

A GIS-based Walkability Index for the City of Cape Town

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## Abstract

Walking is a widely accessible mode of transportation, yet our urban environments are automobile dependent. Automobile dependence, in turn, led to a rise in the level of inactivity amongst urban residents. Studies investigating the relationship between urban form and human health created walkability indices measuring urban environmental features contributing to the walkability of an area. However, walkability has only recently become the subject of research within urban planning. Within a South African context limited research is available on walkability and to date, there is no metropolitan-wide walkability index for any South African metropolitan. The research presented in this dissertation addresses the gap in South African walkability studies through the composition of a walkability index for Cape Town. From previous studies, the research identifies three main measures of walkability. These measures and a fourth Cape Town specific measure of walkable areas around informal and formal destinations are quantified and mapped using GIS research methods and techniques. The GIS results are validated against field validation points depicting streetscapes within enumeration areas. Based on the results and the validation thereof the study suggests possible applications of the walkability index for non-motorised transport planning in Cape Town.

## Abbreviations

CCT	City of Cape Town
GIS	Geographic Information Systems
GWI	Global Walkability Index
LO	Longitude of Origin
NEWS	Neighbourhood Environment Walkability Scale
NMT	Non-motorised transport
UK	United Kingdom
UN	United Nations
US	United States
VCCID	Voortrekker Corridor Central Improvement District

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## 1. Taking the first step

Walking is a widely accessible mode of transportation, yet our urban environments are automobile dependent. Automobile dependence, in turn, led to a rise in the level of inactivity amongst urban residents. Studies investigating the relationship between urban form and human health created walkability indices measuring urban environmental features contributing to the walkability an area. However, walkability has only recently become the subject of research within urban planning. Within a South African context limited research is available on walkability and to date, there is no metropolitan-wide walkability index for any South African metropolitan. The research presented in this dissertation addresses the gap in South African walkability studies through the composition of a walkability index for Cape Town. The research is framed within urban planning and suggests possible applications of the walkability index for non-motorised transport planning in Cape Town.

The first chapter serves as an introduction and outlines the areas of interest the study addresses. This chapter consists of eight sections. The first section states and describes the research problem at hand. The second section explains the motivation for conducting the research. Section three outlines the aim and the underlining objectives of the research project. The fourth section details the research questions of the study. The fifth section briefly describes the research methods and techniques utilised within the research project. Section six contemplates possible ethical consideration and implications related to the study. Section seven provides a brief overview of the study area. The final section outlines the structure of the dissertation.

### 1.1 Research Problem

Historical urban development in South Africa was characterised by unchecked sprawl. The two main drivers of sprawling urban development were the implementation of apartheid urban development policies and automobile-dependent transport infrastructure. The resultant divergent urban fabric is now characterised by high transport costs, which disproportionately affects those falling within the lower income brackets. Statistics South Africa, in measuring household expenditure on transport, found that households falling in the lowest income quintile spent more than a fifth of their household income on public transport (Statistics South Africa, 2015). According to the 2013 National Household Travel Survey, more than 60% of public transport trips are made via minibus taxis and just over a fifth of workers walk to work (Statistics South Africa, 2013).

The reports by Statistics South Africa highlight two important aspects. Firstly, that the current state of South African public transport is expensive and overly reliant on automobile modes of transport. Secondly, more than 20% of workers travel by foot to their place of work, which is a substantial percentage of the workforce. Walking is categorised as a mode of non-motorised transport (NMT) and is thus mentioned as a complementary mode of transport in public transport plans. From reviewing Cape Town's Integrated Transport Plan 2013 – 2018 and Integrated Public Transport Network Plan 2032, it is clear that walking is only considered as an auxiliary mode of transport during a commute (Transport for Cape Town, 2014a; Transport for Cape Town, 2014b). Further, these plans briefly mention walking without the proper analysis to substantiate proposals promoting walking as a mode of transport.

The prioritisation of walking as a mode of transport is a principle of New Urbanism. New Urbanism recognises walking as a viable mode of transport which has three main benefits (CityLab, 2012b; CityLab, 2014; Community builders, 2016). The first is the economic benefits; these are derived from the physical feet on the street creating vibrant street environments which create a market for local businesses (Active Living Research Organisation, 2010; CityLab 2012a; Leinberger and Alfonzo, 2012; Planetizen, 2015). Secondly, there are environmental benefits, as walkable urban environments reduce the reliance on automobile use, thereby reducing the CO2 emissions caused by cars (Gebel et al., 2011; Moayed et al., 2013; CityLab, 2014; Planetizen, 2015). The third group of walking benefits are health-related, as an increase in physical activity decreases people's risk of developing diseases such as obesity and diabetes (Devlin, Frank and van Loon, 2009; Andrew et al., 2012). Given the benefits associated with walkable urban environments, little has been done, within a South African or Cape Town context, to measure how walkable urban environments are and how increasing the walkability of an area could facilitate NMT planning.

The majority of studies measuring the walkability of cities are located in the Global North. Web-based walkability indices such as Walkscore.com in the USA provide a walkability rating for home addresses. Various studies illustrate how Geographic Information Systems (GIS) are effective in compiling walkability indices (Leslie et al., 2007; Giles-Corti et al., 2014; Azmi and Ahmad, 2015; Cubukcu et al., 2015). These studies refer to features from the urban environment influencing the walkability of an area. These features are presented as measures of street connectivity, the land-use mix and residential densities within previous studies. Walkability studies from the Global South are limited, but these studies emphasise the importance of factoring in context-specific variables influencing the walkability of a city (Oyeyemi et al., 2013; Murekatete and Bizimana, 2015; Oyeyemi et al., 2016). In doing so these studies

create walkability indices to inform local planning interventions and identify areas suitable for the creation walkable urban environments.

Due to a divergent urban development pattern, Cape Town has become a sprawling metropolitan region (Turok and Watson, 2001). This development pattern has led to the formation of an urban area that is still segregated both socio-economically and physically. This study aims to fill this research void through an objective assessment of walkability for the City of Cape Town (CCT). To this end, the study will employ GIS to model a walkability index unique to Cape Town which could inform decisions affecting non-motorised transportation planning.

### **1.2 Motivation for the study**

This study adds to the current body of literature on walkability, as few walkability studies have been conducted from an urban planning perspective within the Global South. Walkability indices are prevalent throughout the Global North. General web-based indices for, example Walkscore.com, and other city-specific indices, e.g. Orlando, Florida, assists residents who want assess the walkability of their urban environment for a multitude of reasons. Limited walkability studies have been conducted within the Global South with a small percentage of these studies based within Africa. Walkability is the subject of research within the realm of academic disciplines such as engineering, geography and the health sciences. These investigations focus on the specific infrastructure in place for walking with little regard for the broader context of NMT planning interventions. This study will look to address some of the broader concerns regarding the current state of NMT planning within the CCT.

### **1.3 Aim of the research**

The aim of the research is to create an objective walkability index for the CCT and demonstrate how a walkability index could inform future NMT planning interventions. The research objectives to reach this aim are: establish what urban environmental features affect walkability; acquire the needed spatial data representing these urban features; create non-existing spatial data representing urban features; identify a suitable area of enumeration for the study; create GIS layers representing the urban features affecting walkability; compile the GIS layers into walkability indices; determine the effects of different variables and weightings in compiling a walkability index, present and validate the final walkability index for the CCT; lastly, apply the walkability index within the CCT's existing NMT policy framework.

### **1.4 Research questions**

The main research question is stated as: How can an objective walkability index assist future NMT planning within the CCT? Sub-research questions are: What are the urban environmental features that influence walkability? What are the most suitable measurements of these urban features for the CCT? How does weighting measurements differently affect a walkability index? How well does an objective walkability index correlate to the presence of pedestrian-friendly street design features? How could a walkability index be applied in planning for NMT networks at a metropolitan and local scale? What are possible avenues for future walkability research in South Africa?

### **1.5 Research methods and techniques**

The research employed quantitative research methods based on GIS analysis. To assess the objective walkability of the urban environment spatial data was sourced from existing databases or created in certain cases. From these data, the objective walkability was determined for different enumeration areas within Cape Town.

To compile an objective walkability index, quantitative data relating to the measurements of urban environmental features affecting walkability were needed. The primary measures of walkability were identified from reviewing previous walkability studies. These primary measures are street connectivity, residential density and land-use mix (Frank et al., 2005). A fourth measure, walkable destinations, was also included as it provides a context-specific representation of walkable areas around destinations in Cape Town. Quantifying the walkability measures was done by creating multiple datasets representing each of the walkability measures within GIS. These measures are calculated from different variables (e.g. true intersection density, true intersection to node ratio, etc.). An investigation into how each variable influences a preliminary walkability index allowed the study to determine which variables were best suited. Based on these observations, the measures of walkability incorporated in the final walkability index are stated. Different experimental walkability indices are then presented. These experimental walkability indices illustrate how weighting different measures affect a walkability index. Performing a cluster analysis on the results of the weighted walkability indices allows for the identification of statistically significant enumeration areas. To ascertain whether the final walkability index results correlate to reality, field validation points were taken. These field validation points were taken in areas with different walkability ratings. The field observations are documented by photographs of streetscapes within different enumeration areas under investigation. This data will be communicated through a series of photographs detailing the field observations. The results from the field validation

process allow the study to conclude by presenting possible applications of the final walkability index in the CCT.

It is important to note that the above data does not provide an insight into pedestrians' perceived walkability of an area. To gauge the perceived walkability of neighbourhoods in Cape Town a qualitative investigation is required. This would constitute an extensive field survey of residents' perception of walkability, which the research timeframe did not accommodate. However, the methods mentioned above are most appropriate in reaching the research aim and ultimately answering the main and sub-research questions of this study.

### **1.6 Ethical considerations**

No personal, private or sensitive information was needed for the purpose of the research. One consideration was the possible negative externality that a walkability index could have on actors within the property market. This consideration is based on the effect walkability indices have on real estate prices in America. Where some studies have found that real estate prices are positively related to the aggregate Walkscore.com rating of a neighbourhood. Property prices were found to increase between \$ 750 and \$ 1300 per Walkscore.com rating point increase. Therefore there is a possibility that areas which are well located and affordable could gentrify and possibly cause the market displacement of low-income groups. Therefore it is important that the results from the research be validated appropriately and shared in a responsible manner.

By identifying neighbourhoods with a high or low walkability index rating it is possible to ascertain what could be done to increase the walkability of areas with a low rating or maintain a neighbourhood's high walkability rating. The study could thus facilitate local governments in identifying areas in need of NMT investment. Alternatively, the study could assist local metropolitan governments to identify areas with a high potential for investment in NMT linkages. Further recommendations could be made to those who wish to use the index an advisory tool in deciding where to invest in property.

### **1.7 The study area: The City of Cape Town**

The CCT is located at the south-westerly point of South Africa and the African continent (Figure 1.1). Cape Town has a history of diverse cultural influences contributing to the modern layout of the city. The most prominent and recent of these influences is modernist planning, which took the form of apartheid city planning in South Africa. This system of spatial planning was inherently racist and led to the

displacement of people of colour from the core to the periphery of Cape Town. Apartheid spatial planning along with market forces in the 1980's and 1990's led to urban sprawl and in turn made Cape Town's residents dependent on motorised transportation. This study investigates walkability within the CCT at two scales of investigation. The first scale of investigation is at a Sub Place level and the second is at a Small Area level. These enumeration areas refer to census tracts as defined in the 2011 Census results, with Sub Places covering a larger area than Small Areas.

### **1.8 Structure of dissertation**

This dissertation is structured into seven chapters. The first chapter has been presented above. The second chapter presents the findings from the literature review. Chapter three is a policy review of NMT policies. The fourth chapter explains the research methodology and describes the research process followed within the study. Chapter five presents and discusses the findings of the research. The sixth chapter investigates how a walkability index could be applied within urban planning practice. The dissertation concludes with the seventh and final chapter outlining research recommendations, possible future research opportunities, and a reflection on the research process and product.



Figure 1.1: Study Area – The City of Cape Town

## 2. A walkthrough of previous walkability research

This chapter aims to stress the need for research on walkability within a Global South and South African context. The first section chronicles the progression of urban planning to provide a background to the study. An assessment of past and contemporary urban planning practices highlights the cyclical nature of urban planning. The aim of the assessment is to illustrate the relevance of walkability within contemporary urban planning practice. The existing walkability literature underlines the symbiotic relationship between urban form and urban transport systems. The relationship is described as symbiotic as urban form determines transport systems and in turn transport systems determine urban form. The two urban features are investigated separately in this literature review to assess the features' importance to walkability.

Following the discussion of urban planning, the literature review then turns attention to the construct of walkability. Section three discusses the importance how walkability is defined in previous studies. A working definition of walkability, based on previous studies, is then provided. Based on this definition of walkability a three-pronged argument for walkability is outlined. The three arguments are categorised as the environmental, economic and social justification for encouraging walkability. Trends within previous walkability studies are then reviewed and indicate that walkability is of interest to a variety of academic disciplines. Previous walkability research includes studies measuring objective and/or subjective walkability. Based on previous research the most prominent objective walkability measurements are identified. This serves as the basis for constructing a robust walkability index for the purpose of this research project. The penultimate section discusses the application value of walkability indices to urban planning, as identified from the literature. The final section of the literature review summarises the findings from the literature which in turn serves as a springboard into the methodology section.

### 2.1 Cycles in urban planning

The following section describes a cyclical process within urban planning. The first urban settlements accommodated pedestrians. However, with the advancement of motorised modes of transportation cities were built for the automobile and not the pedestrian. In response to the current state, planners attempt to recreate urban environments reminiscent of older cities. This cyclical process is presented in the following two subsections. The first section discusses the movement away from pedestrian-friendly cities and the second section explains the return to pedestrian centred urban environments.

#### 2.1.1 Chronicling urban planning

This section provides a brief historical account of urban planning from its informal roots to its modern state as a profession. This section first explains the need for urban planning as it arose to address unhealthy urban environments created during the industrial revolution. Thereafter, the first attempts at planned cities are described. Finally, the section concludes with an assessment of the legacy of modernist planning practices.

The first settlements grew organically and were facilitated through subsistence agriculture and later driven by trade. As settlements grew, their structure and function evolved to meet the expanding needs of settlement dwellers. During the second half of the 19<sup>th</sup> century, the industrial revolution drove urbanisation. People abandoned their rural livelihoods to seek employment at factories within emerging industrial cities. The dire living conditions in industrial cities necessitated interventions addressing unhealthy urban environments. In this regard architects and industrialists played an important role. Architects such as Ebenezer Howard sought to preserve country living within the urban environment through his concept of the Garden City. Industrialists' need for a healthy and reliable source of labour drove them to establish labour settlements such as Saltaire in the United Kingdom (UK).

Movements addressing the urban ills of the industrial era gained momentum at the turn of the 19<sup>th</sup> century. In the UK there was the Garden City movement which subscribed to the principles of Ebenezer Howard's Garden City concept. In America, the City Beautiful movement aimed to transform the functional nature of cities to an artistic expression. The Garden City movement sought to decentralise urban populations to satellite towns surrounding primary and regional urban centres. Garden Cities were to adhere to a set of guiding principles dictating the design of a Garden City. The seven main guiding principles were: a target population of 32 000 residents should be reached; each city should provide job opportunities; a diverse range of land uses were to be encouraged; a spacious layout should be followed; a greenbelt would serve as space for agriculture and recreation; municipalities would own the land; and finally growth would occur by colonisation (Pacione, 2005). This type of development would thus, through design, aim to create self-sustaining urban centres linked to the larger urban environment through high-speed transport linkages. In America, the City Beautiful movement resembled the Garden City ideals of a planned urban environment. However, the City Beautiful movement differed as the guidelines were not as prescriptive as that of the Garden City movement. Where Garden Cities had to adhere to a set of guiding principles, the City Beautiful movement did not have such requirements. The City Beautiful movement rather focused on the beautification of cities through design-led interventions. Cities would control the urban environment through the drafting and implementation of a master plan,

the vision of which would be enforced through the enactment of ordinances (Pacione, 2005). Both movements mentioned above sought to address the dire situations in industrial cities through relocating urban growth to Greenfield sites. The Garden City, in particular, sought to create liveable urban environments dependent of non-motorised modes of transportation. However, these movements would set a dangerous precedent for modernist planning of urban development following the Second World War.

Individual interventions, mentioned above, were limited in scope and influence, and it was only in the early 20<sup>th</sup> century that urban planning became a function of the state. This period is seen as the start of modernist planning and was characterised by the creation of exclusionary zoning regulations that addressed unhealthy or unwanted urban environments. The goal of zoning regulations was to cordon off areas in the city for a specific use, e.g. residential, commercial, and industrial. Exclusionary zoning was spurred on by peoples' desire to live in areas untainted by industrial pollution and the proliferation of motorised transport. Consequently, cities sprawled leading to deteriorating urban cores. A prime example of planning policy and practice reflecting the modernist ideals was the development of New Towns.

New Town developments were proposed as a solution to the urban development pressure experienced by established urban areas following the Second World War. New Towns have the following characteristics: they are to be located around established densely populated areas; they have populations between 20 000 and 60 000; they should be Greenfields developments, and finally, they should avoid the consumption of valuable agricultural land (Pacione, 2005). The New Towns development model underwent various changes since the programme's inception in the 1950's with modern New Town developments labelled as New Urbanist or Neo-Traditional. These types of developments advocate for a return to the core urban values in creating walkable urban environments. New Urbanism has gained support from urban policy calling for smart growth and sustainable development. Given the emphasis New Urbanism places on non-motorised transportation, the following subsection will cover this topic in detail.

Modernist urban planning resulted in disjointed cities, both in physical form and socio-economic structure. The separation of land uses encouraged the use of motorised modes of transport. Consequently, this led to a disregard for pedestrian infrastructure and an indifferent approach to creating positive pedestrian experiences. The negative impact of modernist planning on pedestrians is compounded within a Global South context. Cities in the Global South are largely products of modernist

planning but the residents of these cities cannot afford motorised transport. This renders large portions of the residents immobile and leaves them to walk for utilitarian purposes out of necessity. Pedestrian centred planning within cities in the Global South, such as South Africa, is therefore of great importance. Pedestrian centred planning is best encapsulated within New Urbanism, which calls for the building of new- and the retrofitting of existing urban environments prioritising pedestrians.

### **2.1.2 New Urbanism and walkability**

The following overview of New Urbanism describes the field's principles and past descriptive studies. It then addresses some of the major academic concerns regarding urban development driven by New Urbanist principles. These concerns relate to themes such as design, the geography of New Urbanist developments, the social implications of such developments, and how New Urbanist developments relate to sustainable urban development. New Urbanism is of particular interest as it directly relates to the prioritisation of the walkability of new urban environments or retrofitting existing (modernist) urban environments.

New Urbanism has its roots in the response to automobile-dependent cities created through modernist planning. The New Urbanist movement culminated in 1993 with the founding of The Congress for the New Urbanism which consisted of a variety of professionals directly involved with the production or reproduction of the built environment (Leccese and McCormick, 2000). The movement's goals and principles are stated within the Charter of the New Urbanism. The charter aims to address issues such as climate change, urban sprawl, poverty, health issues, underdevelopment, and ecological degradation (Leccese and McCormick, 2000). The charter states 27 principles which address the previously mentioned issues through creating sustainable buildings, neighbourhoods and regions. The core principles of the Charter for the New Urbanism are: prioritising neighbourhood diversity (land use and demographically), design of neighbourhoods for the use of all forms of transport, accessibility to public spaces and institutions, and urban architecture that celebrates local context (Leccese and McCormick, 2000). These core principles are elaborated on within the different urban scales of investigation, i.e. the macro (the region, city and town), the meso (the neighbourhood, district and corridor) and the micro (the block, street and building). Of these three scales, the mesoscale is most relevant to this research project, as it prioritises the use of NMT through the design of pedestrian infrastructure and the diversification of land use.

The above mandate and the resultant principles of The Congress for the New Urbanism seem virtuous. However, the implementation of New Urbanist principles has drawn much criticism and sparked many

an academic debate. A good synopsis of the critiques of New Urbanism is provided by Ellis (2002). Ellis (2002) categorised the critiques of New Urbanism according to those addressing the empirical performance of New Urbanism projects, the battle of ideas (ideological), cultural affinities and lastly the aesthetic qualities of New Urbanist developments. In short Ellis (2002) finds the critique levelled at New Urbanist developments insufficient in various ways. Critiques of New Urbanism tend to be biased in the sampling of New Urbanist projects and lack a clear comprehension of the principles and practices of New Urbanism. Furthermore, New Urbanism is weighed down by unrealistic expectations of its opponents and unfairly judged due to the ideological bias of scholars critiquing it. Thompson-Fawcett (2003) notes the importance of context in the implementation of New Urbanism as it is introduced in varying circumstances. Trudeau (2013b) builds on the importance of context through a study of New Urbanist projects in the United States (US). Based on this study, three types of New Urbanist projects are identified: mainstream urbanism, dense urbanism and hybrid urbanism (Trudeau, 2013b). While the studies mentioned in this section largely reference the physical manifestation of New Urbanism, Dierwechter and Coffey (2017) explore how New Urbanism is represented in the media. They found that the media portray New Urbanism in a positive light at almost a three-to-one ratio (Dierwechter and Coffey, 2017).

The second grouping of studies investigates whether or not New Urbanist design principles are successful in achieving the broad objectives of New Urbanism. Dill (2006) compared the walking behaviour of residents in a New Urbanist development with two conventional neighbourhoods. She found that residents in the New Urbanist development did, in fact, walk more than their counterparts in conventional neighbourhoods (Dill, 2006). However, Dill (2006) also found that the residents in the New Urbanist development did not necessarily drive less. Garde (2006) shifts the focus from residents to practitioners directly involved in the built environment. The study investigated the level of agreement between designers, planners and developers as to whether New Urbanist design principles could affect the proposed benefits. Garde (2006) found a high level of agreement among the practitioners interviewed but notes that the current regulatory environment restricts the implementation of New Urbanist principles (see also Marshall, 2015). The influence of street design elements in creating urban environments based on the principles of New Urbanism is investigated by Cozens and Hillier (2008). They find that focussing on design elements alone is short-sighted and call for more attention to the context wherein New Urbanist projects are undertaken (Cozens and Hillier, 2008). The dynamic between context and design is the focus of the 2009 study of Evans-Cowley and Gough. They studied the implementation of New Urbanist principles as incorporated in the rebuilding of communities in the aftermath of Hurricane

Katrina. Evans-Cowley and Gough (2009) found that communities were disappointed with the designed approach as the proposed design interventions were not suited for the context.

The location of New Urbanist developments is the concern of the third group of New Urbanist research studies. As Ellis (2002) notes, there is a general disregard for New Urbanist projects located in an inner-city context. Instead, studies focus on New Urbanist developments located in suburbia, which is a contradiction to The Charter for the New Urbanism principle of prioritising infill developments (Leccese and McCormick, 2000). Deitrick and Ellis (2004) address this lack of research on the implementation of New Urbanism in inner cities through a study of Pittsburgh in the US. Based on the Pittsburgh experience, Deitrick and Ellis (2004) state lessons for future infill developments: cultivate and encourage a culture of community participation, respect context and local character, link pedestrian orientated environments, clearly define spaces and the back and fronts of buildings, restrict automobile through design and lastly understand the need for amenities (Deitrick and Ellis, 2004). How New Urbanism-influenced suburban development patterns is the subject of Xu (2017). Xu (2017) study the design and urban form features of suburbs in Toronto, Canada. The study found an increase in net density, street connectivity and walkable distances to destinations of interest within suburbs embracing New Urbanism (Xu, 2017).

The fourth grouping of studies pertaining to New Urbanism relates to the social impact of such projects. In a comparative study of Modernism and New Urbanism, Vanderbeek and Irazabal (2007) highlight the difficulties of implementing altruistic design principles into practice. This is further illustrated by Edelman (2009), who investigated how the implementation of New Urbanist principles influenced the social equity of communities. He found that the area under investigation did experience an increase in social equity. However, Edelman (2009) suggests that the implementation of New Urbanist design principles alone does not explain the increase in social equity. Instead, Edelman (2009) contends that community engagement, economic and racial integration and the community's acceptance of diversity were responsible for the increase in social equity of the area. Demographic diversity of New Urbanist developments is investigated by Trudeau and Kaplan (2016). They analysed the demographic components of 70 New Urbanist neighbourhoods to determine the diversity of New Urbanist neighbourhoods. The study showed that New Urbanist neighbourhoods have a low level of racial diversity but did show a high degree of income group diversity (Trudeau and Kaplan, 2016).

Central to the argument for New Urbanism is the need for sustainable urban environments and sustainable urban development. New Urbanism within the sustainability debate is the fifth grouping of

studies regarding New Urbanism. Garde (2004) indicates a strong sense of support for New Urbanist principles in achieving sustainable development goals among designers, planners and developers. However, the study emphasises the importance of neighbourhood level interventions, as the regional planning sphere is too static to adopt New Urbanism (Garde, 2004). White and Ellis (2007) present findings from previous studies illustrating the positive contribution of New Urbanism to the sustainability of urban environments. Key to ensuring this positive link is the use of a framework to ensure that New Urbanist developments continue to positively contribute to sustainable urban developments (White and Ellis, 2007). The challenge to implementing New Urbanism, regarding the sustainability debate, is the subject of a 2009 study by Grant (2009). The study found that a lack of political commitment and market forces inhibits planners' ability to create communities which represent principles of sustainability, including New Urbanism (Grant, 2009). A behavioural study by Podobnik (2011) between a New Urbanist community and conventional neighbourhoods in Portland, Oregon shows the contribution of New Urbanism to neighbourhood sustainability. Podobnik (2011) found an increased level of walking and the occasional use of mass transit of residents in the New Urbanist community compared to residents of conventional neighbourhoods. However, the study also found that in both New Urbanist and traditional neighbourhoods there is a high degree of automobile usage as a primary mode of commuting (Podobnik, 2011). The limitation of New Urbanism in contributing to sustainable development is highlighted by Trudeau (2013a). The study reviews previous research and finds that the implementation of New Urbanism, in certain circumstances, is actually counterproductive to sustainability goals (Trudeau, 2013a). This limitation is not unique to New Urbanism as Sharifi's 2016 study shows. The study reviewed the contribution of five different movements within urbanism and highlights the difficulty of translating sustainability into practice (Sharifi, 2016).

The above subsection provides a brief overview of New Urbanism. The section outlines the origins of New Urbanism and states the principles of the movement. The subsection pertaining to studies investigating the influence of New Urbanist design principles indicate that design-led approaches are insufficient in creating neighbourhoods within the ideals of New Urbanism. What these studies underline is the importance of understanding context wherein New Urbanist projects are undertaken. This is enforced by studies focussing on the importance of the location of New Urbanist projects. Studies investigating the social impact of New Urbanist developments illustrate the limited scope of pure design in creating positive social spin-offs. The literature reviewed reveals that New Urbanist projects tend to contribute positively to addressing the legacy of modernist planning. This study will draw on New Urbanism as it provides sound principles advocating for the creation of walkable urban environments.

From this section, a cyclical process is evident in urban planning. The process is described as cities were initially in form and function dense and diverse, but through planning interventions cities sprawled and promoted mono-function. This research project will consider its findings against the backdrop of current urban planning theory, which seek to prioritise pedestrians such as New Urbanism. Current theoretical debates revolve around how to recreate past urban processes. Key features of the debate are urban form and urban transport, i.e. how the two components relate to one another. The next section delves into the urban form vs urban transport debate.

## **2.2 Urban form and urban transport**

Understanding any symbiotic relationship between two components necessitates the investigation of each component individually. Investigating each component separately identifies the inner function of each component within the relationship. This section is thus divided into two subsections; the first subsection discusses urban form and the second urban transport. Each subsection outlines debates regarding urban form and transport within a Global North and South context. The structure of the subsections aims to point out the similarities and highlight the difference in debates regarding urban form and transport within the Global North and South.

### **2.2.1 Urban form**

The study of urban form is, in essence, a study of the trees that make a forest. Urban form is the product of human processes and environmental considerations. This subsection discusses models of urban form and presents debates about sprawling and compact urban forms. This subsection frames this discussion within a Global North and Global South context.

The quantitative revolution within urban studies drove the proliferation of research seeking to classify features of the urban environment. The product of quantitative based research on urban form was urban models which were based on observations of existing cities. The early models—Concentric Circle (1925), Sector Model (1939), Multiple Nuclei (1945)—attempted to explain urban structure at the hand of the observed land-use patterns and a presumption of what drives human decision-making. Later models—Mann's Model (1965), Urban Realms Model (1964), Kearsley's Model (1983), and White's Model (1987)—either built on the early models or attempted to incorporate the complexity of cities within new models. While all these models underline how urban land use is designated, they fail to encapsulate the drivers of urban land use designation.

Current debates regarding urban form have moved on from abstract models of urban structure to contemplating the costs and benefits of compact or sprawling urban forms. Driving this debate is the growing significance of cities as the primary habitat for humans and how this shift is affecting the environment. The environmental cost of sprawling urban development in form of land consumption and the pollution from motorised transport is much higher than that of compact urban forms. However, some studies have hinted that urban form alone is not the predetermining factor in creating sustainable urban environments. These studies point to the negative environmental impacts of compact cities and the measures to negate the effects of urban sprawl. Environmental considerations aside, urban sprawl led to disjointed cities that are polarised socioeconomically. This is most pronounced within the Global South and Postcolonial context.

The scars of colonialism are evident across countries in the Global South, especially within these countries' urban environments. The effects of colonial urban policies were exacerbated by the formation of racially segregated cities. Segregated cities grouped urban populations along racial lines which served to enforce unjust societal structures. In South Africa, racial segregation was entrenched through the system of apartheid leading to what Davies (1981) refers to the Apartheid City model. The Apartheid City designated land and land use according to the racial classification of an area. People of colour were thus pushed to the periphery while whites were located in areas close to the centre of cities. Apartheid urban policies and post-apartheid urban sprawl led to South African cities which degrade the environment and polarise along socioeconomic lines. Central to these processes is mobility, as the current urban form and development leave those most in need of access to opportunity immobile.

The urban models discussed above emphasise the allocation of land use through the decision of individual actors within an urban environment. This might hold true within the Global North, but within the Global South structural constraints largely moulded urban forms. Cities, especially within the Global South, need to address unsustainable urban form. Accordingly, urban transport, the subject of the next section, is of important concern.

### **2.2.2 Urban transport**

The previous subsection investigated perspectives on how urban form is classified and what the implication of urban form is in the sustainability debate. The following section focusses on how urban transportation perpetuates unsustainable urban forms and how urban transportation can contribute to the sustainable restructuring of urban environments. The section discusses the types and modes of urban transportation within a Global North and Global South context.

Intra and inter transportation networks influence where cities develop and what structure cities take. This segment focusses on transportation within cities. In countries of the Global North, especially in America, there was a shift away from public transport toward private transport. The shift to private transport led to the decay of historic urban cores and decreased the viability of public transport systems such as commuter rails, buses and subways. The proliferation of private transport led to the prioritisation of highway infrastructure above infrastructure for public transport. Along with private transportation came a new set of traffic problems, either foreseen or unforeseen. Traffic problems resulting from private transport include the congestion of traffic, accidents, inadequate pedestrian infrastructure, negative environmental impacts, and parking difficulties (Pacione, 2005). These traffic problems are directly related to the use of motorised modes of transport and are worsened by the disregard of and an abandonment of non-motorised modes of transport. Non-motorised modes of transport, including walking, cycling, skateboarding etc., are thought to pose viable alternatives in solving the issues related to motorised transport.

The higher level of development of countries in the Global North lends itself to a system of private transportation as people are able to afford cars. In countries of the Global South, this is not the case for the majority of the population. Thus the expansion of private transport infrastructure exacerbates the effects of disjointed urban structures as explained in the previous subsection. In spite of this, few countries from the Global South have pursued the development of public transport networks. A lack of investment in public transport has resulted in market responses to the high demand for public transport in the Global South (Pacione, 2005). Informal public transport systems are road based and make use of various types of motorised or in some instances non-motorised modes of transport. Informal public transport operators take advantage of existing road infrastructure provided by the state or parastatal companies. NMT does not enjoy the same advantage as pedestrians and cyclists are vulnerable to motor vehicle collisions if they were to use existing road infrastructure. However, despite a demand for NMT infrastructure transport authorities from the Global South have done little to meet the demand through infrastructure provision.

The above subsection illustrates how private transportation in both the Global North and South facilitates the diffuse nature of current urban development. This type of urban development limits the mobility of people as the transport system only works for those who can afford a motor vehicle. In addressing the challenges with regards to urban transportation it is essential that future transport systems are built on universally accessible modes of transport. No mode of transport is more widely accessible than walking.

The subsections on urban form and urban transport above discussed each feature separately to understand them individually. However, urban form and transport are inextricably linked in the formation and perpetuation of urban environments (Ewing and Cervero, 2001). Older cities developing with modes of non-motorised modes of transport are more compact and clustered than cities developing with motorised modes of transport. Investment in private transport systems instead of public transport systems drives and inherently justifies unsustainable urban development patterns such as sprawl. In South Africa, the effects of apartheid urban geographies are still felt as there is a geographic mismatch between areas of need and areas of opportunity. Making areas of opportunity accessible is an issue of mobility. Mobility, in turn, is limited by the investment and prioritisation of infrastructure provision for private car ownership. The focus of transport investment should shift to public transport systems served by non-motorised modes of transport. The most basic of NMT is walking and the aspects of walkability are the focus of the following section.

