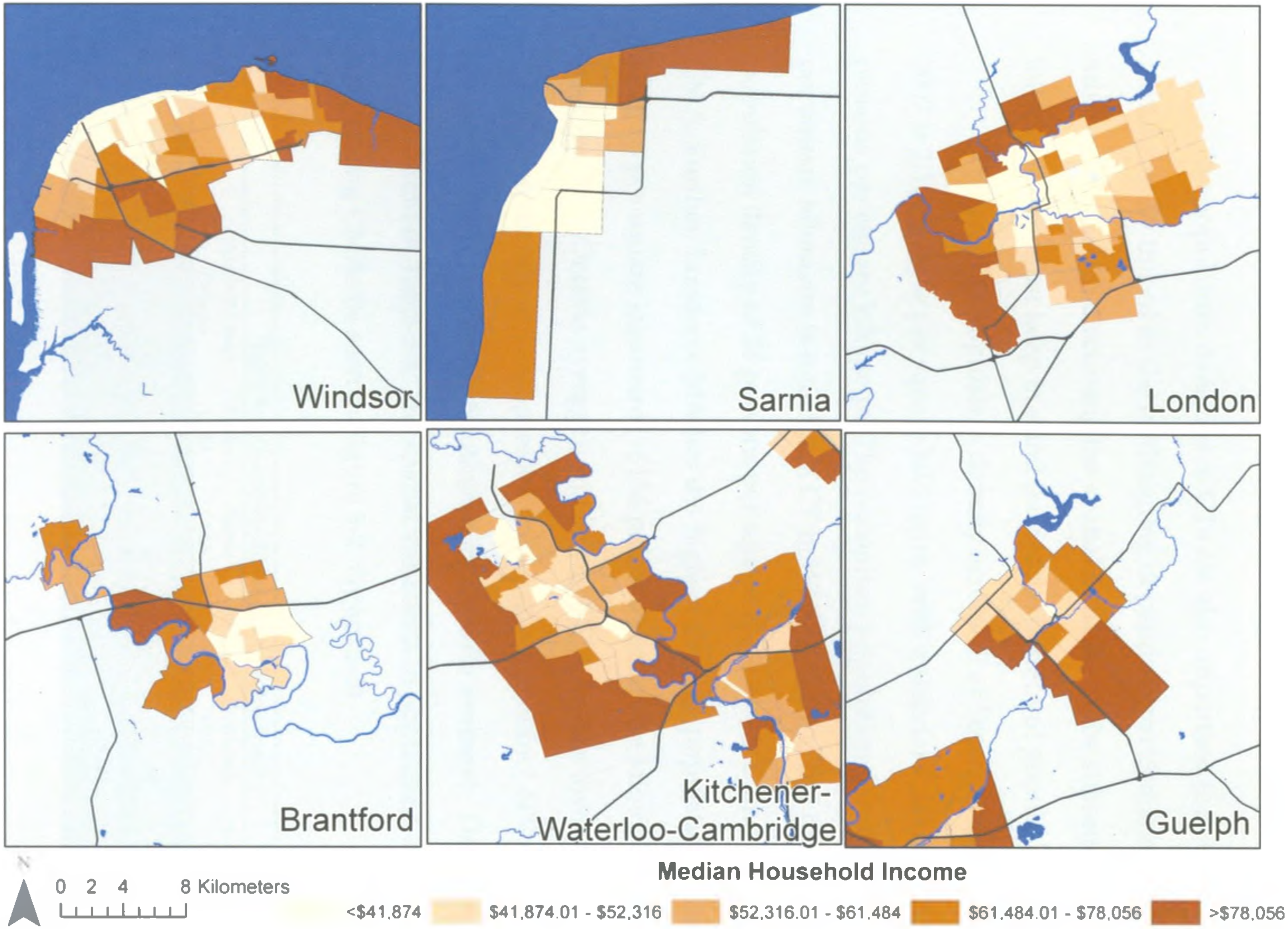


Figure 5-2: Median Household Income in Southwestern Ontario

5.4 Population Density

The population densities of CTs are also important to note, as the values are inherently linked to the forthcoming dependant performance indicators. In other words, when discussing the spatial patterns of the subsequent performance indicators, we must keep in mind the spatial pattern of population density.

The average population density across all of Southwestern Ontario in 2007 is 2,151 people per square kilometre, with a standard deviation of 1,192 persons per square kilometre. The maximum population density of 5,605 persons per square kilometre is found in a CT in Windsor CMA, and the minimum population density of 28 persons per square kilometre is found in a CT in Sarnia CMA. Further, London CMA has the highest average population density at 2,337 persons per square kilometre (+$186 persons per square kilometre over the Southwestern Ontario average), and Sarnia CMA has the lowest average population density at 1,642 persons per square kilometre (-509 persons per square kilometre under the Southwestern Ontario average). Descriptive statistics can be found in Table 5-4. The spatial variations in population density within and among CMAs be seen in Figure 5-2. Figure 5-3)

Table 5-4: Descriptive Statistics: Population Density

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	312	63	22	92	21	90	27
Minimum	28	33	28	63	85	137	415
Maximum	5,605	5,605	3,740	5,341	4,216	5,110	4,883
Mean	2,151	2,156	1,642	2,337	2,104	2,207	1,939
Standard Deviation	1,192	1,217	160	1,207	1,910	1,195	1,042

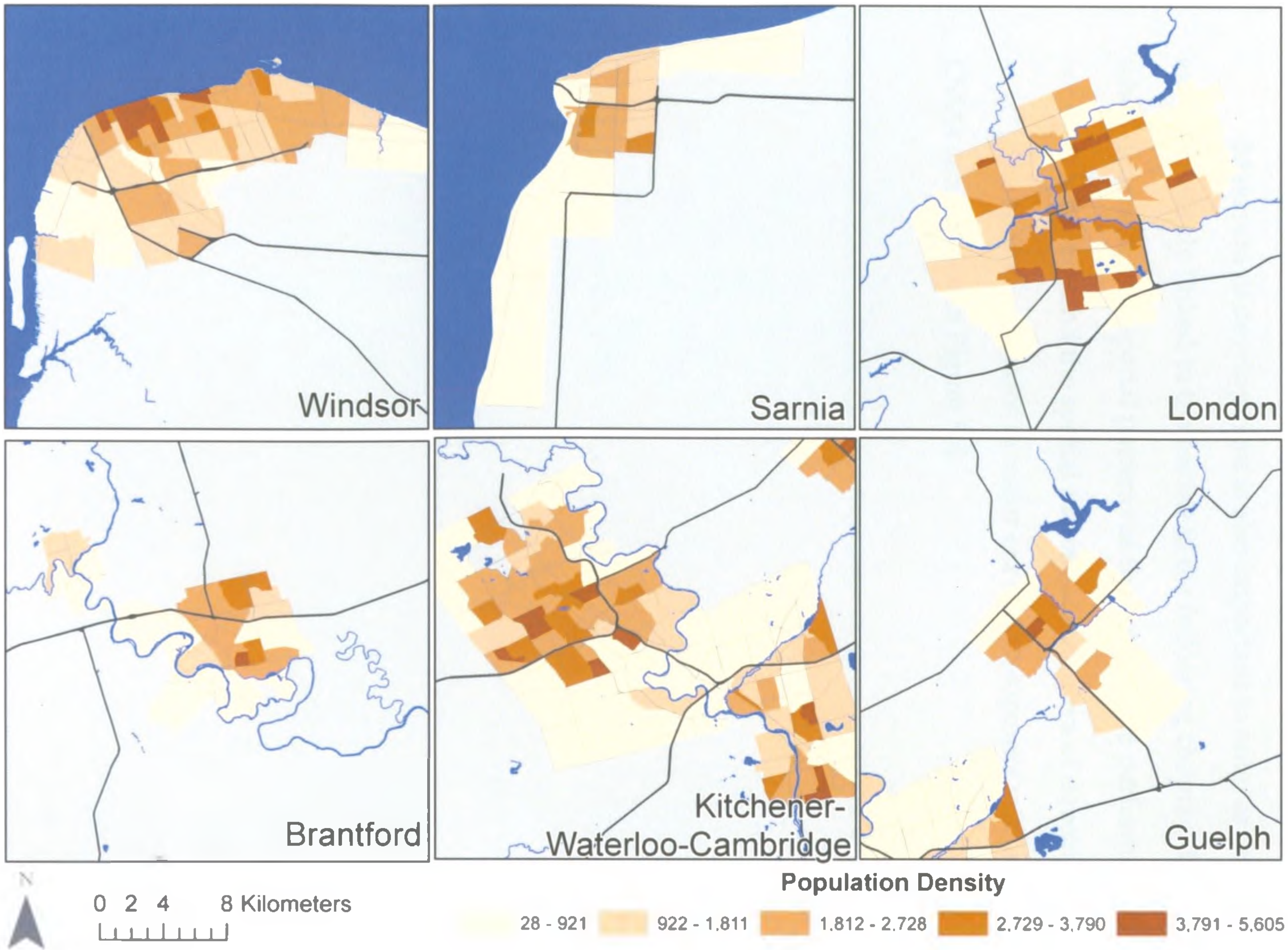


Figure 5-3: Population Density in Southwestern Ontario

5.5 Major Era of Development

Major era of development is also important to note, as the development era is inherently linked to the results in the following chapter. In other words, when discussing the spatial patterns of the subsequent performance indicators, we must keep in mind the spatial pattern of major era of development.

The spatial variations in major era of development within and between CMAs can be seen in Figure 5-4.

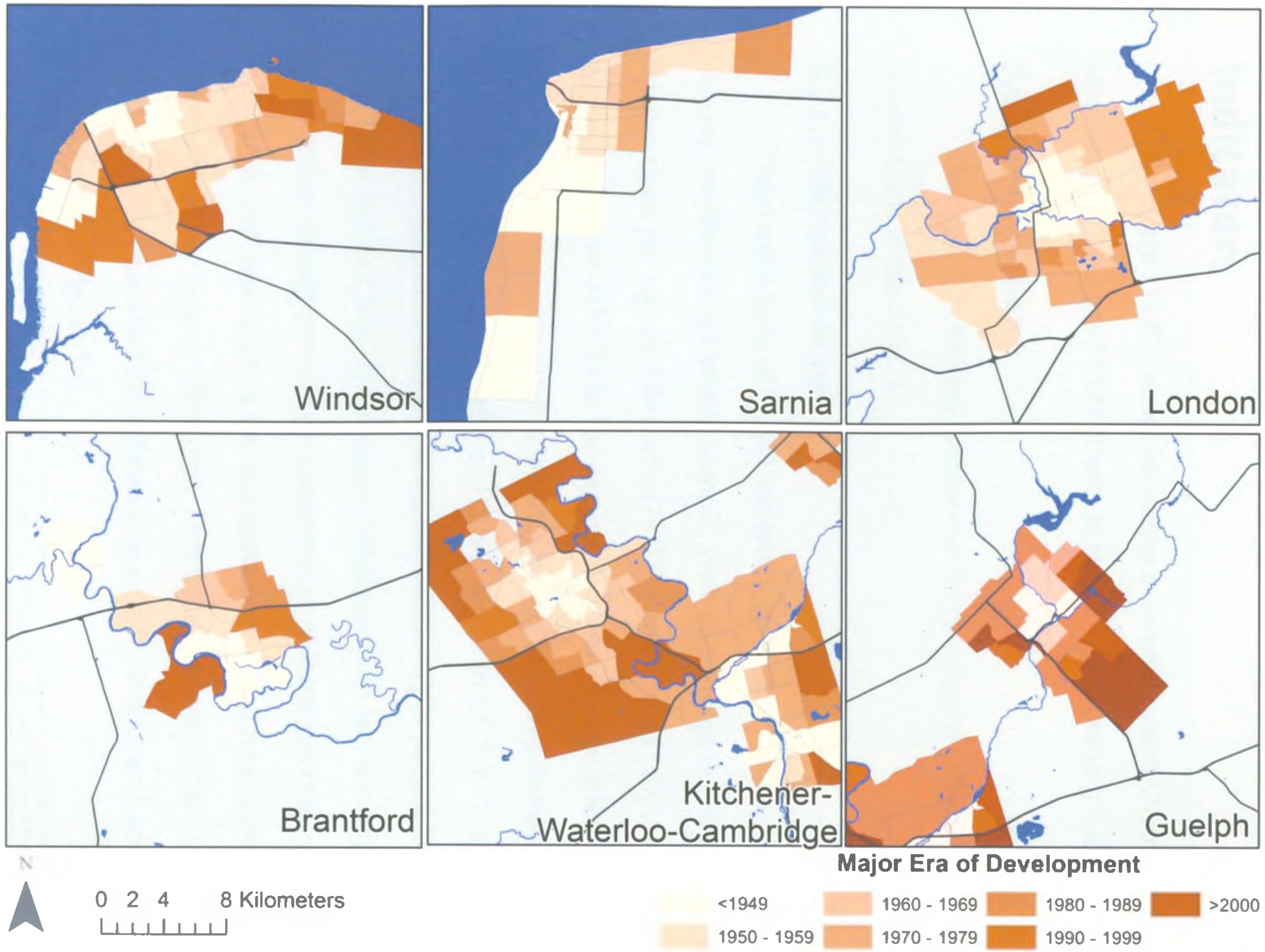


Figure 5-4: Major Era of Development in Southwestern Ontario

5.6 Southwestern Ontario Street Performance Indicators

There are 114,821 street segments in Southwestern Ontario totalling 54,651 kilometres. There are 39,134 streets in the 315 CTs totalling 6,830 kilometres.

5.6.1. Intersections

There are 103,950 intersections in Southwestern Ontario, with 38,862 intersections in the 315 CTs.

5.6.1.1 Intersection Density

There are a total of 31,419 intersections with a valance of 3 or more in the six-city Southwestern Ontario sample, with an average density of 14.89 intersections per square kilometre (79,003 intersections / 37,116 square kilometres). The 315 CTs in the sample have an average intersection density of 42.3 intersections per square kilometre, with a standard deviation of 18.6. The maximum intersection density of 116.4 is found in a CT in Guelph CMA and the minimum intersection density of 4.2 intersections per square kilometre is found in a CT in Sarnia CMA. On average, Windsor CMA has the highest average intersection density per square kilometre, at 44.2 intersections per square kilometre, and Sarnia CMA has the lowest average intersection density at 37.5 intersections per square kilometre. Descriptive statistics can be found in Table 5-5 and spatial variations in intersection density within and among the CMAs can be found in Figure 5-5.

Table 5-5: Descriptive Statistics: Intersection Density per Square Kilometre

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	4.2	10.7	4.2	6.0	4.8	4.5	8.7
Maximum	116.4	87.7	69.6	72.3	110.5	107.1	116.4
Mean	42.3	44.2	37.5	41.98	39.5	43.1	43.6
Standard Deviation	18.6	16.6	18.3	15.19	23.5	20.2	23.3

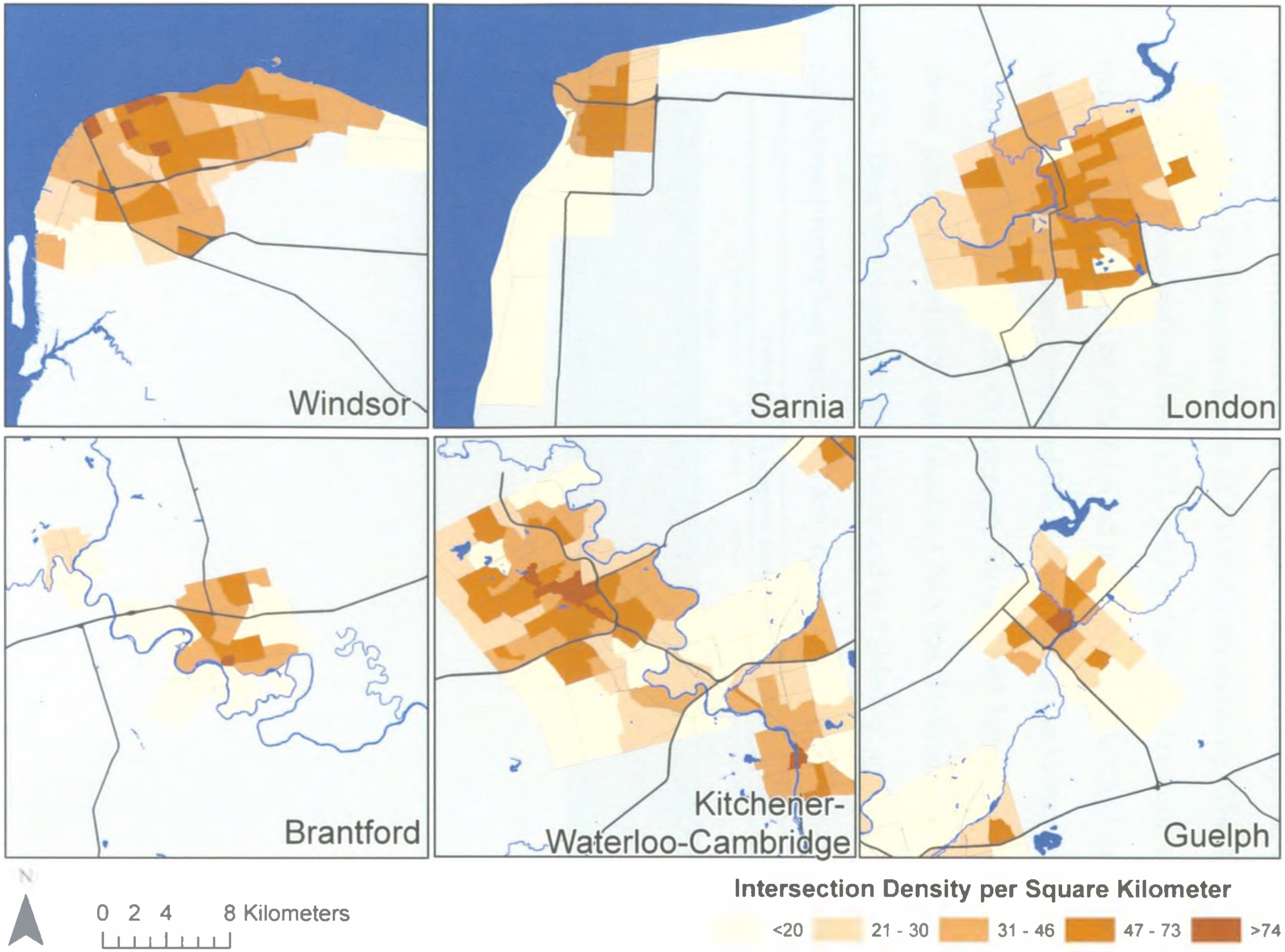


Figure 5-5: Intersection Density in Southwestern Ontario

5.6.1.2 Cul-De-Sac Proportion

There are a total of 16,091 cul-du-sacs (intersections with a valance of 1) in the six-city Southwestern Ontario sample, with an average cul-de-sac proportion of 15.5% (16,091 culs-du-sac out of 103,950 intersections). The 315 CTs have a mean cul-de-sac proportion of 13%, with a standard deviation of 8%. The maximum proportion of 31% is found in a CT in Sarnia CMA and London CMA, and the minimum proportion of 0% is found in CTs in Windsor CMA, Brantford CMA, and Guelph CMA. On average, Sarnia CMA has the highest average cul-de-sac proportion at 15%, and Guelph CMA has the lowest cul-de-sac proportion at 8%. Descriptive statistics can be found in Table 5-6, and spatial variations in cul-du-sac proportion within and among the CMAs can be found in Figure 5-6.