### **2.3 Walkability: what, why, and how much?**

The following section delves into the concept of walkability. The first subsection provides a review of how walkability is defined and explained within the literature. From the review, the key characteristics from definitions are outlined and this study's definition of walkability is stated. The second subsection deals with why it is important from an environmental, economic and social perspective to enhance the walkability of urban environments. The third subsection chronicles the trends identified within previous walkability research. The final subsection reviews how walkability is measured, objectively or subjectively, within the urban environment. The section concludes with a brief synopsis and provides a starting point for the examination of the application value of walkability research to urban planning.

#### **2.3.1 Defining walkability**

As a component of NMT, walking receives much attention as a research topic within a wide spectrum of academic disciplines (Lo, 2009). Walkability forms part of this diverse and ever-growing body of research literature. The diverse incorporation of walkability by various academic disciplines led to similar and divergent definitions of walkability (Southworth, 2005). This subsection provides a chronological account of how walkability was and is defined.

In a study of residents' perception of neighbourhood walkability, Leslie et al. (2005) determine three predetermining factors influencing walkability as intersection density, dwelling unit density, and land-use mix. According to Leslie et al. (2005), a neighbourhood's level of walkability is positively correlated

to density and land-use mix. Frank et al. (2006) builds on the definition of Leslie et al. (2005) but adds the aspect of retail floor area ratio. The inclusion of retail floor area ratio in the definition underlines the importance of destinations for walking. In compiling a Global Walkability Index (GWI), Krambeck (2006) defines walkability as: "the safety, security, economy, and convenience of travelling by foot." (Krambeck, 2006:13). This definition is more general than the previous two and can be explained by the global scale of Krambeck's 2006 study. Forsyth and Southworth (2008) highlight the diversity of what the term walkable i.e. walkability denotes. They express walkability as encapsulating the closeness (short walking distances), traversability of urban environments are, safety (from traffic), pedestrian infrastructure, and a pleasing pedestrian experience.

Park (2008) defines walkability as a walker's perception of the quality of the walking environment measured through urban design attributes. This definition moves toward an abstract conceptualisation of walkability. Lo (2009) turns the definition debate inwards by highlighting how the definition differs across the various academic disciplines studying walkability. The relative nature of defining walkability is illustrated by the Pivo and Fischer's (2011) investigation of how the walkability of an area affects the rate of return when investing in real estate. According to Pivo and Fischer (2011), walkability is the degree to which an area within walking distance of a property encourages walking trips from the property to other destinations (Pivo and Fischer, 2011:186).

A robust definition of walkability is given by Mayne et al. (2013), whereby walkability is defined as the capacity of the built environment to accommodate and support walking for a wide variety of purposes. Moayed et al. (2013) emphasise the importance of differentiating between the concepts of walkability and walking the activity. They assert that the difference is that walking is an activity, whereas walkability is a measure of how conducive the urban environment is to walking (Moayed et al., 2013). Azmi and Karim (2012a) echo the environmental considerations in defining the walkability of an area, as they highlight previous studies referring to how "friendly" an urban environment is to the activity of walking. Gilderbloom, Riggs and Meares (2015:14) argue that accessibility-based factors like destinations, land-use mix and demographic composition are the predetermining factors of the walkability of an area. Walkability is also referred to within the New Urbanism movement as shown by Kim (2015). According to Kim (2015), New Urbanism principles best encapsulate the components of walkability as it encourages short walking distances and pedestrian-friendly street design. Lastly, Yusuf and Waheed (2015) define walkability as how suitable the built environment is to walking. Suitability infers the factors of land-use mix, street connectivity and residential density (Yusuf and Waheed, 2015).

It is clear from the above that there is not a uniform definition of walkability. Instead, definitions relate to the realm wherein studies are conducted. Studies seeking to measure walkability through urban environmental features focus on quantifiable aspects. Other studies investigating perceptions incorporate abstract concepts relating to the sense of place of an area. This research project acknowledges the importance of perceptions of walkability. However, for the purpose of the study and the available data, walkability is defined through the quantitative measurement of street connectivity, residential density, land-use mix and walkable areas around destinations. The following subsection takes the investigation further by highlighting studies arguing for the benefits of walkability.

### 2.3.2 Perspectives on walkability

Jeff Speck, an author and advocate for walkability, states that the argument for walking is threefold (Speck, 2013). Firstly, walking is environmentally friendly as it reduces pollution produced by the use of cars (Whitelegg and Williams, 2000; Toronto Public Health, 2012). Secondly, there are direct and indirect economic benefits in encouraging walking (Sohn, Moudon and Lee, 2012; Litman, 2004). Lastly, the promotion of active transport such as walking benefits the general health of society whilst also reducing the number of traffic collisions (Andrews et al., 2012; Litman, 2004). The following subsection discusses each the arguments for walkability in more detail.

Human-induced climate change poses a threat to every city in the world. Transport is a major contributor to the release of greenhouse gas emissions into the atmosphere (Chapman, 2007; Giles-Corti, Shilton and Falconer, 2010). To cease all transport activities is an unviable solution thus there is a need to explore sustainable transport alternatives. Converting existing fossil fuel dependent modes of transport to run on renewable energy is one such alternative (Chapman, 2007). However, successful conversion solutions have proven to be elusive largely due to the costs involved. NMT, in the form of walking and cycling, poses a viable sustainable cost-effective alternative. Komanoff et al. (1993) estimated that non-motorised modes of transport displace between 1,2% and 5,0% of passenger vehicle emissions. They further estimate that this offset could be increased to between 4% and 16% if transport policy prioritised NMT infrastructure (Komanoff et al., 1993). Mohan and Tiwari (1999) also call for the prioritising of NMT infrastructure and claim that sustainable urban transport is unattainable unless the needs of NMT are met. Chapman (2007) posits a shift to NMT as a feasible short-term solution which only necessitates behavioural changes.

Adam Smith referred to economics as the dismal science given the unpredictable nature of economic processes and actors. Thus the economic benefits of walkability should be considered with caution. In

the year 2000, the Commission for Liveable Communities listed some of the economic benefits recorded from studies investigating the matter (Local Government Commission, 2012). The benefits are; walkable areas outperform car-dependent areas regarding return on investment, restricting the number of cars and introducing traffic calming measures in areas lead to an 18% to 20% increase in house prices, walkable urban environments are magnets for tourism, and lastly walkable environments spur retail sales (Local Government Commission, 2012). Ryan (2003) builds on the previously mentioned studies but adds how walkable environments save costs to the individual (commuting cost: monetary and time) as well as for the public at large as the delivery of public services is cheaper in dense urban environments than suburban developments. Leinberger and Alfonzo (2012) found in their economic study of walkable neighbourhoods that walkable neighbourhoods attract economic opportunities, residents in walkable neighbourhoods save on commuting costs but house prices are higher, and walkable neighbourhoods attract wealthy and highly educated groups.

Modes of active transportation, such as walking, have the potential to address levels of inactivity resulting in obesity. Further, modes of active transport are widely accessible and could substantially increase the level of mobility of a society. Saelens, Sallis and Frank (2003) found that residents in areas with high densities, high degrees of connectivity and a greater mix of land use reported higher rates of walking and cycling than areas without the mentioned attributes. Devlin, Frank and van Loon (2009) found a similar correlation as Saelens, Sallis and Frank (2003) but add that a small investment in walkability translates into noticeable increases in the general health of an area. Elvik's 2009 study shows that as pedestrian traffic volumes increase there is a reduction in the total number of traffic collisions, thereby reducing the risk pedestrians take when walking. Litman (2004) found the following socioeconomic benefits of walkable urban environments: they provide basic mobility, efficient use of land, improve the fitness of residents, spur economic development, and are better suited to meet equity objectives.

The studies mentioned above are categorised according to the environmental, economic and social benefits of walking. In light of the mentioned studies, it can be stated that walking is central to achieving sustainable transport systems as it contributes to the environmental, economic and social goal of sustainability. The following subsection details the various trends from previous walkability research.

### 2.3.3 Trends within walkability research

The importance of context wherein walkability research is conducted was noted in the subsection defining walkability. Therefore this subsection reviews previous walkability studies within the fields of health sciences, urban and transport planning, property studies, and GIS.

Research on the effects of the built environment on health is reminiscent of environmental deterministic studies of the past. However, these studies have provided for a large portion of the literature covering walkability. Some of the earlier research focussed on the positive correlation between aspects of the built environment and the level of physical activity of people (Frank et al., 2005; Frank et al., 2006; Owen et al., 2007; Sundquist et al., 2011). Two successive studies by Frank et al. (2005) and Frank et al. (2006) found a positive correlation between features of the built environment (i.e. residential density, street connectivity and a mix of land-use) and the level of physical activity (i.e. >30 minutes a day) recorded in areas. Owen et al. (2007) also found a positive relationship between an area's level of walkability and the frequency of walking done by individuals for transport.

Other researchers have questioned the validity of studies describing the positive relationship between walking and walkability due to the lack of perceived walkability within these studies (Leslie et al., 2005; Giles-Corti et al., 2006; Frank et al., 2010b; Gebel et al., 2011). How measures of walkability and physical activity can be standardised across countries is the subject of studies within the health sciences (van Dyck et al., 2012; Cerin, 2013; Mayne et al., 2013; Giles-Corti et al., 2014). Recent studies concerned with standardising walkability measures have investigated how to include countries from the Global South given the lack of research within this unique context (Oyeyemi et al., 2013; Reis et al., 2013; Adlakha et al., 2016; Oyeyemi et al., 2016).

Walkability studies relating to urban and transport planning revolve around how design-led interventions could facilitate walkability, how the provision or adaptation of existing infrastructure effects walkability and the importance of studying walkability within the Global South. Southworth (2005) lists six design elements of a successful pedestrian network: connectivity, linkages to other modes, fine-grained land-use patterns, safety, quality of the path and the path context. How these urban design elements are measured is the subject of related studies (Ewing et al., 2006; Park, 2008; Frank et al. 2010a). Recent studies drop down a scale and study design elements separately, or attempt to research the issue as a whole through policy intervention (Learnihan et al., 2011; Blečić, Cecchini and Trunfio, 2015). Research on infrastructural intervention underlines the importance of pedestrian infrastructure and the accessibility of community facilities (Barman and Daftardar, 2010; Azmi and Karim, 2012b; Azmi et al., 2015). In response to a lack of walkability research within a Global South context, recent studies on walkability

have attempted to examine the context-specific elements influencing walkability in Southern countries (Smit et al., 2011; Karim and Azmi, 2013; Singh, 2016).

Recently, the influence of how the walkability of an area affects the real estate market within that area has come to the fore. The economic benefits of walkability were discussed in a previous subsection, with an increase in house prices being positively correlated to the walkability of an area (Local Government Commission, 2012). This relationship is also found in successive studies on the impact of walkability on house prices (Pivo and Ficher, 2011; Gilderbloom, Riggs and Meares, 2015; Kim, 2015; Li et al., 2015). However, the positive relationship between walkability and house prices is not necessarily a rule (Armstrong and Greene, 2009; Boyle, Barrilleaux and Scheller, 2014; Kim, 2015). Armstrong and Greene (2009) highlight the spatial variability in the relationship between walkability and house prices. Their study found a negative relationship between walkability and house prices in Gresham, US (Armstrong and Greene, 2009). Studies by Boyle, Barrilleaux and Scheller (2014) and Kim (2015) found that walkability is not a statistically significant factor influencing the value of homes and suggest that other environmental factors affect the value of homes.

GIS provides an ideal platform for conducting walkability assessments. GIS enables the overlay of different spatial datasets producing integrated spatial representations. GIS is used to quantify urban environmental features influencing walkability (i.e. land-use mix, street connectivity, etc.) by overlaying quantified datasets and producing maps displaying areas of low, medium or high walkability (Leslie et al., 2007; Adams et al., 2014; Azmi and Ahmad, 2015; Cubukcu et al., 2015; Murekatete and Bizimana, 2015). Walkability studies incorporating GIS methods and techniques illustrate that GIS is suited well for accurately measuring urban features affecting walkability. These studies thus present a compelling argument for utilising GIS methods and techniques in measuring walkability. Notwithstanding a relative lack of qualitative validation of the studies' findings, these studies make an invaluable contribution to identifying walkable areas.

This subsection reviewed the different fields of research wherein walkability is studied. Of importance to this research project is research pertaining to urban and transport planning as well as GIS. The above subsection indicates a lack of research focussed on the application of walkability index results within urban planning practices. This project aims to contribute to the literature relating to the application value of walkability indices within the field of urban planning. The numerous studies drawing upon GIS-based walkability assessments serve as a justification for incorporating this assessment method within this

research. The following subsection explores the methods utilised in previous research measuring walkability.

### 2.3.4 Measuring walkability

The previous subsection touched on some of the walkability studies within GIS. This subsection elaborates on similar and different studies measuring walkability. The following two segments discuss studies measuring walkability according to categories relating to the objective (GIS-based) and perceived measures of walkability. The final segment explores literature stressing the importance of considering both objective and perceived measures of walkability.

Studies based on the objective assessment of walkability focus on quantifiable urban features such as street connectivity and residential densities (de Sa and Arden, 2014). However, from the studies reviewed, how objective measures of walkability are determined and weighted differ from study to study. Frank et al. (2005) incorporate three measures in assessing the walkability of an area; net residential density, street connectivity, and land-use mix. They define residential density as “the number of residential units per residential acre”, street connectivity as “the number of intersections per square kilometre”, and land-use mix as “the evenness of distribution of square footage of residential, commercial, and office development” (Frank et al., 2005:119). The same three measures are also included in the study by Leslie et al. (2005). Leslie et al. (2005) define street connectivity as “the number of true interconnections within a given area”, and land-use mix as “the distribution of development across five uses (residential, commercial, industrial, recreation and other)” (Leslie et al., 2005:228). Frank et al. (2006), Leslie et al. (2007) and Frank et al. (2010a) add the retail floor area ratio to the measures of walkability, with floor area ratio defined as “retail building floor area (in square foot) divided by retail land area (in square foot)” (Frank et al., 2006:77). These four measures influence the walkability of neighbourhoods as separate or complementary entities (Frank et al., 2010a).

Giles-Corti et al. (2014) alter the definition of the land-use mix as the proportion of land-use to the total number of relevant land uses in an area. The replicability of walkability incorporating the three base measures of residential density, street connectivity and land-use mix is shown by Adams et al. (2014). They conducted a walkability assessment of 15 cities across 12 countries and found the three mentioned walkability measures are applicable across different cultural settings (Adams et al., 2014). However, Murekatete and Bizimana (2015) highlight the need for context-specific measures of walkability in their walkability assessment of Kigali, Rwanda. Along with the three main measures, Murekatete and Bizimana (2015) add the measure of proximity which includes the sub-measures of “topography and

network-based proximity” and “main destinations”. The inclusion of the sub-measures allows for a locally nuanced walkability assessment.

The above studies cover the objective measurement of walkability but walkability can be subjective (Brown et al., 2007). The subjectivity of walkability is highlighted by the review of literature about the perception of walkability. Krambeck’s 2006 PhD study compiled a GWI based on the three components (safety, security, and policy support) with each component having a set of variables (Krambeck, 2006). The variables as stated by Krambeck (2006) perfectly illustrate the subjective nature of how the GWI assesses walkability. A valid question is how does one decide on what subjective variable to include in such an assessment? Giles-Corti et al. (2006) attempt answer this question. They illustrate the importance of conducting interviews in order to gain a deeper understanding of what variables are deemed important by the residents of a neighbourhood. Cerin et al. (2007) illustrate how perceived measures of walkability can be applied across different geographic and cultural settings. Cerin et al. (2007) used the Neighbourhood Environment Walkability Scale (NEWS) questionnaire to assess the perceived walkability of areas within high and low objectively measured walkability. The research found that the response to the NEWS questionnaire correlated to objectively measured walkability. Manaugh and El-Geneidy (2011) emphasise that walkability measurements have a different impact on individuals and households. A study by Yusuf and Waheed (2015) reviewed a number of walkability measurements and note the importance of on the ground observations in determining the walkability of an area.

Studies incorporating both objective and perceived measures of walkability aim to determine the correlation between two types of walkability assessments. Leslie et al. (2005) use the three primary measures of walkability to investigate residents’ perception of walkability attributes. Similarly to Cerin et al. (2007), Leslie et al. (2005) used the NEWS survey to gain an insight into how walkability is perceived by residents. They found that residents in high-walkable neighbourhoods rate the primary measures of walkability consistently higher than residents from low-walkable neighbourhoods (Leslie et al., 2005). Gebel et al. (2011) demonstrate that perception of walkability is an important factor influencing individuals’ level of physical activity. They found that respondents with a negative perception of a neighbourhood’s walkability led to respondents walking less even in areas that are objectively rated as highly walkable (Gebel et al., 2011). Research by Jun and Hur (2015) illustrate which of the perceived or physical walkability measures affect the social environment most in Franklin County, Ohio. According to Jun and Hur (2015), there is a positive relationship between the level of perceived walkability and the enhancement of a neighbourhood’s social environment.

This subsection highlighted three broad categories of walkability assessments. The review of objective walkability assessments shows that there are at least three common measures of walkability which can be applied across cultural contexts. Studies on perceived walkability assessment stress the importance of qualitative or subjective assessments of walkability. This is reinforced by the number of studies referenced incorporating both objective and perceived walkability assessments. The scope and timeframe of this research project lend itself to an objective walkability assessment of the CCT. However, the study is sensitive to the value of measuring people's perception of walkability.

The above section dealt with aspects regarding the concept of walkability. This review enables an appropriate definition of walkability that matches the scope of the research project. Walkability and the components of walkability will be described in chapter four along with the research methodology. The subsection discussing the environmental, economic and social benefits of walkability provides a sound base and justification for conducting the research from an academic and practical stance. The review of studies from different academic disciplines displays the relevance of this research not only for urban planning but also the field of health sciences, GIS and property studies. Finally, an assessment of previous studies measuring walkability locates the study within the category of objectively assessed walkability measurements. Simply calculating the walkability of areas is of little use. Thus the following section discusses the application value of walkability research to urban planning.

## 2.4 The application of walkability indices

Previous walkability research is not always clear on recommendations to improve the walkability of urban environments. A possible reason for the apprehensive approach to stating interventions or recommendations is the wide range of factors influencing the walkability of a city, neighbourhood or street. Research venturing an opinion on how to improve walkability relates to aspects of pedestrian infrastructure provision, how to design walkable neighbourhoods and policy interventions.

Southworth (2005) identifies six key criteria in creating a successful pedestrian network, stated in a previous section. Designing such pedestrian networks, within an American context, requires a measurement of walkability, a revision of current policy instruments, understanding walking behaviour, and encouraging a collaborative planning process (Southworth, 2005). Barman and Daftardar (2010) qualitatively evaluated the walkability of Lucknow, India and based on their findings recommend design parameters for pedestrian infrastructure. The design parameters recommended relate to safety, convenience and attractiveness, policy support, and integrating pedestrian infrastructure around public

transit nodes (Barman and Daftardar, 2010). Barman and Daftardar (2010) provide elaborate on how to increase the walkability around public transport nodes through: identifying links suitable for fully pedestrian lanes, incorporating "Woonerf" design principles, synchronizing traffic flows, increasing the visibility of police presence, encouraging car-free zones, and lastly to strategically consider the location of parking facilities. Moayed et al. (2013) contend that understanding the qualities of pedestrian infrastructure influencing walkability contributes to achieving larger goals such as sustainable transportation. Moayed et al. (2013) encourage pedestrian-friendly streets through design aspects such as interconnected streets, streets prioritising pedestrian flows instead of vehicular traffic, increasing street intersections, traffic calming measures, appropriate traffic signage, appropriate landscape architecture, pedestrian-scaled street lighting, and the provision of street furnishings.

Smit et al. (2011) consider the effect that urban planning has on the rates of physical activity within low and middle-income countries. Suggestions to increase the walkability of neighbourhoods in low and middle-income countries include: creating finely grained street networks in neighbourhoods, increasing land-use mix, upgrading public spaces (recreation) and sidewalks, and improving street lighting (Smit et al., 2011). In promoting sustainable urban neighbourhoods, Azmi and Karim (2012a) recommend increasing the space/room for walking, locating community facilities at the centre of neighbourhoods, and prioritizing the placement of green design features (trees, gardens etc.). Azmi and Karim (2012b) build on these findings through studying the walking behaviour of residents to community facilities in low-cost and medium-cost housing projects. One of the key recommendations of the study is the creation of a set of accessibility standards, which should ensure that all community facilities are accessible through walking. The accessibility standards should be based on a neighbourhood's unique context which considers the local condition and existing spatial patterns (Azmi and Karim, 2012b).

Designing a walkable neighbourhood can be achieved through design interventions as well as active citizenship, as presented in the Doable City Reader. One such design intervention is the retrofitting of cul-de-sac street patterns for walkability through creating a "fused" street pattern. The intervention "fuses" the area between cul-de-sacs through pedestrian walkways thereby increasing the connectivity of the street network (The Doable City Reader, 2014). A "fused" street pattern is best suited to suburban neighbourhoods with a large number of cul-de-sacs in close proximity to one another. Active citizenship can contribute to walkability through communities self-organising to improve pedestrian signage. For example the pinning of waypoints on street lampposts indicating the walking time to places of interest within a neighbourhood (The Doable City Reader, 2014). Blečić, Cecchini and Trunfio (2015) present how a walkability index contributes to the design of neighbourhoods through identifying design features

hampering the walkability of an area. Blečić, Cecchini and Trunfio (2015) further model, by means of an algorithm, how improvements in design features could affect the walkability of a neighbourhood.

This approach is in stark contrast to the research of Stafford and Baldwin (2017) stressing the importance of considering the diversity of residents' needs within a neighbourhood. The study focused on how walkability studies overlook the characteristics of pedestrians such as ability and age. Stafford and Baldwin (2017) recommend the inclusion of such characteristic within neighbourhood design practices, thereby creating an inclusive pedestrian environment. The relationship between the built environment and health is the subject of a study by Stockton et al. (2016). The study claims that a walkability index is not only of value to urban planners but also to healthcare professionals as it provides insights to what design elements contribute to healthy neighbourhoods. This recommendation is supported by Zuniga-Teran et al. (2017), which found a positive relationship between walkability and physical activity. Based on their findings, Zuniga-Teran et al. (2017) encourage the use of walkability frameworks to promote physical activity within neighbourhoods.

Walkability research also addresses how policy environments affect walkability. Stonor et al. (2002) conducted a qualitative walkability assessment within London, the UK. The study assisted the Transport for London's walking policies and encouraged policies to consider two variables related to walkability as identified in the study. The two variables are footway access and ground floor activity (Stonor et al., 2002). Park's 2008 walkability study proposed two policy recommendations which relate to transport oriented development policies and street design guidelines. Walkability assessments assist transport-oriented developments through identifying a critical walking zone wherein efforts to increase path walkability should be concentrated (Park, 2008).

Park (2008) set out five principles essential to street design guidelines aimed at increasing the walkability of an area; these principles are: the buffering of traffic impacts (reducing negative impacts of vehicular traffic movement), improving the sidewalk environment, eliminating the barriers between public and private spaces (increasing the visual access between the two spaces), find the right scale and enclosure, find the "right" combinations of building uses (e.g. prioritise pedestrian related businesses above auto and construction-related businesses) (Park, 2008:197-200).

Frank et al. (2010a) note the opportunities of walkability indices informing urban planning and engineering practice in the assessment of areas. Walkability index results can provide a good indicator of an area's suitability for public transit investment (Frank et al., 2010a). Walkability indices can assess the

climate change impacts of the relationship between the design of neighbourhoods and travel behaviour and patterns (Frank et al., 2010a). A walkability index can also help determine where certain types of destination should be located (Frank et al., 2010a). Walkability indices serve as a tool in assessing mental health, sense of community, and what actions would contribute most to increase the overall quality of life in an area (Frank et al., 2010a).

The Doable City Reader references two examples from the US illustrating the effect of policy interventions on walkability. The first relates to how the prioritisation of modes of NMT can result in an increase in walkability. The residents of Hamburg, New York were in opposition to a state plan seeking to widen a road to increase vehicular traffic. In consultation with a walkability expert, the community compiled an alternative plan. The alternative plan narrowed vehicle lanes, added bicycle lanes on either side of the road, placed more pedestrian crossings along the road, shortened pedestrian crossing distances, and planted more trees along the road (The Doable City Reader, 2014). This change in policy priority led to a rise in business occupancy rates and an increase in property values along the street. Another policy intervention related to walkability is the Safe Routes to School program, which aimed to encourage school children to walk to school. The actions taken to achieve this goal was both design-led (providing dedicated pedestrian walkways, increasing traffic calming elements etc.) and community-based (chaperoned walking busses, public education etc.) (The Doable City Reader, 2014).

The above section discussed the recommendations of previous studies in applying the findings of walkability research. Recommendations relate to pedestrian infrastructure provision, neighbourhood design and policy assistance. Based on these recommendations, walkability indices have the potential to identify suitable areas of pedestrian infrastructure investment and assess what neighbourhood design elements are required to increase the walkability of a neighbourhood. Policies relating to urban planning are inherently bound to space and constrained by a finite amount of available resources for implementation. A walkability index poses an opportunity as it locates areas where best to concentrate planning interventions that would affect the greatest public value. The following section concludes the chapter by reflecting on the theme covered in the chapter.

## 2.5 Walk the talk

This literature review provides the academic background to this research project and covers topics regarding urban planning debates, the relationship between urban form and transport, and the academic and practical discourse regarding walkability. The section on urban form and transport illustrates the

importance of considering the effects modes of transport have on the structure of the urban form. The section on walkability provided a review of definitions of walkability, the benefits of encouraging walking as a mode of transport, and the perspectives on measuring walkability. The second to last section assessed the application value of walkability research. GIS is a recurring research tool in most of the studies objectively measuring walkability. How this study incorporates GIS will be justified and discussed in chapter four of the dissertation. Chapter two provides a good context for the current status quo of what is hindering walking and what could be done to enhance walking as a transport mode of choice. This chapter provides the necessary background for the research to review NMT policy and approach research methodology which is the subject of chapters three and four, respectively.

### 3. Walkability within transport policy discourse

The preceding chapter provided the theoretical base and frames for this research project within academic discourse regarding walkability. The following chapter builds on the academic base by reviewing NMT policy discourse. The chapter first highlights some examples of effective NMT policy interventions from around the world, which underlines the impact NMT policies have on walkability. The chapter then presents a policy review at three broad scales, an international scale, nation scale (South African NMT policy), and a local scale (specifically the Western Cape and the CCT). A discussion of all three scales is presented as these three spheres operate in relation to one another. This is most evident in countries where the national policies set the legislative framework wherein local NMT policies are drafted. This chapter highlights trends in NMT policies, identifies challenges to urban transport based on the policy review and outlines the policy mechanisms to facilitate the walkability of urban environments.

#### 3.1 The importance of non-motorised transport policy

The previous chapter dealt with academic insights and perspectives on the application of walkability research. This section gives attention to the examples of cities' efforts to encourage walking as a preferred mode of transport. The cities discussed in the section are located in differing contexts e.g. Europe, North America, and Australia. The examples provided present some plausible policy interventions which could be adopted to encourage walking in the CCT.

The first city presented as a possible precedent is the city of Zurich in Switzerland. The city is old and therefore was designed to accommodate pedestrians. How the city has resisted the temptation of vehicular traffic is noteworthy. In 1996 Zurich accepted a decree described as "a historic compromise", which simply addressed how the city dealt with parking (Eckerson, 2014). According to the decree, the number of parking spaces within the city was capped, indefinitely. This meant that if any new parking was built in the city the same number of parking spaces would be cleared from somewhere else in the city and converted to public spaces (Eckerson, 2014). This decree has led to innovation in the supply of parking (mostly supplied underground) and an increase in the number public spaces encouraging an active street life i.e. walking.

Today Copenhagen is viewed as one of the most pedestrian-friendly cities not only in Europe but also the world. Copenhagen's reputation was earned through a set of urban planning and design principles which were included in policy documents and implemented from the 1960's. Copenhagen transformed into a pedestrian-friendly city through adopting a ten-step plan, these steps are: convert streets into

pedestrian thoroughfares, reduce traffic and parking gradually, keep scale dense and low, honour the human scale, populate the core, encourage student living, adapt the cityscape to changing seasons, promote cycling as a major mode of transportation, and make bicycles available (Newurbanism.org, 2017). In taking and committing to these steps, Copenhagen proved that active living is first, not climate dependent and secondly, cost-effective.

Amsterdam is regarded as the active transport capital of Europe with a large percentage of people making use of either walking or cycling as their primary mode of transport. However, bicycling has become the preferred mode of transport which necessitated the city to encourage walking through investing in walkability (Embark Network, 2017). The city is investing in walkability through the creation of new public spaces. These new public spaces feature two important design elements encouraging walking. The first is the reduction of the speed limits around these public spaces to 30 km/h. This increases pedestrian safety and reduces the opportunity costs of using active transportation (Embark Network, 2017). The second feature is the provision of segregated lanes for different modes of transport. This buffers pedestrians from vehicles and contributes to the room available for walking (Embark Network, 2017).

Some of the examples referred up until this point could raise questions regarding the cost of implementing some of the reforms mentioned. Another point of contention, when considering Cape Town, is that the cities mentioned above are all old cities, i.e. were built for pedestrian transport. In many regards, Cape Town today resembles an urban form which is more reminiscent of a typical sprawling American city such as Oklahoma City. Oklahoma City demonstrated that urban form can be changed. The city started its transformation 20 years ago when the newly elected mayor sought to reduce the incidence of obesity in the city (Leach, 2015). In support of this objective, the city council voted for an additional tax dedicated to funding infrastructure improvements projects encouraging active transport (Leach, 2015). Oklahoma City represents a feasible example that it is possible to transform a sprawling city into a city embracing active transport.

Like an American city Melbourne, Australia experienced urban decay during the latter half of the 1980's, which in turn fuelled suburban development. However, the city turned this downward trend around through pursuing urban policies which increased the walkability of the inner city. The main design feature was a set of building design rules which prohibited the construction of buildings with long blank facades. These design rules led to the construction of buildings with active frontages and a diversity of small-scale commercial spaces. Another success of Melbourne is the conversion of laneways

to pedestrian-only thoroughfares. Laneways are reminiscent of 10 meter wide alleyways which were converted into a pedestrian network housing an assortment of destinations for pedestrians. The Melbourne experience shows how small but holistic interventions result in massive increases in the walkability of cities.

The above examples illustrate a wide range of possibilities and options to any city looking to foster or maintain a strong pedestrian culture. Successful cities in this regard are those that have a long-term planning horizon and have an integrated approach to transport related issues. The mentioned examples represent how increasing walkability is a viable and cost-effective solution to urban transport problems. The following section reviews the NMT policies of international governing bodies.

### 3.2 International policy review

NMT policies drafted by international governing bodies are not enforceable and should rather be viewed as policy guidelines. In this regard, United Nations Habitat (UN-Habitat) released a set of policy guidance documents addressing the challenges in achieving sustainable urban transport. Other UN-Habitat policy guideline documents focus on the relationship between poverty and mobility, and also the specific urban transport challenges of different regions of the world.

A UN-Habitat working paper regarding the relevance of street patterns and public space illustrates how UN-Habitat conceptualises transport systems. According to this working paper, cities with sufficient streets, public spaces and a high degree of connectivity are highly liveable and more productive (UN-Habitat, 2013a). The policy guideline document calls for developing cities to be proactive in the provision of transport infrastructure through promoting street patterns which enhance connectivity. The UN-Habitat's Global Report on Human Settlement notes that in 2005 nearly 40% of urban trips are made with non-motorised modes of transport (UN-Habitat, 2013b). This percentage rises to 90% for poorer and smaller cities across the world (UN-Habitat, 2013b). Despite these percentages little is invested by cities, especially in developing countries, in the expansion of NMT infrastructure. The report lists the benefits of NMT as saving users the cost involved with motorised transport, being accessible to the most vulnerable members of societies, reducing traffic congestion, offering cities costs savings through limiting the construction costs of roadways and parking for cars, reducing pollution, encouraging compact land-use patterns, and increasing the economic productivity of cities (UN-Habitat, 2013b). The document calls for a revitalisation of urban and transport planning which encourage NMT systems that complement public transport systems around mixed land-use patterns.

Starkey and Hine (2014) investigated how policies could address the dual challenges of poverty and sustainable transport. They found a key challenge within urban transport is the delivery of cost-efficient transport services (Starkey and Hine, 2014). In solving the cost challenge Starkey and Hine (2014) emphasise the role modes of NMT, especially walking, can play in providing a cost-effective transport alternative in urban areas. Policy guidelines regarding mobility identify similar challenges as highlighted above but emphasise the socioeconomic constraints on mobility within developing countries (UN-Habitat, 2011). This is why region-specific policy guidelines for Asia and Africa were drafted (UN-Habitat, 2010; UN-Habitat, 2013c). The policy guideline for Africa states that African NMT policies need to foster a positive image of the use of NMT modes (UN-Habitat, 2010).