Table 5-6: Descriptive Statistics: Cul-de-sac Proportion

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0	0	0.02	0.02	0	0	0
Maximum	0.31	0.30	0.31	0.31	0.26	0.26	0.23
Mean	0.13	0.10	0.15	0.17	0.14	0.09	0.08
Standard Deviation	0.08	0.07	0.08	0.07	0.07	0.06	0.05

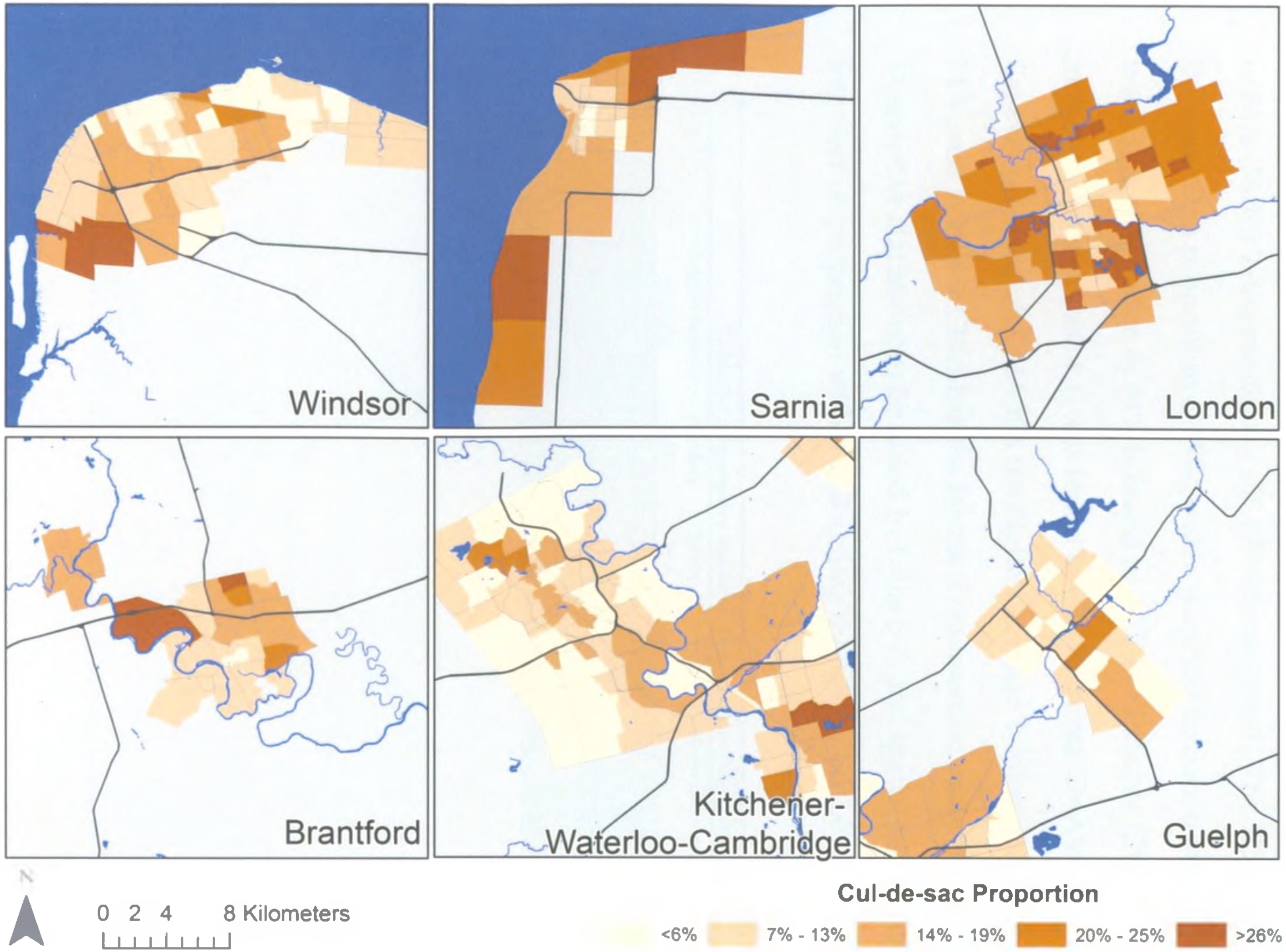


Figure 5-6: Cul-de-sac proportion in Southwestern Ontario

5.6.1.3 T-Intersection Proportion

There are 23,862 T-intersections (intersections with a valance of 3) in the six-city Southwestern Ontario study, with an average T-intersection proportion of 56% (58,401 T-intersections / 103,950 intersections). The 315 CTs have a mean T-intersection proportion of 79%, with a standard deviation of 61%. The maximum proportion of 94% is found in a CT in Kitchener CMA, and the minimum proportion of 11% is found in CTs in Sarnia CMA and London CMA. On average, Guelph CMA has the highest average T-intersection proportion at 71%, and Windsor CMA has the lowest T-intersection proportion at 52%. Descriptive statistics can be found in Table 5-7, and spatial variations in T-intersection proportion within and among the CMAs can be found in Figure 5-7.

Table 5-7: Descriptive Statistics: T-Intersection Proportion

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.03	0.11	0.03	0.03	0.13	0.21	0.48
Maximum	0.94	0.92	0.75	0.79	0.82	0.94	0.86
Mean	0.61	0.52	0.59	0.61	0.56	0.66	0.71
Standard Deviation	0.13	0.15	0.10	0.09	0.15	0.12	0.11

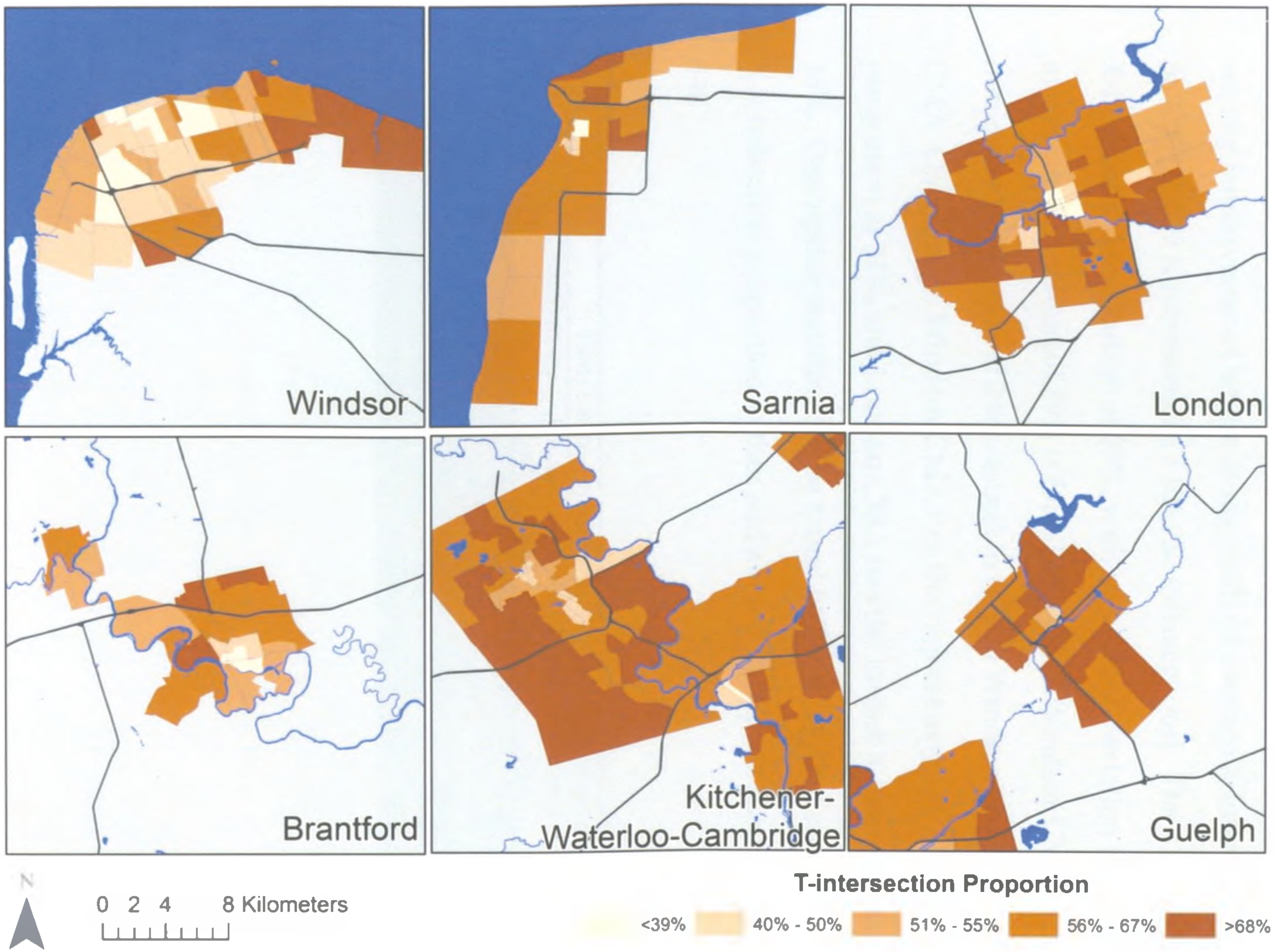


Figure 5-7: T-intersection proportion in Southwestern Ontario

5.6.1.4 X-Intersection Proportion

There are 20,359 X-intersections (intersections with a valance of 4) in the six-city Southwestern Ontario study, with an average X-intersection proportion of 20% (20,359 X-intersections / 103,950 intersections). The 315 CTs have a mean X-intersection proportion of 20%, with a standard deviation of 14%. The maximum proportion of 89% is found in a CT in Windsor CMA and the minimum proportion of 2% is found in CTs in Windsor CMA and Kitchener CMA. On average, Windsor CMA has the highest average X-intersection proportion at 31%, and London CMA has the lowest X-intersection proportion at 16%. Descriptive statistics can be found in Table 5-8, and spatial variations in the X-intersection proportion within and among the CMAs can be found in Figure 5-8.

Table 5-8: Descriptive Statistics: X-Intersection Proportion

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.02	0.02	0.07	0.03	0.05	0.02	0.08
Maximum	0.89	0.89	0.65	0.55	0.85	0.68	0.40
Mean	0.20	0.31	0.21	0.16	0.25	0.17	0.19
Standard Deviation	0.14	0.17	0.13	0.10	0.20	0.11	0.07

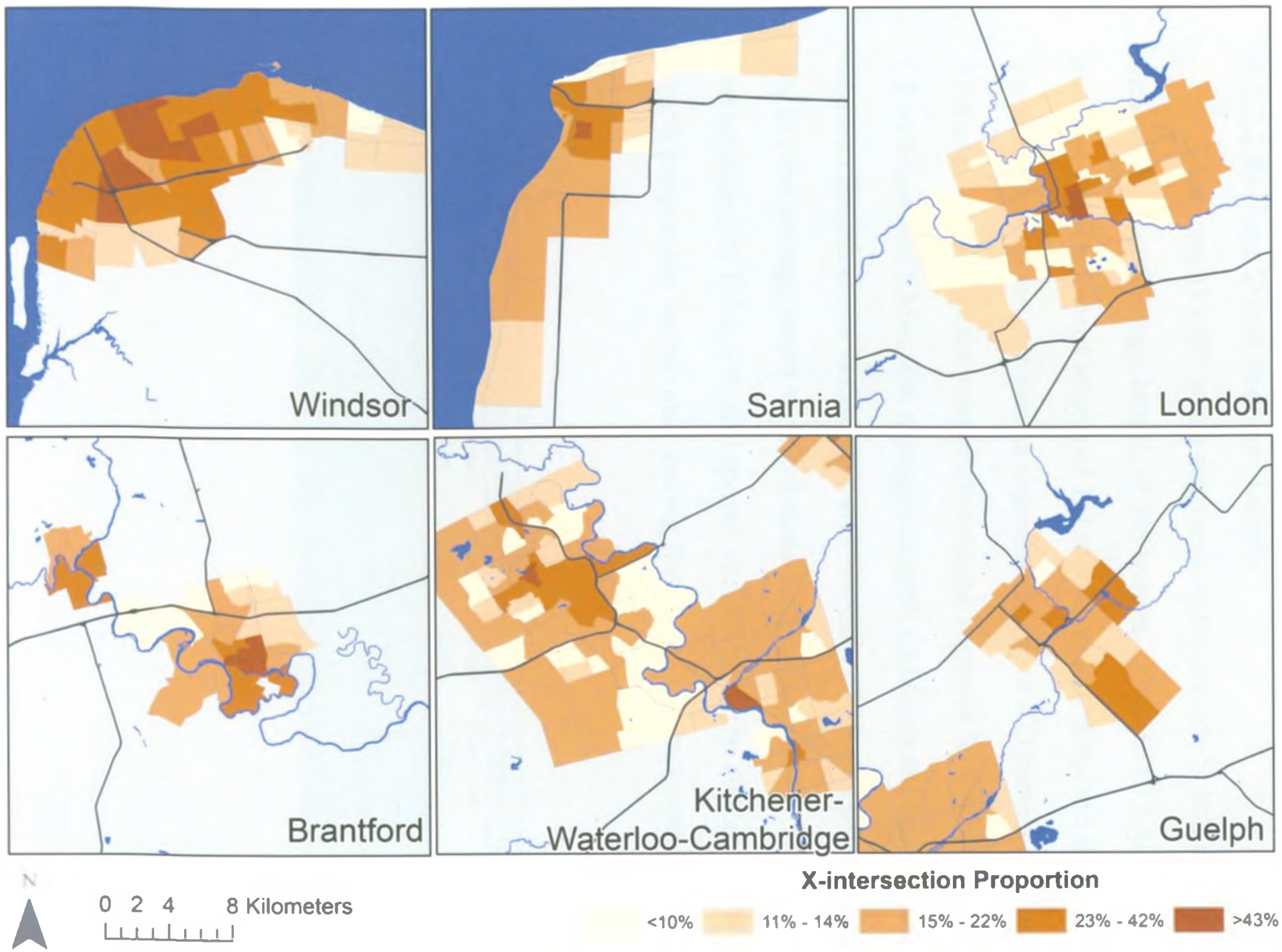


Figure 5-8: X-Intersection Proportion in Southwestern Ontario

4.6.2 Street Segment Length

4.6.2.1 Average Street Segment Length

There are 114,821 street segments in the six-city Southwestern Ontario sample, with an average length of 448 metres. The 315 CTs have an overall average street segment length of 191 metres with a standard deviation of 54 metres. The maximum average segment length of 423 metres is found in a CT in Kitchener CMA and the minimum average segment length of 103 is found in a CT in Brantford CMA. On average, Guelph CMA has the highest average street segment length at 205 kilometres, and Windsor CMA and Brantford CMA have the lowest average street segment sizes at 177 kilometres). Descriptive statistics can be found in Table 5-9, and spatial variations in the average street segment length proportion within and among the CMAs can be found in Figure 5-9.

Table 5-9: Descriptive Statistics: Average Street Segment Length

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	103	110	136	108	103	107	124
Maximum	423	295	363	403	334	423	334
Mean	191	177	199	191	177	195	205
Standard Deviation	54	36	62	49	61	59	60

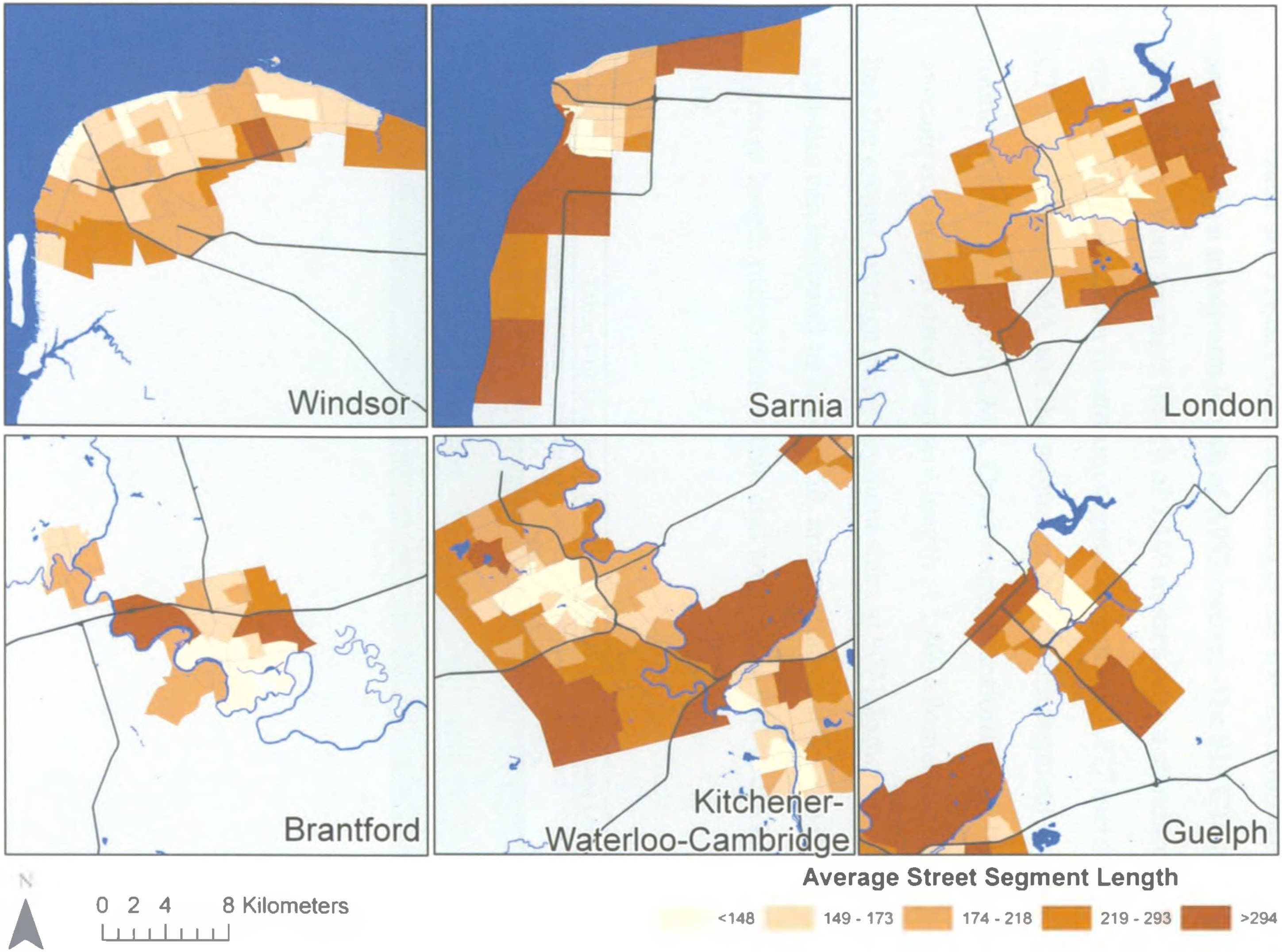


Figure 5-9: Average Street Segment Length in Southwestern Ontario

4.6.2.2 Maximum Street Segment Length

There are 114,821 street segments in the six-city Southwestern Ontario sample, with a maximum length of 8,992 metres. The 315 CTs have an average maximum street segment length of 1,149 metres with a standard deviation of 748 metres. The maximum maximum segment length of 3,827 metres is found in a CT in Kitchener CMA and the minimum maximum segment length of 250 is found in a CT in London CMA. On average, Brantford CMA has the highest average maximum street segment length at 1,460 kilometres, and Windsor CMA has the lowest average street segment sizes at 907 kilometres. Descriptive statistics can be found in Table 5-10, and spatial variations in the maximum street segment length proportion within and among the CMAs can be found in Figure 5-10.

Table 5-10: Descriptive Statistics Maximum Street Segment Length

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	250	271	361	250	265	296	345
Maximum	3,827	2,486	2,869	2,499	2,781	3,827	2,272
Mean	1,149	904	1,434	1,014	1,460	1,286	1,276
Standard Deviation	748	532	860	595	730	933	623

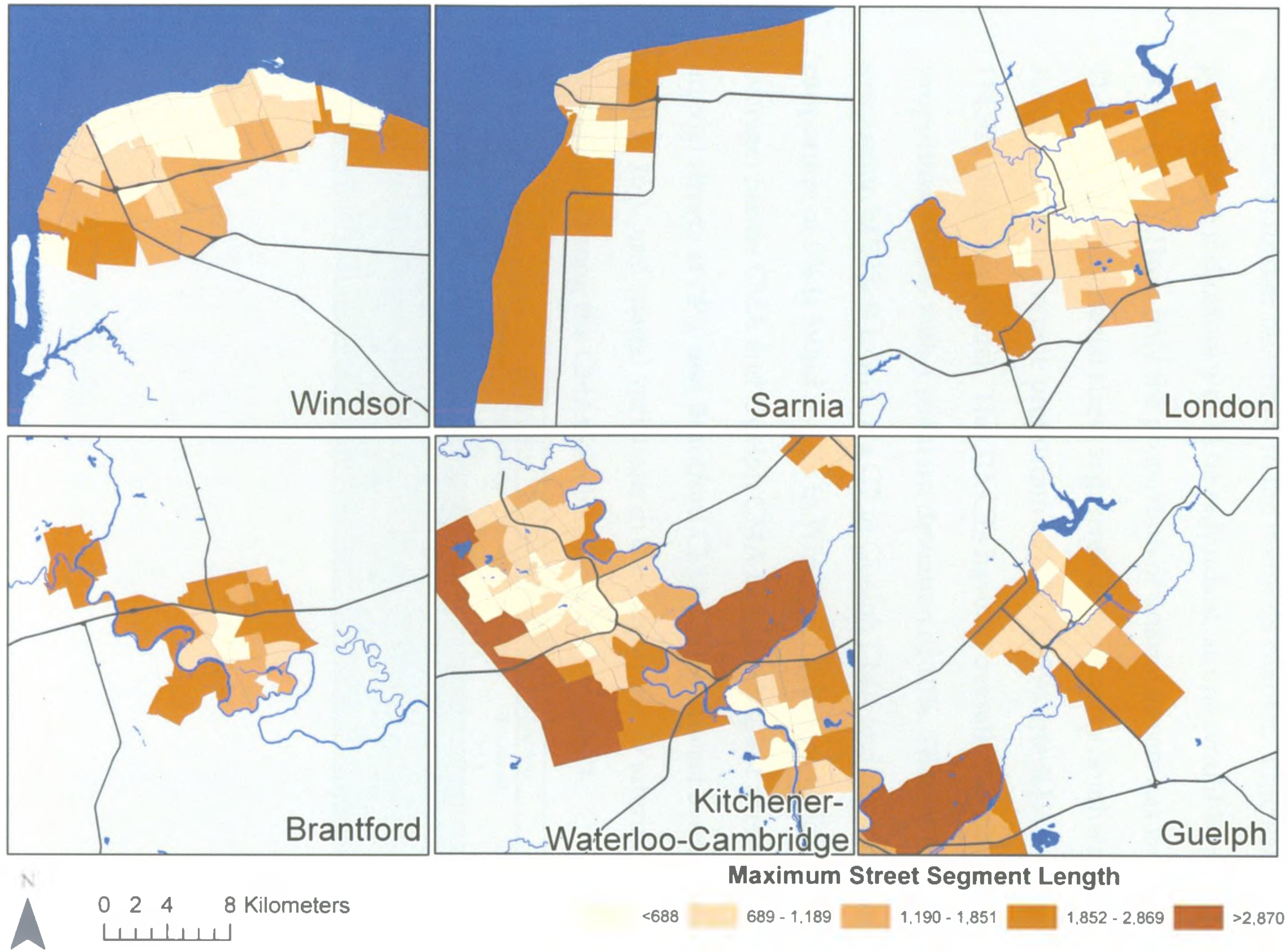


Figure 5-10: Maximum Street Segment Length

5.6.3 Proportion of Arterial Streets

Streets were classified as either Arterial or Local/Collator using the DMTI street file as further described in the methods chapter. Calculating both performance indicators would be redundant, as one would be the direct opposite of the other. Thus, only the proportion of arterial streets has been calculated. There are 24,296 arterial street segments in the six-city Southwestern Ontario sample, with an average proportion of 21% (24,294 arterial street segments / 114,821 street segments). The 315 CTs have an overall arterial street segment proportion of 20% with a standard deviation of 10%. The maximum arterial proportion of 59% is found in a CT in Guelph CMA and the minimum arterial proportion of 0% is found in CTs in Windsor, London, and Kitchener CMA. On average, Sarnia CMA and Guelph CMA have the highest average proportion of arterial streets at 24%, and Brantford CMA has the lowest average street segment sizes at 16%. and spatial variations in the proportion of arterial streets proportion within and among the CMAs can be found in Figure 5-11.

Descriptive Statistics Arterial Street Proportion

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0	0	0.06	0	0.01	0	0.06
Maximum	0.59	0.41	0.51	0.43	0.34	0.48	0.59
Mean	0.20	0.15	0.24	0.19	0.16	0.21	0.24
Standard Deviation	0.10	0.08	0.09	0.09	0.08	0.10	0.12

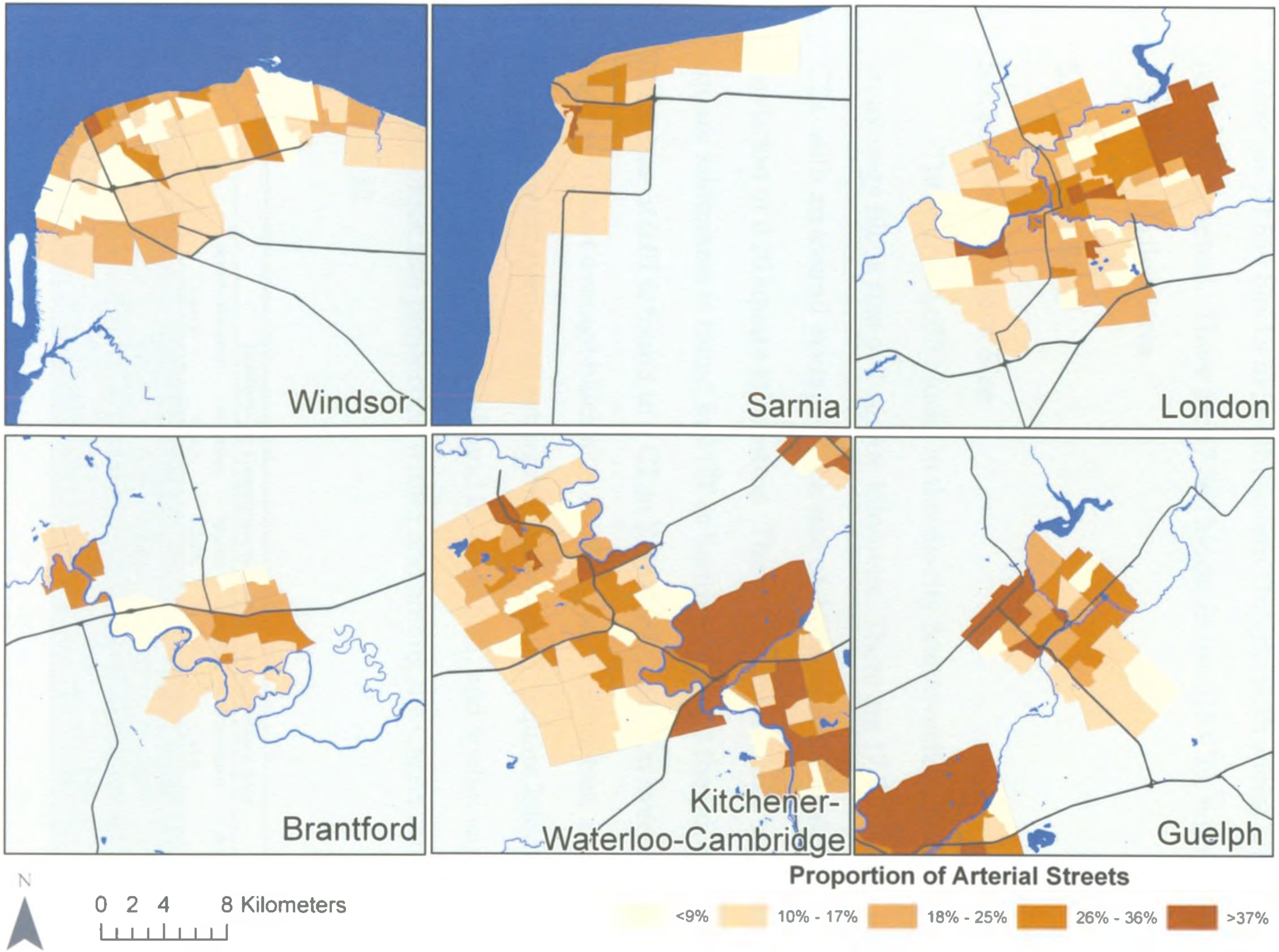


Figure 5-11- Proportion of Arterial Streets in Southwestern Ontario

5.7 Southwestern Ontario Blocks

There are 34,659 blocks in Southwestern Ontario with a total area of 37,116 square kilometres. There are 17,360 blocks in the 315 CTs, with a total area of 3,376 square kilometres

5.7.1 Block Size

5.7.1.1 Average Block Size

There are 34,659 blocks in the six-city Southwestern Ontario sample, with an average block size of 1 square kilometre. There are 17,360 blocks in the 315 CTs, with an overall average block size of 0.20 square kilometres and a standard deviation of 0.20 square kilometres. The maximum average block size of 1.27 square kilometres is found in a CT in Sarnia CMA and the minimum average block size of 0.01 is found in a CT in Brantford CMA. On average, Sarnia CMA has the highest average block size at 0.28 square kilometres, and Windsor CMA has the lowest average street segment sizes at 0.12 square kilometres. Descriptive statistics can be found in Table 5-11, and spatial variations in the average block size proportion within and among the CMAs can be found in Figure 5-12.

Table 5-11: Descriptive Statistics: Average Block Size

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.01	0.02	0.025	0.03	0.01	0.02	0.05
Maximum	1.27	0.48	1.27	0.98	0.99	1.12	0.82
Mean	0.20	0.12	0.28	0.19	0.26	0.24	0.25
Standard Deviation	0.20	0.11	0.29	0.15	0.24	0.22	0.19

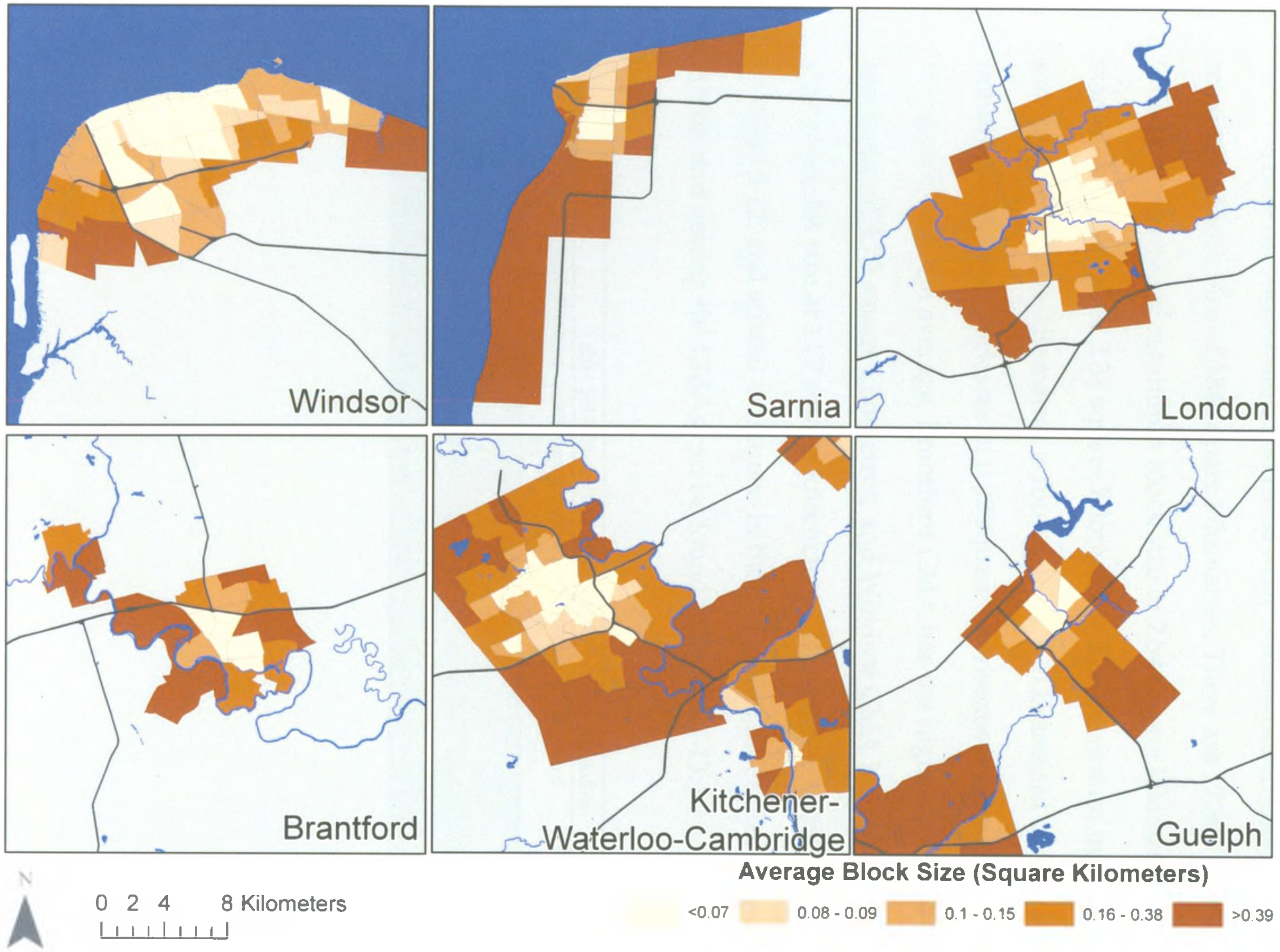


Figure 5-12: Average Block Size in Southwestern Ontario

5.7.1.2 Maximum Block Size

There are 34,659 blocks in the six-city Southwestern Ontario sample with a maximum block size of 184 square kilometres. There are 17,360 blocks in the 315 CTs, with an overall maximum block size of 2.54 square kilometres and a standard deviation of 2.38 square kilometres. The maximum maximum block size of 10.23 square kilometres is found in a CT in Brantford CMA and the minimum average block size of 0.07 square kilometres is found in a CT in Windsor CMA. On average, Brantford CMA has the highest average maximum block size at 4.70 square kilometres, and Windsor CMA has the lowest average maximum lot size at 1.77 square kilometres. Descriptive statistics can be found in Table 5-12, and spatial variations in the maximum block size proportion within and among the CMAs can be found in Figure 5-13.

Table 5-12: Descriptive Statistics : Maximum Block Size

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.07	0.07	0.13	0.13	0.08	0.18	0.26
Maximum	10.23	8.60	7.81	8.53	10.23	10.09	9.45
Mean	2.54	1.77	3.62	1.97	4.7	2.79	2.81
Standard Deviation	2.38	1.80	2.66	1.66	3.4	2.60	2.15

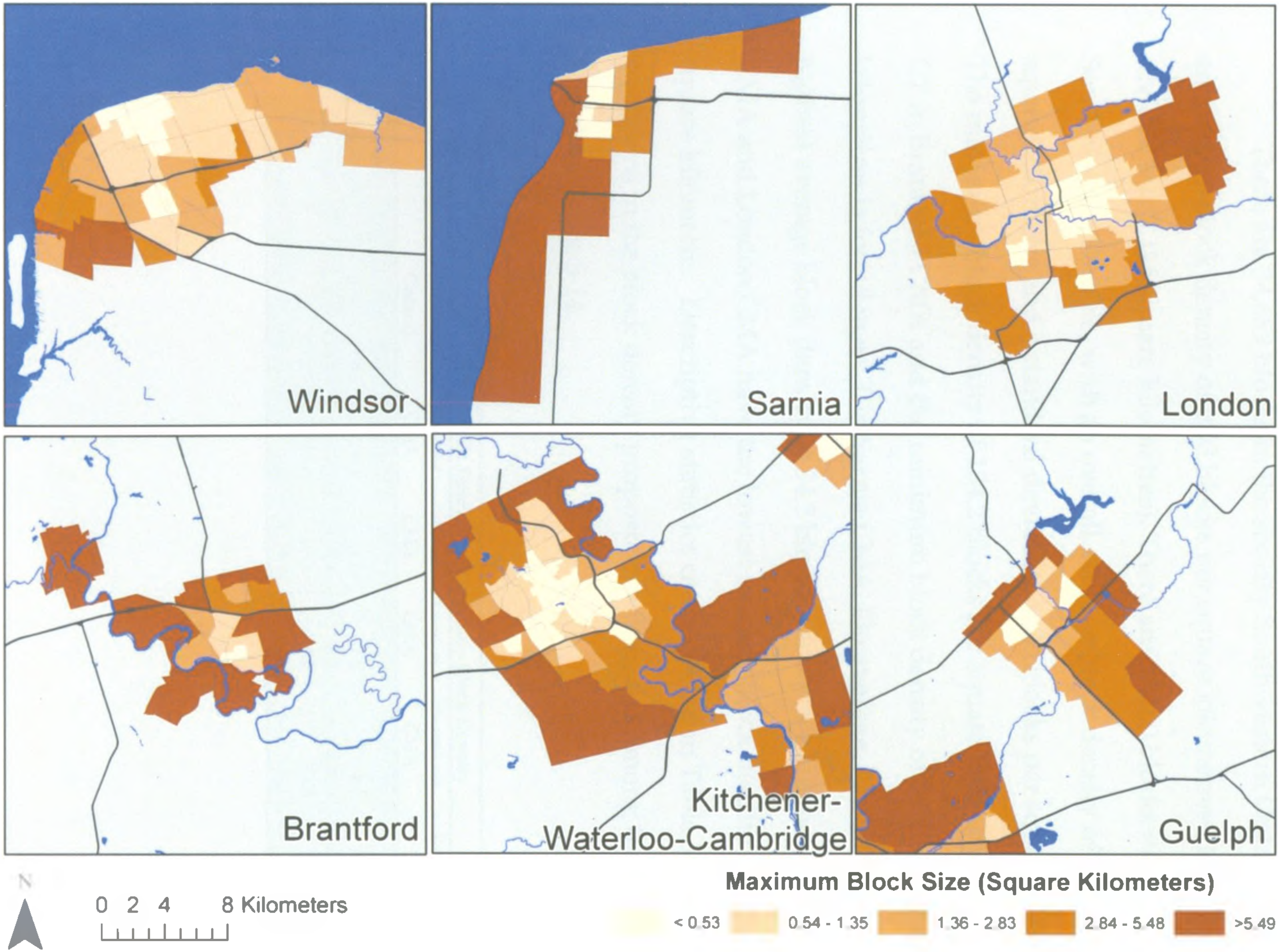


Figure 5-13: Maximum block size in Southwestern Ontario

5.7.2 Block Density

There are 34,659 blocks in the six-city Southwestern Ontario sample, with an average block density of 0.93 blocks per square kilometres (34,659 blocks divided by 37,116 square kilometres). There are 17,360 blocks in the 315 CTs in Southwestern Ontario, with an overall average block density of 27 blocks per square kilometre and a standard deviation of 20 blocks per square kilometre. The maximum block density of 134.2 blocks per square kilometre is found in a CT in Brantford CMA and the minimum block density of 1.8 blocks per square kilometres is found in a CT in Sarnia CMA. On average, Brantford CMA has the highest average block density at 34.3 blocks per square kilometre, and Sarnia CMA and London CMA have the lowest average block density at 26 blocks per square kilometre. Descriptive statistics can be found in Table 5-13, and spatial variations in the block density proportion within and among the CMAs can be found in Figure 5-14.