The above section illustrates that NMT is a policy priority of the UN and UN-Habitat. Although this trend is encouraging, it remains to be seen whether these policy guidelines are taken to heart by national transport policymakers. The following section explores whether these policy guidelines are specifically influencing South African NMT policies.

### 3.3 South African policy review

Evident from the international policy review is the importance of NMT in contributing to sustainable transport systems in developing countries. The following section investigates NMT within South African transport policy. The section outlines the current transport policy and then presents some academic perspectives on South Africa's policy approach to NMT.

During apartheid transport infrastructure was used as a physical barrier to spatially segregate different race groups. South African transport infrastructure was designed to limit connectivity instead of enhancing it. Post-apartheid transport policies sought to reconfigure and integrate cities. NMT was emphasised by the publication of the National Non-Motorised Transport Policy in 2008. The policy acknowledges the importance of NMT to the wider transport strategy and provides a detailed section highlighting the role of walking. The national policy seeks to enhance walking as a mode of transport through regulation (enforcing existing road laws), infrastructure (prioritising pedestrian infrastructure delivery), transport planning (including walking in travel demand management), safety (protection from cars and crime), and funding support (Department of Transport, 2008).

Mkhize, Mouws and Linders (2009) compared the provision of NMT infrastructure between South Africa and The Netherlands. The study identified three opportunities which are most relevant during the

planning stages of the implementation of NMT infrastructure. The opportunities are: “during the new development planning phase, incorporation in rehabilitation projects, and in identifying NMT networks.” (Mkhize, Mouws and Linders, 2009:1). Bickford (2013) states that an effective South African NMT policy hinges on a better understanding of the demand for NMT and the requirement of NMT infrastructure. Labuschagne and Ribbes (2014) critique the implementation phase of South African NMT policy. According to Labuschagne and Ribbes (2014), implementation is ineffective as the policy lacks conceptual design thinking as for example Universal Design and Complete Streets design paradigms (Labuschagne and Ribbes, 2014).

The above section illustrates that NMT, i.e. walking, is a South African policy priority. However, the critiques presented show that the policy framework has room for improvement. Key to the national policy is the policy statement calling for local municipalities to amend by-laws to reflect the objectives of the national NMT policy. The following section considers the NMT policy of the Western Cape Province and the CCT.

### **3.4 Western Cape Province and City of Cape Town policy review**

South Africa’s commitment to NMT is evident from the national policy review. This subsection provides a review of the NMT policies for the Western Cape Province and the CCT. Both policies should be related to the national policy objectives. How these policy objectives are achieved is left to the provincial and local policy environments.

The Western Cape NMT policy provides a clarification of the roles of each level of government. The National government is concerned with setting the policy, legislation and guidelines for provincial and local government. However, the national government has limited specific NMT tasks such as formulating NMT strategies. Provincial and local government have more responsibilities in the implementation of NMT policy. The provincial NMT policy focusses on guiding the planning process for NMT initiatives. The policy defines each stage in the planning process, from the identification of stakeholders to the maintenance of NMT infrastructure. The policy explains the guiding principles which NMT projects should aim to achieve. These principles are appropriate facility design, integrated transport, ensuring safety, increasing accessibility, sustainability, facilitating the provision of NMT infrastructure through institutional reform (Department of Transport and Public Works, 2010).

The CCT has an NMT strategy which is dealt up into two volumes. Volume 1 explains the status quo of NMT within the CCT. Volume 2 is the policy framework and sets out the problems with, strategies for, and design guidelines of NMT in the CCT. The problems which the policy aim to address are; inaccessibility, the poor state of NMT environments, poverty, existing unsustainable transport system, the negative perceptions regarding NMT, and silo approach to transport planning (City of Cape Town, 2005a). Each problem statement has a set of policies which aim to address the problem statement, either by policy reform or through infrastructural interventions. The design guidelines draw heavily on existing design guidelines as provided by the national and provincial government. The policy calls for the consulting of guidelines from the start of the planning process thereby prioritising the inclusion of NMT (City of Cape Town, 2005b).

The above section provides a general account of the provincial and local policy environments regarding NMT. The section explains the policy environment for NMT in the CCT. Specific strategies related to walking will be discussed in chapter six which demonstrates the application value of the walkability index to NMT planning the CCT.

### **3.5 Policy lessons**

This chapter provides a brief revision of the international, national and local policies guiding NMT. Walking is a mode of NMT, thus policies addressing NMT is of special concern for this study. From the precedent presented and the policies reviewed it is clear that there is recognition of the current and potential role NMT plays in creating sustainable urban transportation. This is stated at the hand of the number international policy guideline documents and initiatives driving NMT policy. The drafting of a separate national NMT strategy for South Africa is encouraging and signifies the attention national government is giving to NMT matters. The supra policy levels referred to until now have little real effect on how NMT is best affected. Local government is best suited to drive NMT policy implementation in South Africa. In this regard, the CCT, as well as the Western Cape Government, should be commended for their efforts to create a facilitative regulatory environment for NMT. How and where to apply these regulations, as they relate to walking, is the focus of this study. The following chapter thus presents the research methodology in compiling the walkability index.

## 4. Measuring Walkability

The literature review identified three main measures of walkability included in previous walkability assessments. These three measures are street connectivity, residential density and land-use mix. How these measures are calculated largely correspond across the studies reviewed with the exception of the land-use mix. The use of GIS as a research tool is a shared research characteristic in the majority of the studies reviewed in chapter two. This study also uses GIS, based on the sheer quantity of walkability studies employing GIS and also given these studies successfully validating research findings. Given the lack of walkability assessments within South Africa, a GIS approach allows the study to draw comparisons and highlight possible differences to previous research. This chapter outlines the GIS methods and techniques used in data collection, processing, and analysis. The first section of this chapter explains the reasons for choosing the scale of investigation. The second section describes how the data utilised in the study was sourced, processed, and presented for the variables of each measurement. The third section discusses the inherent pitfalls in quantifying urban environmental features.

### 4.1 Step 1: Choosing a suitable scale of investigation

The scale of investigation is an important factor in conducting walkability assessments in both a Global North and South context. This section describes how the enumeration areas for this study were determined. This section first discusses how the enumeration areas in previous studies were determined. Based on previous studies this section then explains how the enumeration areas for this study were determined. The section concludes by presenting the enumeration areas of the study.

The purpose of walkability assessments is a strong determining factor in the choice of enumeration area. Initial walkability assessments aimed to establish a relationship between physical activity and the built environment (Frank et al., 2005; Leslie et al., 2005). These studies investigated the physical activity of research participants in relation to the built environment around the research participants' residential addresses. These areas were drawn in one of two ways, the first was through creating a simple one-kilometre ring buffer around a participant's residential address and the second was through creating a one-kilometre network buffer from a participant's residential address. The difference in the two types of enumeration areas mentioned is significant. As a ring buffer is a conceptual area and does not take into account the aspect of street network connectivity. Within a ring buffer, adjacent areas that are close to each other, if measured in absolute distance, could be relatively far from each other when travelling along a real street network. The street network buffer thus provides a more realistic representation of where participants can walk to from their homes.

Studies focussed solely on assessing the walkability of areas have used predefined enumeration areas (Dobesova and Krivka, 2012; Jun and Hur, 2015; Murekatete and Bizimana, 2015). An example of such predetermined enumeration areas is census tracts. The smallest available census tract is preferable as it allows for the production of detailed disaggregated results. Utilising census tracts have both advantages and disadvantages. An advantage of using census tracts is that the results are easily relatable to other demographic data. This allows the results from walkability assessments to be easily cross-tabulated with other census data, making an investigation of relationships between walkability and other socio-demographic data possible. A disadvantage of using census tracts as enumeration areas is that it presents a conceptual area which does not incorporate limitations of the street network connectivity.

Previous studies investigating the physical activity and the built environment proved a positive relationship exists between walking and the presence of certain features of the urban form. Given this positive relationship, this study thus focusses on the objective assessment of walkability in the CCT. This purpose lends itself to using census tracts as enumeration areas. The 2011 Census tracts were thus used.

South African census tracts present various scales of investigation with the country as a whole being the largest and Small Areas being the smallest. This study incorporates two enumeration areas, the first is the Sub Place area census tract and the second is the Small Areas census tract (Figure 4.1 and 4.2). The Sub Place areas aggregate results but allow for the easy identification of areas that record high measures as calculated in this chapter. The Small Areas census tracts provide a disaggregated representation of the Sub Place results and allow for a detailed investigation into how walkability and its' measures differ within Sub Places.

The study thus includes two enumeration areas. This allows for the identification of broad trends as well as a detailed investigation of the results. The biggest difference between the two enumeration areas is the average area covered by a Sub Place or Small Area. The average area of Sub Places is 2.56 km<sup>2</sup> and 0.42 km<sup>2</sup> Small Areas. The measures of walkability within enumeration areas and how the variables of each measure were calculated is the subject of the following section.

### 4.2 Step 2: Measures of walkability

The selection of enumeration areas enables the measurement of walkability. The preceding chapters and sections refer to three main measures influencing walkability. This section discusses these three

measures along with a fourth which was included in this study. Each measure has a subset of one or two variables determining the quantity of the measure.

The first of the measures is that of street connectivity. According to Tresidder (2005) street connectivity is defined at the hand of five terms; “link”, “node”, “real node”, “dangle node”, and “circuit”. These terms of reference are used to measure street connectivity by calculating variables such as the intersection density, the street density, the connected node ratio, link-node ratio, average block length, effective walking area, gamma index, and alpha index of a given enumeration area (Tresidder, 2005). Each of these measurements requires specific sets of data. Based on the data available to this study two of the mentioned variables were incorporated in the analysis. The first is that of the true intersection density and the second is the true intersection to node ratio. Residential density is probably the least complicated measure included in this study. However, the availability of residential dwelling data for the study area limits the application of the measurement. To overcome the limitation of data availability household density was included as a variable of residential density. The land-use mix diversity for the enumeration areas was measured through two variables. The first is a land-use diversity index calculated using the CCT’s integrated zoning scheme data. The second is a land-use diversity index using the Department of Environmental Affairs’ land cover dataset. The final measure included in this study was that of destinations. Destinations were categorised into seven groups and a network buffer representing walking distances around each destination was calculated.

One measure utilised in previous studies is retail floor area ratio, i.e. the total retail floor area divided by the total area of the enumeration area. The retail floor area was omitted, as the data is unavailable due to the lack of building footprint data for the CCT. However, the inclusion of destination data, which includes commercial destinations, serves to offset possible limitations to the final result. The following subsections further detail the data collection, data processing and the representation of results for each of the variables calculated in the study.

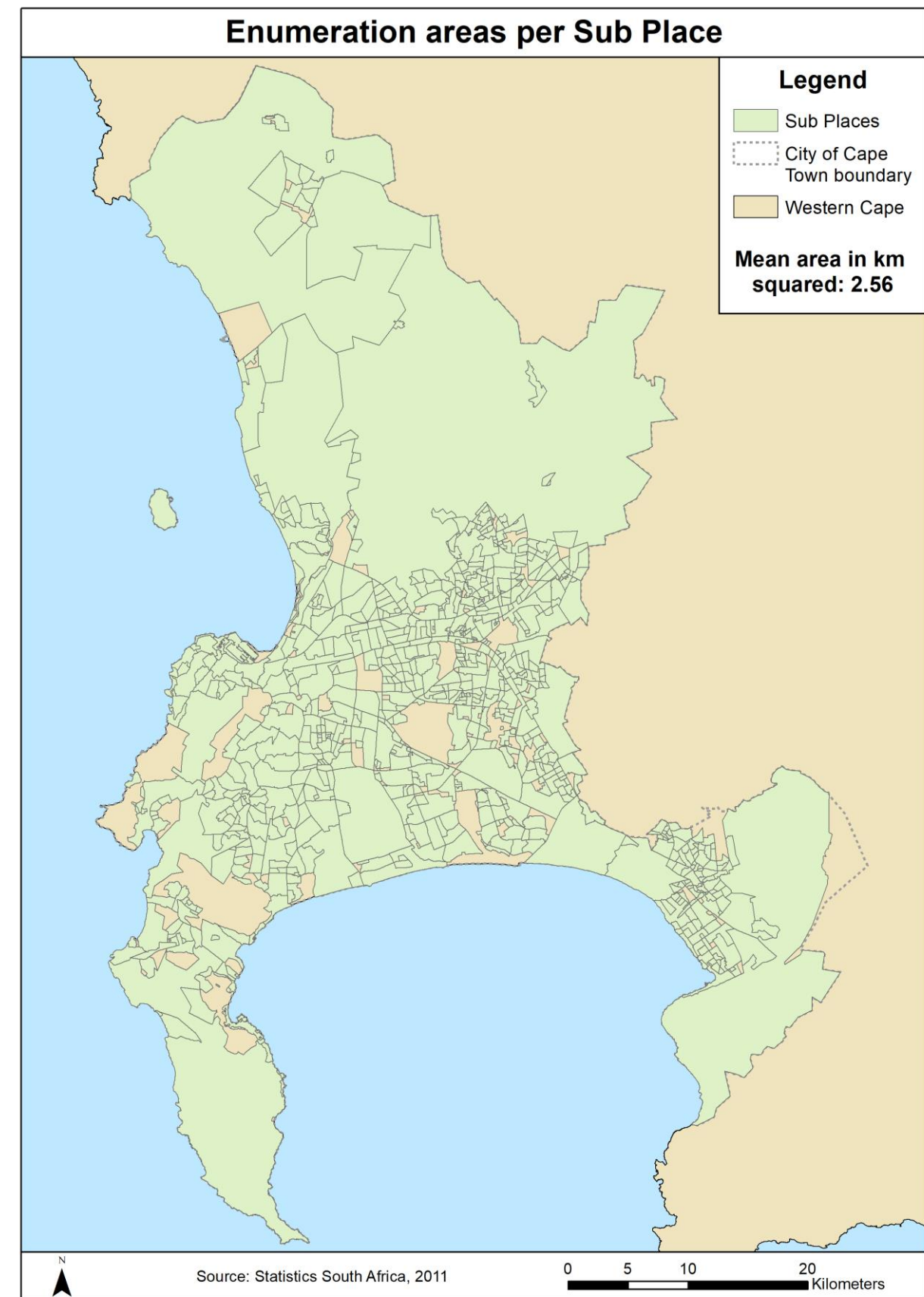


Figure 4.1: Enumeration areas per Sub Place

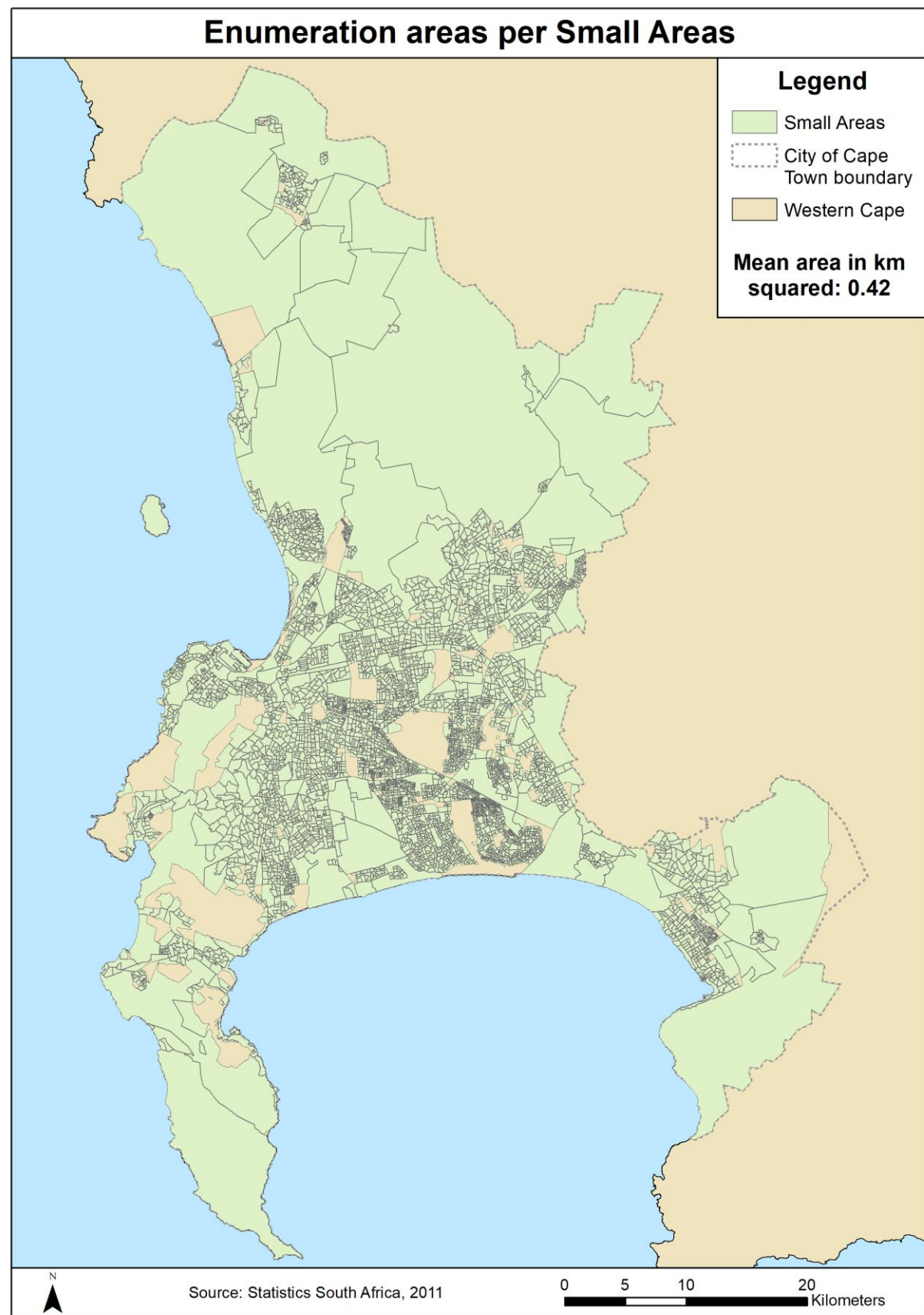


Figure 4.2: Enumeration areas per Small Areas

#### 4.2.1 True intersection density

The data for the true intersection density were sourced from the National Geospatial Information (NGI) database. Highway features were removed from the roads data. This was done as highways or other types of freeways do not allow for pedestrian traffic. The streets dataset was then reprojected to a Longitude of Origin (“LO”) 19 projected coordinate system and then clipped to the administrative area covered by the CCT.

In order to obtain the number of true intersections within the adapted street network, two processes were conducted. The first process is an intersect analysis on the street dataset itself. The intersect analysis creates a point dataset containing the points in the streets dataset where the line features intersect with one another. However, the intersect function did not create a single point feature for each of the intersections of the streets dataset. In order to extract a single true intersection, a street network dataset was created. The street network dataset was created in a file geodatabase and transformed the roads dataset into a network of links and nodes. The nodes in the street network dataset include all nodes i.e. true and dangling nodes. To extract the true intersections from the street network dataset an overlay analysis was conducted. The overlay analysis included the intersection dataset and the nodes from the street network dataset. From the overlay analysis, the number of true intersections was identified by extracting the nodes which intersected with features from the intersections dataset. This created a new dataset of true intersections, the distribution of which can be described as concentrated toward the southeast of the CCT (Figure 4.3).

True intersection density requires that the total number of true intersections be divided by the area of an enumeration area. To select the number of true intersections per Sub Place and Small Area a spatial join between the dataset containing the extent of Sub Places and Small Areas and true intersections dataset were performed. The spatial join counts the total number of features from the true intersections dataset contained within a given enumeration area within a new field (Figure 4.4 and 4.5). In the attribute table of the feature created from the spatial join, another field was added to calculate the area in square kilometres of each Sub Place and Small Area. The true intersection density was then calculated by dividing the number of true intersections by the area of each Sub Place and Small Area. The subsequent result of the calculation was converted to z-scores by subtracting the data range’s mean from each row value and then dividing that value by the standard deviation of the data range. Z-scores normalise data which allows for comparisons between different datasets.

The true intersection density per Sub Place shows that there are only a few Sub Places in Cape Town with a relatively high true intersection density. These areas are randomly distributed across Cape Town with a slight concentration toward the southeast of the city (Figure 4.6). The results as displayed per Small Area provide a disaggregated version of the true intersection density for the CCT. However, on uniform distribution is visible, as in the case of the results per Sub Place (Figure 4.7). The results per Small Area indicate the presence of Small Areas with relatively high true intersection density within Sub Places with low true intersection density. The results per Small Area also point to a concentration of high true intersection densities toward the southeast as well as showing concentrations toward the south and west of the city (Figure 4.7).