Table 5-13: Descriptive Statistics: Block Density

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	1.8	4.4	1.8	2.5	2.4	2.1	5.3
Maximum	134.2	92.5	68.4	78.7	134.2	107.1	86.9
Mean	27.0	33.0	26.0	26.0	34.3	26.2	24.5
Standard Deviation	20.0	19.8	18.7	14.7	32.6	20.8	19.2

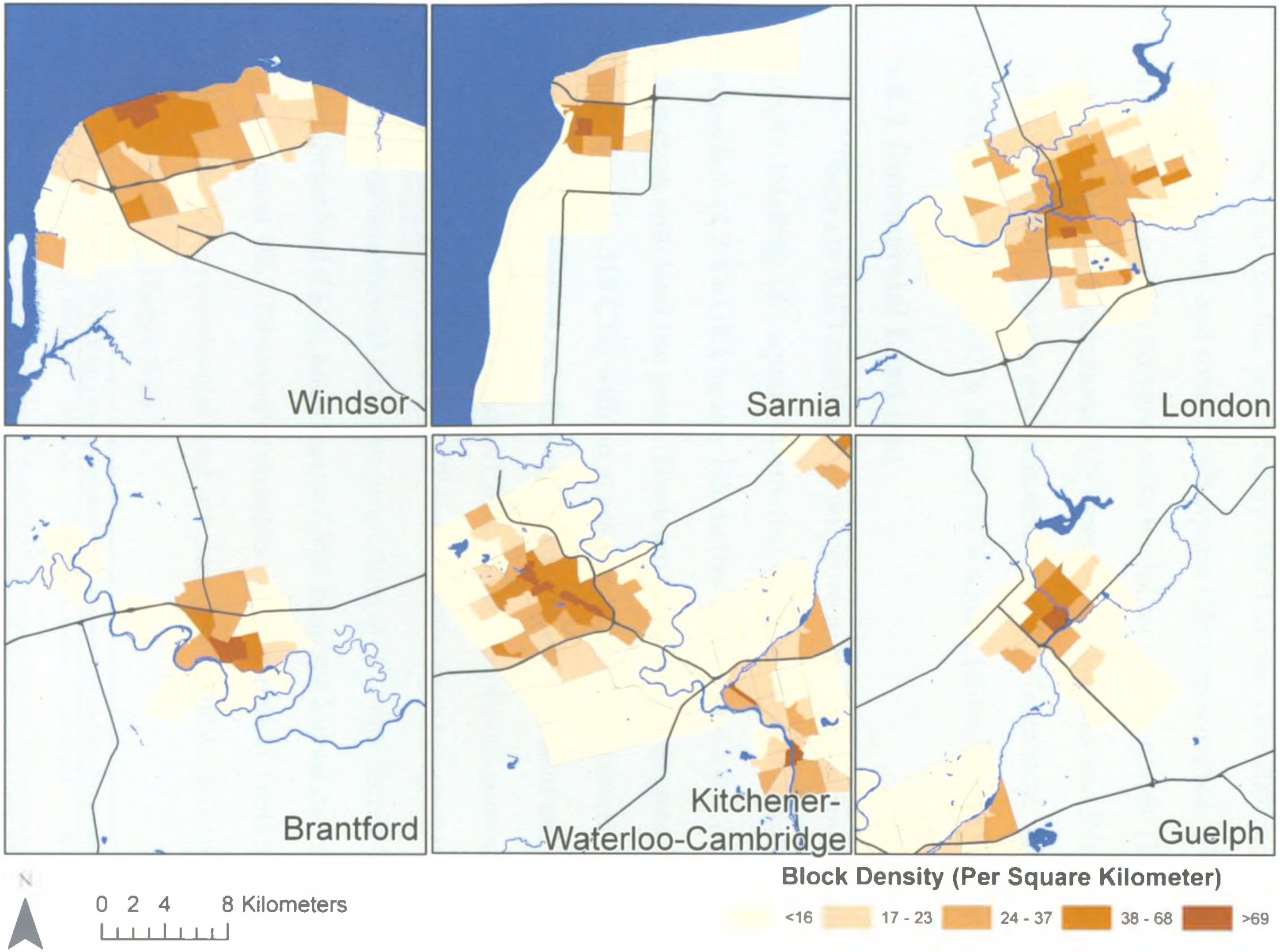


Figure 5-14: Block density in Southwestern Ontario

5.8 Southwestern Ontario Land Use

The land use file, provided by DMTI for the year 2007, contains 49,822 land use polygons and totals 7,303 square kilometres in area. The file attributes a land use code to each polygon, with the following categories: (1) Commercial, (2) Government and Institutional, (3) Open Area, (4) Parks and Recreational, (5) Residential, (6) Resource and Industrial, and (7) Waterbody. Within the 315 Southwestern Ontario CTs, there is 6276 square kilometres of land use area.

5.8.1 Commercial Land Use

There are 5,171 commercial polygons in the six-city Southwestern Ontario sample ,totalling 18.1 square kilometres, with an average commercial land use proportion of 2.4% (18.1 square kilometres commercial lots / 7,303 square kilometres total land use area). There are 23 square kilometres of commercial land use in the 315 CTs, with an average commercial proportion of 3% and a standard deviation of 3%. The maximum commercial land use proportion of 23% is found in a CT in London CMA and the minimum commercial land use proportion of 0% is found in a CT in all CMA's. On average, London CMA has the highest commercial land use proportion at 4%, and Sarnia CMA, Windsor CMA, Brantford CMA, and Guelph CMA have the lowest commercial land use proportion at 1%. Descriptive statistics can be found in Table 5-14, and spatial variations in the commercial land use proportion within and among the CMAs can be found in Figure 5-15.

Table 5-14: Descriptive Statistics: Commercial Land Use Proportion

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
CT Count	315	63	22	92	21	90	27
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.23	0.08	0.12	0.23	0.05	0.13	0.11
Mean	0.03	0.01	0.01	0.04	0.01	0.02	0.01
Standard Deviation	0.03	0.02	0.03	0.05	0.02	0.03	0.02

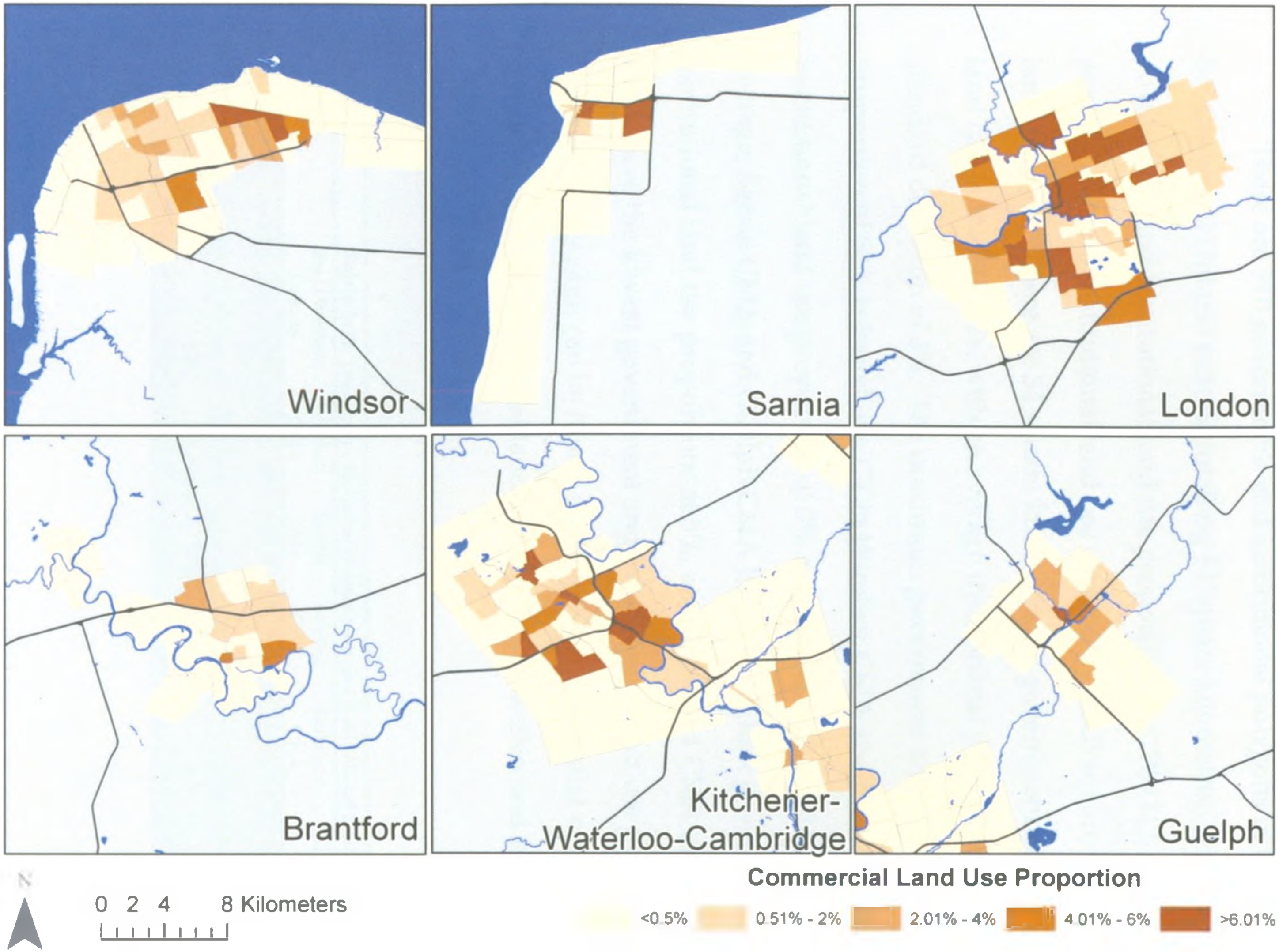


Figure 5-15: Commercial Land Use Proportion in Southwestern Ontario

5.8.2 Government and Institutional Land Use

There are 910 government and institutional polygons in the six-city Southwestern Ontario sample totalling 64 square kilometres, with an average government and institutional land use proportion of 8.7% (14.5 square kilometres government and institutional land use divided by 7,303 square kilometres total land use area). There are 54 square kilometres of government and institutional land use in the 315 CTs, with an average institutional proportion of 4% and a standard deviation of 3%. The maximum government and institutional land use proportion of 62% is found in a CT in Windsor CMA and the minimum institutional land use proportion of 0% is found in a CT in all CMA's. On average, Sarnia CMA and Guelph CMA have the highest government and institutional land use proportions at 5%, and Brantford CMA and Kitchener CMA have the lowest government and institutional land use proportions at 3%. Descriptive statistics can be found in Table 5-15, and spatial variations in the government and institutional land use proportion within and among the CMAs can be found in Figure 5-16.

Table 5-15: Descriptive Statistics: Government and Institutional Land Use

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.62	0.62	0.14	0.21	0.16	0.22	.022
Mean	0.04	0.04	0.05	0.04	0.03	0.03	0.05
Standard Deviation	0.03	0.10	0.05	0.05	0.04	0.04	0.06

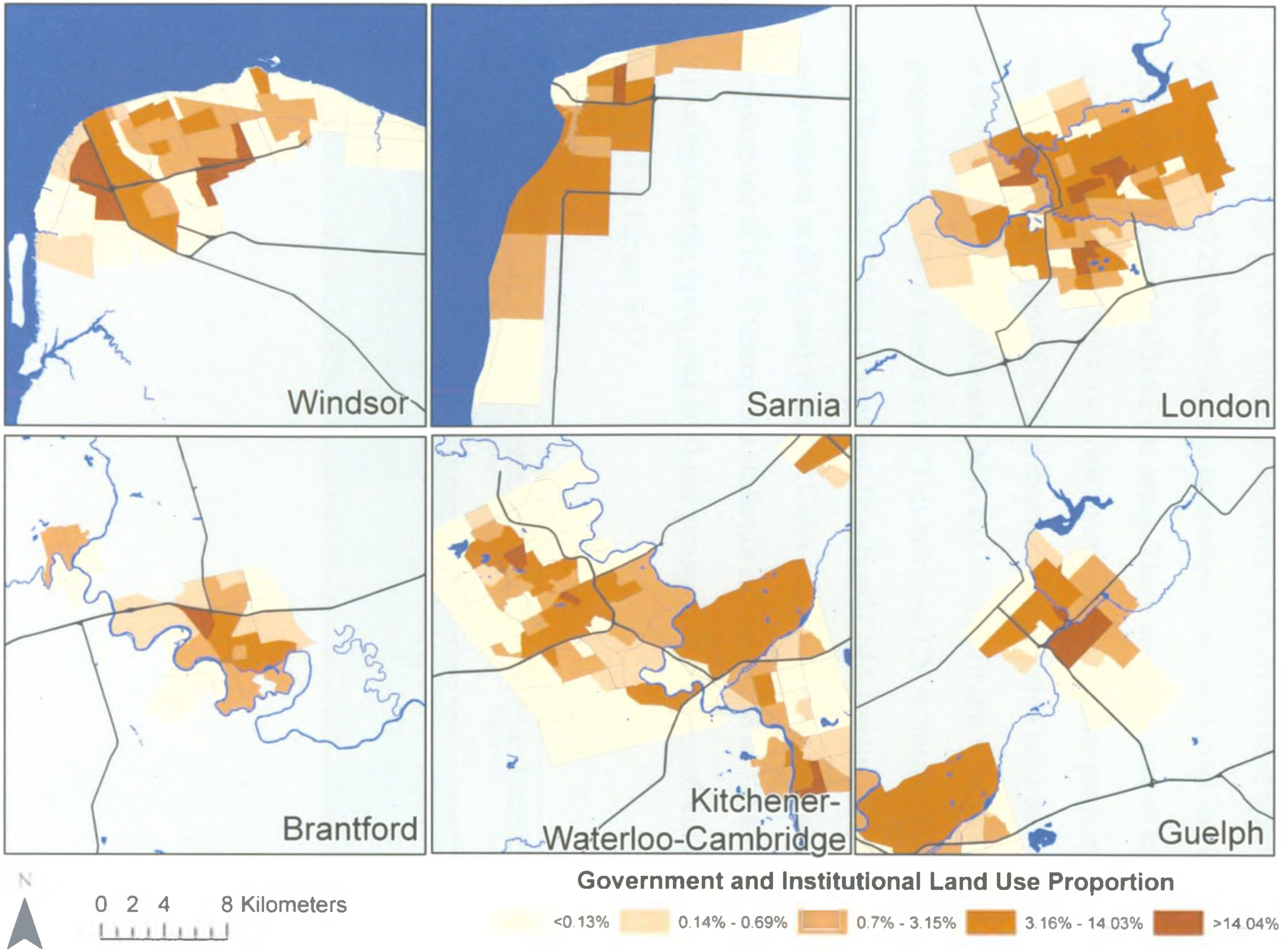


Figure 5-16: Government and Institutional Land Use

5.8.3 Open Area Land Use

There are 12,730 open area polygons in the six-city Southwestern Ontario sample, totalling 5,285 square kilometres, with an average open area land use proportion of 72% (5,285 square kilometres open area land use divided by 7,303 square kilometres total land use area). There are 1,266 square kilometres of open area land use in the 315 CTs, with an average open area proportion of 28% and a standard deviation of 28%. The maximum open area land use proportion of 94% is found in a CT in Kitchener CMA and the minimum open area land use proportion of 0% is found in a CT in Windsor CMA, Sarnia CMA, London CMA, and Brantford CMA. On average, Brantford CMA has the highest open area use proportions at 45%, and Windsor CMA has the lowest open area land use proportions at 14. Descriptive statistics can be found in Table 5-16, and spatial variations in the open area land use proportion within and among the CMAs can be found in Figure 5-17.

Table 5-16: Descriptive Statistics: Open Area Land Use Proportion

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Maximum	0.94	0.77	0.78	0.89	0.88	0.94	0.86
Mean	0.28	0.14	0.18	0.31	0.45	0.31	0.37
Standard Deviation	0.28	0.17	0.21	0.26	0.27	0.30	0.36

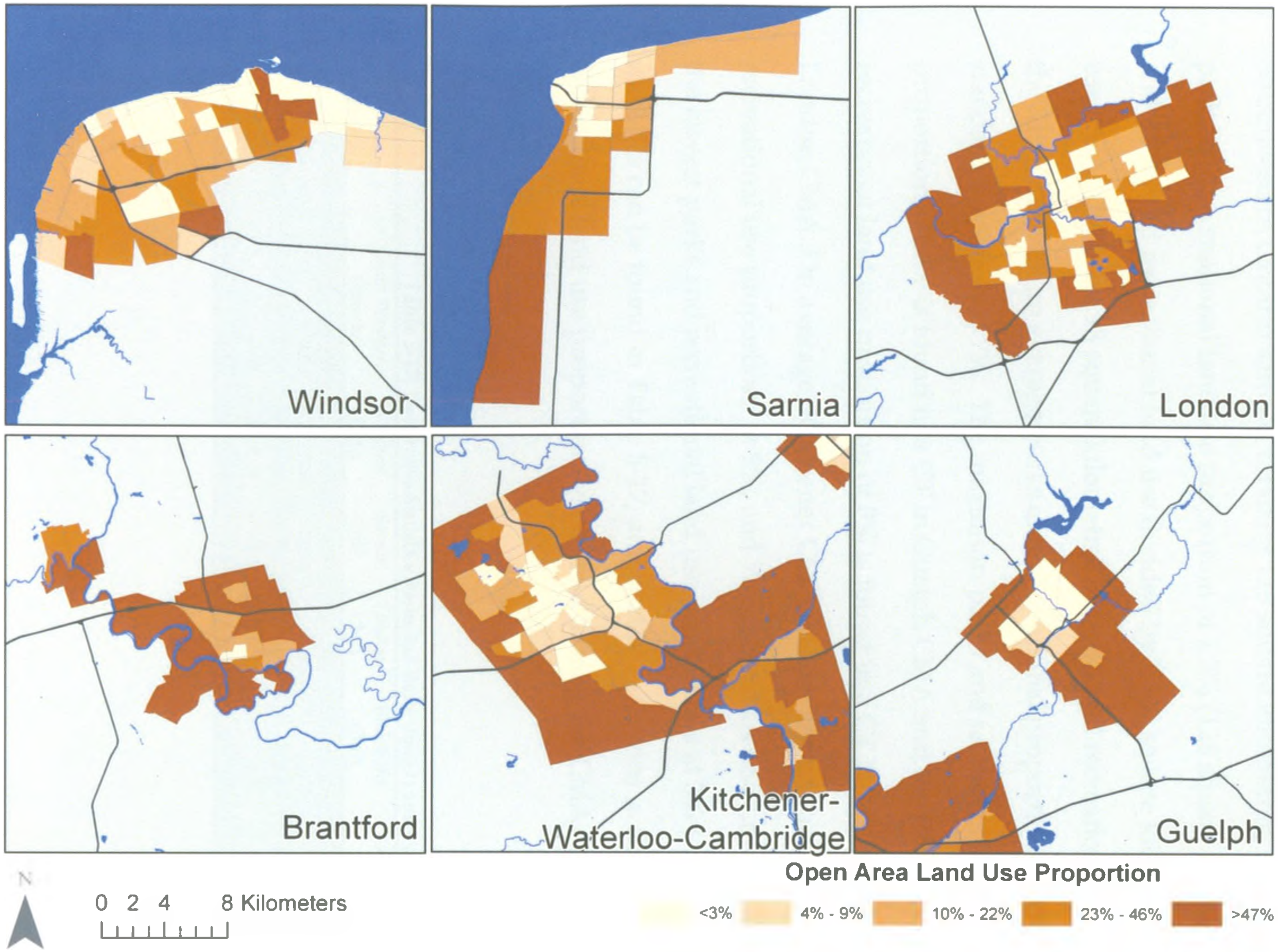


Figure 5-17: Open Area Land Use in Southwestern Ontario

5.8.4 Parks and Recreational Land Use

There are 3,716 parks and recreational polygons in the six-city Southwestern Ontario sample, totalling 126 square kilometres, with an average parks and recreational land use proportion of 1.7% (126 square kilometres parks and parks and recreational land use divided by 7,303 square kilometres total land use area). There are 98 square kilometres of parks and recreational land use in the 315 CTs, with an average parks and recreational proportion of 5% and a standard deviation of 7%. The maximum parks and recreational land use proportion of 56% is found in a CT in Guelph CMA and the minimum parks and recreational land use proportion of 0% is found in a CT in Windsor CMA and London CMA. On average, Kitchener CMA has the highest parks and recreational use proportions at 9%, and Windsor CMA and London CMA have the lowest parks and recreational land use proportions at 3% (-. Descriptive statistics can be found in Table 5-17, and spatial variations in the parks and recreational land use proportion within and among the CMAs can be found in Figure 5-17.