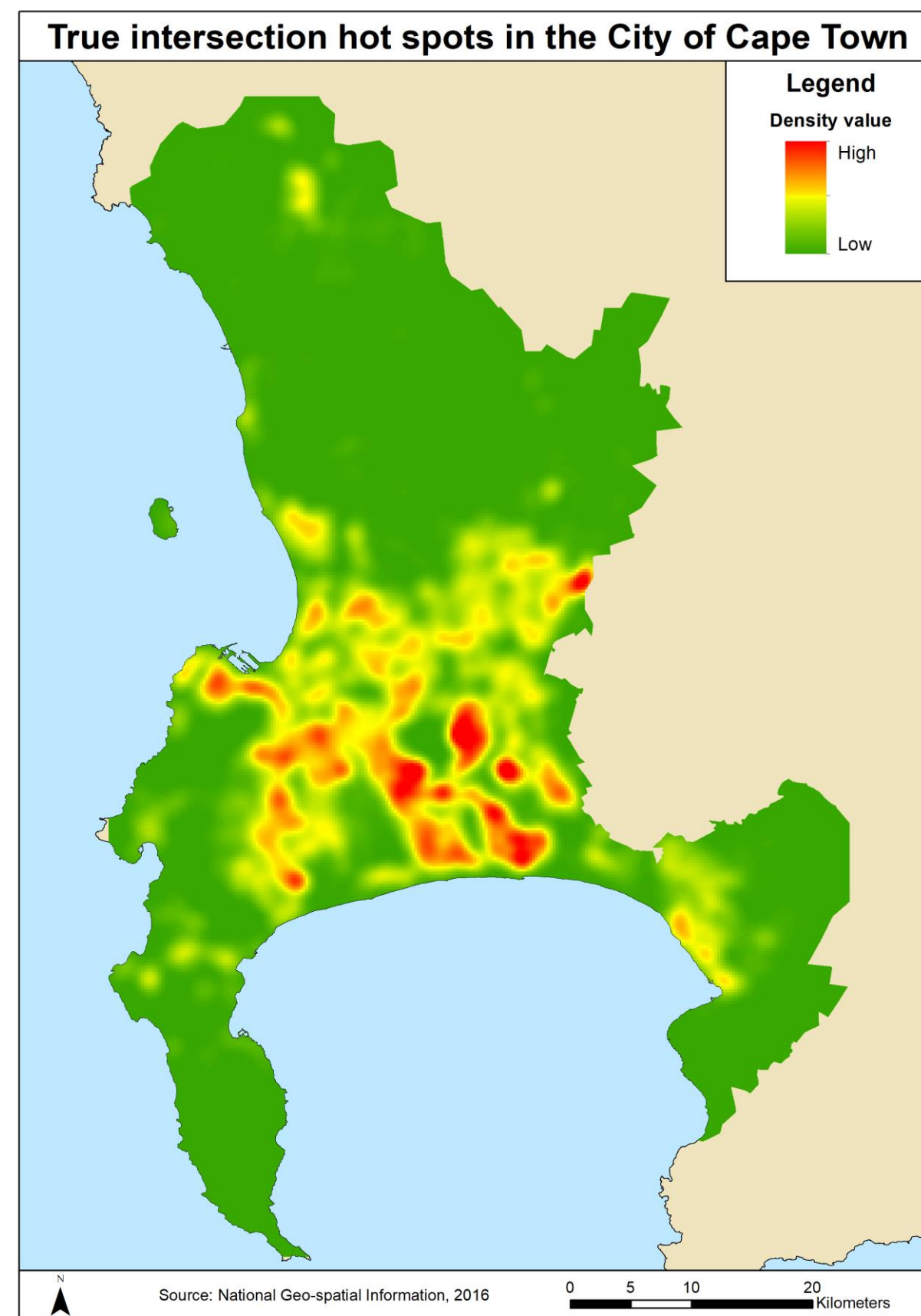


Figure 4.3: True intersection hot spots in the City of Cape

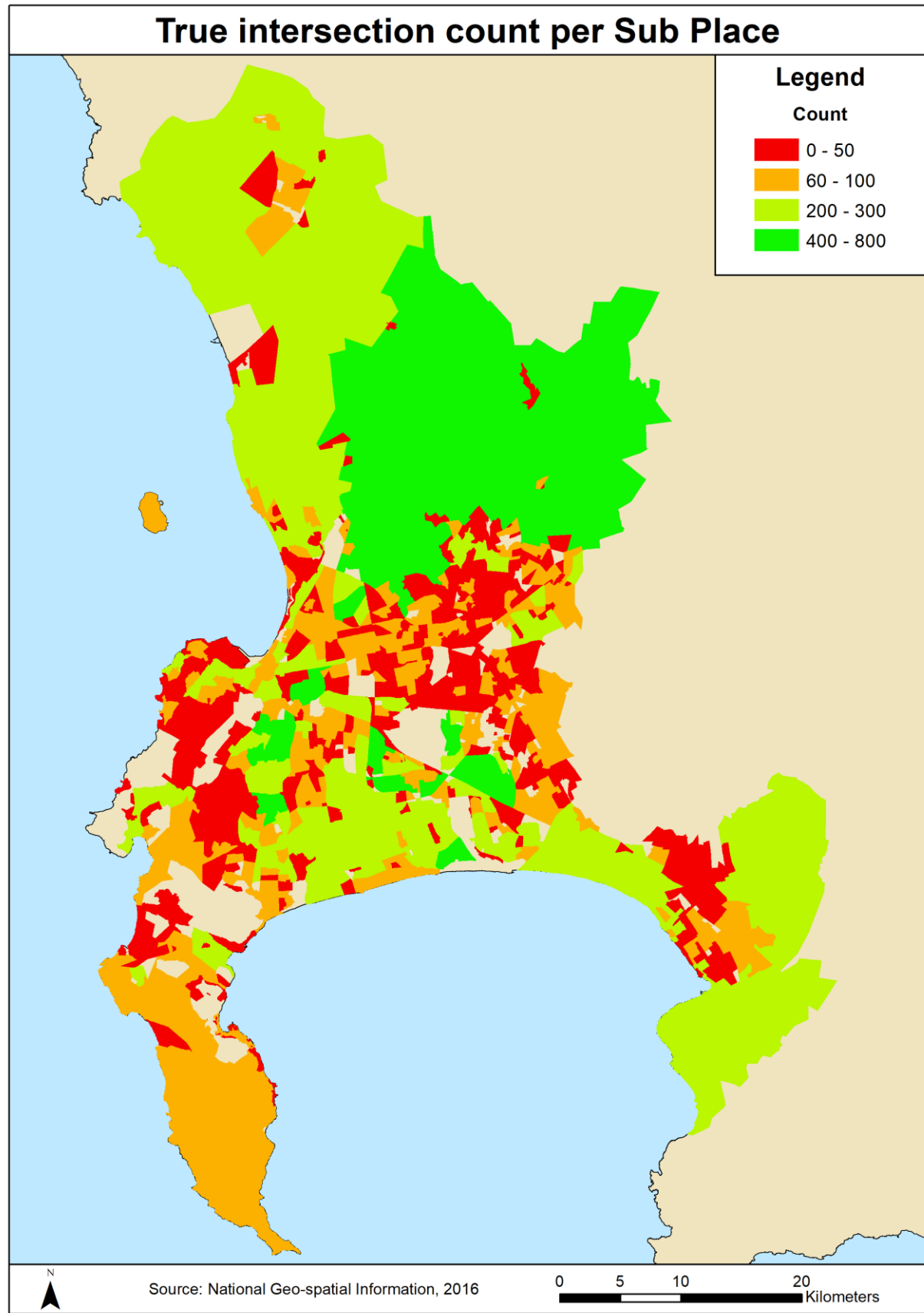


Figure 4.4: True intersection count per Sub Place

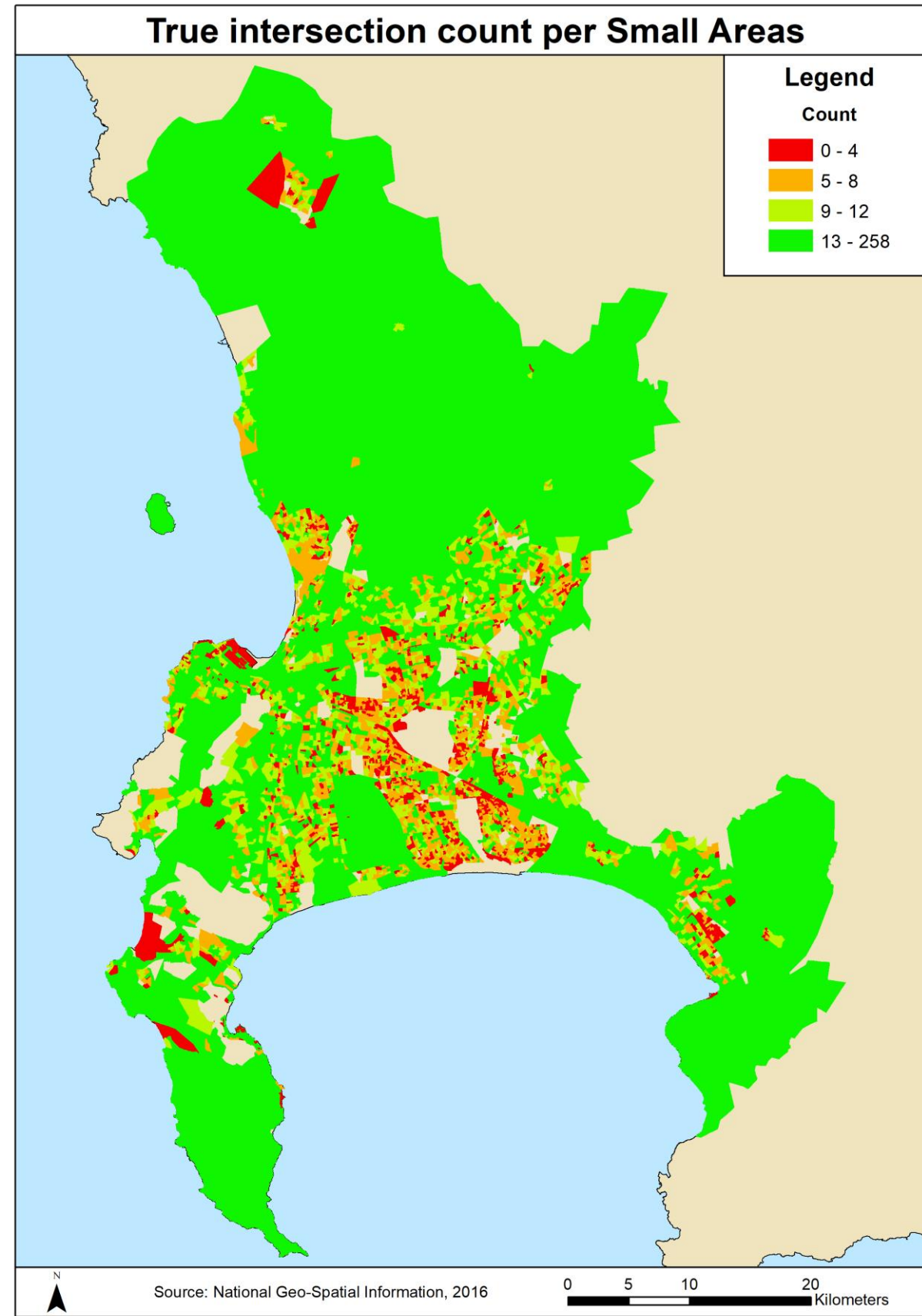


Figure 4.5: True intersection count per Small Area

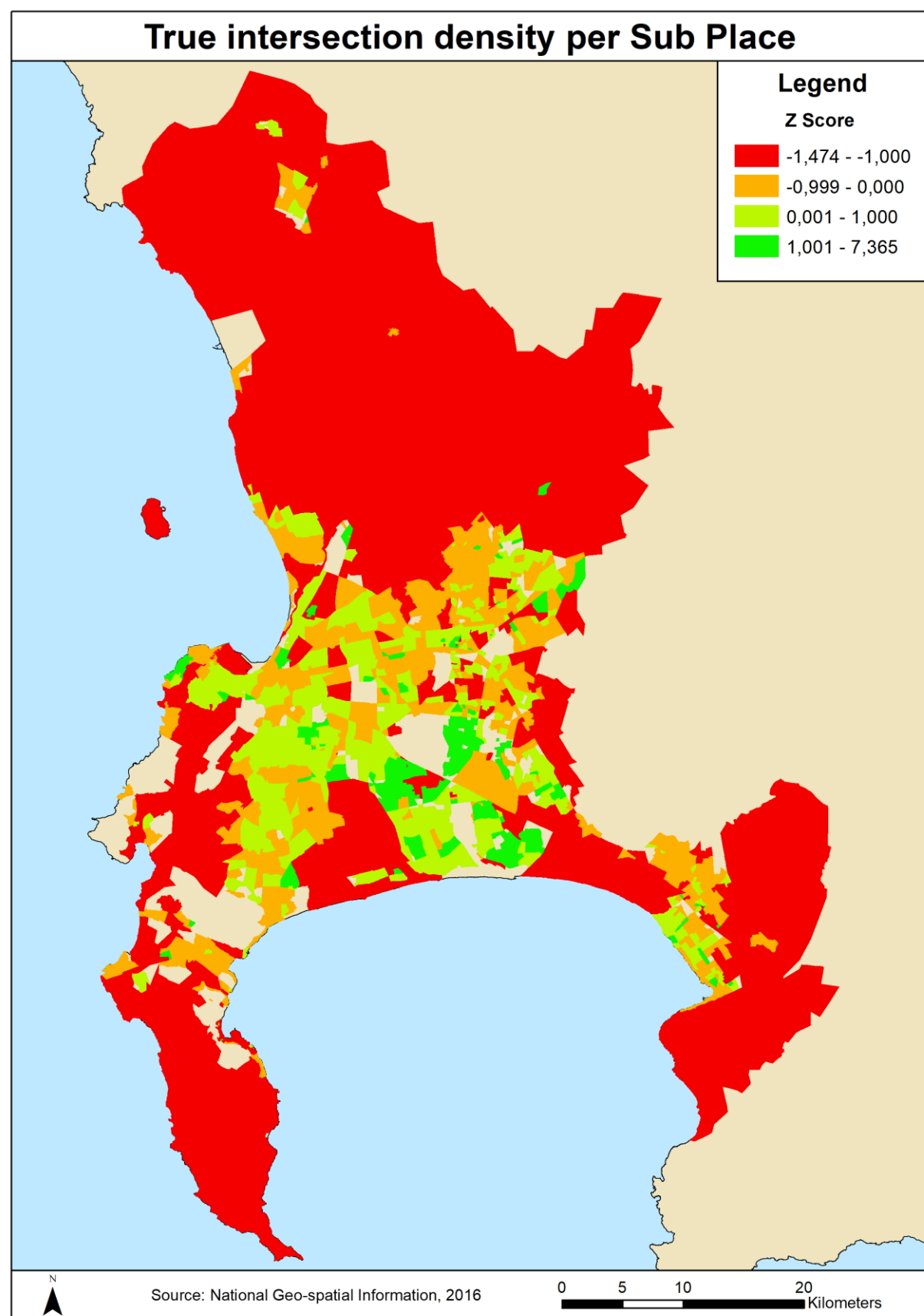


Figure 4.6: True intersection density per Sub Place

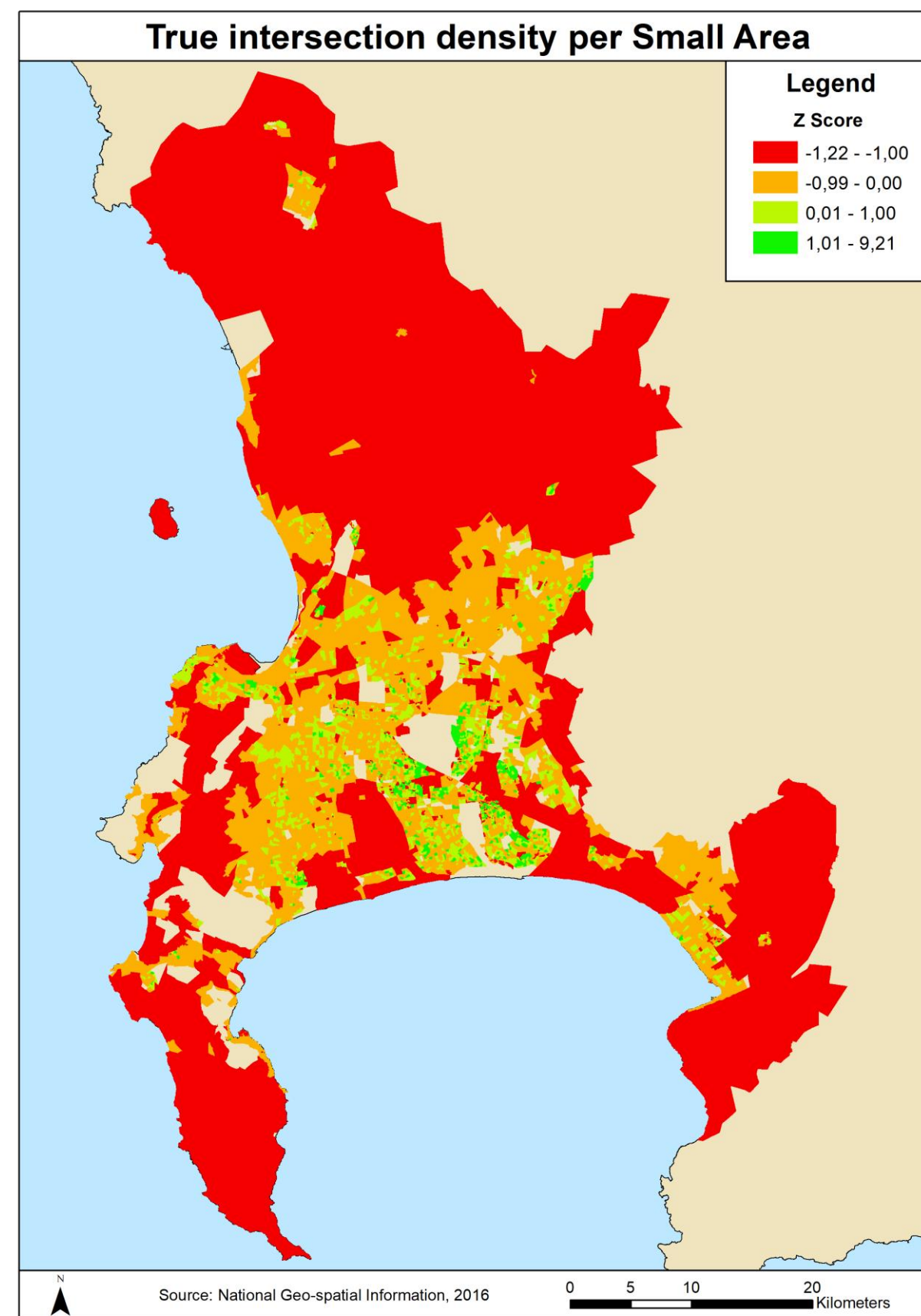


Figure 4.7: True intersection density per Small Area

#### 4.2.2 True intersection to node ratio

The data used in calculating the true intersection to node ratio was sourced and processed as described in the previous subsection. The following subsection thus highlights the specific processes performed in calculating the true intersection to node ratio.

The distribution of nodes in the CCT resembles the distribution of true intersections as discussed in the previous section (Figure 4.8). In calculating the true intersection to node ratio per enumeration area a spatial join was done with the nodes dataset and the census tract datasets. The number of nodes per Sub Place and Small Area was calculated (Figure 4.9 and 4.10). This count was then joined to the dataset containing the true intersection count per Sub Place and Small Area. A new field was added to the attribute table to calculate the true intersection to node ratio by dividing the number of true intersections by the number of nodes per Sub Place and Small Area. The calculated true intersection to node ratio was then converted to z-scores.

The true intersection to node ratio per Sub Place displays a random distribution of Sub Places with high z-scores (Figure 4.11). The true intersection to node ratio per Sub Place is far more graduated than that of the true intersection density as presented in the previous subsection. As there are more Sub Places within the second and third z-score categories (Figure 4.11). The results of the true intersection to node ratio per Small Area resemble that of the results per Sub Place. However, at a Small Area level, there are few areas within the top z-score bracket (Figure 4.12). This indicates that a large portion of Small Areas have a true intersection to node ratio between 0 and 1, with one indicating a highly connected street network and zero a poorly connected street network. This is in contrast to the results of the true intersection density per Small Area, which recorded results within the first and second z-score brackets.

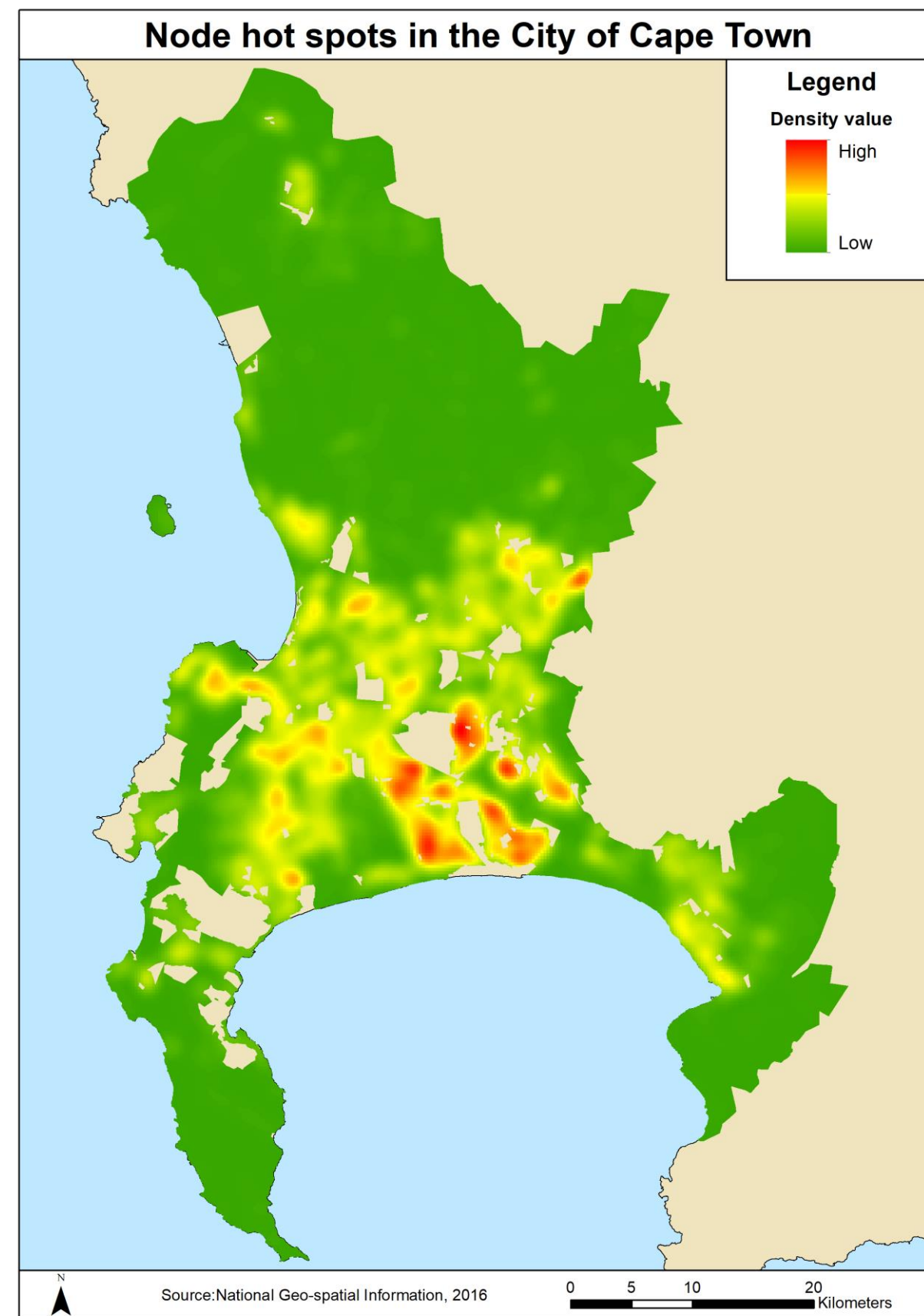


Figure 4.8: Node hotspots in the CCT

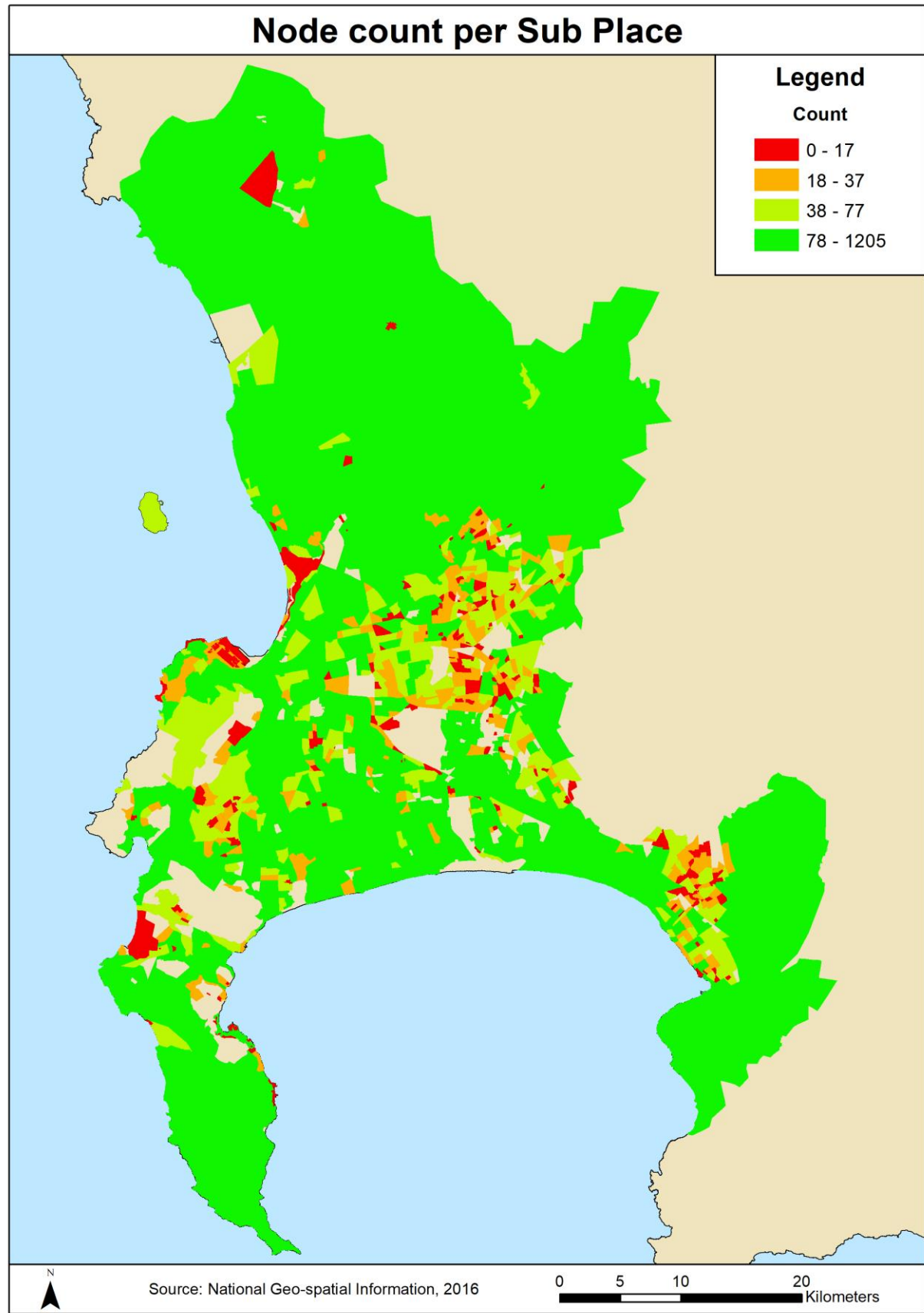


Figure 4.9: Node count per Sub Place

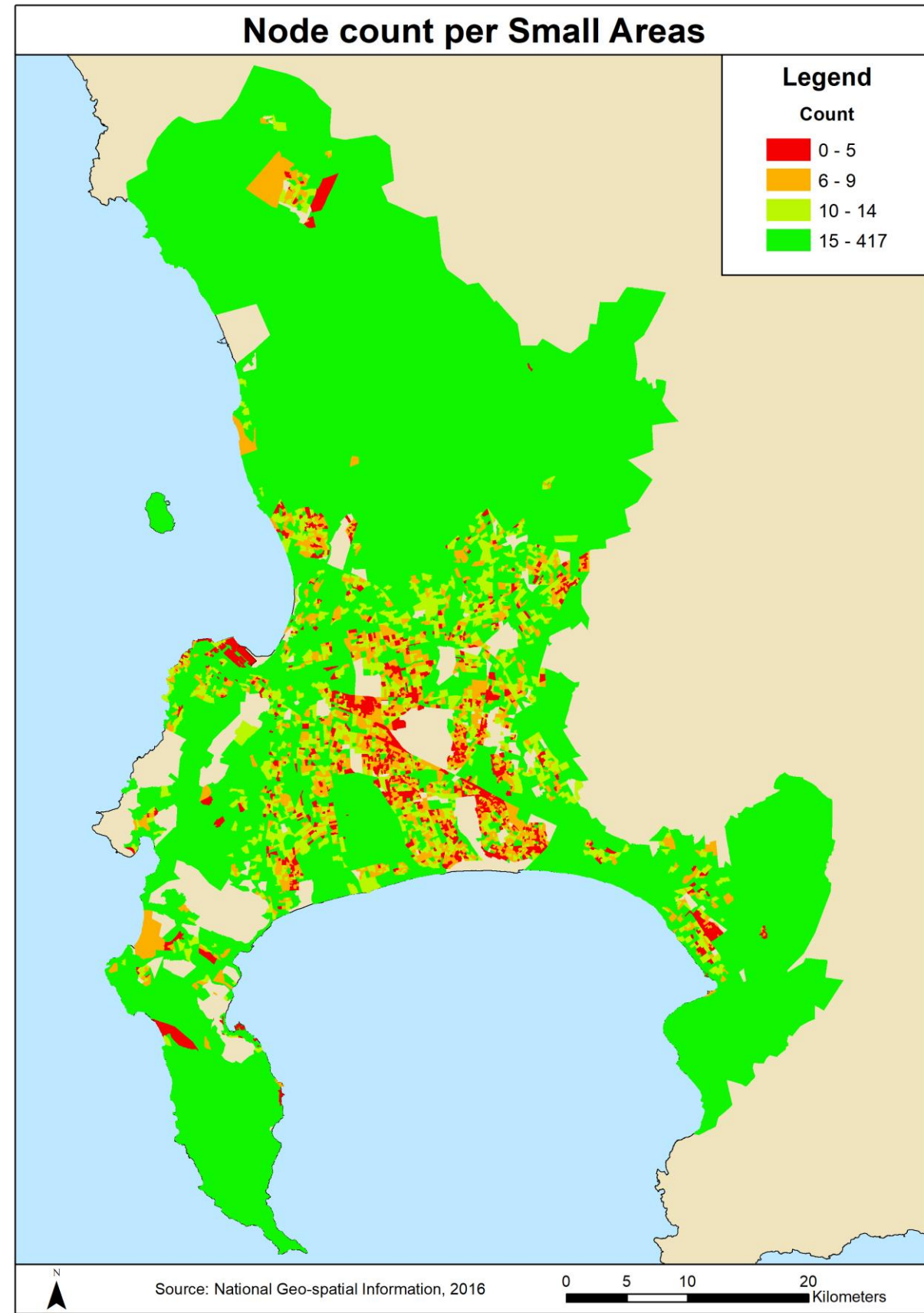


Figure 4.10: Node count per Small Area

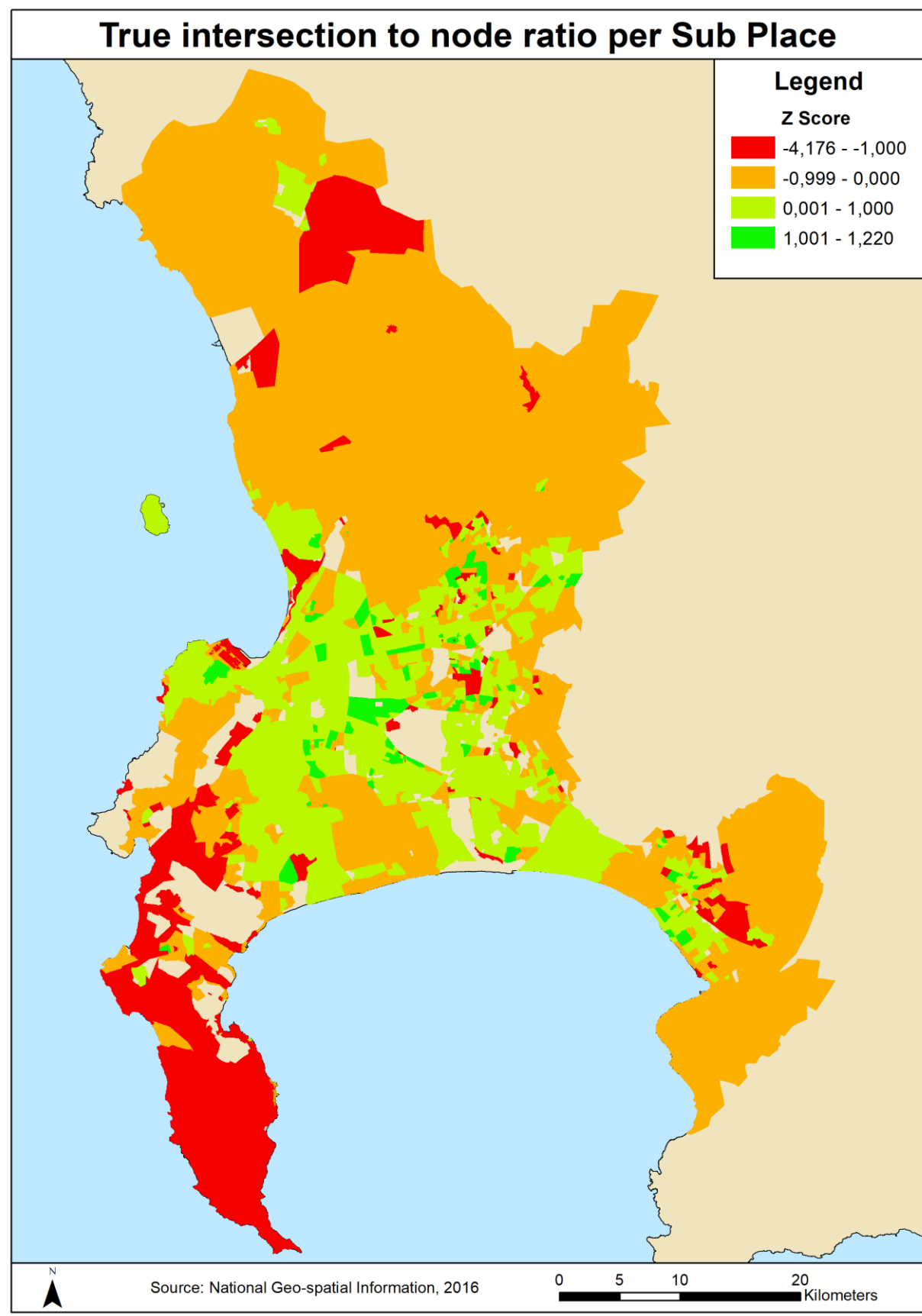


Figure 4.11: True intersection to node ratio per Sub Place

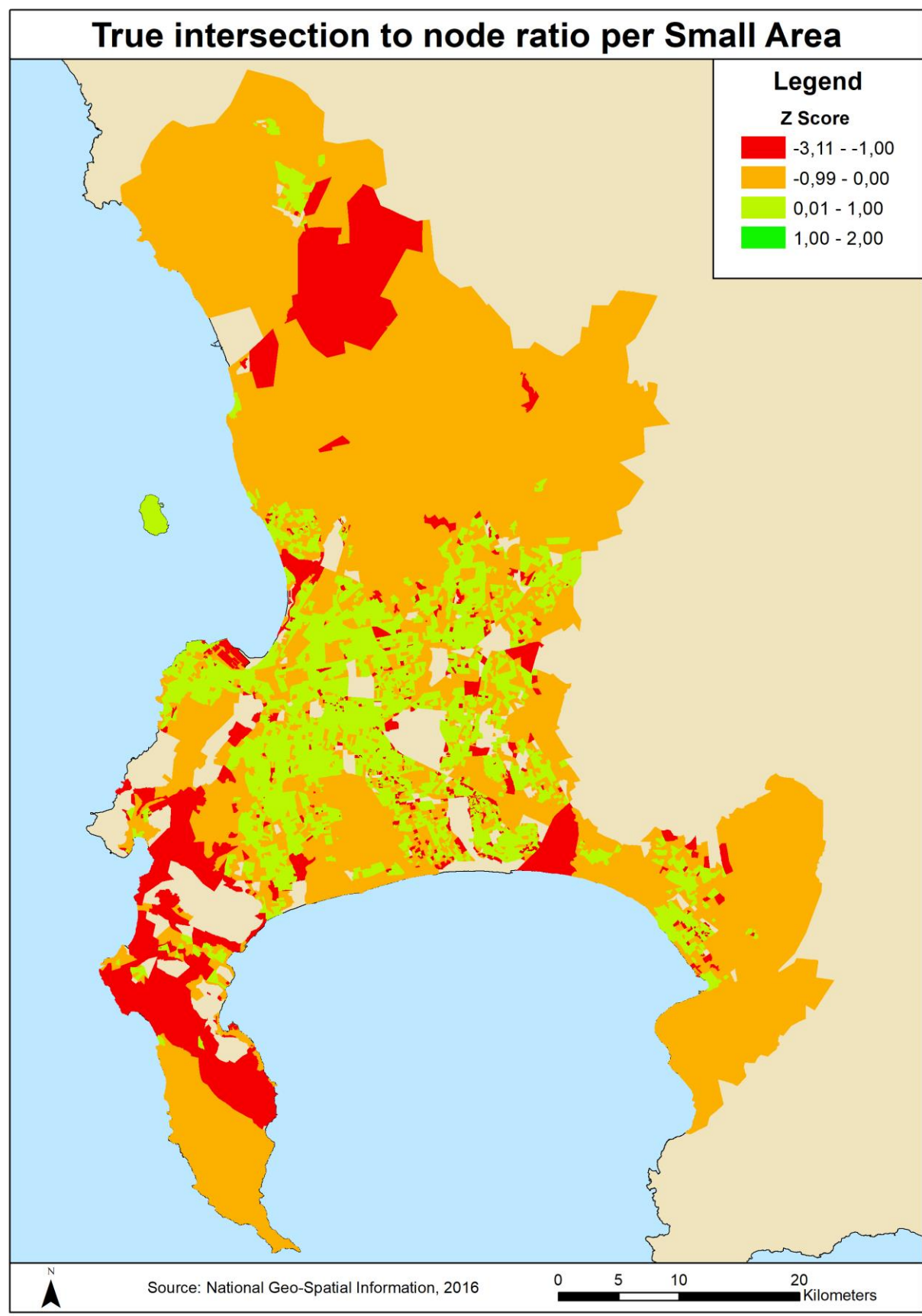


Figure 4.12: True intersection to node ratio per Small Area

### 4.2.3 Residential dwelling density

The data for the residential dwelling density were sourced from the 2011 Eskom Spot Building Count. Residential dwellings were selected from the building count data and exported as a separate dataset. This was done as the building count contains commercial, industrial and other features which are superfluous to the requirements of this investigation. The residential dwelling data were then reprojected to an LO 19 projected coordinate system and then clipped to the administrative area covered by the CCT.

Residential dwellings in the CCT are spatially concentrated in the southeast of the city (Figure 4.13). A spatial join was conducted between the residential dwellings dataset and the census tract dataset to count the number of residential dwellings per Sub Place and Small Area (Figure 4.14 and 4.15). The spatial join created a field containing the total number of residential dwellings per Sub Place and Small Area. A field was added to the attribute tables to calculate the area of each Sub Place and Small Area in square kilometres. Another field was then added to the attribute table to calculate the residential dwelling density, which was calculated by dividing the total number of residential dwellings by the area of a Sub Place or Small Area. The values calculated from the residential dwelling density equation were then converted to z-scores.

A clear spatial pattern is evident from the residential density per Sub Place. This is stated as Sub Places with high levels of residential dwelling density are spatially concentrated in the southeast of the city (Figure 4.16). The residential dwelling density results per Small Areas resemble that of the results per Sub Place. However, the results per Small Areas allows for the identification of Small Area clusters with high z-scores within Sub Places (Figure 4.17). From figure 4.17 it is apparent that within Sub Places toward the southeast of the city there are various high z-score Small Area clusters.