Table 5-17: Descriptive Statistics: Parks and Recreational Land Use

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.00	0.00	0.01	0.00	0.01	0.00	0.01
Maximum	0.56	0.24	0.22	0.20	0.09	0.35	0.56
Mean	0.05	0.03	0.04	0.03	0.04	0.09	0.08
Standard Deviation	0.07	0.04	0.05	0.04	0.02	0.09	0.11

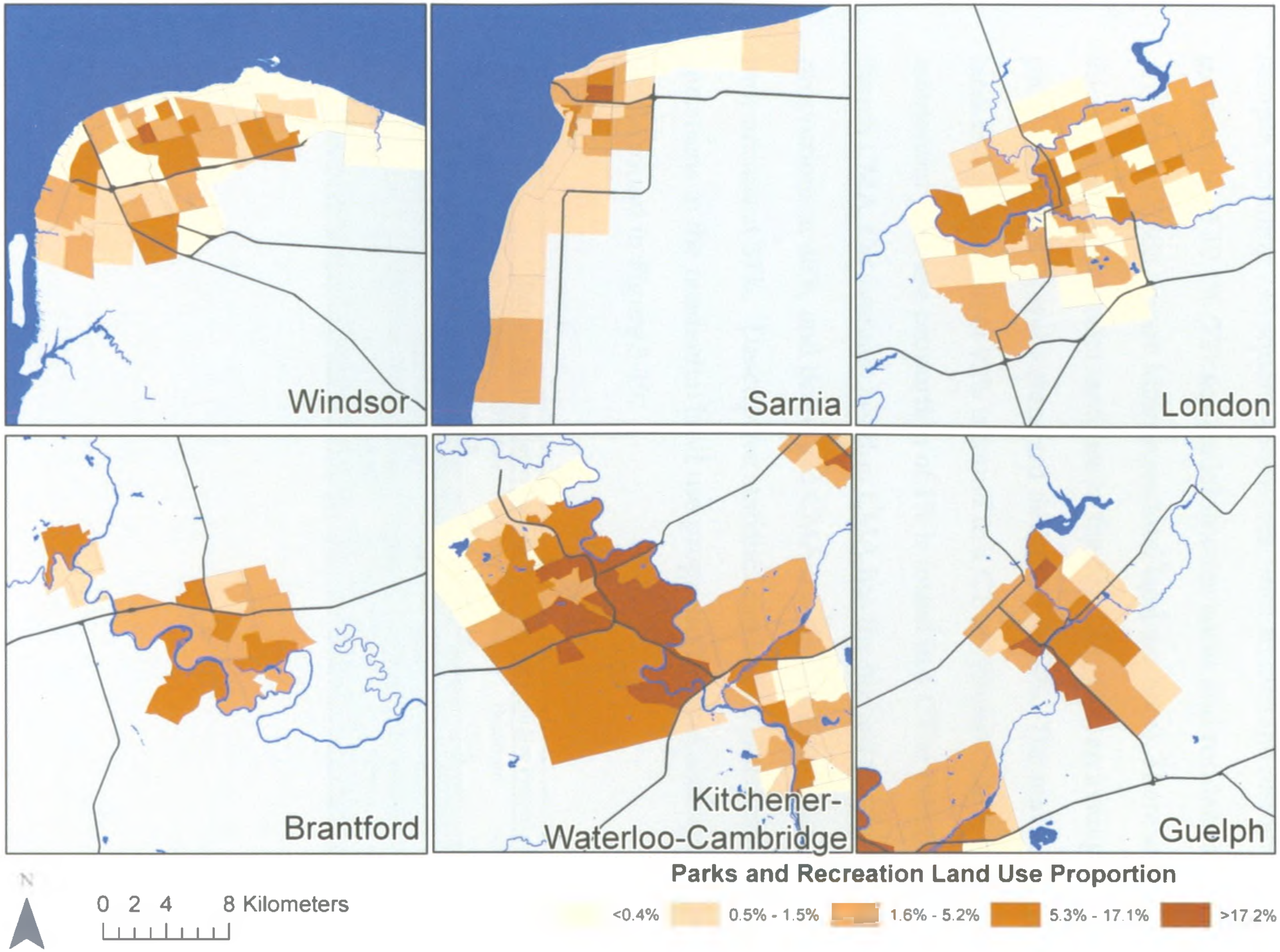


Figure 5-18: Parks and Recreational Land Use in Southwestern Ontario

5.8.5 Residential Land Use

There are 20,605 residential polygons in the six-city Southwestern Ontario sample, totalling 737 square kilometres, with an average residential land use proportion of 10.1% (737 square kilometres parks and residential land use divided by 7,303 square kilometres total land use area). There are 602 square kilometres of residential land use in the 315 CTs, with an average residential proportion of 37% and a standard deviation of 24%. The maximum residential land use proportion of 93% is found in a CT in Windsor CMA and the minimum residential land use proportion of 1% is found in a CT in Windsor CMA and Sarnia CMA. On average, London CMA has the highest residential use proportions at 46%, and Brantford CMA has the lowest residential land use proportions at 31%. Descriptive statistics can be found in Table 5-18, and spatial variations in the residential land use proportion within and among the CMAs can be found in Figure 5-19.

Table 5-18: Descriptive Statistics: Residential Land Use Proportion

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.01	0.01	0.01	0.04	0.08	0.04	0.03
Maximum	0.93	0.93	0.82	0.93	0.76	0.92	0.83
Mean	0.39	0.35	0.36	0.46	0.31	0.41	0.34
Standard Deviation	0.24	0.27	0.30	0.22	0.20	0.22	0.23

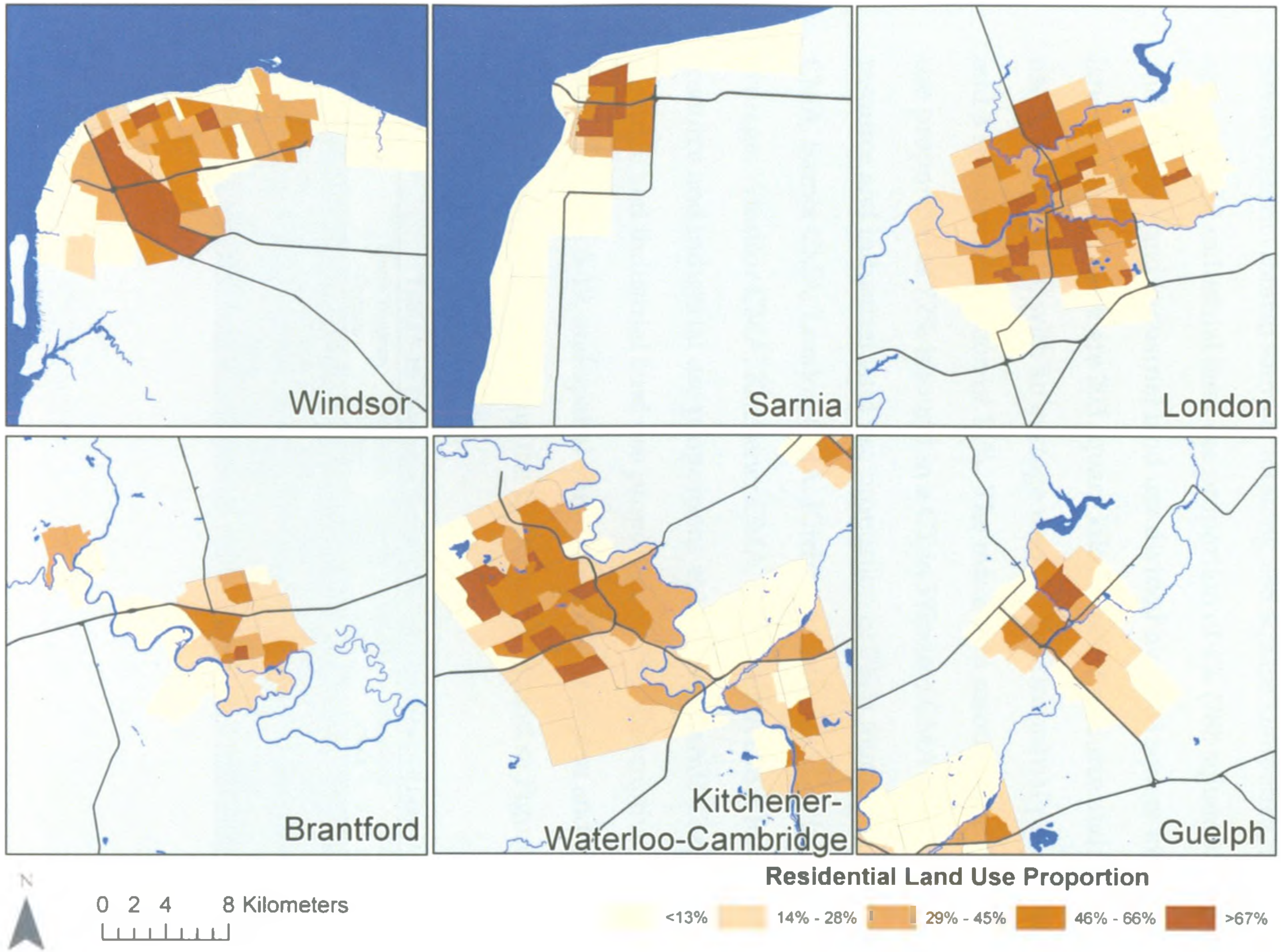


Figure 5-19- Residential Land Use in Southwestern Ontario

5.8.6 Resource and Industrial Land Use

There are 910 resource and industrial polygons in the six-city Southwestern Ontario sample, totalling 288 square kilometres, with an average resource and industrial land use proportion of 4% (288 square kilometres parks and resource and industrial land use divided by 7,303 square kilometres total land use area). There are 203 square kilometres of resource and industrial land use in the 315 CTs, with an average resource and industrial proportion of 12% and a standard deviation of 14%. The maximum resource and industrial land use proportion of 72% is found in a CT in Windsor CMA and the minimum resource and industrial land use proportion of 0% is found in a CT in Windsor CMA, Sarnia CMA, London CMA, Kitchener CMA, and Guelph CMA. On average, Windsor CMA, Kitchener CMA, and Guelph CMA have the highest resource and industrial use proportions at 13%, and Sarnia CMA has the lowest resource and industrial land use proportion at 7%. Descriptive statistics can be found in Table 5-19, and spatial variations in the resource and industrial land use proportion within and among the CMAs can be found in Figure 5-20.

Table 5-19: Descriptive Statistics: Resource and Industrial Land Use

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Maximum	0.72	0.72	0.30	0.60	0.39	0.45	0.61
Mean	0.12	0.13	0.07	0.10	0.12	0.13	0.13
Standard Deviation	0.14	0.16	0.08	0.11	0.11	0.13	0.16

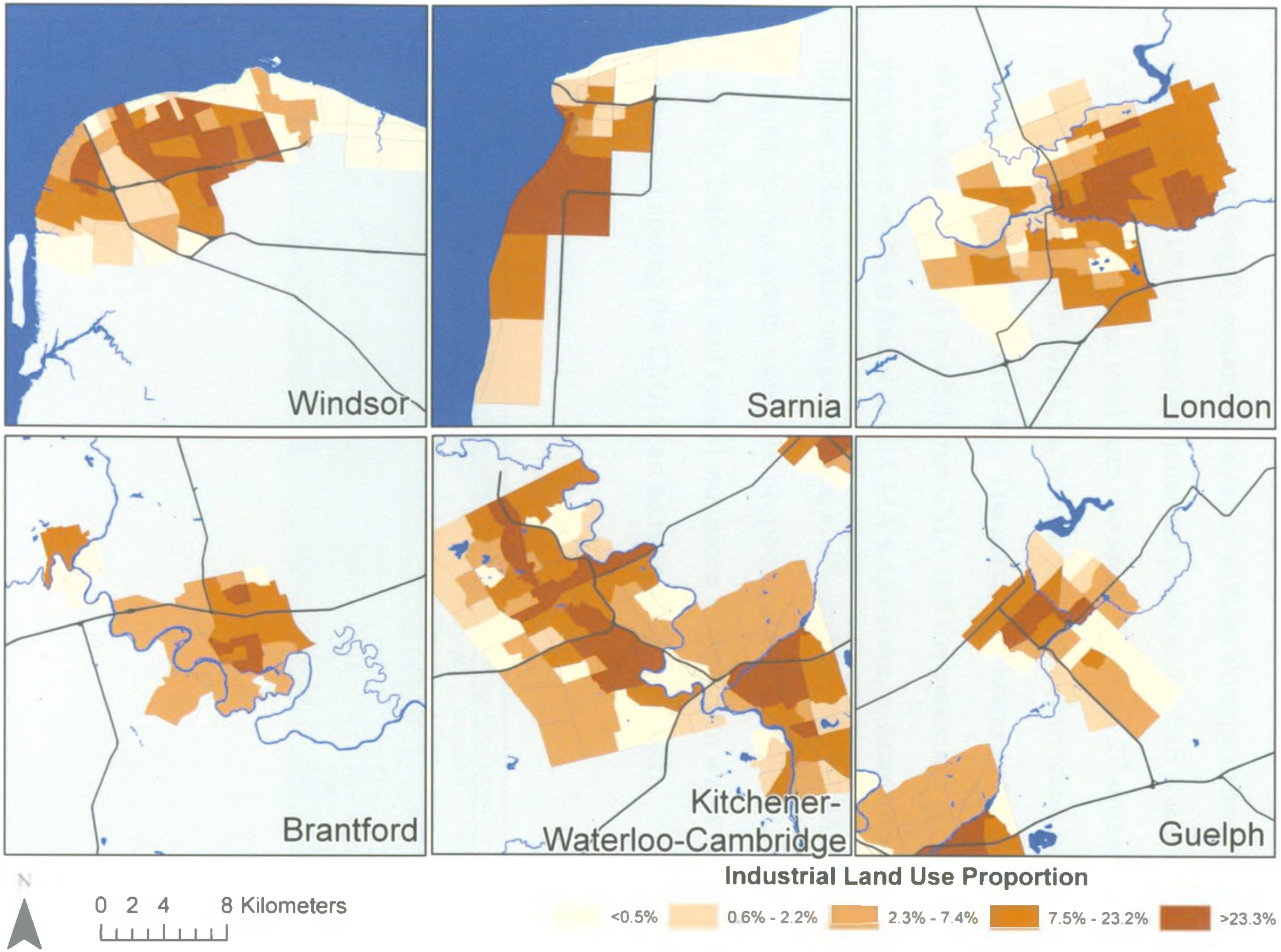


Figure 5-20: Industrial Land Use in Southwestern Ontario

5.8.7 Urban Water Land Use

There are 315 urban water polygons in the six-city Southwestern Ontario sample, totalling 71 square kilometres, with an average urban water use proportion of 1% (71 square kilometres parks and urban water use divided by 7,303 square kilometres total land use area). There are 27 square kilometres of urban water use in the 315 CTs, with an average urban water proportion of 2% and a standard deviation of 4%. The maximum urban water use proportion of 35% is found in a CT in Kitchener CMA and the minimum urban water use proportion of 0% is found in all CMA's. On average, Brantford CMA has the highest urban water use proportion at 4%, and Windsor CMA and Sarnia CMA have the lowest urban water use proportions at 1%. Descriptive statistics can be found in Table 5-20, and spatial variations in the urban water use proportion within and among the CMAs can be found in Figure 5-21.

Table 5-20: Descriptive Statistics: Urban Water Use Proportion

	South Western Ontario	Windsor CMA	Sarnia CMA	London CMA	Brantford CMA	Kitchener CMA	Guelph CMA
Count	315	63	22	92	21	90	27
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.35	0.03	0.05	0.24	0.25	0.35	0.22
Mean	0.02	0.01	0.01	0.03	0.04	0.03	0.03
Standard Deviation	0.04	0.01	0.01	0.05	0.06	0.06	0.04

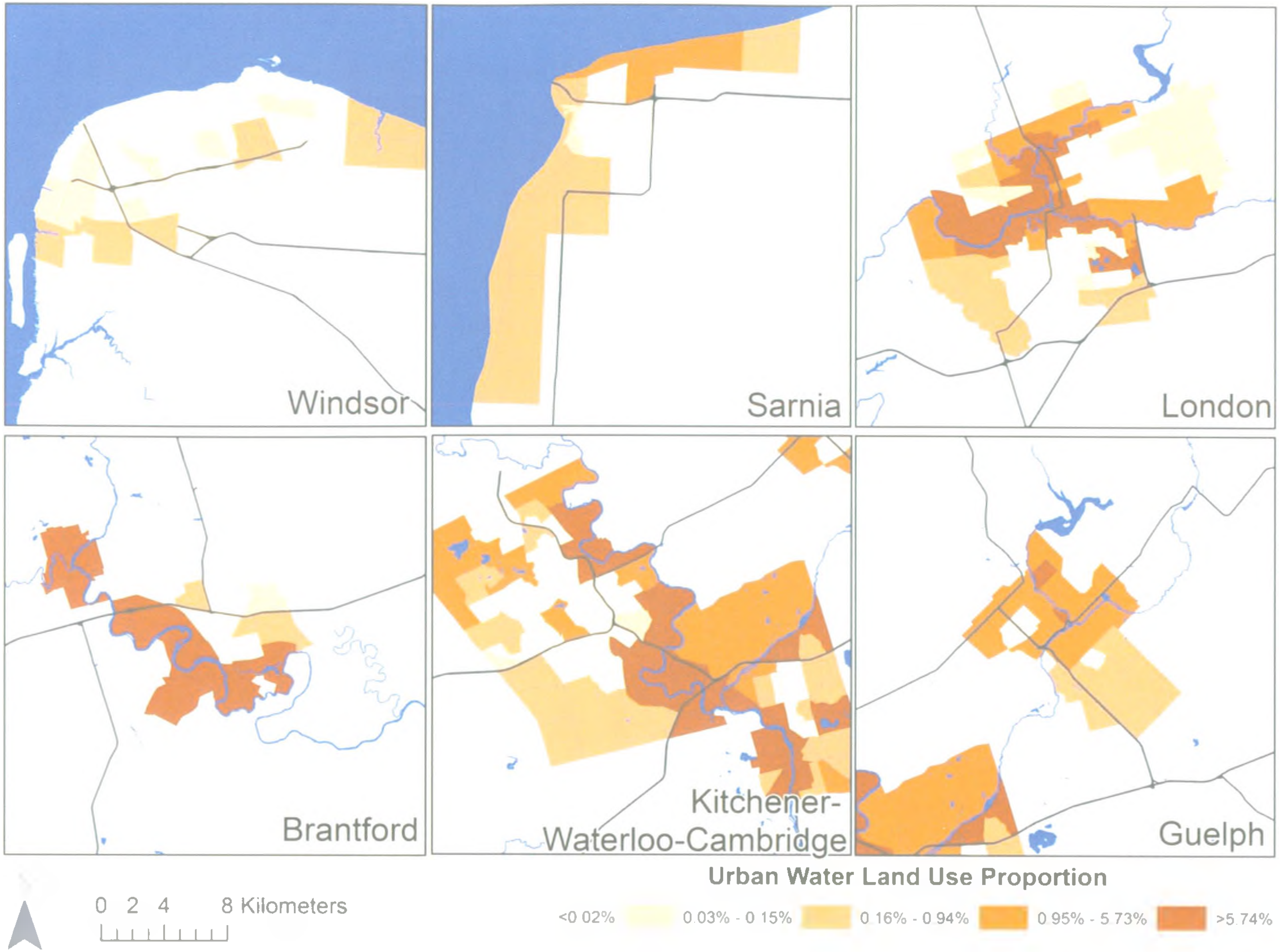


Figure 5-21: Urban Water Land Use Proportion in Southwestern Ontario

5.9 Southwestern Ontario Statistical Analysis

A Spearman's rank correlation coefficient was conducted on all variables in the six-city Southwestern Ontario sample. The mechanics of this statistical analysis are described in detail in the methods section.

5.9.1 Spearman's rank correlation coefficient

The Spearman's rank correlation coefficient, as described in detail in the methods section, is a non-parametric measure of statistical dependence between two variables. It assesses how well the relationship between two variables can be described using a monotonic function. A perfect Spearman correlation of +1 or −1 occurs when each variable is a perfect monotone function of the other.

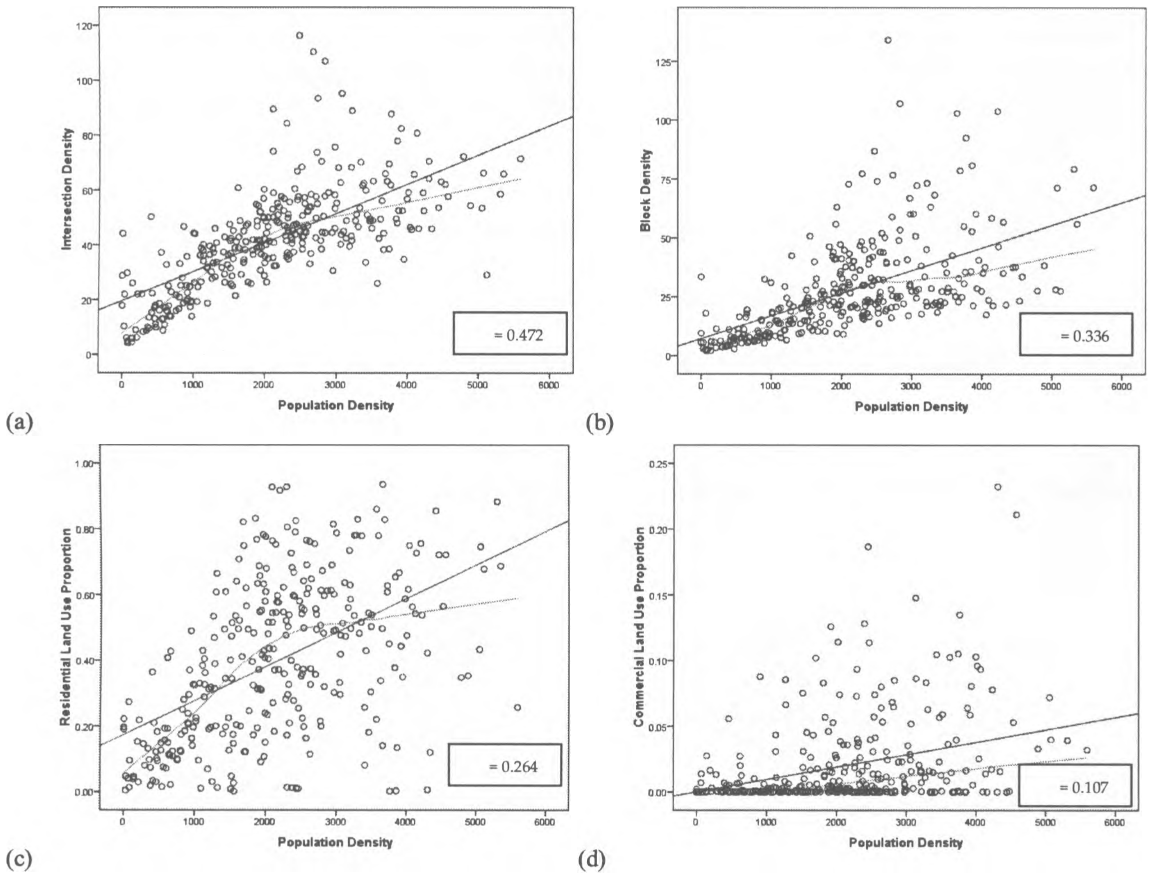
The three independent variables of this study, population density, median household income, and era of development, were found to be significantly correlated with many performance indicators. The following chart (Table 5-21) shows how independent variable ranked agents each performance indicator.