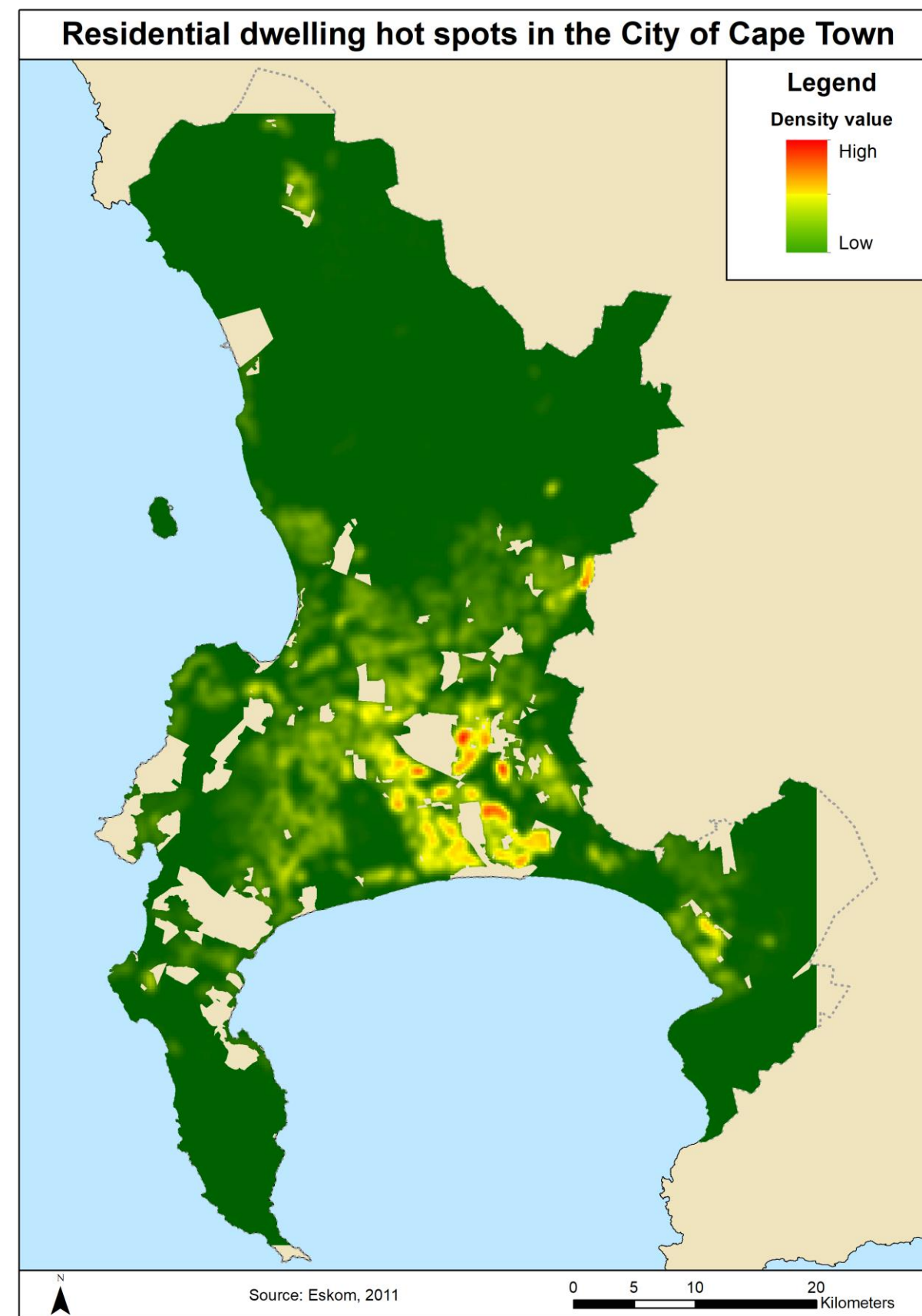


Figure 4.13: Residential dwelling hot spots in the CCT

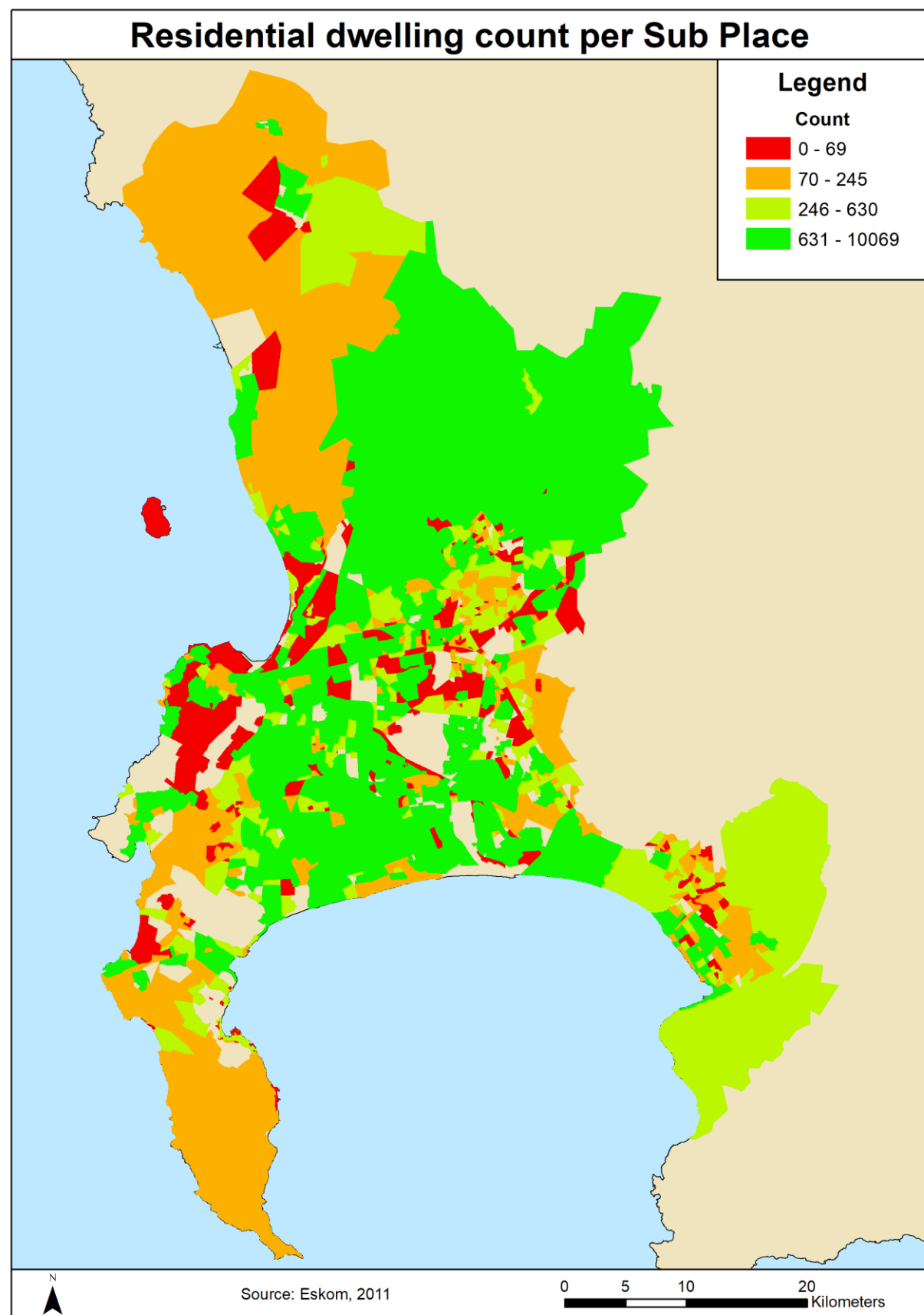


Figure 4.14: Residential dwelling count per Sub Place

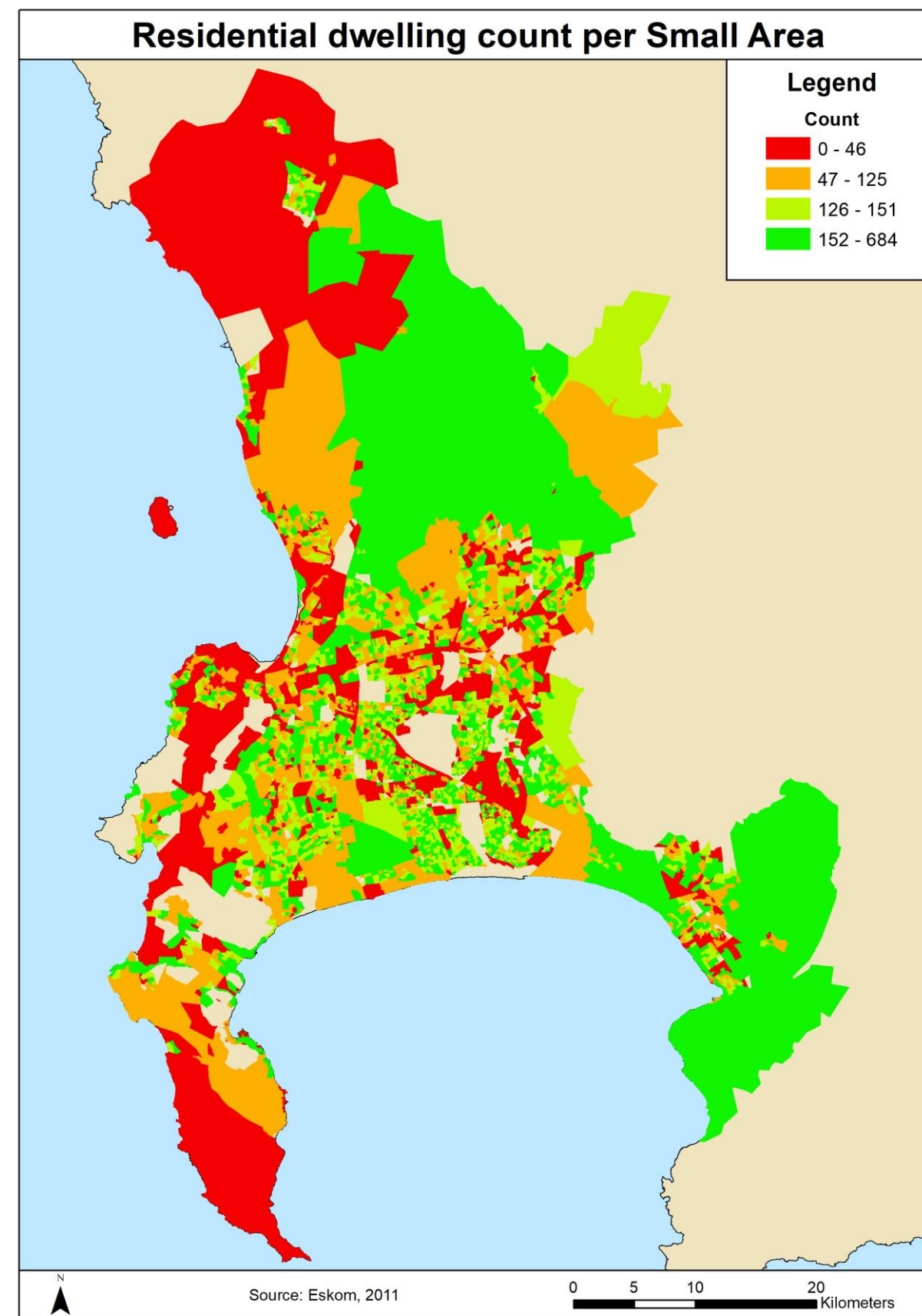


Figure 4.15: Residential dwelling count per Small Area

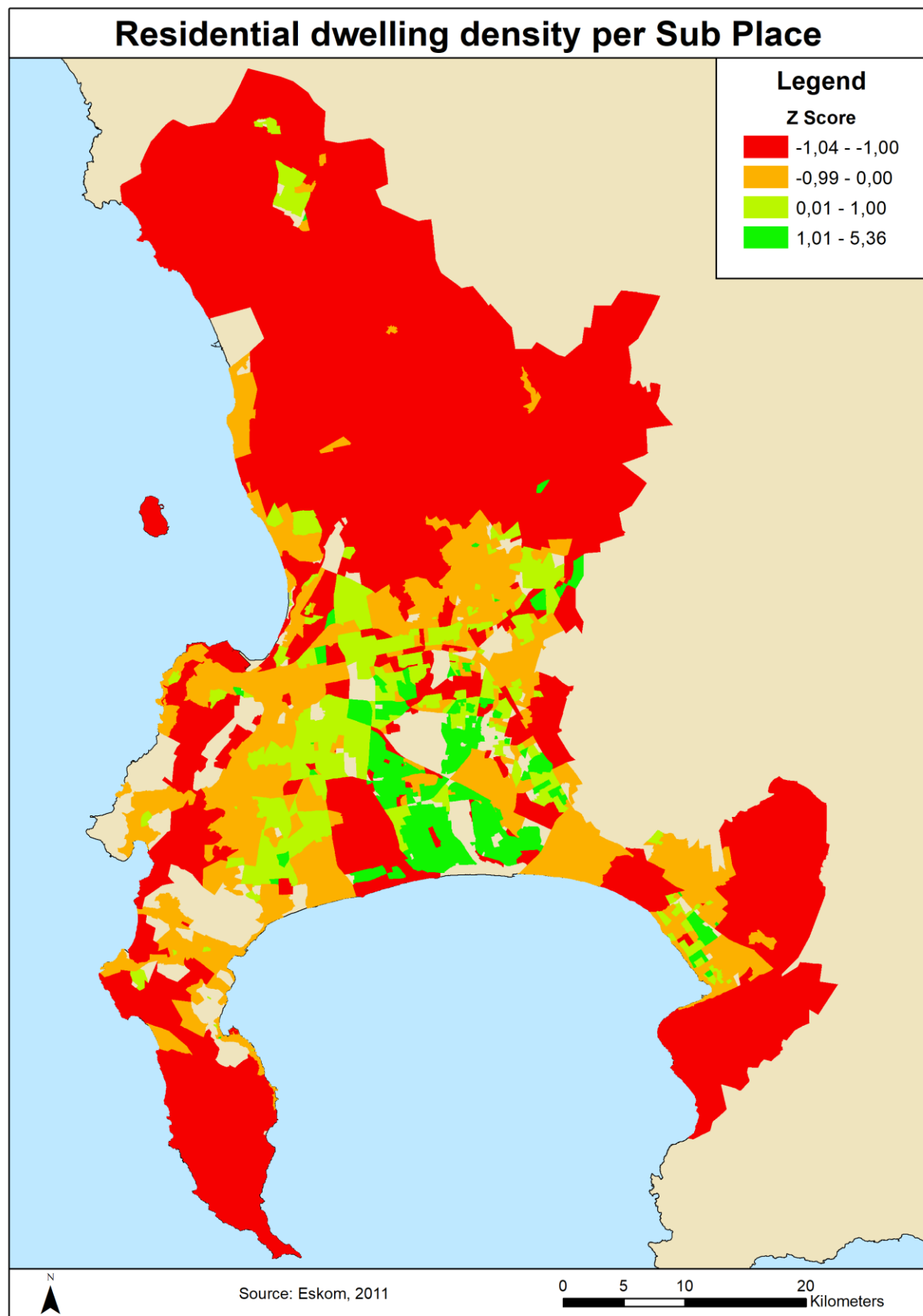


Figure 4.16: Residential dwelling density per Sub Place

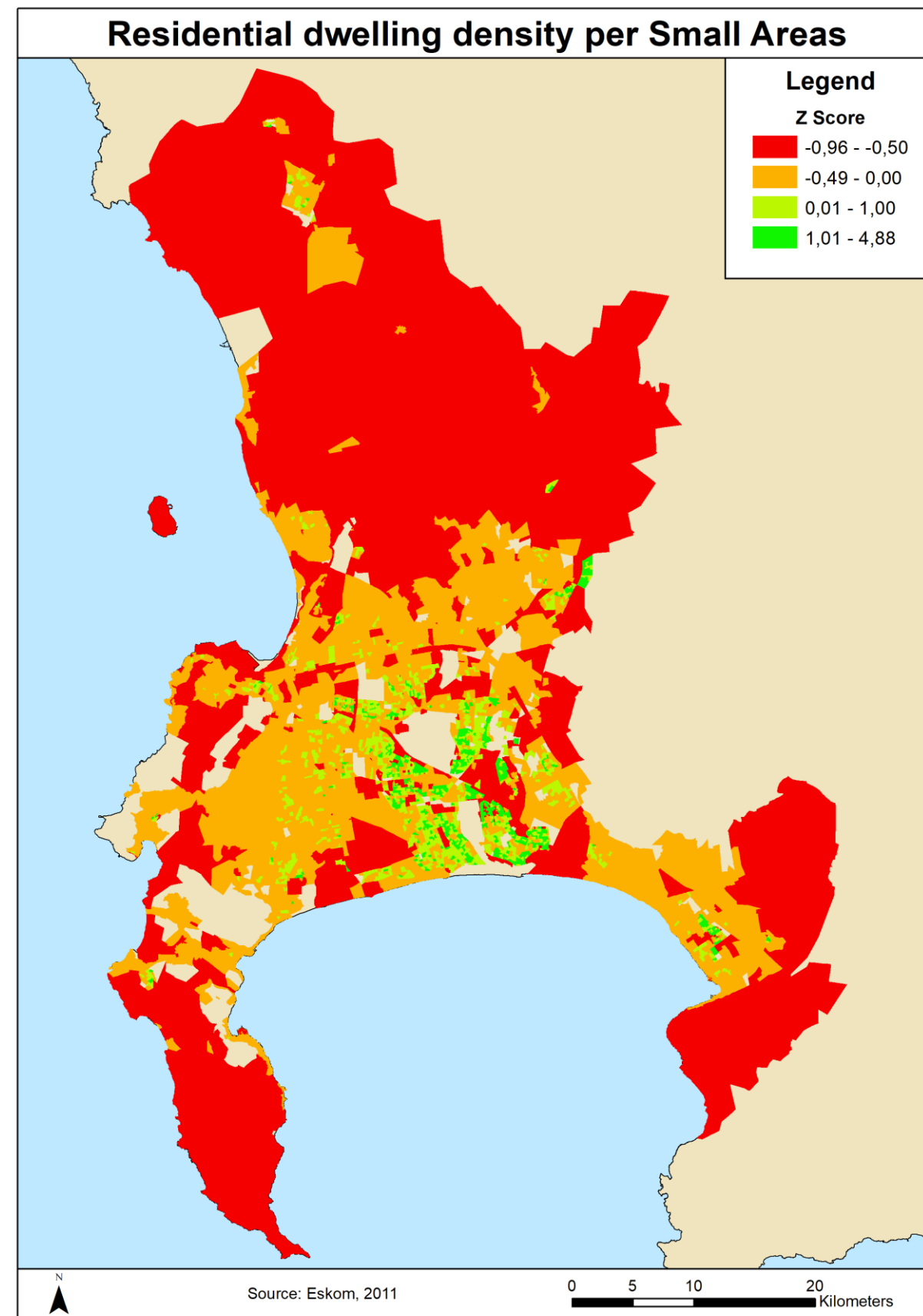


Figure 4.17: Residential dwelling density per Small Area

#### 4.2.4 Household density

The data for the household density were sourced from the 2011 Census results. The number of households per Sub Place and Small Area for the City of Cape was selected within the SuperCross statistical package and exported to an Excel spreadsheet. The spreadsheet data was then joined to the spatial data of the area extents of Sub Places and Small Areas within ArcGIS. The table joins were then exported as separate shapefiles. The exported shapefile data were then reprojected to an LO 19 projected coordinate system.

Household density is calculated by dividing the number of households per Sub Place or Small Area by the area of a Sub Place or Small Area. The total number of households was already given when the household data was selected within SuperCross (Figure 4.18 and 4.19). From the household counts, it is clear that the majority of households in Cape Town reside in the southeast of the metropolitan. Furthermore, a large portion of areas to the southeast fall within the highest household count bracket (Figure 4.18 and 4.19). In calculating the area of each Sub Place and Small Area a field was added to the attribute table and the area was calculated in square kilometres. A second field was added to the attribute table to calculate the household density for each Sub Place and Small Area. This was done by adding a third field to the attribute table and dividing the values in the number of households fields by the values contained in the area field per Sub Place and Small Area. The household density values were then converted to z-scores.

The spatial distribution of household density per Sub Place and Small area are also clustered toward the southeast of Cape Town (Figure 4.20 and 4.21). This corresponds well with the spatial distribution observed in the household count per Sub Place and Small Area. However, household density is further concentrated towards the southeast of the metropolitan, as the majority of Sub Places and Small Areas fall inside of the highest z-score bracket (Figure 4.20 and 4.21).

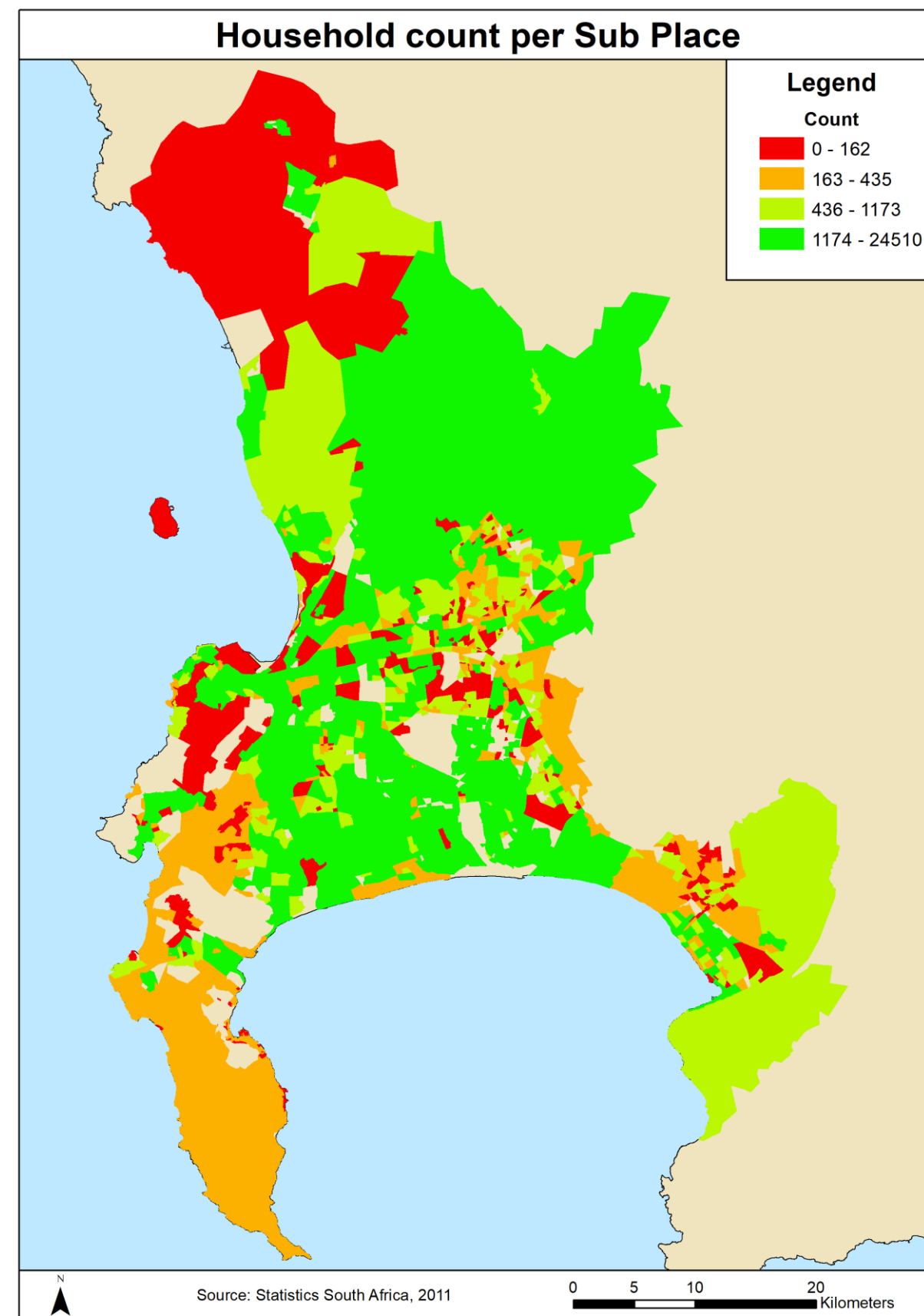


Figure 4.18: Household count per Sub Place

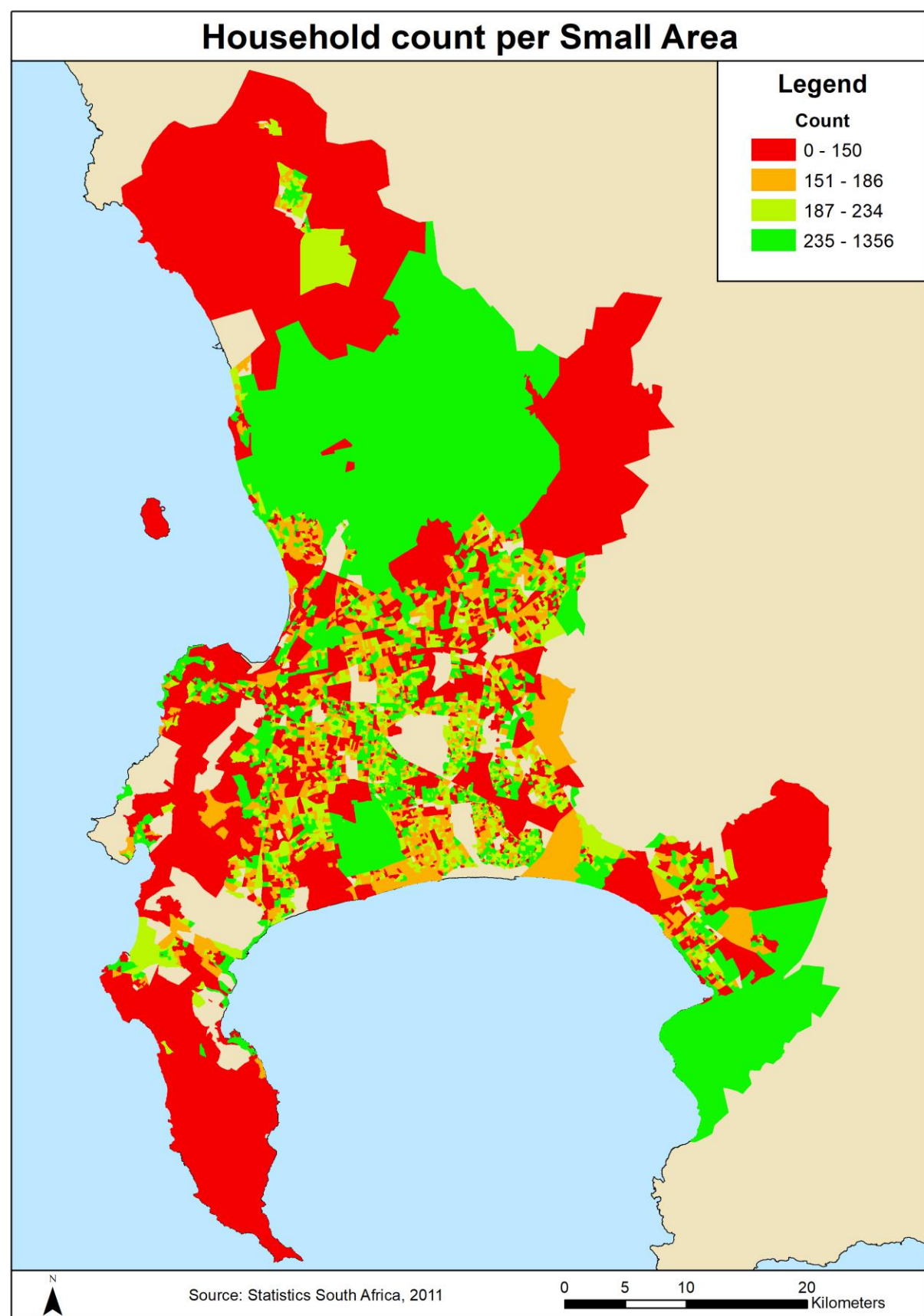


Figure 4.19: Household count per Small Area

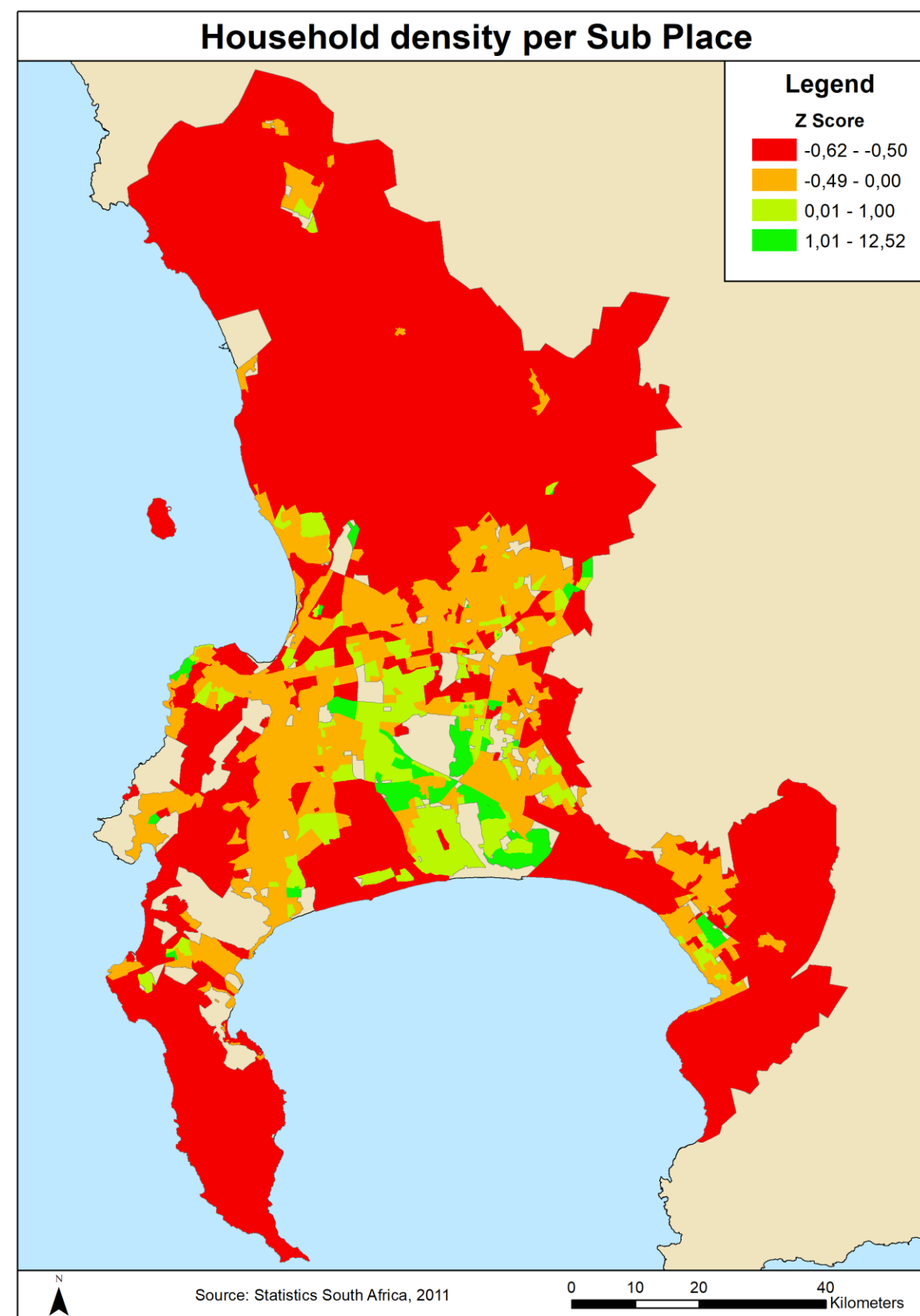


Figure 4.20: Household density per Sub Place

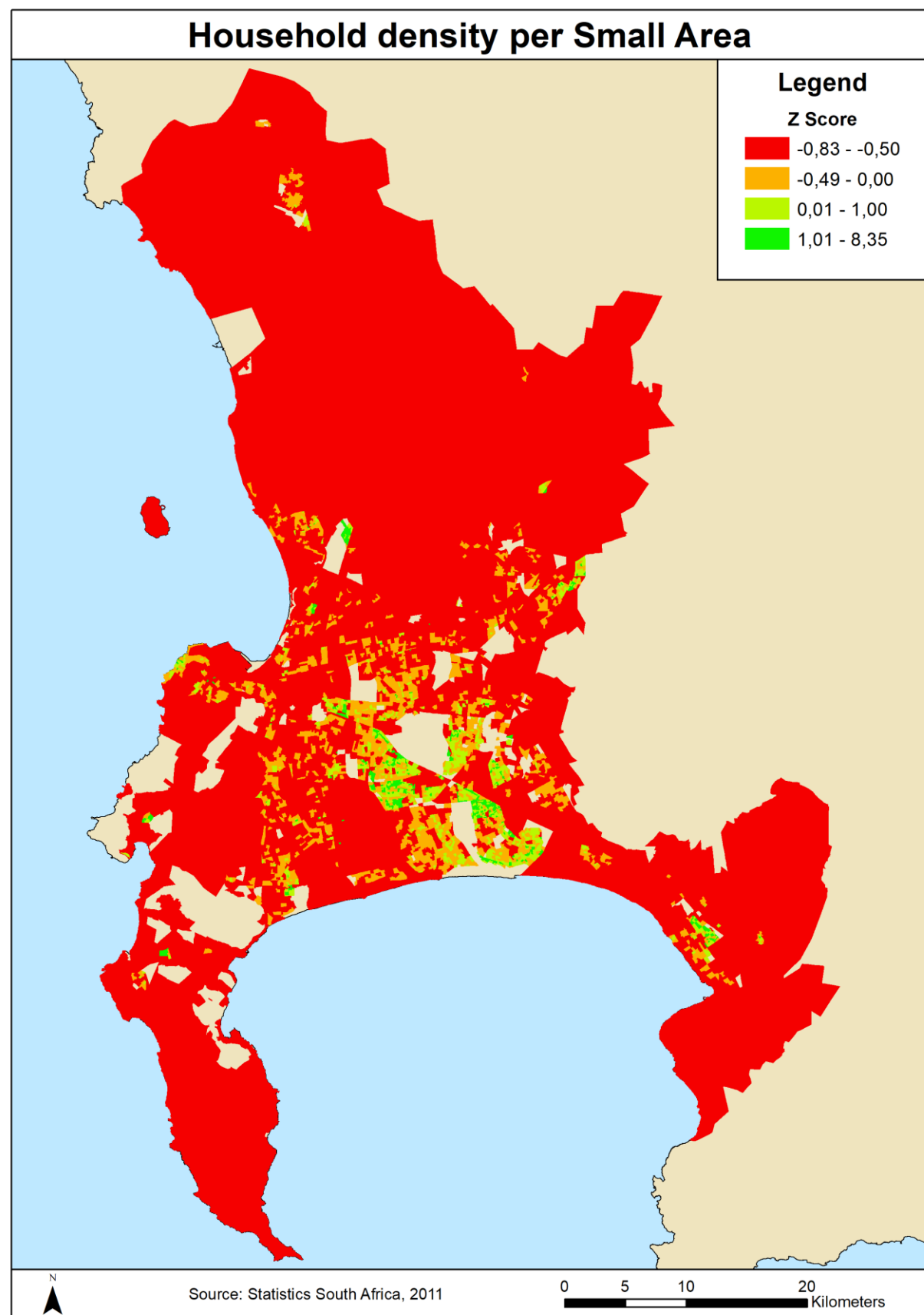


Figure 4.21: Household density per Small Area

#### 4.2.5 Land-use mix – entropy scores

The data for land use were sourced from the CCT’s open data portal. The data contains land-use information categorised according to the city’s integrated zoning management scheme. The data was downloaded in shapefile format, reprojected to an LO 19 projected coordinate system and then clipped to the extent of the CCT’s administrative area.

In order to determine the land-use mix diversity within a given area, an entropy index for each Sub Place and Small Area needed to be calculated. An entropy index is used to determine the level of diversity within a given area, be it biodiversity or in this study’s case land-use diversity. The equation for the entropy index is stated as:

$$E.I = \frac{-\sum_{i=1}^n \left[ \left( \frac{P_{ij}}{P_j} \right) \times \ln \left( \frac{P_{ij}}{P_j} \right) \right]}{\ln(n)}$$

“Where E.I is the Entropy Index; n as the number of land-use types in an area;  $P_{ij}$  representing the area occupied by a specific land-use type within an area; and  $P_j$  as the total area occupied by all land-use types within an area. For these measures, results are values ranging from 0 to 1. Values closer to 0 indicate highly homogeneous land-use mix while values closer to 1 indicate high heterogeneity of land-use mix diversity in an area.” (Murekatete and Bizimana, 2015:3). Thus to calculate the entropy index for each Sub Place and Small Area the area of each land use, the total area covered by all the land uses, and the total number of land-use types per Sub Place and Small Area need to be calculated or determined.

Before any processing of the data commenced, the land uses in the zoning dataset needed to be reclassified. This was done as the integrated zoning management scheme contains a plethora of zoning subcategories for residential, commercial, industrial etc. The reclassification simplified the number of land-use classes to six land uses. These land uses are residential, commercial, industrial, institutional, mixed, and open space. The result from the reclassification enables a clearer representation of the distribution of land use throughout the city (Figure 4.22). To assign a land use to a given Sub Place or Small Area an intersect analysis was conducted, which created a multitude of zoning entries as one zoning could intersect with more than one Sub Place or Small Area.