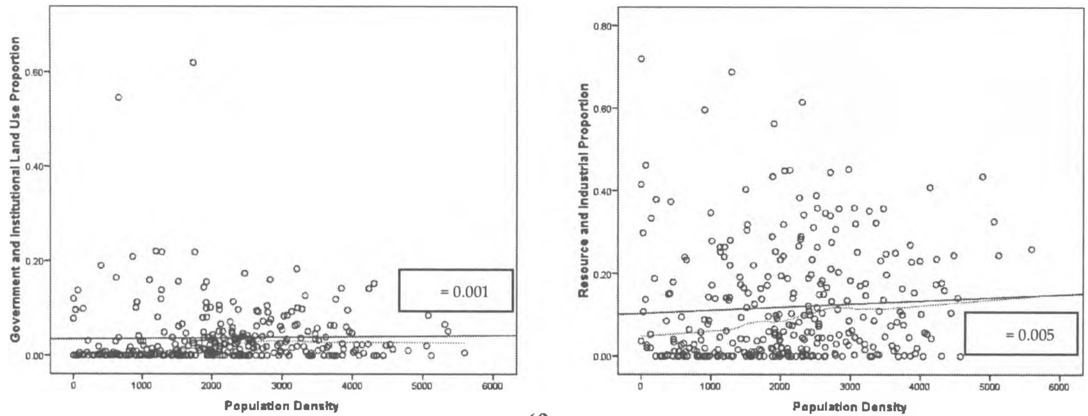
Table 5-21: Spearman's correlation coefficients

		Population Density	Median Household Income	Major Era of Development
Population Density	Correlation Coefficient		-.275**	-.162**
	Sig. (2-tailed)		0	0.004
	N		315	315
Median Household Income	Correlation Coefficient	-.275**		.577**
	Sig. (2-tailed)	0		0
	N	315		315
Major Era of Development	Correlation Coefficient	-.162**	0.577**	
	Sig. (2-tailed)	0.004	0	
	N	315	315	
Intersection Density	Correlation Coefficient	.758**	-.330**	-.332**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Cul-de-sac Proportion	Correlation Coefficient	-.209**	-0.033	0.087
	Sig. (2-tailed)	0	0.561	0.124
	N	315	315	315
T intersection Proportion	Correlation Coefficient	0.053	.434**	.412**
	Sig. (2-tailed)	0.349	0	0
	N	315	315	315
X Intersection Proportion	Correlation Coefficient	.124*	-.483**	-.501**
	Sig. (2-tailed)	0.028	0	0
	N	315	315	315
Average Street Segment Length	Correlation Coefficient	-.400**	.452**	.629**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Maximum Street Segment Length	Correlation Coefficient	-.529**	.522**	.550**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Arterial Street Proportion	Correlation Coefficient	-.133*	-.349**	-.171**
	Sig. (2-tailed)	0.018	0	0.002
	N	315	315	315
Average Block Area	Correlation Coefficient	-.547**	.513**	.614**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Maximum Block Area	Correlation Coefficient	-.557**	.470**	.478**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Block Density	Correlation Coefficient	.698**	-.520**	-.590**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Residential Land Use Proportion	Correlation Coefficient	.536**	-.136*	-.194**
	Sig. (2-tailed)	0	0.015	0.001
	N	315	315	315
Commercial Land Use Proportion	Correlation Coefficient	.327**	-.426**	-.269**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Government and Institutional Land Use Proportion	Correlation Coefficient	.208**	-.402**	-.385**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Open Area Land Use Proportion	Correlation Coefficient	-.460**	.377**	.408**
	Sig. (2-tailed)	0	0	0
	N	315	315	315
Parks and Recreational Land Use Proportion	Correlation Coefficient	0.003	-0.09	-.125*
	Sig. (2-tailed)	0.951	0.112	0.027
	N	315	315	315
Resource and Industrial Land Use Proportion	Correlation Coefficient	.163**	-.546**	-.380**
	Sig. (2-tailed)	0.004	0	0
	N	315	315	315
Urban Water Proportion	Correlation Coefficient	-.431**	.147**	-.015
	Sig. (2-tailed)	0	0.009	0.791
	N	315	315	315

5.9.1.1 Population Density

Population Density is significantly positively correlated with the variables intersection density (0.758), block density (0.698), residential land use proportion (0.536), commercial land use proportion (0.327), government and institutional land use proportion (0.208), and resource and industrial land use proportion (0.163). Scatter plots of these positive correlations are shown in Figure 5-22.

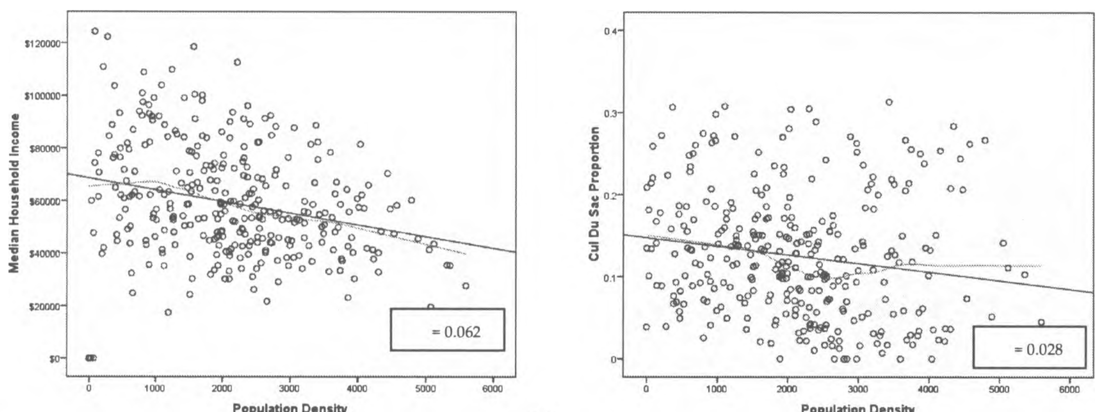




(e) (f)

Figure 5-22: Scatter plots of Population Density and Positive Correlations
(a) intersection density, (b) block density, (c) residential land use proportion, (d) commercial land use proportion, (e) government and intuitional land use proportion, and (f) resource and industrial land use proportion, showing linear fit line with r square value and loess fit line.

Population Density is significantly negatively correlated with the variables median household income (-0.275), era of construction (-0.162), cul-de-sac proportion (-0.209), average and maximum street length (-0.400, -0.529), average and maximum block area (-0.547, -0.557), open area land use proportion (-0.460), and urban water land use proportion. Scatter plots of these negative correlations are shown in Figure 5-23.



(a) (b)

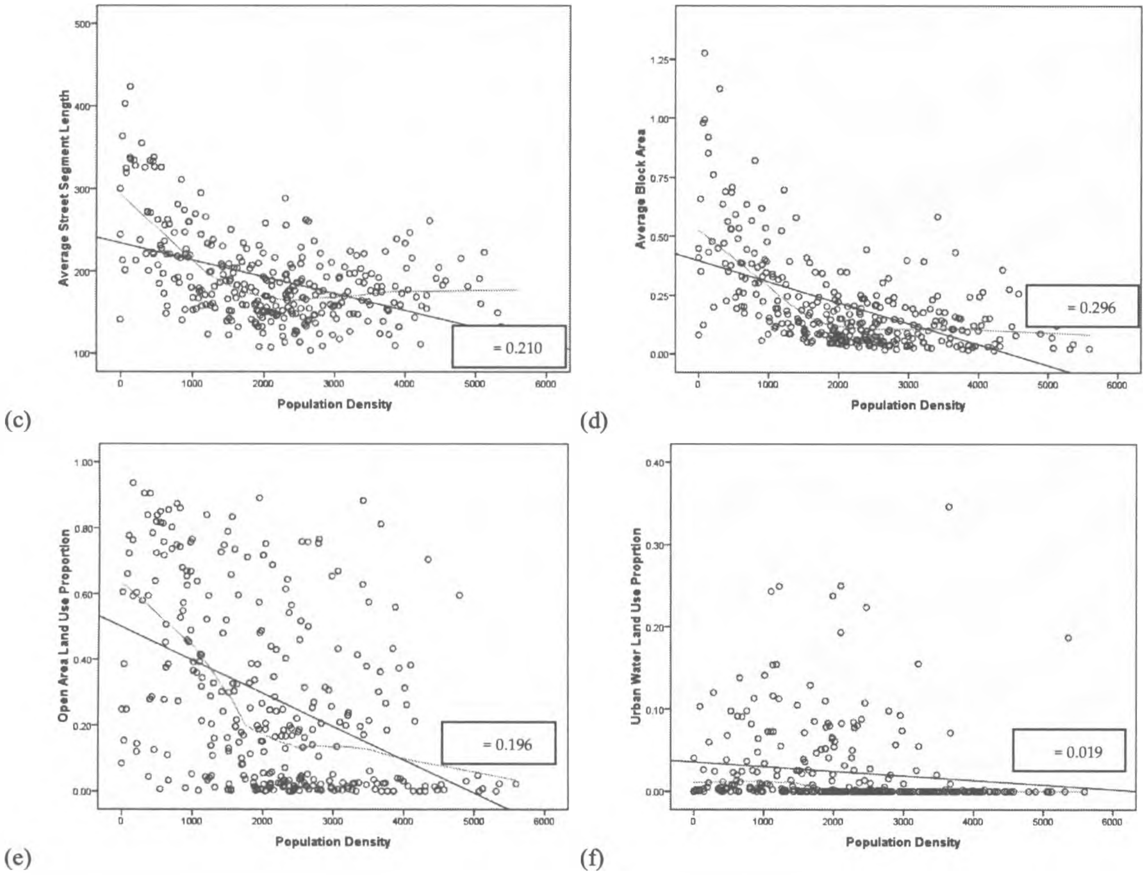


Figure 5-23: Scatter plots of Population Density and Negative Correlations
(a) median household income, (b) cul-de-sac proportion, (c) average street segment length, (d) average block area, (e) open area land use proportion, and (f) urban water land use proportion, showing linear fit line with r square value and loess fit line.

5.9.1.2 Median Household Income

Median Household Income is significantly positively correlated with the variables major era of construction (0.577), T-intersection proportion (0.434), average and maximum street segment length (0.452, 0.522), average and maximum block area (0.513, 0.470), and open area land use proportion (0.377). Scatter plots of these positive correlations are shown in Figure 5-24.

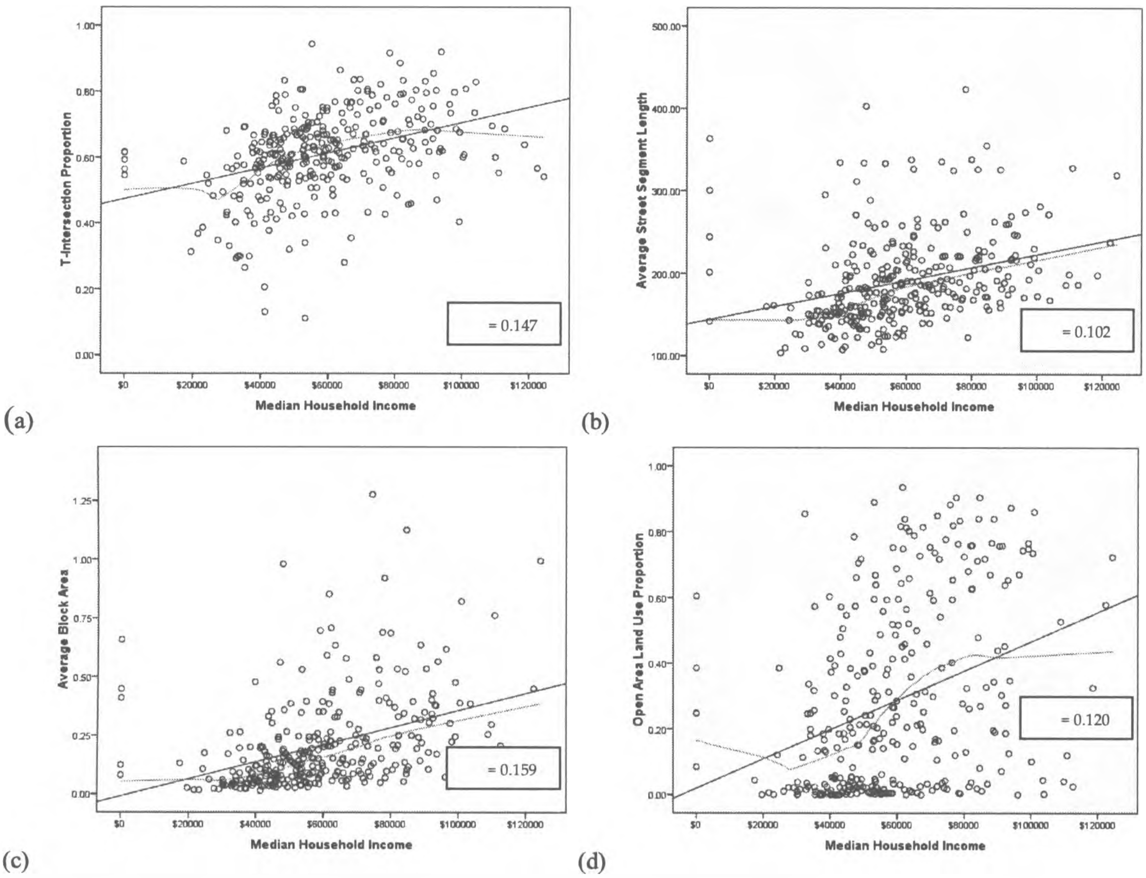
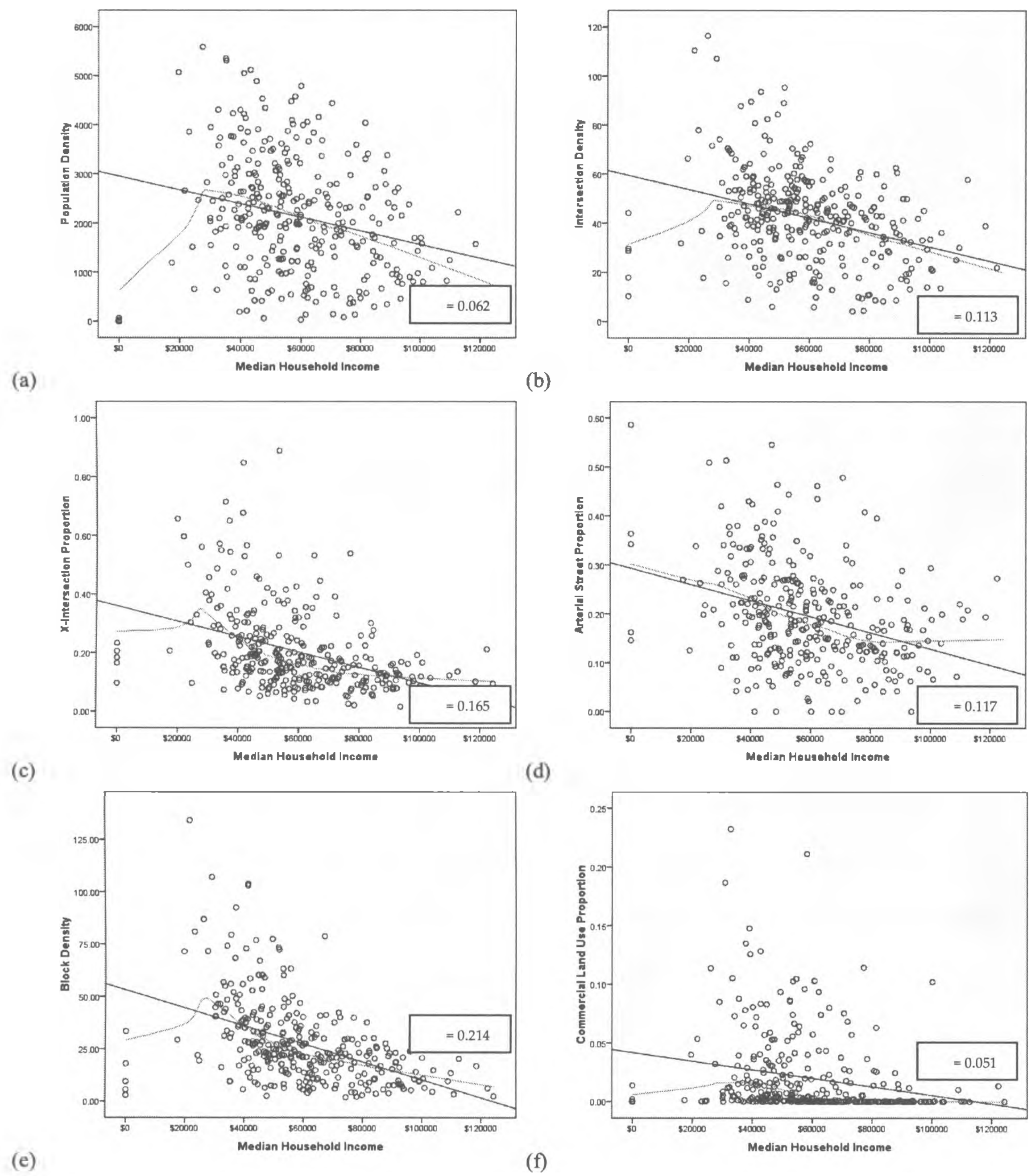
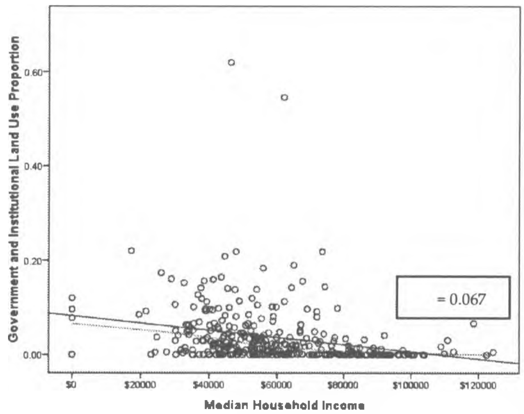


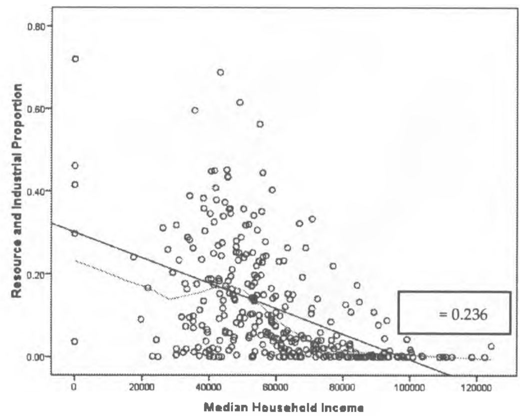
Figure 5-24: Scatter plot of Household Income and Positive Correlations
(a) T-intersection proportion, (b) average street segment length, (c) average block area, and (d) open area land use proportion, showing linear fit line with r square value and loess fit line.

Median Household Income is significantly negatively correlated with the variables population density (-0.275), intersection density (0.330), X-intersection proportion (-0.483), arterial street proportion (-0.349), block density (-0.520), commercial land use proportion (-0.426), government and institutional land use proportion (0.402), and resource and industrial land use proportion (-0.546). Scatter plots of these negative correlations are shown in Figure 5-25.