In calculating the areas of each new zoning segment six new fields were added to the attribute table. Through a “select by attributes” query, each separate land use was selected and the area was calculated for the selected entries in square kilometres. To determine how many land uses there are within a Sub

Place or Small Area six new fields were added to the attribute table. Each field represents one of the six reclassified land uses. A selection by attribute was done for each of the six land uses and consequently, the selected entries' values were set at 1 and the unselected remained 0. The "select by attribute" queries and calculations allowed for the recognition of the area for each land-use category and the presence of each land use per Sub Place and Small Area. The multiple entries per Sub Place and Small Area needed to be simplified to an amalgamated entry for each Sub Place and Small Area. A dissolve analysis based on the unique Sub Place and Small Area codes were done, with the fields indicating the presence of a land-use type being summarised according to the maximum value occurring in the field and calculating the sum of the area fields. The dissolve analysis determined whether a given land use is present and calculated the total area covered by a given land use within a Sub Place or Small Area. Finally, the total land uses and the area covered by all the land uses present within a Sub Place or Small Area could be calculated. This was done by adding two fields to the attribute table and calculating the sum of the fields containing the presence of land-use types and the area of the land uses.

The entropy index for each Sub Place and Small Area could now be calculated. However, ArcGIS has limited capacity to calculate natural log functions. The attribute table was thus exported to an Excel file format. Within Excel, a new column was added to calculate the entropy index for each Sub Place and Small Area. The entropy equation was entered in and was applied to both the Sub Place and Small Area datasets. After the entropy index scores were calculated the entropy index values were converted to z-scores and joined to the census tract datasets in ArcGIS.

The land-use mix z-scores reflect that the majority of Cape Town has a good mix of land uses, as a large portion of Sub Places and Small Areas falling within the third highest z-score bracket (Figure 4.23 and Figure 4.24). The z-scores per Small Area illustrate the diversity of land use within a Sub Place and also show the close proximity that areas with a high and low land-use mix are located to one another. This is stated as Small Areas with z-scores over 1 are closely located to Small Areas with negative z-scores.

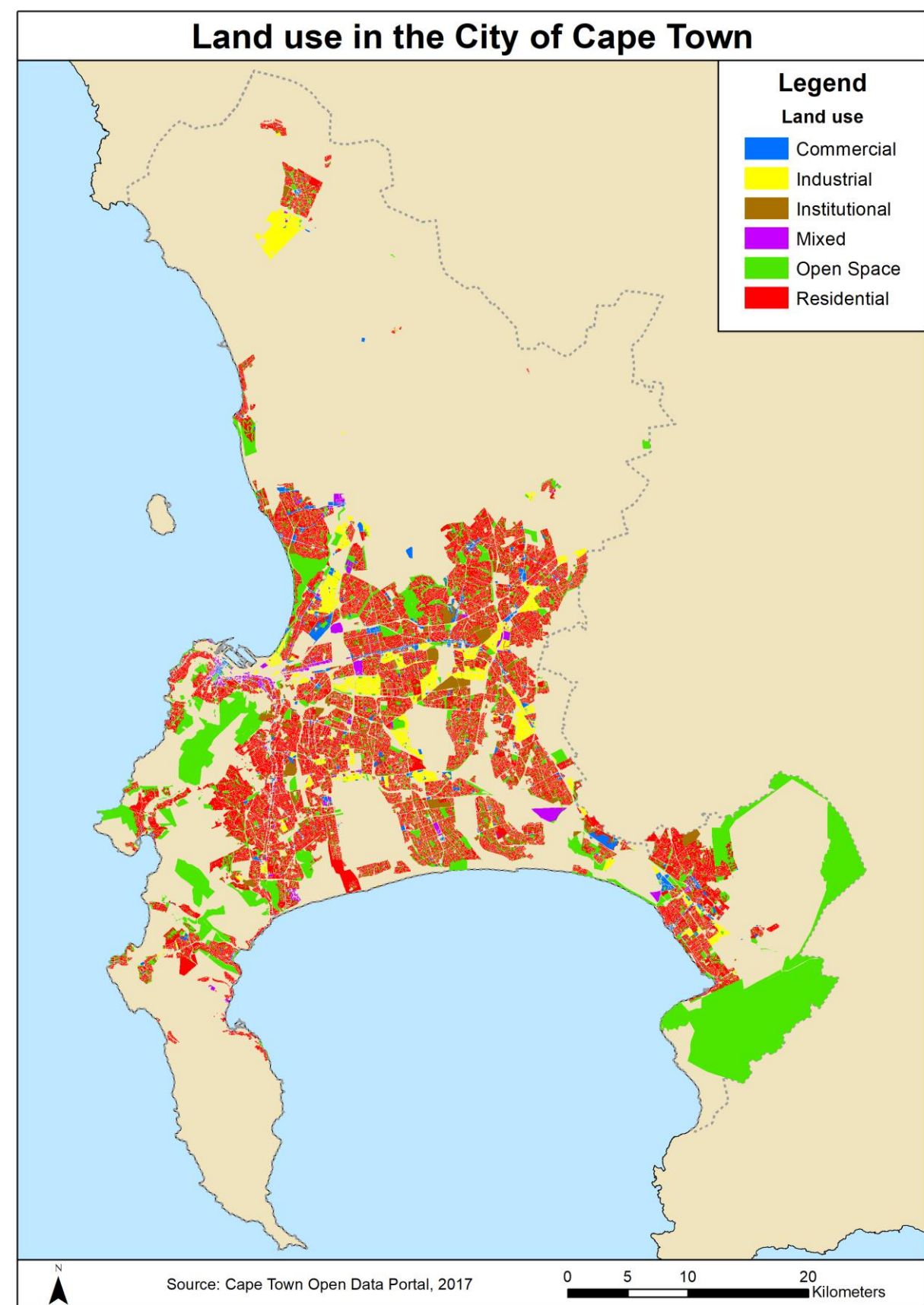


Figure 4.22: Land use in the CCT

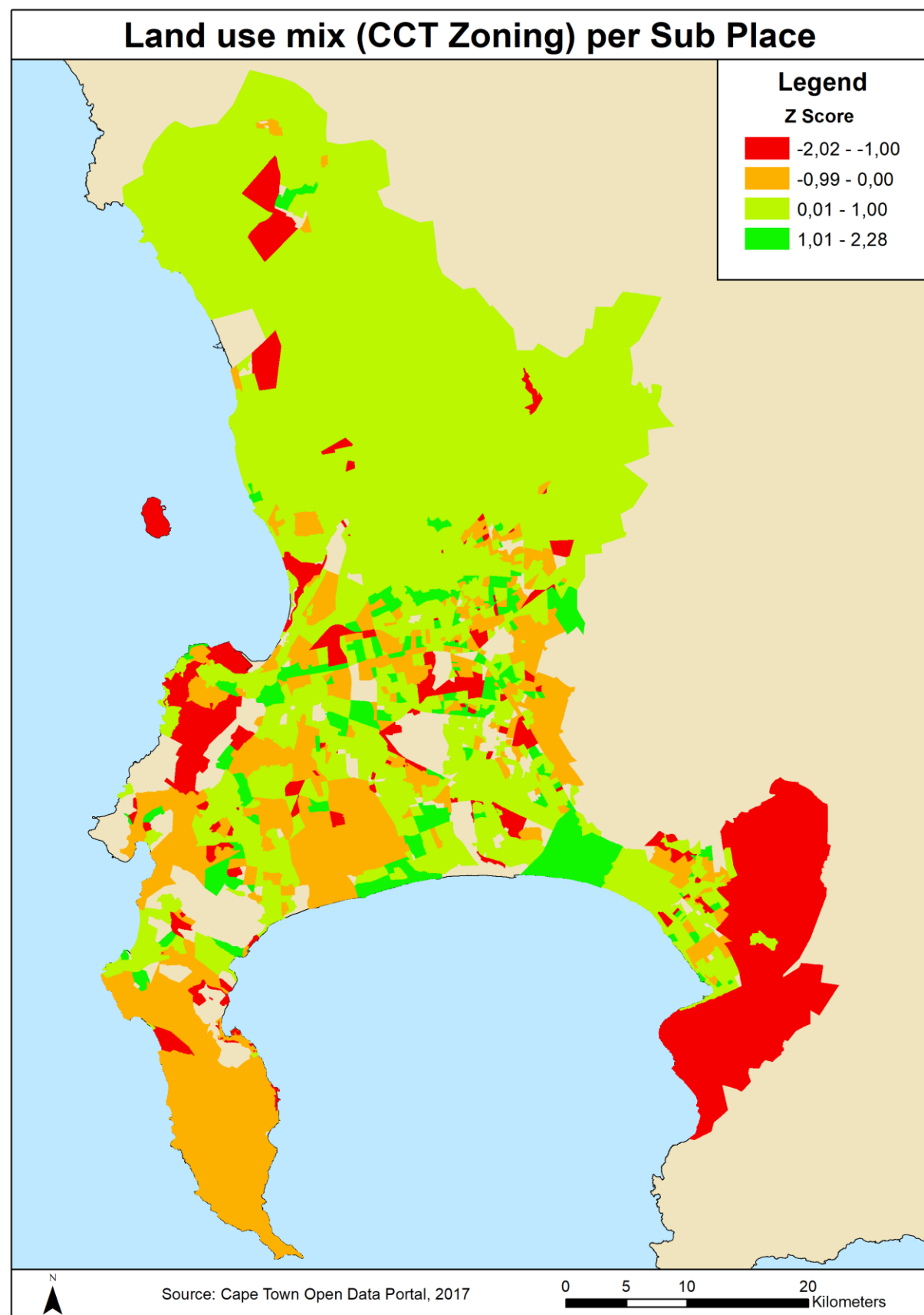


Figure 4.23: Land-use mix (CCT Zoning) per Sub Place

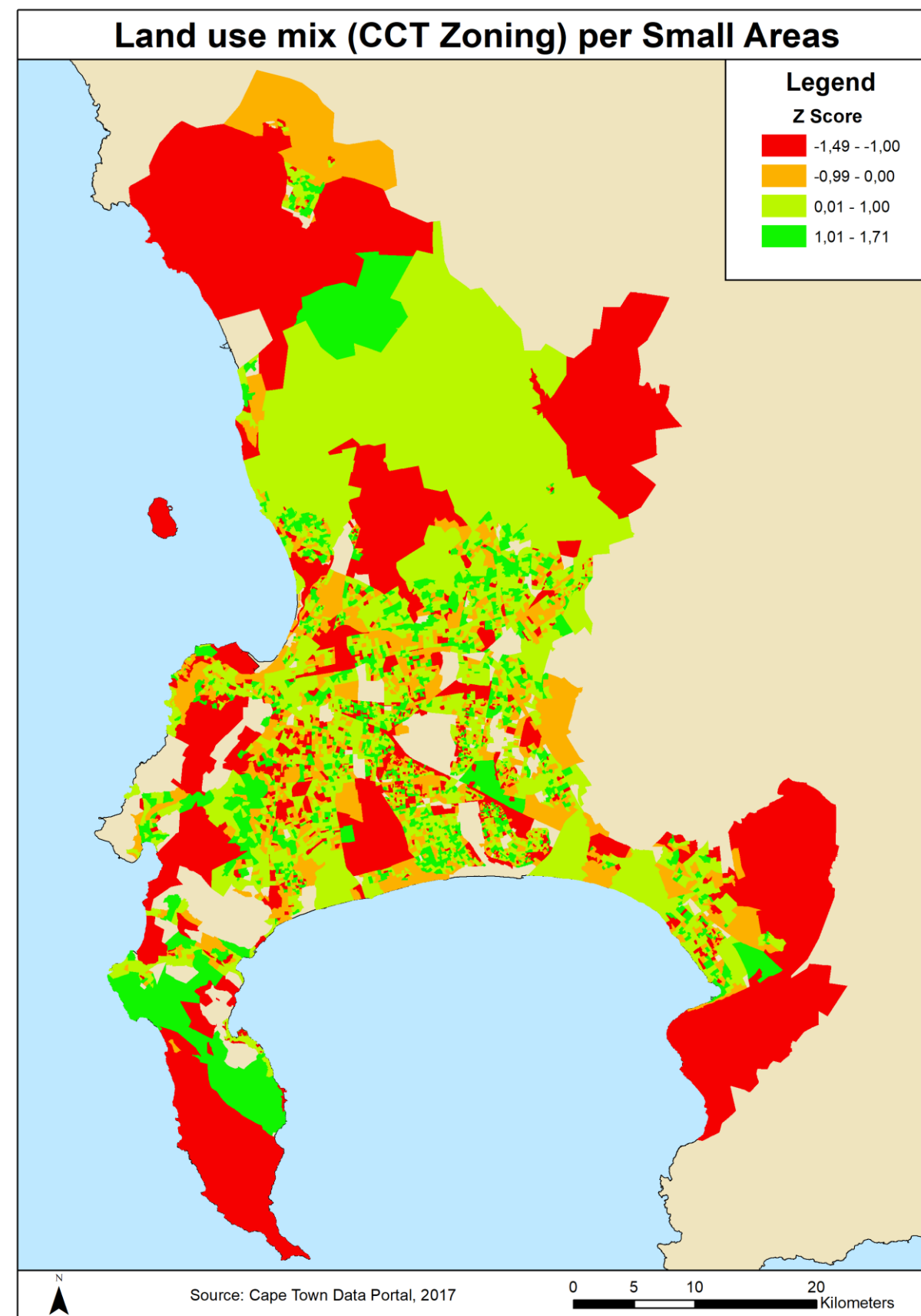


Figure 4.24: Land-use mic (CCT Zoning) per Small Area

#### 4.2.6 Land cover mix – entropy scores

The land cover data were sourced from the Department of Environmental Affairs' EGIS database. The data contains land cover information categorised according to 72 land cover classes. The data was downloaded in raster format, reprojected to an LO 19 projected coordinate system and then clipped to the extent of the CCT's administrative area.

In order to determine the land cover mix diversity within a given area, an entropy index for each Sub Place and Small Area needed to be calculated. An entropy index is used to determine the level of diversity within a given area, be it biodiversity or as in this study's case land cover. The equation for the entropy index is:

$$E.I = \frac{-\sum_{i=1}^n \left[ \left( \frac{P_{ij}}{P_j} \right) \times \ln \left( \frac{P_{ij}}{P_j} \right) \right]}{\ln(n)}$$

“Where E.I is the Entropy Index; n as the number of land-use types in an area; P<sub>ij</sub> representing the area occupied by a specific land-use type within an area; and P<sub>j</sub> as the total area occupied by all land-use types within an area. For these measures, results are values ranging from 0 to 1. Values closer to 0 indicate highly homogeneous land use while values closer to 1 indicate high heterogeneity of land-use categories in an area.” (Murekatete and Bizimana, 2015:3). Thus to calculate the entropy index for each Sub Place and Small Area the area of each land cover class, the total area covered by all the land cover classes, and the total number of land cover classes per Sub Place and Small Area need to be calculated.

A reclassification of the land cover classes was needed before any processing of the data commenced. This was done as the dataset contains a superfluity of land cover classes including cultivated fields, plantation, mining etc. The reclassification thus simplified the number of land cover classes to five land uses relevant to the study. These land uses are residential, commercial, industrial, natural, and recreation. The result from the reclassification enables a clearer representation of the distribution of land use throughout the city (Figure 4.25). The reclassified dataset was in raster format which is incompatible with the other vector shapefiles in the analysis. The reclassified land-use data was thus converted to vector data format which enabled the dataset to be included it in the analysis. This allowed for conducting an intersect analysis which assigned land uses to a given Sub Place or Small Area. This created a multitude of land use entries as one land-use class could intersect more than one Sub Place or Small Area.

In calculating the areas of each new land-use segment five new fields were added to the attribute table. Through a “select by attributes” query, each separate land use was selected and the area was calculated for the selected entries in square kilometres. To determine how many land uses are within a Sub Place or Small Area, five new fields were added to the attribute table. Each field represents one of the five reclassified land uses. A selection by attribute was done for each of the five land uses and consequently, the selected row values were set at 1 and the unselected remained 0. The “select by attribute” queries and calculations allowed for the identification and calculation of the area and the presence of each land use per Sub Place and Small Area. The multiple entries per Sub Place and Small Area needed to be simplified to an amalgamated entry for each Sub Place and Small Area. A dissolve analysis based on the unique Sub Place and Small Area codes were done, with the fields indicating the presence of a land-use type being summarised according to the maximum value occurring in the field and calculating the sum of the area of the fields. The dissolve analysis determined whether a given land use is present and calculated the total area covered by a given land use within a Sub Place or Small Area. Finally, the total number of land uses and the area covered by all the land uses present within a Sub Place or Small Area could be calculated. This was done by adding two fields to the attribute table and calculating the sum of the fields containing the presence of land-use types and the area of the five land uses.

The entropy index for each Sub Place and Small Area could now be calculated. However, ArcGIS is limited in its capacity to calculate natural log functions. The attribute table was thus exported to an Excel file format. Within Excel, a new column was added to calculate the entropy index for each Sub Place and Small Area. The entropy equation was entered in and was applied to both the Sub Place and Small Area datasets. After the entropy index scores were calculated the values were converted to z-scores and joined to the census tract datasets in ArcGIS.

The land-use mix (based on the land cover data) z-scores reflect that land-use mix is concentrated in Cape Town, as the areas around the central business district fall in the highest and second highest z-score brackets (Figure 4.26 and 4.27). The z-scores per Small Area correspond to that of the land-use mix based on the zoning, as it also displays a high degree of spatial variance between Small Areas with high and low z-scores.

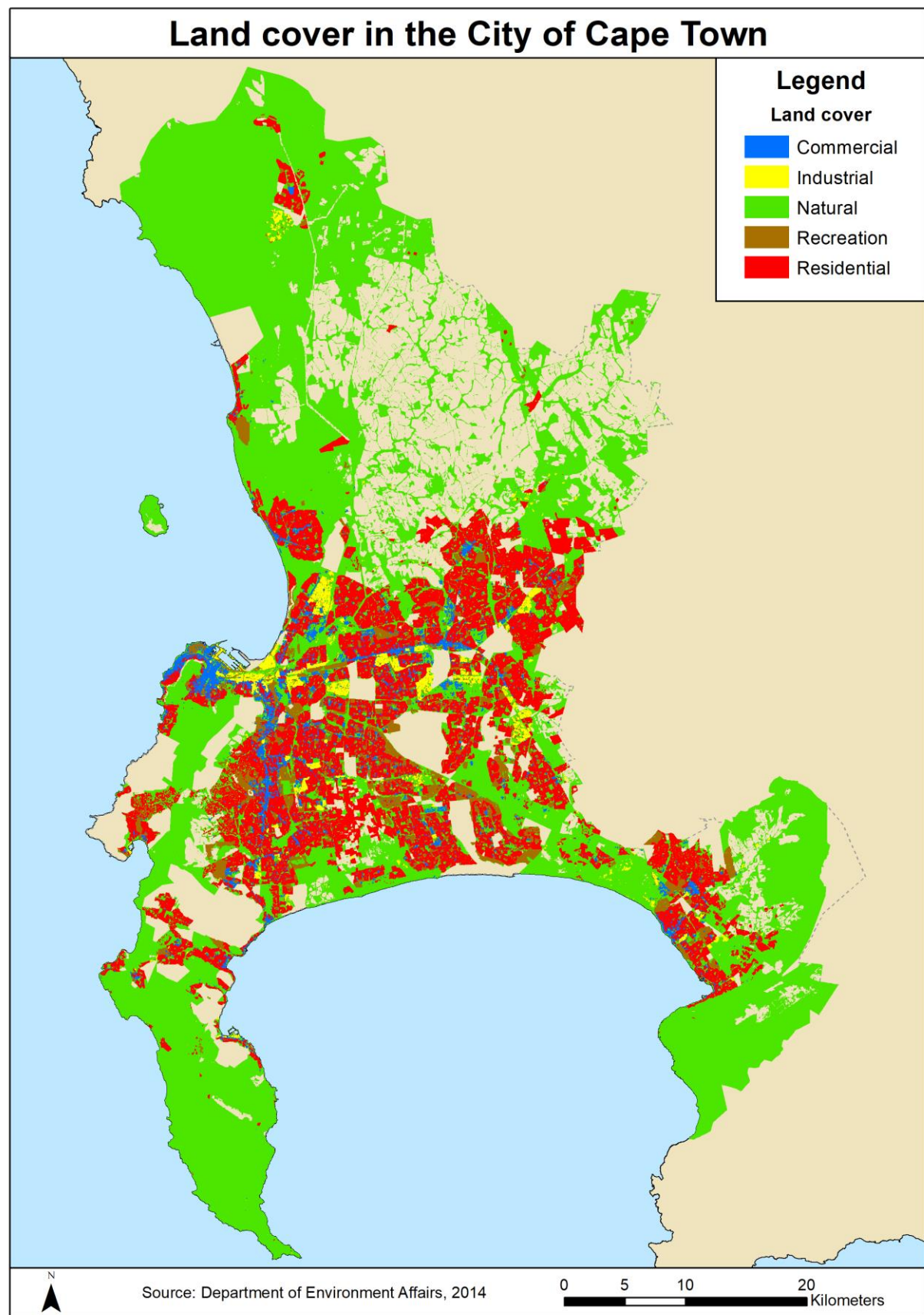


Figure 4.25: Land cover in the CCT

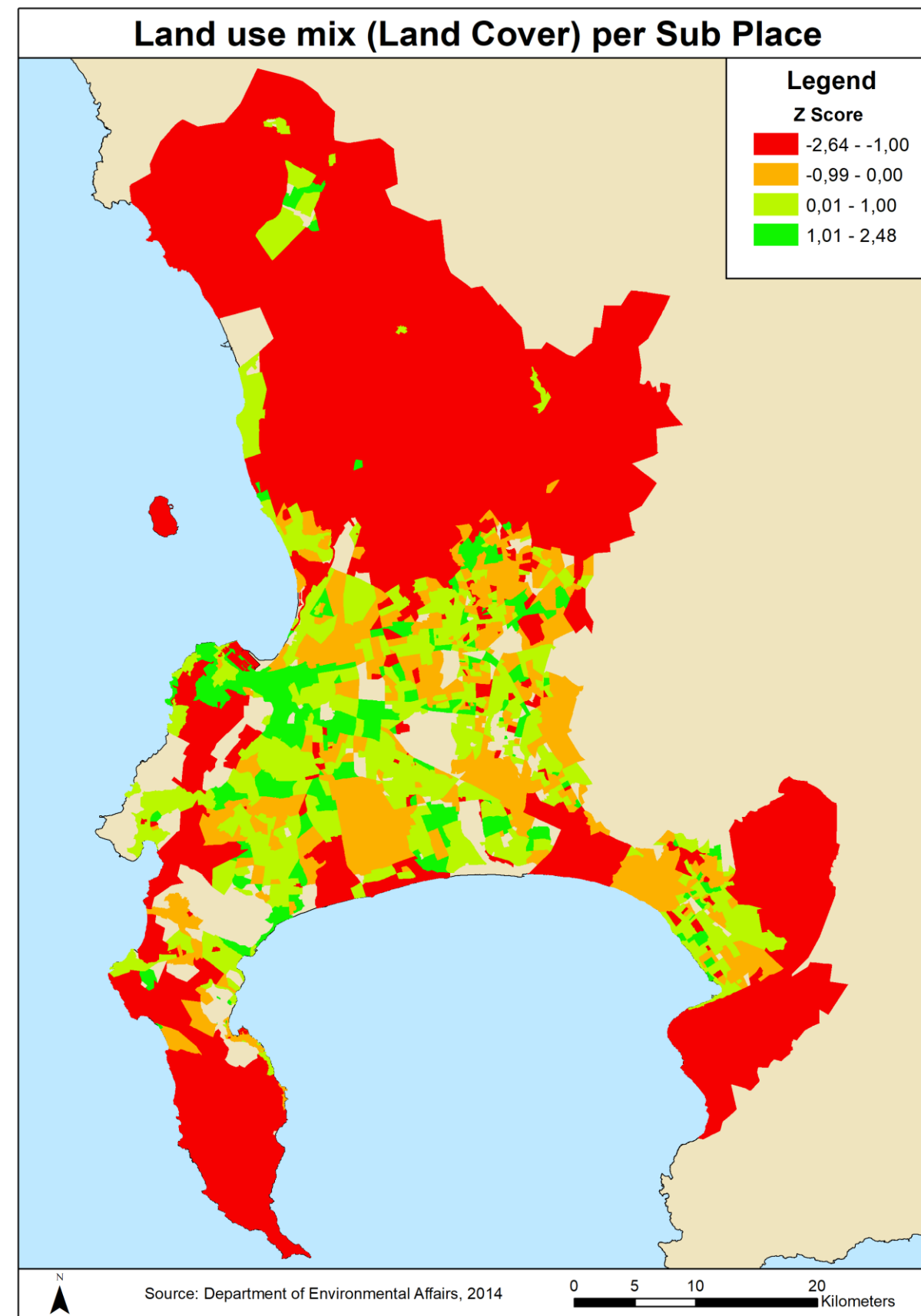


Figure 4.26: Land-use mix (Land Cover) per Sub Place

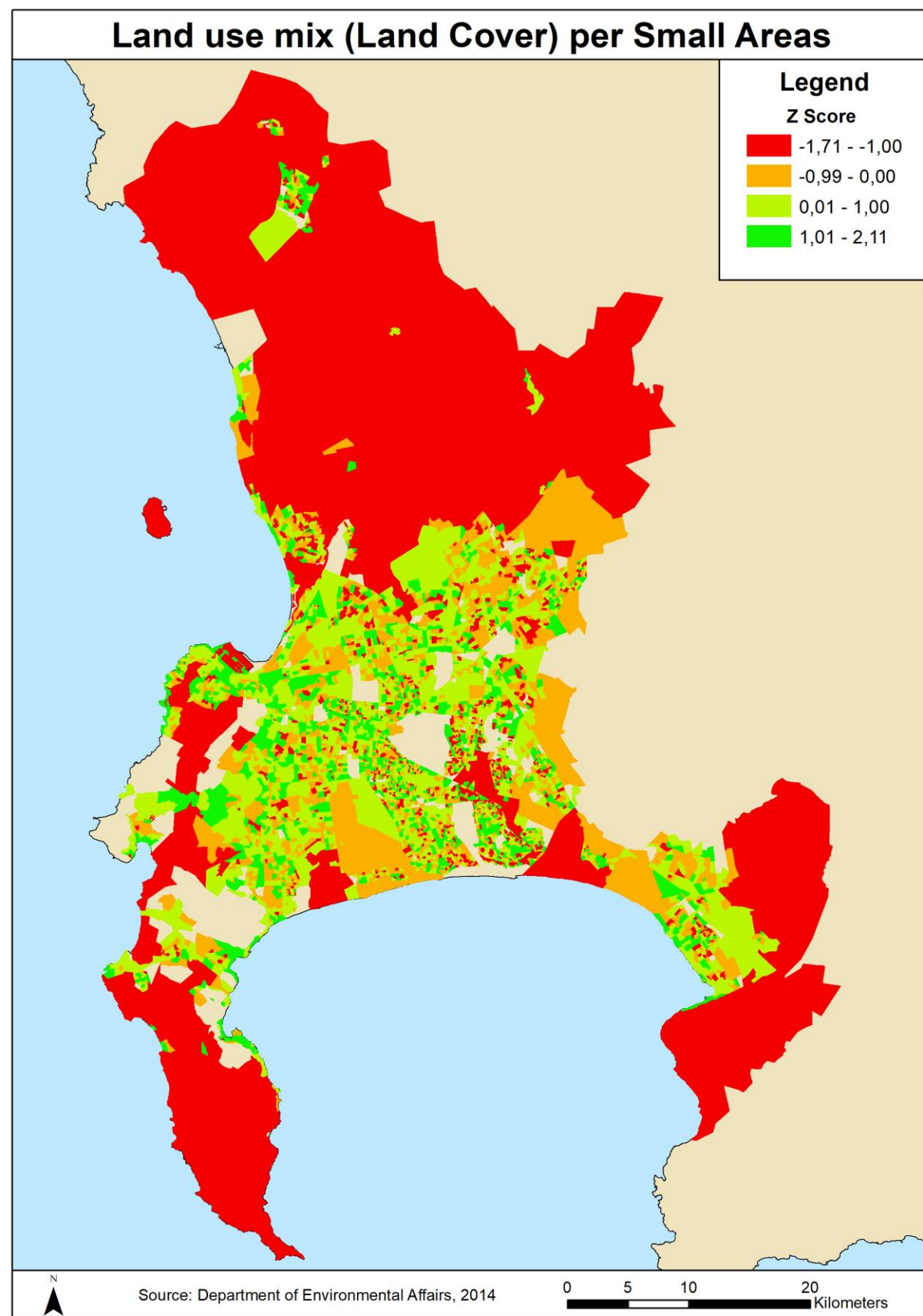


Figure 4.27: Land-use mix (Land Cover) per Small Area

#### 4.2.7 Destinations - weighted overlay

The destination data were sourced from a wide variety of sources which included the CCT's open data portal, data from the Cape Town Metropolitan Authority (UCT Library), and Open Street Maps. The destination data was categorised according to seven groups: transit, education, healthcare, community, entertainment, parks, and commercial (see Appendix A for a breakdown of the destination groups). The some of the groups included formal and informal destinations. Each grouped dataset was reprojected to an LO 19 projected coordinate system and then clipped to the extent of the CCT's administrative area.

A hot spot analysis presents the spatial distribution of all destinations across the metropolitan. The hot spot analysis shows that there are various clusters of destinations. These destination clusters are within the central business district and areas to the south and southeast of the city (Figure 4.28). The absolute locations of destinations are not a predetermining factor of a destination's accessibility but rather a destination's location within a network.

In order to gain an insight as to the accessibility of each destination grouping, a walking time analysis was conducted. The streets network dataset used in the first two subsections of this section was utilised again. The walking time analysis was conducted based on an average walking speed of 4,5 km/h, which represents a moderate walking pace. The walking time around each destination group was done according to five walking times a 5-minute walking area, a 10-minute walking area, a 20-minute walking area, a 40-minute walking area, and a 60-minute walking area. These walking areas represent the areas within reach at a constant walking pace of 4,5 km/h of a given destination. An example of the resulting walking time analyses for each destination group is figure 4.29. The area coloured in green indicate areas that are within a 5-minute walking distance, along the street network, of a commercial destination. Areas coloured in red indicate areas that are an hour away from a commercial destination.

The above walking time analysis only provides a separate account of the walking time around each destination group. The walking time results need to be combined to produce a destination accessibility layer for the CCT. This was done through a weighted overlay analysis requiring raster data as input datasets. Before the walking time analysis layers were converted to raster each walking time category was assigned a value according to the level of accessibility. Areas within a 5-minute walking distance from destinations were given a value of 5, areas within a 10-minute walking distance a value of 4, areas within a 20-minute walking distance a value of 3, areas within a 40-minute walking distance a value of 2, and areas within a 60-minute distance a value of 1.

Each of the walking time layers was then converted to raster datasets as displayed in figure 4.30, with values closer to 5 representing highly accessible areas and values closer to 0 represent inaccessible areas. The seven layers were combined in a single layer through utilising the raster calculator tool in ArcGIS. Each of the layers was assigned an equal weighting. Figure 4.31 represents the result of the weighted overlay. Different weightings were considered but it was decided that for the purpose of this study that an equally weighted overlay would be best.

In order to assign a walking time score to each Sub Place and Small Area, the weighted overlay layer was converted back to a vector format. This conversion allowed for an intersect analysis to be conducted which assigned multiple walking time scores to each Sub Place and Small Area. In determining the walking time score for a Sub Place and Small Area a dissolve analysis was done. The dissolve analysis was done on the unique Sub Place and Small Area codes whilst also calculating the average walking time score for each Sub Place and Small Area. The average walking time scores per Sub Place and Small Area were then converted to z-scores.

The Sub Place results for the destination weighted overlay reveal areas located to the centre of the City are most accessible when considering walking times (Figure 4.32). When the Small Area results are studied it is clear there is a linear pattern to the distribution of accessible areas as one moves out of the central business district and toward the south of the city (Figure 4.33).