Population Density
Median Household Income
= 0.062
(a)
Intersection Density
Median Household Income
= 0.113
(b)
X-Intersection Proportion
Median Household Income
= 0.165
(c)
Arterial Street Proportion
Median Household Income
= 0.117
(d)
Block Density
Median Household Income
= 0.214
(e)
Commercial Land Use Proportion
Median Household Income
= 0.051
(f)



(g)



(h)

Figure 5-25: Scatter plot of Household Income and Negative Correlations
(a) population density, (b) intersection density, (c) X-intersection ratio, (d) arterial street proportion, (e) block density, (f) commercial land use proportion, (g) government and institutional land use proportion, and (h) resource and industrial land use proportion, showing linear fit line with r square value and loess fit line.

5.9.1.3 Major Era of Development

Major era of development is significantly positively correlated with the variables median household income (0.577), T-intersection proportion (0.412), average and maximum street segment length (0.629, 0.550), average and maximum block area (0.614, 0.478), and open area land use proportion (0.408). Line graphs of these positive correlations can be found in Figure 5-26.

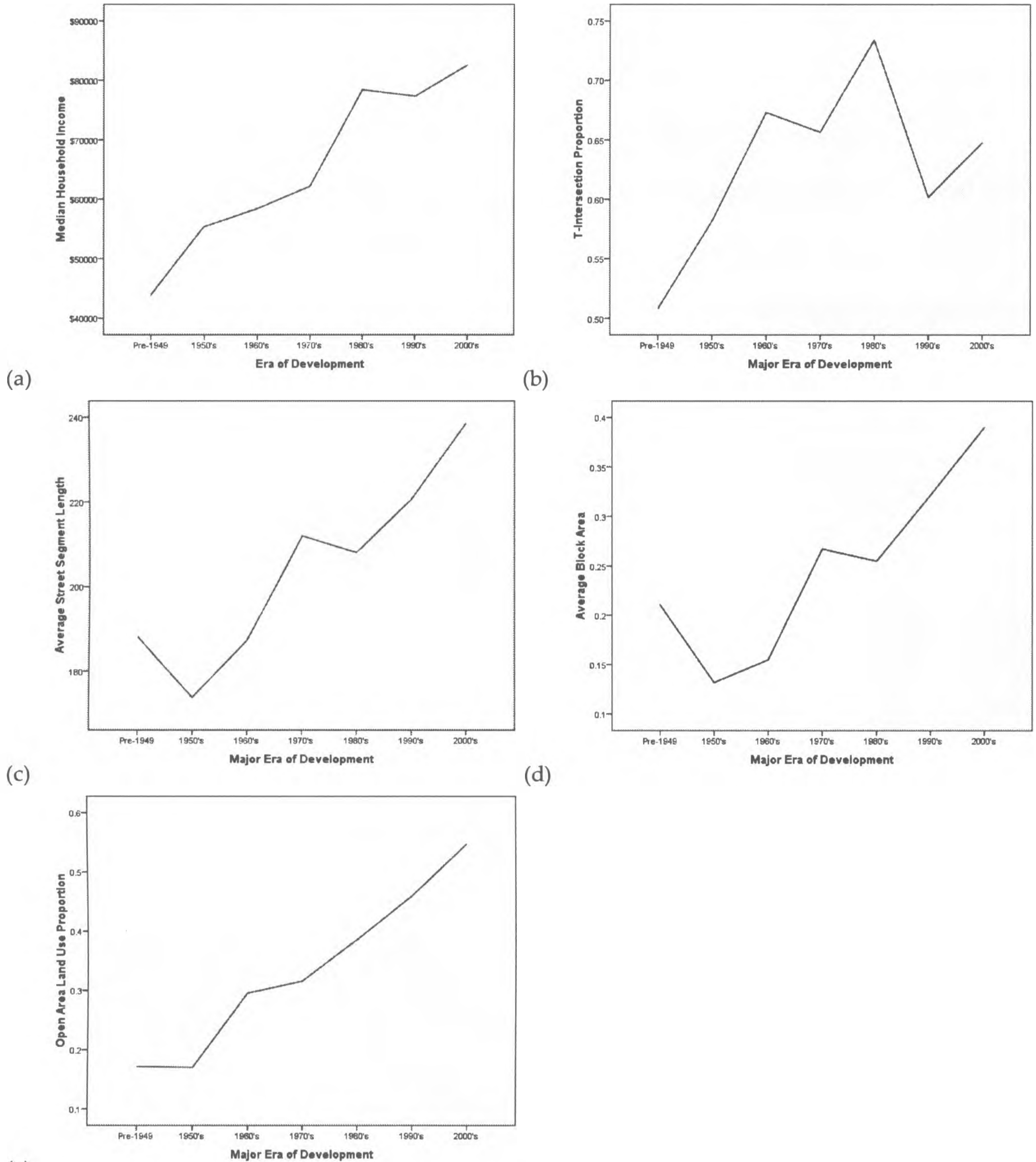
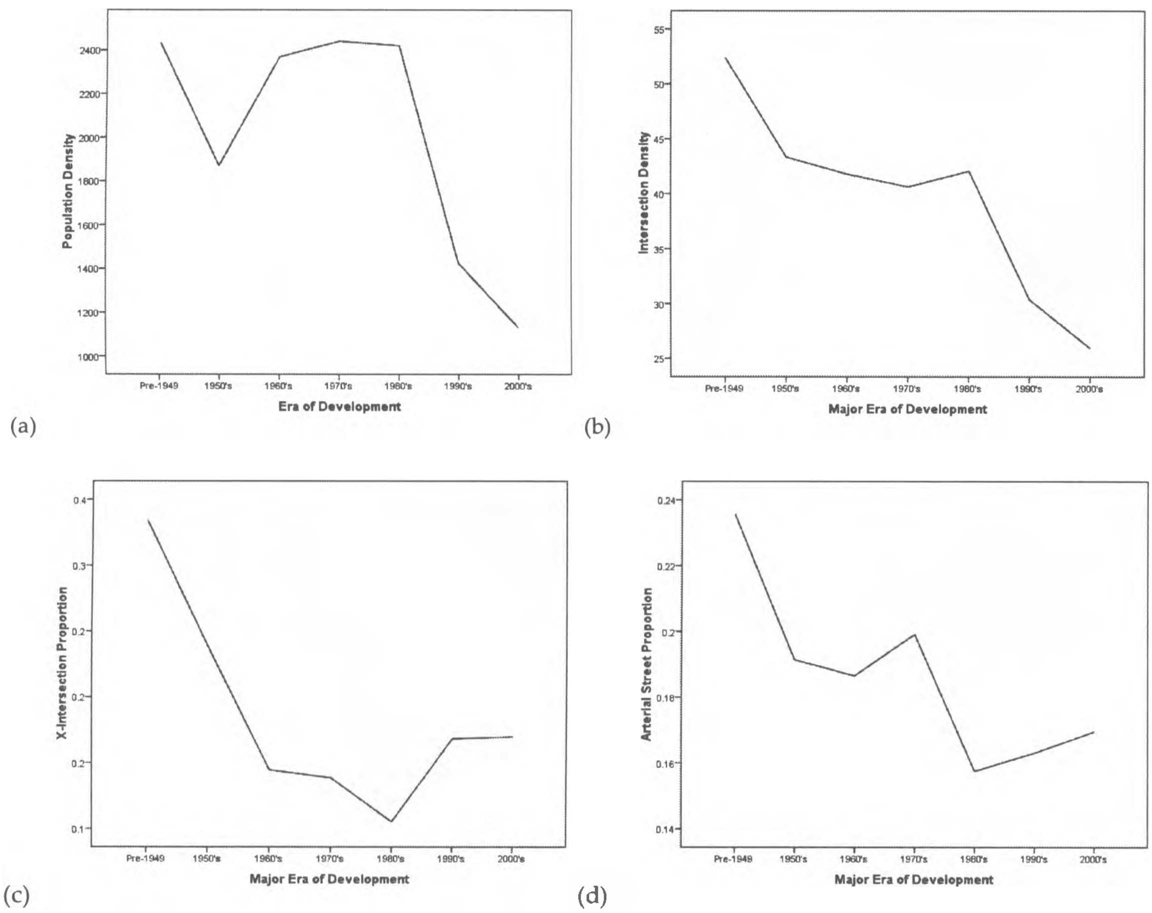


Figure 5-26: Line graph of Era of Development and Positives Correlations
(a) median household income, (b) T-intersection ratio, (c) average street segment length, (d) average block area, and (e) open area land use proportion.

Major era of development is significantly negatively correlated with the variables population density (-0.162), intersection density (-0.332), X-intersection proportion (-0.501), arterial street proportion (-0.171), block density (-0.590), residential land use proportion (-0.194), commercial land use proportion (-0.269), government and institutional land use proportion (-0.385), and resource and industrial land use proportion (-0.380). Line graphs of these negative correlations can be found in Figure 5-26.



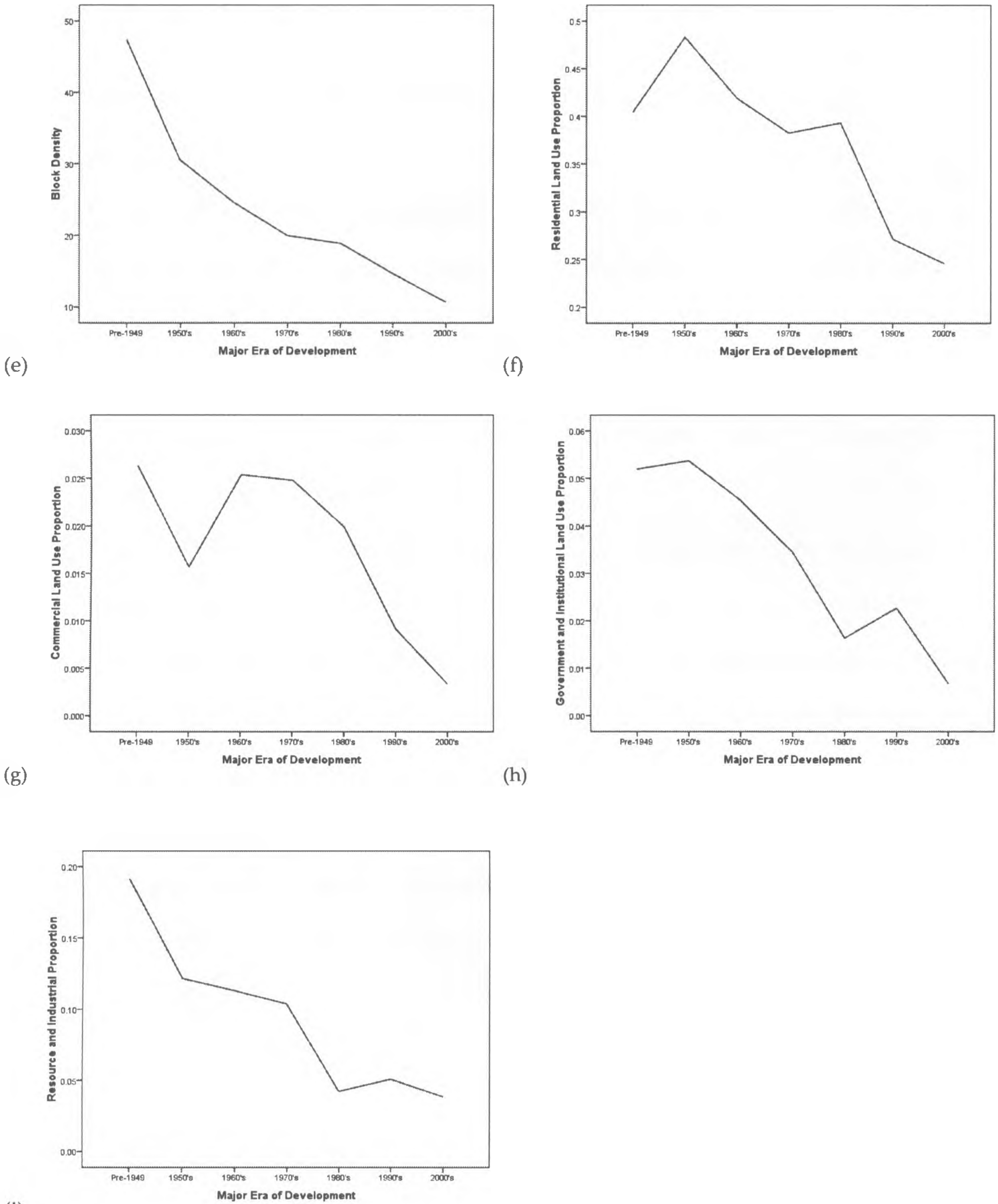


Figure 5-27: Line graph of Era of Development and Negative Correlations
(a) population density, (b) intersection density, (c) X-intersection proportion, (d) arterial street proportion, (e) block density, (f) residential land use proportion, (g) commercial land use proportion, (h) government and institutional land use proportion, and (i) resource and industrial land use proportion.

5.10 Conclusions

This chapter provided a detailed examination of the urban form of Southwestern Ontario Census Metropolitan Areas (CMA's), using the quantitative methodology outlined in Chapter 3. To analyze the built form of individual neighbourhoods, the CMAs were divided into 315 Census Tracts (CTs). For each CT, a comprehensive set of performance indicators was derived to describe, analyze, and compare the morphological characteristics of streets, blocks, and land uses. Findings regarding the similarities and differences in the morphology of neighbourhoods within and between cities were identified by presenting the values for each performance indicator in a series of maps and descriptive statistics. Relationships among all variables were then evaluated using Spearman's rank correlation. In addition, findings were reported for any statistically significant relationships between a morphological variable and any key non-morphological variable of interest, including: historical timing of neighbourhood development; median household incomes of neighbourhood residents; and neighbourhood population density. The upcoming chapter provides a detailed discussion of these findings in conjunction with the findings from Chapter 5.

CHAPTER 6 DISCUSSIONS AND CONCLUSIONS

6.1 Introduction

The current chapter discusses the key findings resulting from the analyses presented in the previous chapters. The first section discusses the spatial patterns of morphological variables and the statistical relationships between individual variables. The second section follows with a discussion of the results of the analyses with the three important social and historical variables, including their spatial distributions, descriptive statistics, and significant correlations with other variables. This discussion chapter provides the necessary information for answering the key research questions outlined in Chapter 1. Significant contributions will be discussed, as will limitations of the study. Significant conclusions will be discussed in detail, followed by closing comments.

It was assumed at the outset of this study that many of the morphological variables would be highly correlated with each other; however, to the author's knowledge, these correlations have never been thoroughly identified or quantified before. For example, it is known that block size and intersection density should be highly correlated, as smaller blocks correspond to a greater density of intersections. The fact that this thesis confirms this prior knowledge not only proves validity to other previously unknown correlations in this study, but provides future researchers with proxy variables in studies where a particular variable is not available.

6.2 Patterns of Morphological Variables

Based on a careful examination of the entire series of maps in Chapters 5 and 6, which show how the values for each morphological variable are spatially distributed within each case study CMA, it appears that all variables fall into one of three groups. Hereafter, the discussion will be organized according to these three variables rather than as isolated individual variables. Individual variables will be grouped based on similar spatial patterns and discussed in these groups. As the spatial extent of cities is typically representative of the historical timing of development (i.e., cores of cities were built in early-nineteenth century and the peripheries constructed in present times), the significant spatial patterns of variables are also significantly correlated with historical era of development. Figure 6-1 displays a schematic of each group. The schematic graphically displays intra-urban patterns of each performance indicator, or how the generated values of individual variables in each group similarly increase or decrease over the spatial extent of each of the Southwestern Ontario CMAs. Two of the three groups are divided into two sub-groups, each showing the reverse/opposite pattern to the other. Below each schematic in Figure 6-1 is a list of variables which fall in the corresponding group. Within each sub-group, variables are significantly positively correlated with each other, significantly negatively correlated with variables in the opposite subgroup, and are not significantly correlated with variables in other main groups.

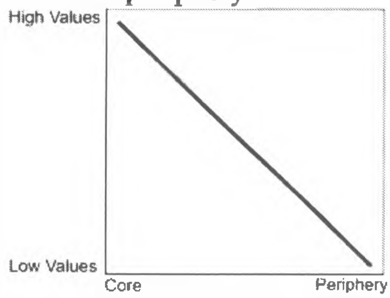
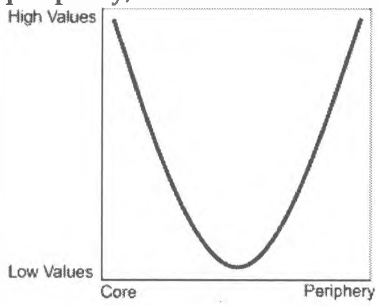
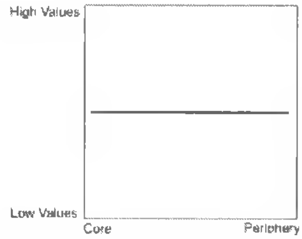
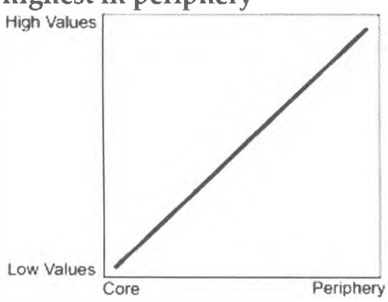
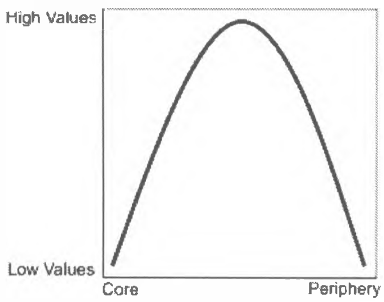
A- Direct Core-Periphery Spatial Patterns	B- Core- Older Suburbs -Periphery Spatial Patterns	C- Random Spatial Patterns
A(i) Highest values in core, lowest in periphery  Intersection Density X-Intersection Proportion Street Area Density Sidewalk to Street Proportion Median Connectivity Local Integration Block Density Building Coverage Proportion	**B(i) Highest values in core and periphery, lowest in older suburbs**  Street Width Arterial Street Proportion Proportion of Undeveloped Lots Lot Frontage Average Building Footprint Size Distance Between Buildings Commercial Land Use Retail Land Use Industrial Land Use	 Pathway to Road Proportion Irregular Angled-Intersections Building to Block Proportion Recreational Land Use Park Area Urban Water Area Institutional Land Use
A(ii) Lowest values in core, highest in periphery  Cul-de-sac Proportion Street Segment Length Global Integration Block Size Lot Size Lots per Block Building Setback	**B(ii) Lowest values in core and periphery, highest in older suburbs**  T-Intersection Proportion Lot Density Building Density Residential Building Density Residential Building Proportion Buildings to Lot Proportion Residential Land Use Single Family Land Use	

Figure 6-1: Schematic of general spatial patterns, showing trend of performance indicator over space; A(i) displays variables which have high values in the core of the city and low values in the periphery; A(ii) displays variables which ha low values in the core of the city and high values in the periphery; B(i) displays variables which have high values in the core and periphery of the city and low values in older suburbs; B(ii) displays variables which have low values in the core and periphery of the city and high values in older suburbs; C displays variables which have no spatial pattern.

6.2.1 Direct Core-Periphery Spatial Patterns

The first group of variables (a) has one extreme (the highest or lowest values) in the centre of the city, and the opposite extreme in the periphery of the city. The area between the core and the periphery shows a gradual and mostly-uninterrupted shift from one extreme to the other. Variables which fall into this pattern and have high values in the city's core are shown in Figure 6-1 a(i), while variables which fall into this pattern and have low values in the cities core are shown in Figure 6-1 a(ii). These two patterns are inverses of each other, with variables in column a(i) being highly positively correlated with each other, and highly negatively correlated with all variables in group a(ii).

6.2.1.1 Highest values in core, lowest in periphery

The first set of variables in this category include those variables which have their highest values in the core and decline steadily towards the periphery of the city, where they reach their lowest values (see Figure 6-1 a(i)). This group of variables includes intersection density, X-intersection proportion, street area density, sidewalk to street proportion, median connectivity, global integration, local integration, block density, and building coverage proportion. These variables are all highly positively correlated with each other, negatively correlated with variables in 6-1 a(ii), and not correlated with variables in the other categories. These variables show significantly different values between the core and periphery of the city. Since the core is the oldest neighbourhood of each city, these variables show a significant decrease in their values between when they were built in the mid-nineteenth century to today. In the mid-nineteenth and early-twentieth centurys, streets were laid out for travel by horse or foot, producing morphology on a denser scale (often referred to by urban designers and planners as "human scale"). Blocks were smaller with higher densities, intersections were closer together, and buildings covered much of the block due to the high value of land. Today, with the automobile as the main mode of travel, streets are laid out for motor vehicles. This change in transportation technology allows for larger lots at lower densities and further distances between street intersections. This also allowed for cheaper land to be purchased further from the core, leading to lower building densities on this peripheral land.

6.2.1.2 Lowest values in core, highest in periphery

The second set of variables in this category include those variables which have their highest values in the periphery and decline steadily towards the core of the city, where they reach their lowest values (see Figure 6-1 (ii)). This group of variables includes cul-du-sac proportions, street segment length, block size, lot size, and building setback. These variables are all highly positively correlated with each other, negatively correlated with variables in 6-1 a(i), and not correlated with variables in the other categories. These variables show significantly different values between the core and periphery of the city. Since the core is the oldest neighbourhood of each city, these variables show a significant increase in their values between when they were built in the mid-eighteenth century to today. In the mid-eighteenth and early nineteenth centuries, streets were laid out for walking and horses, producing morphology on a smaller scale. Blocks and lots were smaller, intersections were closer together creating shorter street segments, and streets were laid out in a grid-iron fashion without cul-du-sacs. Today, with the automobile used as the main source of transportation, streets are laid out for cars. This change in transportation technology allows for larger blocks and lots, further distances between street intersections, producing longer street segments, and gave rise to the heavy use of culs-du-sac.

6.2.2 Core-Older Suburbs -Periphery Relationship

The second main group of variables (b) has the extreme (the highest or lowest values) in the center and periphery of the city, and the opposite extreme in the oldest residential areas of the city. The area between the core and the oldest residential areas shows a gradual and mostly-uninterrupted shift from one extreme to the other, followed by a second shift back to the first extreme. The resulting spatial pattern forms a 'donut'-like shape in the oldest residential neighbourhoods around the core of the city. Variables which fall into this pattern and have high values in the city's core and periphery are shown in Figure 6-1 b(i), while variables which fall into this pattern and have low values in the city's core and periphery are shown in Figure 6-1 b(ii). These two patterns are inverses of each other, with variables in column b(i) being highly positively correlated with each other, and highly negatively correlated with all variables in group b(ii). Neighbourhoods with extreme values include Old North, Old East, Old South, as well as the Blackfriers neighbourhood west of the downtown.

6.2.2.1 Highest values in core and periphery, lowest in suburban

The first set of variables in this category include those variables which have their highest values in the core and periphery, and their lowest values in the oldest residential suburbs (see Figure 6-1 b(i)). The spatial pattern displays a "donut"-like shape of low values in the oldest residential neighbourhoods. This group of variables includes street width, arterial street proportion, proportion of undeveloped lots, lot frontage, average building footprint size, distance between buildings, commercial land use, retail land use, and industrial land use. These variables are all highly positively correlated with each other, negatively correlated with variables in 6-1 b(ii), and not correlated with variables in the other categories. The oldest residential neighbourhoods, built in the early nineteenth centenary, were built with both the pedestrian and automobile in mind, and show significantly lower values in these variables over the core and the periphery of the city. These neighbourhoods, predominantly residential in nature, were built with narrower and more secondary streets than the core or the periphery to facilitate residential safety. These areas have very low amounts of undeveloped lots, as the land is very desirable for residential dwellings. Lot frontages, building sizes, and the distance between buildings are smaller, which makes these areas very dense and highly compact. These areas have significantly lower commercial, retail, and industrial land use than the core and periphery areas of the city due to their residential character.

6.2.2.2 Lowest values in core and periphery, highest in suburban

The second set of variables in this category include those variables which have their lowest values in the core and periphery, and their highest values in the oldest residential suburbs (see Figure 6-1 b(ii)). The spatial pattern displays a "donut"-like shape of high values in the inner-city neighbourhoods. This group of variables includes T-intersections, lot density, building density, residential building density, residential building proportion, building to lot proportion, residential land use, and single family residential land use. These variables are all highly positively correlated with each other, negatively correlated with variables in 6-1 b(i), and not correlated with variables in the other categories. The oldest residential neighbourhoods, built in the early nineteenth centenary, were built with both the pedestrian and automobile in mind, and show significantly higher values in these variables over the core and the periphery of the city. These neighbourhoods, predominantly residential in nature, were built with an increased amount of T-intersections over the core or the periphery, as well as an increase in the densities of lots and buildings. These highly dense and compact areas have very high amounts of buildings per lot, and have significantly higher residential land use over other areas of the city

6.2.3 Random Distribution

The third main group of variables (c) contains variables with little to no apparent spatial pattern across the city. These variables include pathway to road proportion, proportion of irregular angled intersections, building to block proportion, recreational land use, park area, urban water area, and institutional land use. These variables for the most part do no correlate with any other variables in this study, and do not appear to have any pattern of distribution over space or time.

While all variables in this study are regulated by the government to some degree, most of the variables found in this category are more highly regulated by the government. For example, sidewalks and pathways, recreational land use, parks, and institutional land use are meant to be uniformly distributed across the city to provide equal access and service. Institutional land including schools and fire stations are highly regulated to ensure even coverage.

6.2.5 Relating to theories on urban form

Chapter two included a brief discussion on the history of the North American city and classical theories on urban form. After analyzing the results of this thesis, comparisons can be made between the results and the theories.

The pedestrian city is present in all 6 case study CMAs as the current historic downtowns. Built in the mid 1800s these areas are small, dense, and have well-integrated, gridded street networks. The land uses in the cores of each city are mixed, with a high amount of office/commercial as well as residential uses.

Surrounding the cores of Southwestern Ontario cities are areas of old residential development. While these areas are primarily residential in land use, they include a mix of commercial land use within them. They also display both high density and high integration values. These areas are products of the early industrial revolution, and were built without the automobile as a major source of transportation.

Finally, the old residential areas are surrounded by newer suburban areas, built with the automobile as the prime mode of transportation. These areas of low density, with lower street integration are characterized by clusters of segregated residential and commercial land uses.

The above descriptions of Southwestern Ontario cities generally conform to the history of the general North American City. Further, a number of development models hold true. The cities roughly conform to Hoyt's Sector Model (1969), where corridors of industry tend to be surrounded by sectors of working class housing, while middle income housing tend to act as a buffer between the industrial half of the city and the city's main sector of elite neighbourhoods.

Further, the six CMA's loosely conform to Alonso's bid rent theory of urban land use (1964), with the most central areas of cities being the most attractive, which in turn allows for higher prices to be demanded for land. Different land uses in Southwestern Ontario cities appear to follow bid rent curves from the center to the periphery, with office land use located in the city centres, and light manufacturing, residential, and heavy industry are located in concentric zones outward from the core. The model of Harris and Ullman (1945) can be somewhat applied to newer suburban developments, with automobile based suburban nodes of commercial and industrial activity not being arranged in any predictable fashion, except in relation to their surrounding land uses.

Overall, there were many forces which dictate the distinctive change in morphology over the spatial extent of the city. From the time the initial core was built until today, there has been several n enormous changes in transportation technology, which allowed for the development of vastly different morphologies in newer neighbourhoods. Further, changes in urban form can be attributed to increases in income, changes in planning code, changes in building code and building methodology, and changes in societal norms.

6.3 Social and Historical Variables

6.3.1 Major Era of Development

Major era of development varies spatially across London and all Southwestern Ontario cities. In London, a gap of over 150 years can be seen between the highest and lowest density neighbourhoods. The oldest neighbourhoods are located in the central neighbourhoods of the city, while the newest neighbourhoods are located at the periphery of the city. This spatial pattern is almost completely uniform, although some peripheral neighbourhoods, e.g. older absorbed villages of Lambeth and Byron, have old major eras of development.

Similar spatial patterns can be seen in the other Southwestern Ontario cities, with the major era of development in the central areas being the oldest, and the major era of development in the periphery being the newest.
These spatial patterns show clear correlation with many of the morphological variables assessed in this study. As past literature has revealed, there is high correlation between major era of development and median household income. Furthermore, newer neighbourhoods have statistically significant larger street, blocks, lots, and building footprints. In the Southwestern Ontario study, newer neighbourhoods have more T-intersections, and open area land-use proportion. Conversely, older neighbourhoods have significantly more intersections, sidewalks, building and block densities, and building to lot proportions. All space syntax measures (local integration, global integration, and connectivity) are also highly significantly correlated with older neighbourhoods. In addition, the Southwestern Ontario study shows that older neighbourhoods have more X-intersections, residential land-use, commercial land-use, institutional land-use, and industrial land use.

There are variables that are not significantly correlated with the major era of construction. Many of these variables have roughly U-shaped curves through time. For example, in London, neighbourhoods built pre-1949 had very few T-intersections, while neighbourhoods built in the 1980s had a large amount of T-intersections. However, newer neighbourhoods built in the 1990s and 2000s have much lower amounts of T-intersections. This low-high-low pattern is present in a number of variables, including pathways, lot frontages, building footprints area, the number of buildings per block, and institutional and recreational land uses. Other variables show a high-low-high pattern, where there is an increased amount of the variable pre-1949, low amount of the variable in the 1970s and 1980s, and return to an increased amount in the 1990s and 2000s. Such variables include X- intersections, building setbacks, and commercial land-use portion.

Overall, in both studies is clear that those areas with older major eras of construction have significant morphological differences over those areas with newer major eras of construction. Over time, building practices change, government legislation changes, and consumer tastes change, resulting in neighbourhoods being built with very different morphologies then those neighbourhoods built before.

6.3.2 Median Household Income

Median household income varies spatially among neighbourhoods throughout London and all Southwestern Ontario cities. In London, a gap of $110,000 can be seen between the richness and poorest neighbourhoods, with the lowest median household income MUs located in the centre of the city, and the highest median household income MUs located in the north and west areas of the city.

These spatial patterns are also seen in all Southwestern Ontario cities, with large divides between higher median household incomes and lower median household incomes. The historic downtowns of these cities all display the lowest median household incomes, while suburban CTs to the west are for the most part the highest areas of median household income. This spatial pattern changes in the cases of Windsor and Sarnia due to their downtowns being on the south-east side of large bodies of water which also serve as international borders with the United States of America.

These spatial patterns show clear correlation with era of construction, land use mix, and densities. As median household income increases, there is a strong increase in the proportion of T-intersections, and in London, culs-du-sac. Culs-du-sac are significantly correlated with median household income in London, but are not in the other case of Southwestern Ontario. As median household income increases, so does the length of street segments and, thus the sizes of blocks and the number of lots per block. The proportion of residential buildings increases, as well as the sizes of buildings. Finally, open area and agricultural land uses are more prevalent in high median household income neighbourhoods.

Conversely, as median household income increases, population density decreases along with intersection density and X-intersections. Neighbourhoods become significantly more spread out in terms of population, lots, blocks, and the street network, with the street network displaying lower arterial road proportions and lower connectivity, local integration and global integration. As median household income increases, the proportion of sidewalks significantly decreases as well as the building to lot proportion, indicating larger lots. In terms of land use, as median household income increases, there is significantly less government and institutional, industrial, and commercial/retail land use.

Overall, in both case studies, it is clear that those areas with higher median household incomes have significant morphological differences over those areas that have lower median household incomes. To determine the causality of this is beyond the scope of this research, but due to the obvious importance of this variable on a cities vitality, is of utmost importance for future research.

Neighbourhoods with higher land values are more highly demanded over those areas with lower land values. This higher demand could be due to a number of characteristics of the neighbourhood beyond the morphological performance indicators, for example, location, social environment. However, if it is found that morphological variables do come into play when demanding residential land, then those variables highly correlated with median household income are the most demanded, and therefore the morphological variables that people want the most. This could have a profound effect on the way we create new neighbourhoods and improve old.

6.3.3 Population Density

Population density varies spatially across London and all Southwestern Ontario cities. In London, a gap of 4230 persons per square kilometre can be seen between the highest and lowest density neighbourhoods. Neighbourhoods with the highest population density per square kilometre are located primarily the central areas of the city, while neighbourhoods the lowest population density per square columnar by located in the peripheral areas of the city. However, this pattern is not consistence over the entire city with some suburban areas toward the periphery having high population densities per square kilometre.

Similar spatial divides are seeing in the other Southwestern Ontario cities, with higher population densities per square kilometre in the centre of Southwestern Ontario cities, and lower population densities per square kilometre located in the periphery of Southwestern Ontario cities. Again, these patterns are not uniform across space, with neighbourhoods of the highest population densities located toward the periphery of each city.

These spatial patterns show clear correlation with many of the morphological variables assessed in the study. As expected, as population density increases, there is a very strong increase in intersection density, lot density, as well as block density. Further there is an increase in sidewalk to street proportion, and building coverage proportion. Both overall billing density and residential building density increase as population density increases. Many of the proportions increase as population density increases, such as residential building proportion, building coverage proportion, building to lot proportion, and building to block proportion,. Land uses such as residential, commercial, institutional, and retail all increase as population density increases. In Southwestern Ontario, population density is also positively correlated with government and institutional land-use as well as resource and industrial land use.

Conversely as population density increases, a number of morphological variables significantly decrease. For example, higher population densities are correlated lower median household incomes. Greater population density is also correlated with lower amounts of cul-de-sacs, arterial streets, block size, and undeveloped lots. Finally, as population density increases, land uses such as industrial, institutional, urban water, and open area decrease.

Overall, in both studies, it is clear that those areas with higher population density have significant morphological differences over those areas with lower population densities. Population density is a catalyst for urban development, and therefore higher amounts of population density must exist for certain types of morphology to exist. Future studies may want to determine what population density thresholds must exist in order for particular piece of the morphology to exist.

This previous half of this chapter analyzed the results presented in the preceding two chapters. First, morphological variables were grouped into two groups based on high correlations between them and similar spatial patterns. This analysis is useful for planners, developers, and other "agents of change" due to the fact that one can understand what a change in one variable in the morphology will have on others. For example, an increase in connectivity in a neighbourhood will also likely bring about an increase in building density and sidewalks, and a decrease in street width and commercial land use. The understanding of these relationships is a powerful tool in creating new neighbourhoods and changing old neighbourhoods. Second, social and historical variables were discussed in relation to the morphological variables. Only two morphological performance indicators, distance between buildings and park proportion, did not correlate with at least one of the three social and historical variables. This is significant as it shows that neighbourhoods with different social and historical variables have different morphologies. The link between the social and historical variables and the morphological variables is found is further discussed when answering the research questions.

6.4 Study Objectives

After a detailed analysis of a host of morphological variables across Southwestern Ontario cities, the research questions, as originally stated in the introductory chapter, can be answered.

Primary Question:

What are the similarities and differences in the urban morphology of Southwestern Ontario cities?

Secondary Questions:

1) How do the morphological characteristics of neighbourhoods within and among cities compare in relation to the historical timing of neighbourhood development?

2) How do the morphological characteristics of neighbourhoods within and among cities compare in relation to the incomes of neighbourhood residents?

3) How do the morphological characteristics of neighbourhoods within and among cities compare in relation to neighbourhood population density?

The main question of this research asks if differences in the urban morphology of Southwestern Ontario cities exist, and if they do, what their magnitude is. To accomplish this, a multitude of morphological 'performance indicators' were identified and quantified over Southwestern Ontario CMAs within a Geographic Information System. Values of each performance indicator were identified within defined neighbourhood boundaries, and were assessed. This research has shown that most morphological performance indicators behave in spatially non-random patterns across London and Southwestern Ontario cities. Most morphological variables were found to behave in one of two patterns across cities in Southwestern Ontario. The remainder variables were found to have no pattern across space and little correlation to other variables. The two patterns of spatial distribution both show that most variables have significantly different values depending upon where they are located in the city. As location within the city is tied to historical era of development, this shows that the development patterns of most morphological variables have changed over time. Further, these spatial and statistical patterns are consistent for all 6 study CMAs.

The first sub question asks if morphological performance indictors vary over historical time periods within and between cities in Southwestern Ontario. Each defined neighbourhood unit's major era of construction was identified and compared with the level of each performance indicator. Using a Spearman correlation, it was identified that levels of many morphological performance indicator change in relation to the date they were constructed. The development patterns of Southwestern Ontario Cities substantially changed between the mid-eighteenth century and early ninetieth centaury, and then again between the mid-nineteenth century and the late nineteenth century.

The second sub question asks if morphological performance indictors vary over neighbourhoods with different income levels within and between cities in Southwestern Ontario. Each defined neighbourhood unit's median household income was identified and compared with the level of each performance indicator. Using a Spearman correlation, it was identified that levels of most performance indicators change in relation to median household income. In other words, neighbourhoods with low median household income have significantly different morphology than neighbourhoods with high median household income.

The third sub question asks if morphological performance indictors vary over neighbourhoods with different population densities within and between cities in Southwestern Ontario. Each defined neighbourhood unit's population density was identified and compared with the level of each performance indicator. Using a Spearman correlation, it was identified that most morphological performance indicator change in relation to population density. In other words, neighbourhoods with low population densities have significantly different morphology than neighbourhoods with high population densities.

The vast majority of performance indicators show very similar spatial patterns across the six study CMAs of Southwestern Ontario. Slight alterations need to be made when comparing Windsor and Sarnia to the other 4 CMAs, as their downtowns are located on waterfronts which also serve as the international boundary of Canada and the United States of America, which therefore restricts growth.

Overall, in both studies, it is clear that those areas with older major eras of construction have significant morphological differences compared to newer developments. This research shows that over time, as building practices change, government legislation changes, and consumer tastes change, the resulting neighbourhoods being built are comprised of very different morphologies than those neighbourhoods built prior.

6.5 Limitations

This study has a number of limitations which need to be addressed. They are generally described as data quality and availability, container approach methodology, and the large scope of this research.

Data quality and availability is the largest limitation for research of this kind. A number of performance indicators were not able to be studied because of lack of available data. Innovative measures within a Geographic Information System were used in order to tease out many variables that were not directly provided, and while a way to create most variables was derived, not all of them were able to be created. While this study does not address every performance indicator imaginable, it does add a very large number of variables that have never been assessed before in academia.

Another limitation is data quality. For example, the Southwestern Ontario land use file provided by DMTI, while the best available, has many known data quality issues. For example, land use that is known to be residential is zoned as open space in the file. It is hoped that on such a large scale, small issues like this would dissipate, but nevertheless, they exist. Unfortunately, no other consistent land use file was available for use.

Further, data was provided by a variety of sources, all with different methodologies and goals. While it is trusted (and in some cases, verified), that data is correct, it is reasonable to assume that small errors in these files do exist.

Limitations to the container approach methodology were discussed in detail in the methods chapter. The container approach groups data together in bins, and while doing so, data variation within the container is lost. To try to minimize this issue, specific types of containers were chosen to allow for similar morphological features.

Finally, the very large scope of this thesis can be seen as a limitation. While there is a good argument to be made for a large amount of breadth, much depth on individual performance indicators is lost in order to keep the thesis size manageable. It is thought that the large breadth results of this study justify the lack of depth of individual performance indicators.

6.6 Calls for Future Research

The measurement of urban form at the neighbourhood scale using GIS is relatively new. Future research, using the performance indicator framework, could create new comprehensive sets of urban descriptors formulated for various urban form typologies at neighbourhood and local scales. Potential performance indicators could function as benchmarks for environmental sustainability appraisals, land use regulation, and land development. Further research would be required to determine actual performance indicators relating to community behaviour patterns.

The results of this study could be used by researchers, planners, and private companies alike. The understanding of which performance indicators are significantly correlated with others is beneficial in planning, studying, and developing neighbourhood form. The results could be used by those studying economics, transportation, and health. For example, the results of this research could aid home buyers in making better decisions about the types of neighbourhoods they want to live in.

This said, it is clear that this is just a starting point into new possibilities of GIS related morphological research. Further studies should build upon these results, compare them to cities around the world, and further study the depth of individual performance indicators.

6.7 Conclusion

This research provides improved methods to quantitatively characterize urban development forms at the micro level. It employs micro-level measures to investigate relationships among local built form, land uses, and era of development. The research empirically verifies well-known historical trends, for example, that intersection density declines through time, and building footprints and lots become larger over time. Less well-known, but also revealed in this study, are the ways in which trends in residential density relate to trends in road/lot layout and land-use, both of which have been greatly influenced by trends in planning practice. Particularly indicative of these trends are the street-related measures of road density, intersection density, and sidewalk proportion, all of which decreased over time. Results showed that the vast majority of morphological variables have systematic spatial patterns and high levels of correlation to other variables. Most variables tended to either increase or decrease from the city centre outward, or have their extreme values in the oldest residential neighbourhoods of the city. Further, results showed that social and historical variables of a neighbourhood are highly correlated with morphology. This research has implications for planners, land developers, and other agents of urban change in understanding how to better develop new neighbourhoods and redevelop old neighbourhoods.

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