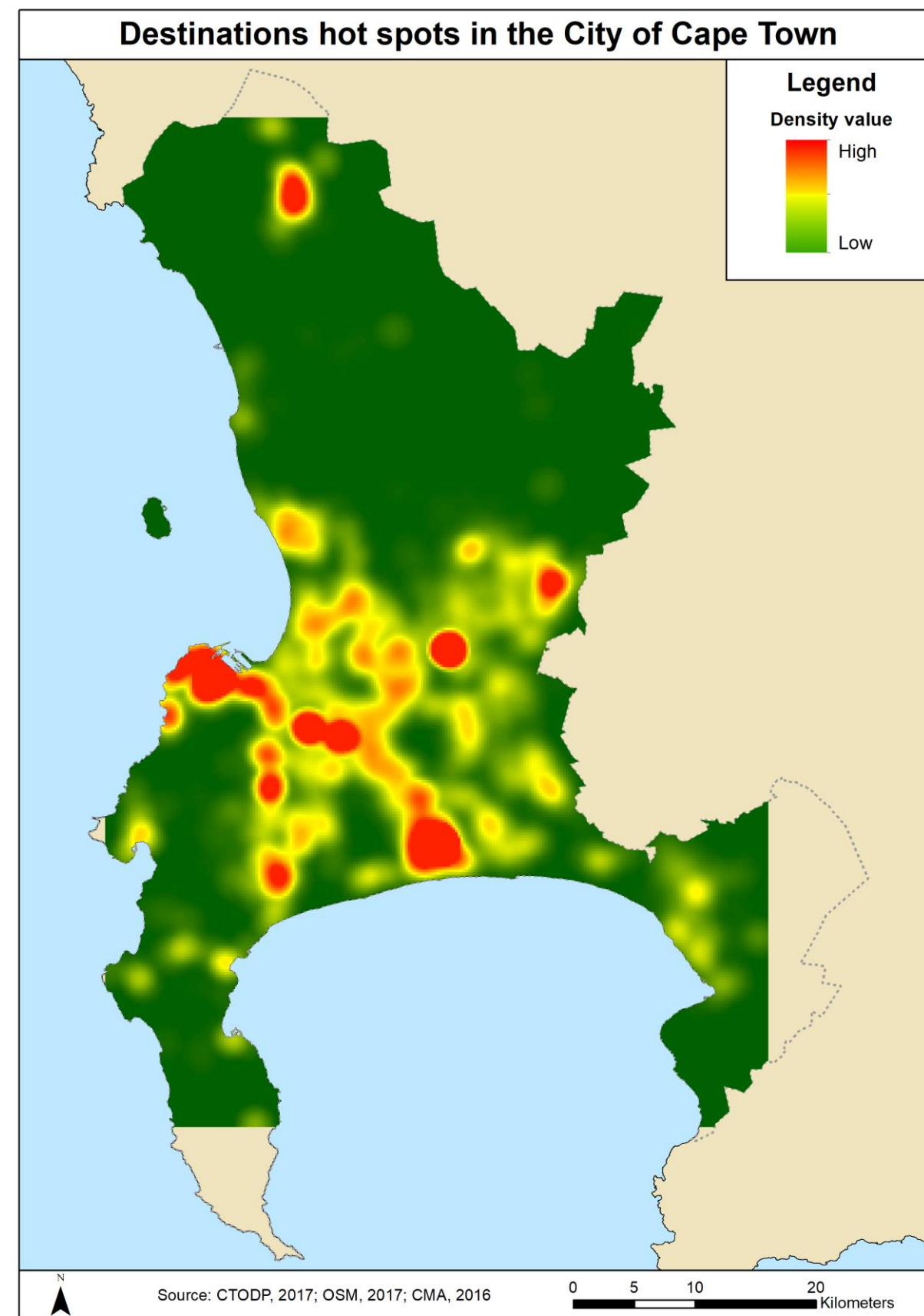


Figure 4.28: Destination hot spots in the CCT

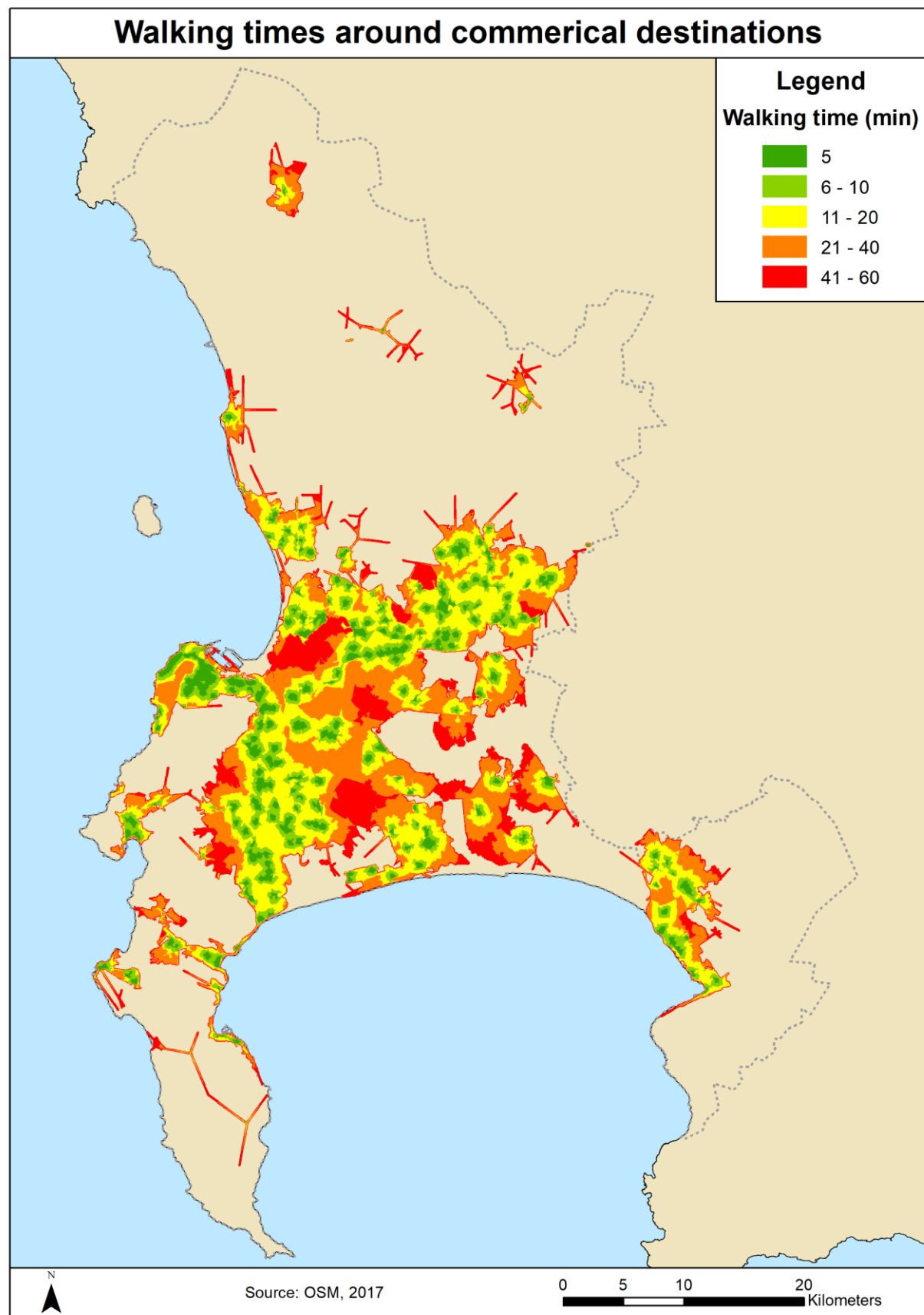


Figure 4.29: Walking times around commercial destinations

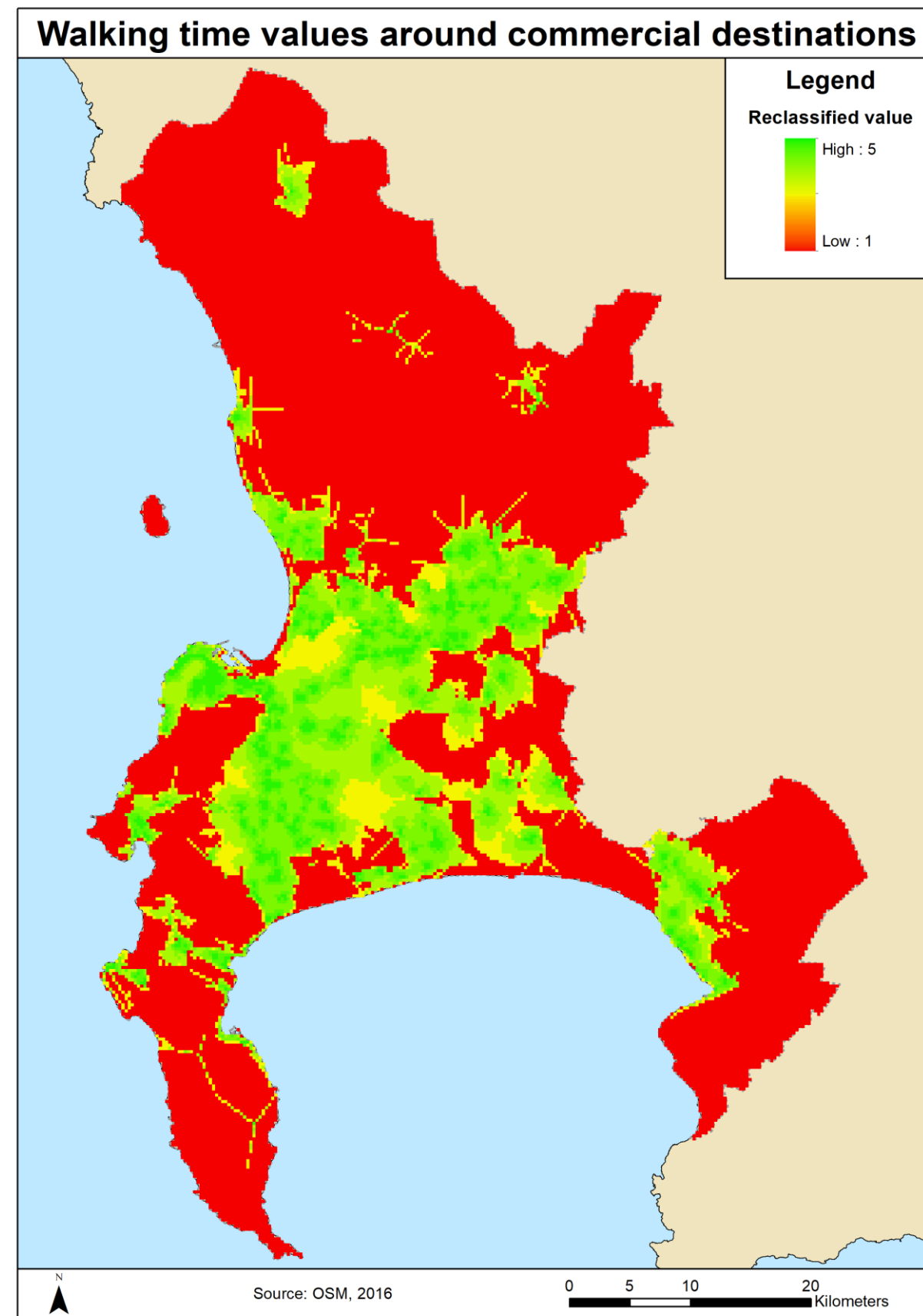


Figure 4.30: Walking times around commercial destinations

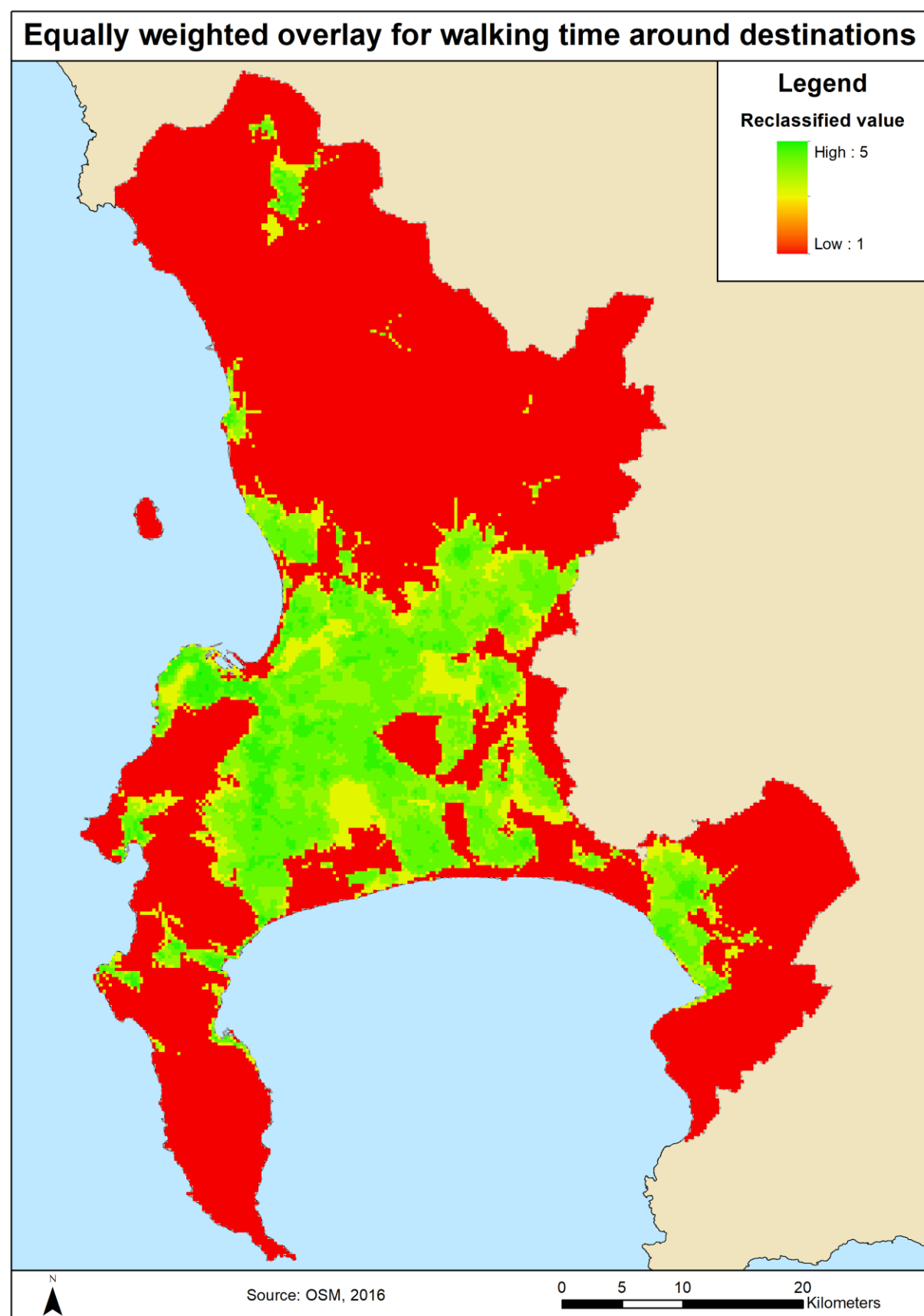


Figure 4.31: Equally weighted overlay for walking times around destinations

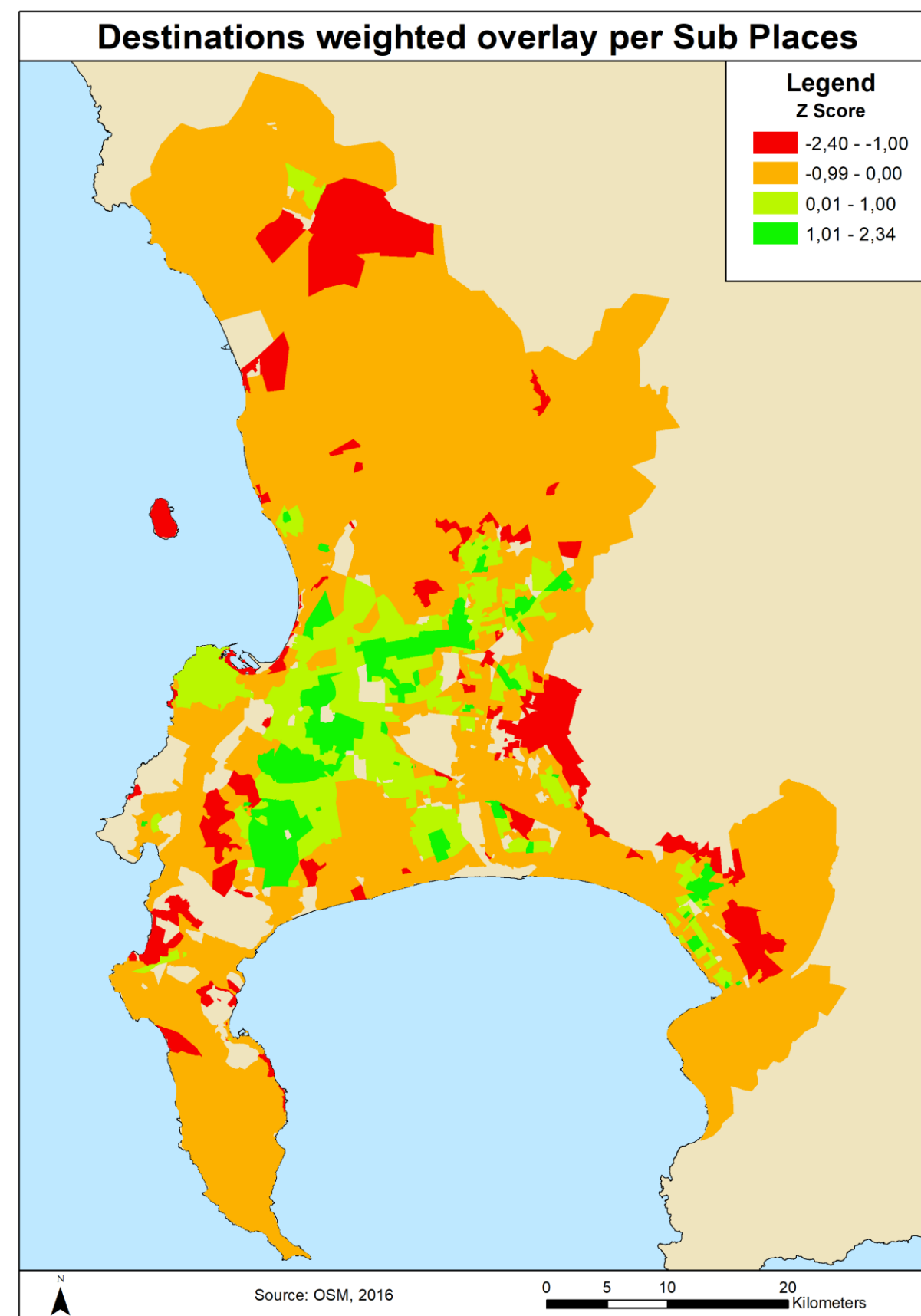


Figure 4.32: Destinations weighted overlay per Sub Place

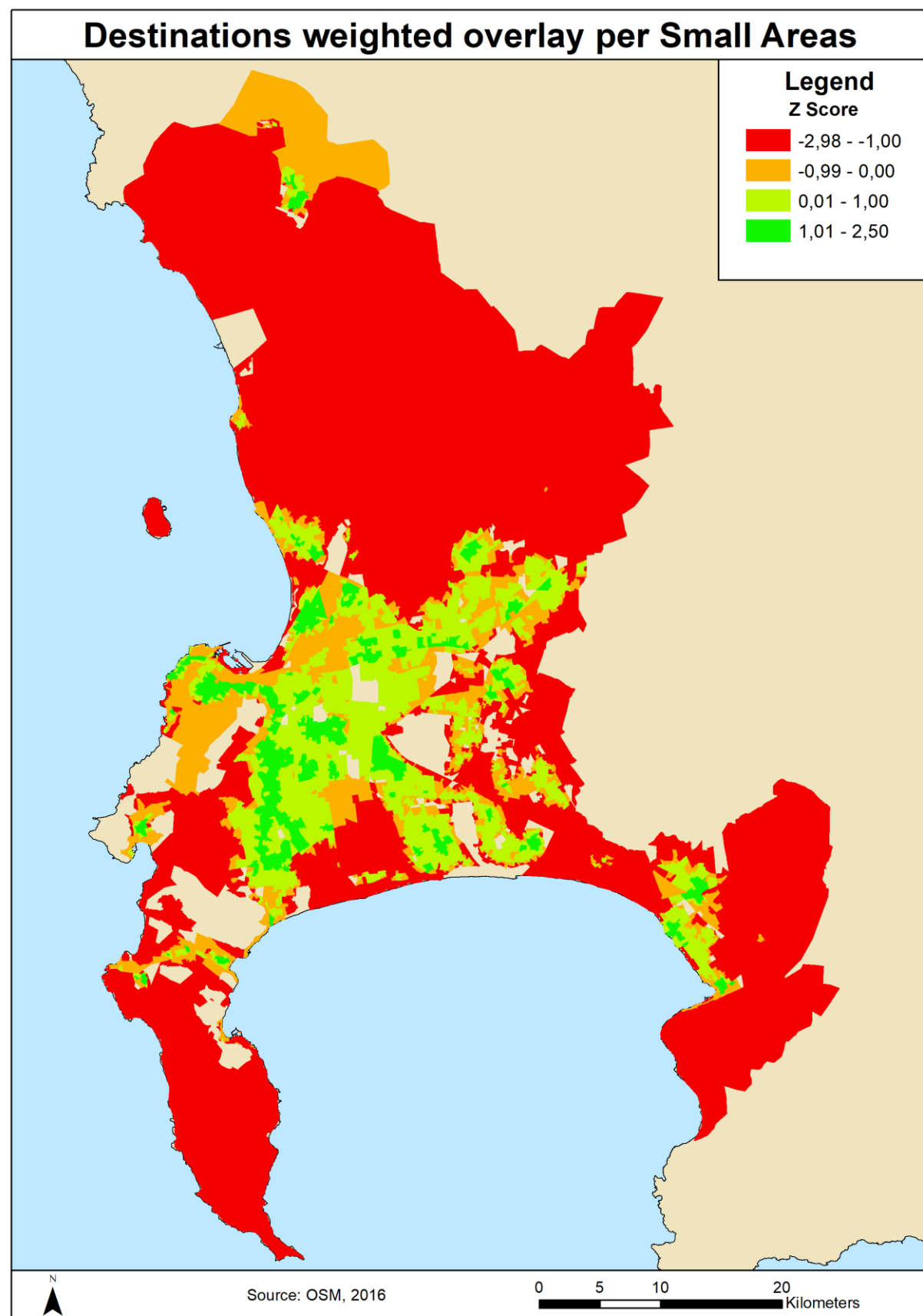


Figure 4.33: Destinations weighted overlay per Small Area

### 4.3 Step 3: Possible limitations

This section contemplates the limitation of the variables described and calculated in the preceding subsections. Critically reviewing each of the variables is essential as these variables are open to error in calculation or scope of application. A critical assessment of the variables improves the quality of the final product, i.e. the walkability index, as it allows the research to make better decisions related to what variables to include in the final product.

In determining the measurement of street connectivity two variables were calculated. These variables are true intersection density and true intersection to node ratio. Both these variables provide an insight into the connectivity of a given street network. However, the calculated values of the variables are influenced by different factors which could possibly warp the variable's relative value. In the case of true intersection density, the biggest factor influencing the final value is that of the area, as the number of true intersections is divided by the area of the given enumeration area. Thus two enumeration areas of different area sizes with the same number of intersections would have differing true intersection density values. The enumeration area with the smaller area would have a higher true intersection density value than the enumeration area with a larger area. This is exactly what the true intersection density is supposed to do but lacks the inclusion of street pattern. Street pattern is important as it influences the walkability of an area.

The true intersection to node ratio provides a better comparative measure of street connectivity between enumeration areas. The true intersection to node ratio calculates a value of between 0 and 1, with 1 being the highest indicating that all the nodes within a given enumeration area are true intersections and 0 being the lowest with no true intersections present within a given enumeration area. This measurement, however, does not provide an indication of the number of true intersections. Thus a score of one could be derived from an enumeration area with a very low number of true intersections over a very large area. This would place the validity of such a high value in doubt. Finally, as Tresidder (2005) notes, in both the cases of true intersection density and true intersection to node ratio, it is important to remember that no measure of street connectivity tells us anything about whether a street network is suitable for walking or not. This refers to the presence of dedicated pedestrian infrastructure which allows for pedestrians to take advantage of a well-connected street network.

Residential dwelling and household densities present the study with a value denoting the number of people per square kilometre. The Eskom Spot Building Count was used to calculate the residential

dwelling density for the CCT. Under closer inspection of the results, two errors were discovered in the dataset. The first error was the omission of certain areas from the count, and the second was the classification of mixed-use buildings as commercial instead of residential. A limitation of the residential dwelling density calculations is that it only counts the buildings. This leads to single residential dwellings carrying as much weight as multi-storeyed apartment buildings housing multiple families. This leads to the residential dwelling density value under-representing the actual density of an area. In addressing the undercounting of the residential dwelling density calculation this study also calculated the household density for the different enumeration areas. The household data were sourced from the 2011 Census, and thus reflects any under and over counting in these data (Berkowitz, 2012).

The land-use mix measure has two broad limitations. The first relates to the types of data utilised, and the second regards determining the level of diversity per enumeration area. Two types of data were utilised in the calculation of land-use diversity: zoning data according to the CCT's integrated zoning scheme, and the Department of Environmental Affairs land cover data. The zoning data provides an up to date version of the zoning of a parcel. This does not, however, give an indication as to whether the parcel is in fact actually being used as per the zoning category. A vacant parcel could thus be zoned but no activity would be taking place on said parcel. This brings into question whether such a parcel adds to the land-use mix diversity of an enumeration area. In order to overcome this lack of data relating to land use activity land cover data was also included in the study. The land cover dataset is from 2014 but presents the land use activity of an area according to the observed activity.

The methodology used to determine the land-use mix diversity is also imperfect. An entropy index was used to determine the land-use mix diversity of the two sets of data referred to earlier. As Brown et al. (2009) note, there are six ways in which an entropy index does not deliver ideal results in calculating walkability. The first is that an entropy index does not indicate the presence of a wide variety of land uses; as one divides by the number of land-uses present in the enumeration area and not the total number of land uses in the dataset (Brown et al., 2009). The second limitation is that categorisation of land uses or the number of land-use categories could lead to important land uses not featuring strong enough within the equation (Brown et al., 2009). The third restraint of the entropy index is that it does not account for the imbalances in land use that could have a greater influence on the walkability of an area (Brown et al., 2009). The fourth problem with entropy results is that the results fail to fully encapsulate the qualitative differences of different land uses (Brown et al., 2009). The fifth limitation relates to how this quantitative measure could assign similar entropy results to areas with different levels of walkability (Brown et al., 2009). The final limitation referred to by Brown et al. (2009) is the missing land problem.

This problem relates to how the entropy index only considers the area of land uses present in an enumeration area and not the entire area of the enumeration area.

The destination-based measure is the last of the four measures calculated in this chapter. The calculation of destination accessibility differs to previous studies, as this study calculated the walking distances around destinations. In previous studies, distances were calculated to destinations from the homes of research participants. In this study, walking distances were presented through creating a network buffer around destinations at a constant walking speed of 4,5 km/h. This is an aggregated speed and does not take into account physical aspects which could affect the walking speed of an individual. Factors adversely affecting walking speed could be the incline of a road or intersections which reduce walking speeds. In order to get an aggregate walking time layer around destinations, a weighted overlay was done. All the different layers were equally weighted which ignores inherent biases in walking behaviour, as certain destinations tend to draw more pedestrians than others. The study does not ignore this reality; however, there is no data available on the walking behaviour or preferences of Capetonians. Thus if any weighting of the layers were done it would have been based on the findings taken from differing contexts. Thus limiting this study's ability to ascertain what the effect of such a destination layer would be on the final walkability index.

The above section outlines some the main limitations facing the measures of walkability included in this study. A general limitation from each of the measure relates to the quantitative nature of how the measures were calculated or determined. This is a limitation as there are various qualitative features which influence the walkability of an area. However, this study is concerned with features relating to the built environment and therefore employed methods from previous studies where a direct link between physical activity and the built environment was found. These methods were reviewed and adapted to measure urban features affecting the walkability of Cape Town.

#### **4.4 Step 4: Stepping forward**

This chapter described the research methodology and techniques used in the creation of the GIS layers necessary in compiling a walkability index. Regarding street connectivity, two variables were investigated, which were true intersection density and true intersection to node ratio. The lack of data coverage relating to residential dwellings necessitates the inclusion of household density within the walkability index. The land use data from the city provides a conceptual representation of zoning in the city. This is addressed through incorporating the land cover data, which is a reflection of the land use

activity recorded in an enumeration area. The destination weighted overlay provides an amalgamated representation of accessibility in an area, which is a strong factor in determining how walkable an area is. The following chapter will discuss the compilation of a walkability index using the GIS layers referred to in this chapter.

## 5. Findings and analysis

The presentation of findings is a critical step in the research process. This chapter presents the findings of the walkability ratings for the CCT. The majority of findings will be presented in the form of maps compiled from combining the variables, as discussed in the previous chapter, into different walkability indices. However, before the presentation of the indices, the chapter contemplates aspects regarding the validation and the representation of the walkability indices. The validation process is important and enables the study to correlate whether the quantitative representations reflect reality. How the research findings are represented is also contemplated, as it is possible to display quantitative data in a variety of ways. Manipulative representation could substantiate false arguments; therefore this chapter explains how previous research findings were displayed and substantiates the presentation of this study's findings. The chapter then presents the different walkability indices. The influence of each variable on the walkability index is then investigated through a series of maps of two different areas. The effect of weighting variables is also investigated. Based on the preceding steps a final walkability index for the CCT is presented. This walkability index is then validated through field observations selected on the basis of the walkability rating of the enumeration area.

### 5.1 Validating walkability indices

From the literature presented in chapter two, it is clear that there are numerous studies on the creation of walkability indices. Chapter two notes two broad categories of walkability research, i.e. studies determining walkability through objective measures and studies determining walkability through perceived measures. Another noteworthy collection of literature on walkability is the validation of walkability indices. The following section explores the validation processes that previous studies employ to validate walkability indices.

Studies focused on the validation of walkability indices consider both objective and perceived studies of walkability. This is well illustrated by the study of Adams, Norman and Frank (2009), which aimed to validate the walkability findings of the NEWS survey. The NEWS is an example of a measurement of perceived walkability as it collects qualitative data regarding research participants' perceptions of the walkability of their neighbourhood. Adams, Norman and Frank (2009) aimed to validate the findings of the NEWS survey through objective measurements. Adams, Norman and Frank (2009) utilised GIS in objectively determining the walkability of the built environment within a one-mile street network buffer of research participants' homes. The study found a positive relationship between the walkability of areas

based on perceived and objective measurements. Therefore, Adams et al. (2009) claim that there is a concurrent validity between perceived and objectively measures of walkability.

Glazier et al. (2012) created a walkability index for the city of Toronto in Canada and validated the findings of the index through relating it to public health data. Public health data refers to data pertaining to physical activity (active transportation), transportation choices and body mass index of the population. Glazier et al. (2012) found a positive relationship between the walkability index and the two related measures of active transportation and the use of public transportation. Manaugh and El-Geneigy (2011) made use of the results from the Montreal Origin-Destination survey to validate the scores of a walkability index. The study found a strong correlation between high walkability ratings and walking trips for non-work purposes (Manaugh and El-Geneigy, 2011). Manaugh and El-Geneigy (2011) also note that the correlation between the walkability index rating and travel behaviour is not applicable to all individuals or households. Therefore they state that a singular walkability index needs to account for the differences in travel behaviour between individuals.

Hajna et al. (2013) turn the focus to validating neighbourhood walkability through field observations. This study made use of two qualitatively assessed walkability datasets. The first dataset was an assessment of the pedestrian environment which took into account pedestrian design aspects. The second dataset was compiled from questionnaires which gathered information regarding research participants' perceptions of the walkability of an area. The study found that the results of a GIS-based walkability index, which included measures of land-use mix, street connectivity and residential density, had a strong positive relationship to both datasets of pedestrian design and perceived walkability (Hajna et al., 2013).

A cluster of validation studies has focussed on validating the walkability rating of an area as assigned by Walk Score (Carr, Dunsiger and Marcus, 2011; Duncan et al., 2011; Nykiforuk et al., 2016; Koschinsky et al., 2017). Walk Score is an example of an objective measurement of walkability. Walk Score differs from walkability indices within the academic realm as walking distance to destinations is the primary component of the walkability index rating. Carr, Dunsiger and Marcus (2011) investigated whether Walk Score provided a reliable measure of the walkability of an area. In determining the validity of Walk Score, Carr, Dunsiger and Marcus (2011) used GIS and publicly available data of the location of amenities. Carr, Dunsiger and Marcus (2011) found significant correlations between the Walk Score rating and all the aggregated walkable destinations within a one-mile buffer from the selected addresses (Carr, Dunsiger and Marcus, 2011).

Duncan et al. (2011) support the findings of Carr, Dunsiger and Marcus (2011) that Walk Score is a valid measure of Walkability. Duncan et al. (2011) used a similar methodology, as Carr, Dunsiger and Marcus (2011) in determining the validity of Walk Score ratings. However, Duncan et al.'s (2011) scale of investigation differed from Carr, Dunsiger and Marcus (2011), as they investigated the walkability of four neighbourhoods each located in a different metropolitan area. The findings of Duncan et al. (2011) illustrate that Walk Score is of such a general nature that it can be applied in varying spatial contexts.

Validating Walk Scores through qualitative measures was done by Nykiforuk et al. (2016). This study explored the validity of Walk Score ratings for both rural and urban areas through relating street level systematic observations to the Walk Score rating of an area (Nykiforuk et al., 2016). Nykiforuk et al. (2016) found a high correlation between the walkability scores derived from the street level observations and the Walk Score rating of an area. This extends the validity of Walk Score as a measure of neighbourhood walkability even when validated against qualitative measures of walkability.

The final study relating to validating Walk Score ratings is Koschinsky et al.'s 2017 study. This study analysed whether there was any relationship between the Walk Score rating and the qualitatively measured walkability of an area (Koschinsky et al., 2017). Koschinsky et al. (2017) found a strong positive relationship between the Walk Score rating and the qualitatively measured walkability of an area. The study did, however, find that this relationship does not apply similarly to all areas in the study. Koschinsky et al. (2017) found that Walk Score tended to mask the deficiencies in the quality of the walking environment, especially within the low-income areas.

The above studies reveal a wide variety of methods to validate the results of walkability indices. What is clear from these studies is that there is a general trend towards a correlation between walkability indices created from GIS-based and qualitative measurements of walkability. Some of the qualitative datasets referred to in the studies are available to this study. However, the scale at which these qualitative datasets were captured is too broad for comparison. What is available to the study is field observations, which allow for the validation of results generated from the final walkability index. However, before the final walkability index is presented and validated, the following section discusses the importance of data representation.

## 5.2 Data representation

The following section addresses matters relating to the presentation of this study's research findings. The section describes how data from various variables were standardised allowing for the comparison of values from different variables. After explaining the rationale for data standardisation, the section turns to the categorisation and representation of the research findings.

Standardisation of data is required to relate values from differing measures to one another. For example, it is nonsensical to add data which represents a ratio e.g. a value between 0 and 1, to a value consisting of a natural number. The data calculated for the true intersection to node ratio is an example of this. Further, the standardisation of data is necessary to normalise values between variables as the value ranges differed greatly among the variables.

From the literature, there are two methods of data standardisation employed within the creation of a walkability index. The first is the categorisation of data into deciles and then reclassifying the first decile being the lowest and the tenth decile being the highest (Leslie et al., 2005; Leslie et al., 2007; Owen et al., 2007; Gebel et al., 2011; Giles-Corti et al., 2014; Stockton et al., 2016). A walkability index is then computed by summing the values of each variable according to the assigned decile value. This produces a walkability index with ratings ranging from 4 to 40, with 4 being the least and 40 the most walkable.

The second method of data standardisation observed from the literature is the calculation of z-scores (Frank et al., 2005; Frank et al., 2006; Frank et al., 2010; Adams et al., 2014; de Sa and Arden, 2014; Murekatete and Bizimana, 2015). A z-score is calculated by subtracting the mean of the data range from the row value and dividing the calculated value by the standard deviation of the data range. This produces a set of standardised values which allows calculations between datasets. Both these methods of data standardisation have been employed by various accredited studies and are thus both acceptable. This study has utilised the z-score method as the decile method seems to generalise values. The reason for using the z-score method is that the method preserves the disaggregated nature of the original datasets.

Categorising summed walkability scores determines how the results are visually communicated. Previous walkability research present results categorised according to quartiles (Frank et al., 2005; Leslie et al., 2005; Frank et al., 2006; Leslie et al., 2007; Owen et al., 2007; Frank et al., 2010; Gebel et al., 2011; de Sa and Arden, 2014; Stockton et al., 2016). Categorising walkability into quartiles assigns the lowest walkability ratings to the first quarter and the highest walkability ratings to the fourth quarter.

Studies that do not categorise the summed walkability rating into quartiles either leave the summed values in deciles (Giles-Corti et al., 2014) or simply do not refer to the rationale for categorising the final results (Murekatete and Bizimana, 2015). Drawing from previous studies this study also categorises the summed walkability ratings according to quartiles. This allows for the comparison of this study's findings to previous studies mentioned throughout this and preceding chapters.

This section provided an overview of the rational and logic in how the study presents its findings. Methods of data standardisation and categorisation from previous studies were presented. This study will present the findings through a series of maps and tables. The maps will be thematic in nature, with the theme of each map being walkability. The tables assist the presentation of the maps by displaying important statistical information of significant maps. The following section presents the research findings of the summed walkability index.

### 5.3 Research findings

The findings of the research project are presented in this section of the chapter. The section consists of three subsections, the first subsection presents the results of a preliminary walkability index, the second subsection investigates how each of the variables influences the preliminary walkability index, and the third subsection presents the final walkability index and the validation thereof.

#### 5.3.1 Findings from the preliminary walkability index

A walkability index is the product of the sum of all relevant measures of the built environment which affects walking behaviour. In chapter four the variables relating to the measurement of walkability were calculated. This subsection presents the results of a preliminary walkability index based on the summation of all the variables calculated in chapter four. This walkability index is described as preliminary as it provides a point of departure for the validation of the final walkability index. This index differs from previous walkability indices which consist out of three measurements, street connectivity, residential density and land-use mix; and are usually weighted (Frank et al., 2005; Frank et al., 2006; Frank et al., 2010; Dobesova and Krivka, 2012; Adams et al., 2014; de Sa and Arden, 2014; Reyner et al., 2014). The equation for the preliminary walkability index is:

$$\text{Street Connectivity (true intersection density + true intersection to node ratio)} + \text{Residential Density (dwelling unit density + household density)} + \text{Land-use Mix (land cover data + zoning data+ Destinations)}$$

The resulting walkability index is presented in figures 5.1 and 5.2 for the Sub Places and Small Areas of the CCT. Statistical information regarding the variables included in the composition of the walkability index is contained in tables 5.1 and 5.2.

**Table 5.1: Statistical information for preliminary walkability index per Sub Place**

Variable	Minimum	Maximum
True intersection node ratio	0,03	1,22
True intersection density	-0,42	7,37
Residential density	-1,04	5,36
Household density	-0,44	12,52
Land-use mix - zoning	-2,02	2,10
Land-use mix - land cover	-2,05	2,35
Destinations	-0,88	2,05

**Table 5.2: Statistical information for preliminary walkability index per Small Area**

Variable	Minimum	Maximum
True intersection node ratio	-0,65	0,74
True intersection density	-0,29	8,00
Residential density	-0,95	4,74
Household density	0,05	6,62
Land-use mix - zoning	-1,48	1,70
Land-use mix - land cover	-1,71	2,06
Destinations	-1,15	1,88

The results per Sub Place indicate spatial clustering of highly walkable Sub Places toward the southern portions of the CCT; these Sub Places are indicated bright green on figure 5.1. Conversely, Sub Places with a “Very low” walkability index rating are located to the periphery of the CCT. The results per Small Area indicate spatial clustering of highly walkable Small Areas in the southeast of the CCT (Figure 5.2). Small Areas with a “Very low” rating are located on the periphery of the city (Figure 5.2). This is consistent with the results per Sub Place. A difference between figures 5.1 and 5.2 is the location of a large number of Small Areas with a rating of “Low to moderate” located in between Small Areas with a “Moderate to high” rating (Figure 5.2). This spatial distribution is a sign of a high degree of spatial variance within the dataset.

The differences observed in figures 5.1 and 5.2 can be explored through the statistical information contained in tables 5.1 and 5.2. Little difference was recorded in the mean values of the variables.

However, the minimum and maximum values of the variables as calculated per Sub Place or Small Area differ from one another. The variable differing most between the two enumeration areas is household density, as the maximum value per Sub Place area is almost double that of the household density calculated per Small Area. Maximum and minimum values are significant as the values indicate the range of the data for the measures. Z-scores greater than 3 and less than -3 indicate outliers within the data range, as these values fall outside three standard deviations from the mean. Outliers skew data ranges and should be considered when including or excluding a variable to/from a walkability index.

The results presented in the above section provide valuable insight as to how the scale of investigation affects walkability ratings. Sub Places span a larger area than Small areas and therefore the results are more generalised. Thus to gain a nuanced understanding, Small Areas are used in the following sections to investigate how the different variables affect the walkability ratings.

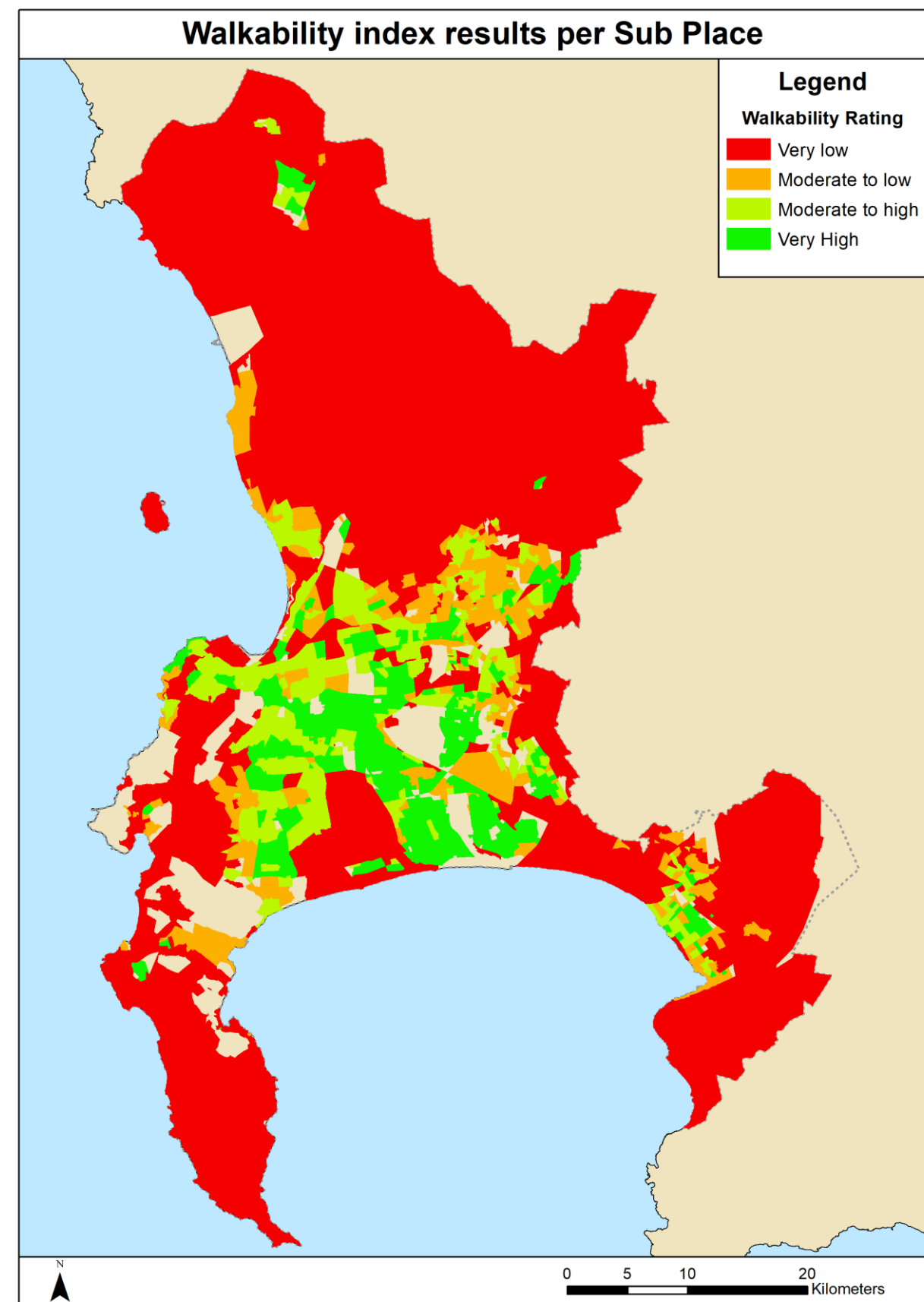


Figure 5.1: Walkability index results per Sub Place

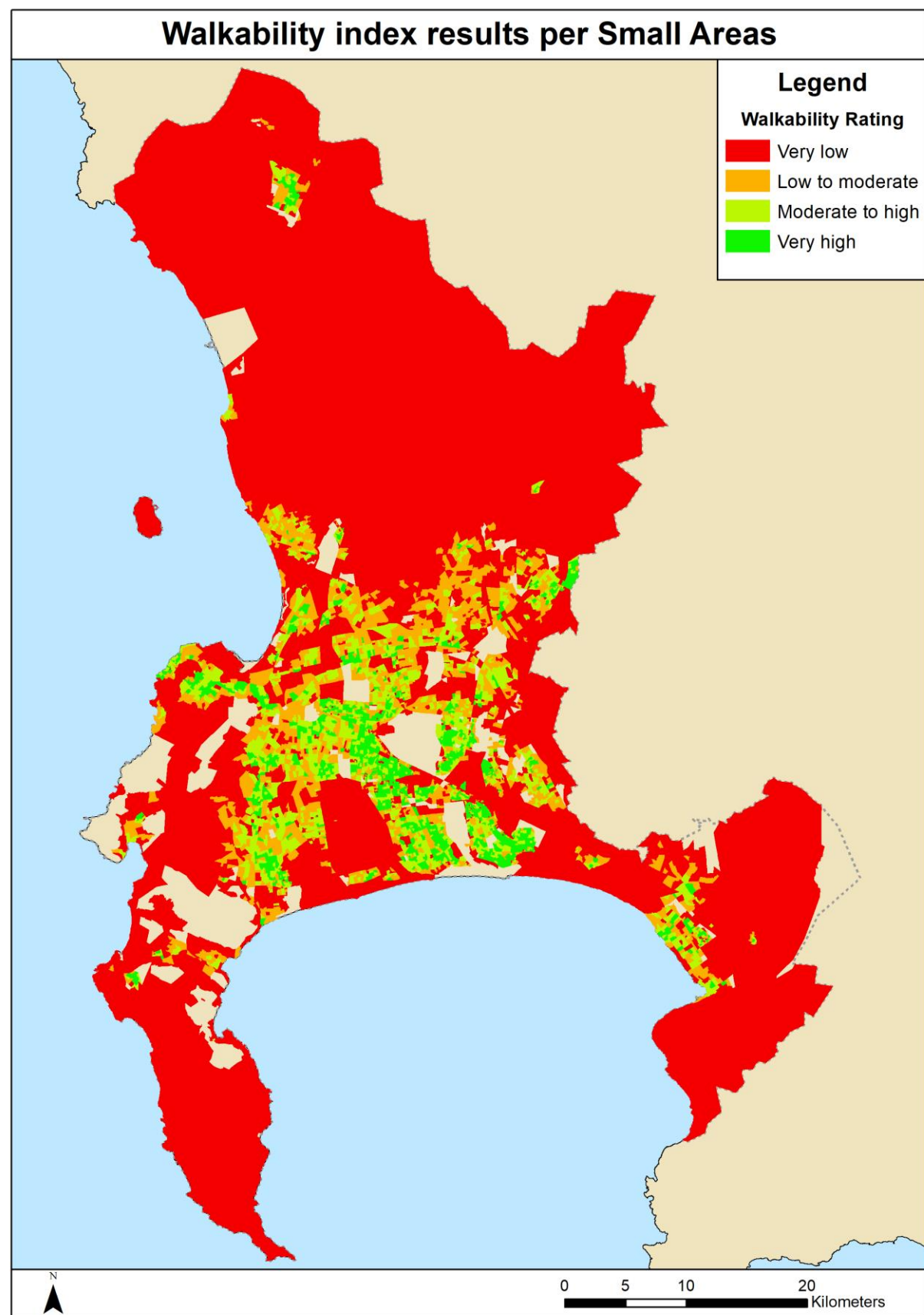


Figure 5.2: Walkability index per Small Area

### 5.3.2 Understanding the influence of variables

The previous subsection presented the results of the preliminary walkability index for the entire CCT, as calculated at a Sub Place and Small Area level. In order to ascertain the influence of each variable on the walkability index, a microscale investigation is required. The study, therefore, investigates two areas. These areas are the Cape Town City Bowl area and the suburb of Kuils River. These areas were chosen for two reasons. The first reason is the researcher's intimate knowledge of the two areas and the second reason is the stark difference in context between the two areas. The Cape Town City Bowl is the hub of activity and has the characteristics of a central business district with a mix of land uses. Conversely, Kuils River is a suburb situated on the edge of the metropolitan area and could be described as a dormitory town with mono-functional land-use patterns. The following subsection presents a series of walkability indices comprised through the summation of selected variables.

The location of the two areas is indicated in figure 5.3. The Cape Town City Bowl area is indicated by the yellow extent rectangle and the location of Kuils River is indicated by the red extent rectangle (Figure 5.3). From figure 5.3 it is clear that the two areas do not just differ in geography but also in terms of the walkability rating. Figure 5.3 displays the walkability results according to the standard deviation of the preliminary walkability ratings. According to this classification, the Cape Town City Bowl area has walkability ratings close to the mean as well as above the mean. Kuils River largely consists of areas that fall below the mean walkability ratings for the entire city.

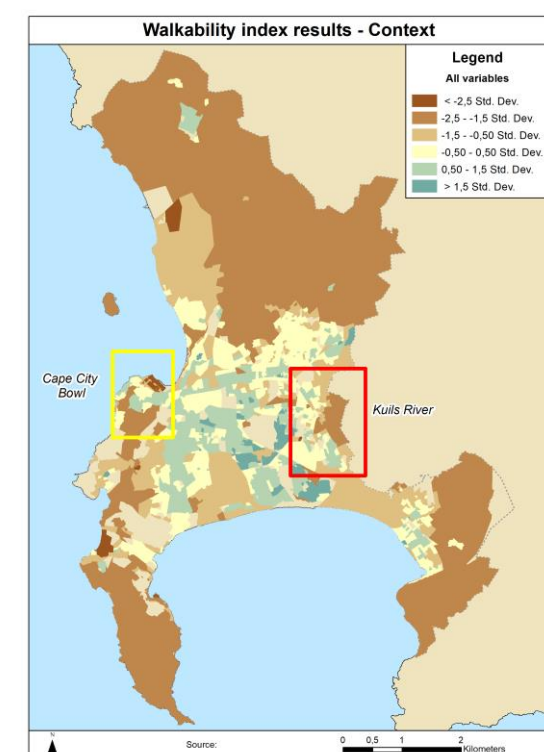


Figure 5.3: Walkability index results - Context

Figure 5.4 represents the preliminary walkability ratings for the Cape Town City Bowl and Kuils River. Small Areas located to the centre of the Cape Town City Bowl fall within the "Very high" walkability rating. It is important to note that the Small Areas rated as "Low to moderate" and "Very low" are located within green spaces such as Lion's Head and Table Mountain National Park. In Kuils River Small Areas within the "Very high" and "Moderate to high" rating category are clustered toward the

northwest of the suburb. Small Areas falling within the “Low to moderate” and “Very low” rating category are situated to the southeast of the suburb.

Comparisons between the two areas as well as within each area were considered. When the Small Areas with a “Moderate to high” walkability rating are considered between the two areas, a disparity is evident. The Cape Town City Bowl is an area consisting of a high degree of land-use mix and a large number of transit destinations. In contrast, Kuils River is an area characterised by low densities and few transit destinations. Thus it is highly unlikely whether these two areas have similar levels of walkability. However, the expected walkability ratings corresponded to the results from the preliminary walkability index. In Cape Town City Bowl the Small Areas with a walkability rating of “Very high” and “Moderate to high” are concentrated in the historic core of the central business district as well as in Sea Point. In Kuils River the Small Areas rated as “Very high” and “Moderate to high” are located along Van Riebeeck Road which is the traditional centre of the suburb with different land uses present along this road.

To determine how each measurement affects the preliminary walkability index a set of differing walkability indices were composed. Each of the walkability indices included all the measurements except one of the variables relating to street connectivity, residential density and land-use mix. The destination measurement only has one variable and was not included in the investigation. Figure 5.4 presents the preliminary walkability rating for the areas of the Cape Town City Bowl and Kuils River.

Street connectivity can be calculated through various measures. This study calculated street connectivity based on the true intersection density and the true intersection to node ratio. The values for the measures of street connectivity were calculated for both Sub Places and Small Areas. Figures 5.5 and 5.6 represent the influence of street connectivity measures on the preliminary walkability index for the Cape Town City Bowl and Kuils River, respectively. Within the Cape Town City Bowl, the biggest difference is evident in the Foreshore area. This area is rated as “Moderate to low” in the walkability index excluding the true intersection to node ratio variable. The same area is rated as “Moderate to high” in the walkability index excluding true intersection density. The former representation is more accurate as this area is largely isolated from the rest of the central business district due to the N1 highway.

A similar change in walkability rating is evident in Kuils River. The change in Kuils River is seen in the Small Areas to the southeast of the “Moderate to high” (northwest) cluster (Figure 5.6). The Small Areas, to the southeast, are rated as “Very low” in the walkability index excluding true intersection node

ratio and rated as “Moderate to low” in the walkability index excluding true intersection density (Figure 5.6). The representation excluding true node density is accurate as the area to the southeast of Kuils River consists of industrial, agricultural and vacant lands, which do not contribute to the walkability of an area.

In both the Cape Town City Bowl and Kuils River, the change in walkability in the Small Areas referred to is attributed to the area covered by the Small Areas. The area is a determining factor as it is included in the calculation of true intersection density and not in the true intersection to node ratio. Thus larger Small Areas would most likely have a lower true intersection density. Although the areas investigated show that the true intersection density provides an accurate representation of walkability, it is not appropriate for the rest of the metropolitan.

The variance in the area of Small Areas is too large and skews the data range of the true intersection density, as displayed by z-scores of more than 3 and less than -3 (Table 5.2). In previous studies, true intersection density is used as a measure of street connectivity. However, these studies use constant enumeration areas of similar areas, which allows for a normal distribution of the data range of true intersection density. Therefore this study will use the true intersection to node ratio as the measure of street connectivity, as the variable is independent of area.

Residential density is calculated by dividing the number of residential dwellings by the area of a given enumeration area. This study calculated two variables to measure residential density. These variables are dwelling density and household density. Figures 5.7 and 5.8 represent the walkability ratings excluding residential dwelling density and household density for the Cape Town City Bowl and Kuils River, respectively. Based on Figure 5.7 there is little change between the dwelling density and household density. The only noticeable change is a few Small Areas being rated as “Very high” based on the walkability index excluding household density. For Kuils River the results were almost identical (Figure 5.8). Only one Small Area differed between the two walkability indices. The results investigated in this segment show that there is a high degree of correlation between residential dwelling density and household density. Thus either variable would be suitable for inclusion in the final walkability index. However, given the lack of coverage in the residential dwelling count dataset, this study will include the household density variable as the measure of residential density.

The land-use mix diversity is the final measure investigated in this section. The land-use mix is calculated through an entropy index, which calculates the diversity of land use within an area. Two land-

use mix variables were calculated based on two sets of data, the one is based on a land cover dataset and the other based on the CCT’s integrated zoning management scheme. Figures 5.9 and 5.10 display the walkability ratings excluding the zoning dataset and the land cover dataset for the Cape the Town City Bowl and Kuils River, respectively. For the Cape Town City Bowl, there is a difference in the number of Small Areas rated as “Moderate to high” and “Low to moderate”. The results from the walkability index, excluding the land-use mix calculated from the zoning data, rated more Small Areas as “Moderate to high” (Figure 5.9).

Conversely, the walkability index, excluding the land-use mix calculated from the land cover dataset, has more Small Areas rated as “Low to moderate” (Figure 5.9). The walkability index, excluding the land cover dataset, concentrates the Small Areas with a “Very high” and “Moderate to high” rating in the historic centre of Cape Town as well as within Sea Point (Figure 5.9). Both the historic centre of Cape Town and Sea Point are known to have a high mix of land uses and high densities. The walkability index, excluding the land cover dataset, thus represents a more detailed version of land use within the Cape Town City Bowl.

The results for Kuils River are more identical than for the Cape Town City Bowl. Small Areas rated as “Moderate to high” in the walkability index, excluding the land cover dataset, are concentrated to the northwest of Kuils River and has almost a linear spatial pattern (Figure 5.10). The result of this walkability index is also more detailed than the walkability index excluding the land cover data, as less Small Areas are rated as “Moderate to high”.

This investigation illustrates that there are differences between the walkability indices which excluded either the land cover dataset or the zoning dataset. The walkability index, excluding the zoning dataset, tends to generalise the results of the walkability index. The level of detail provided by the zoning dataset necessitates that this variable is included in the study as the measure of the land-use mix.

The above subsection serves to explain the inclusion or exclusion of certain variables from the final walkability index. Based on the investigation; street connectivity is measured by the true intersection to node ratio, residential density is measured by the household density, and the land-use mix is measured through the entropy index results calculated from the zoning data. The walkability indices presented thus far are all the product of the summation of equally weighted variables. The following subsection considers the weighting of measurements in calculating a walkability index.

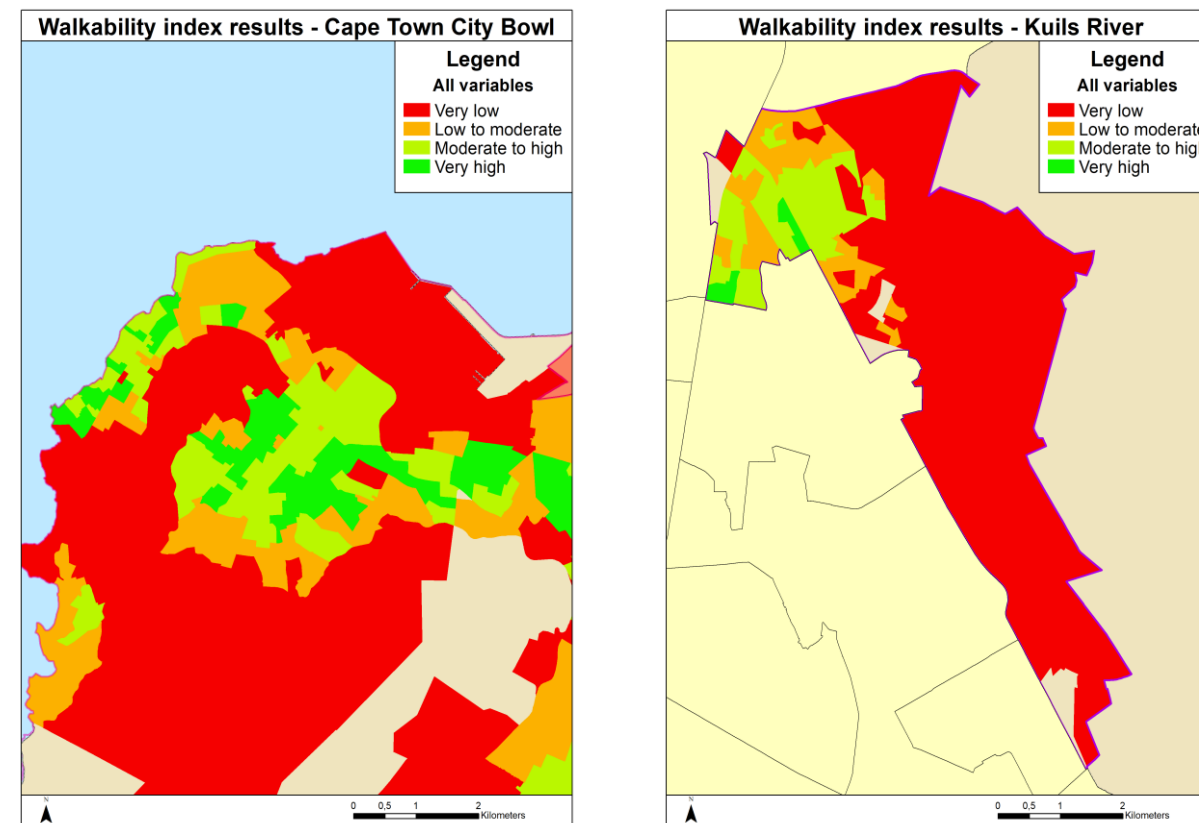


Figure 5.4: Walkability index results - Cape Town City Bowl and Kuils River

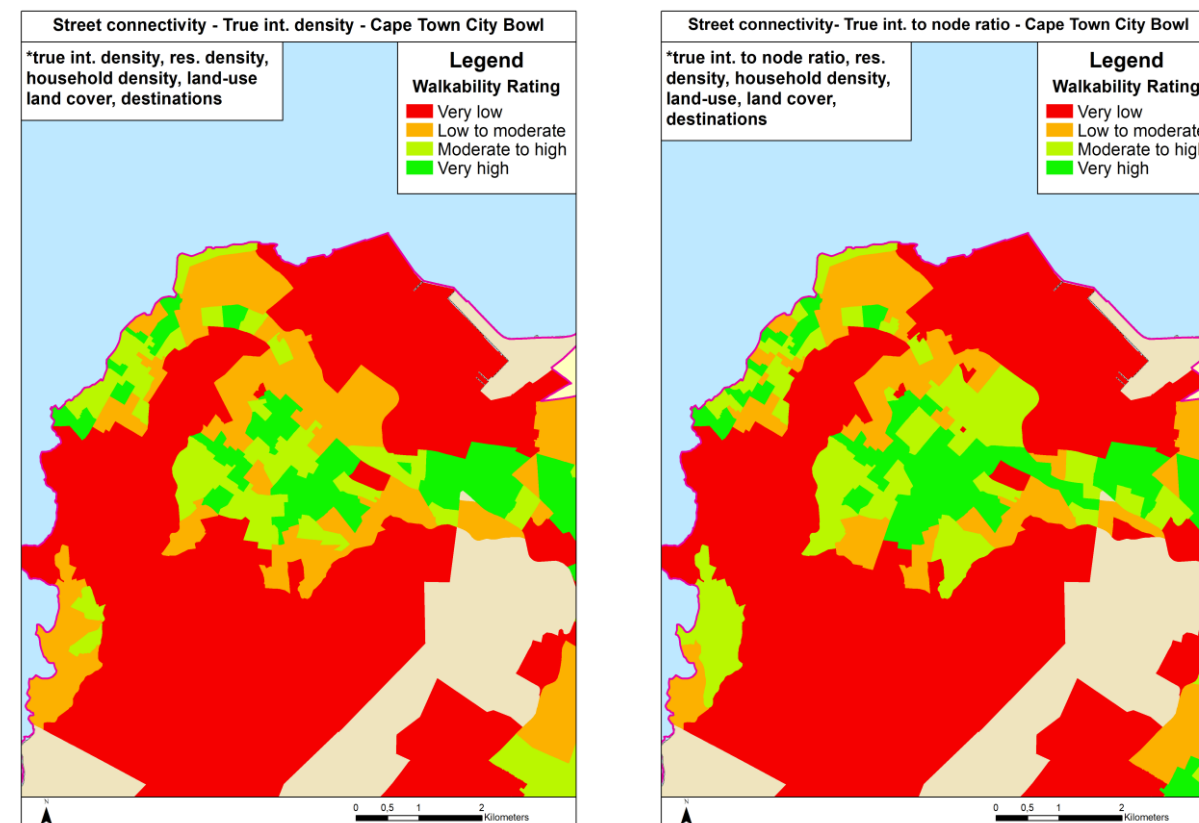


Figure 5.5: Street connectivity - Cape Town City Bowl

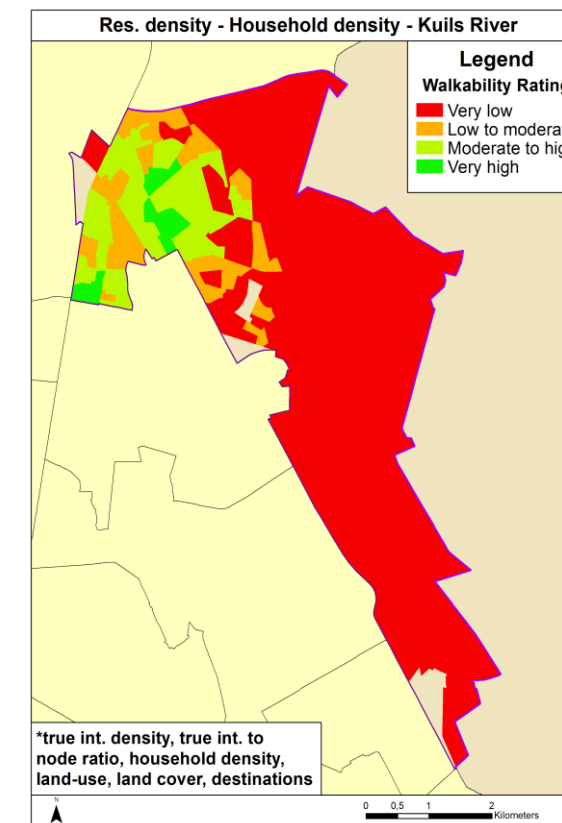
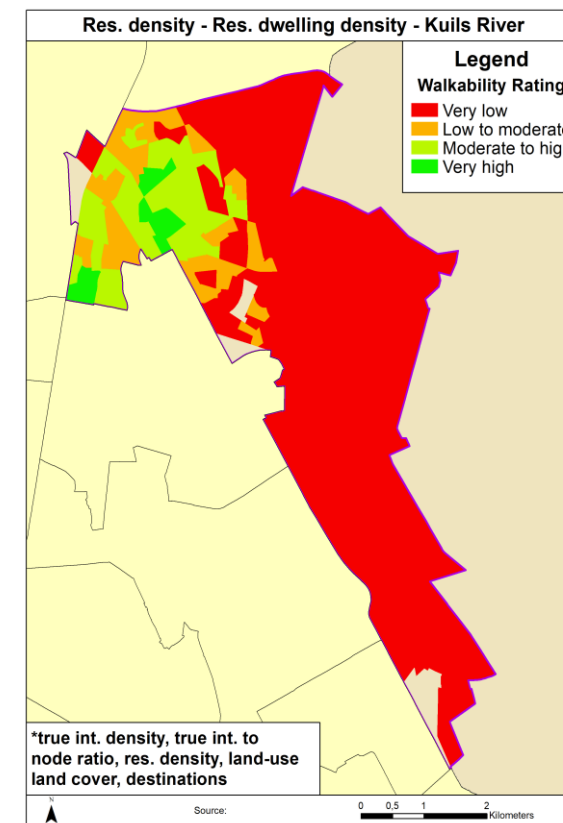
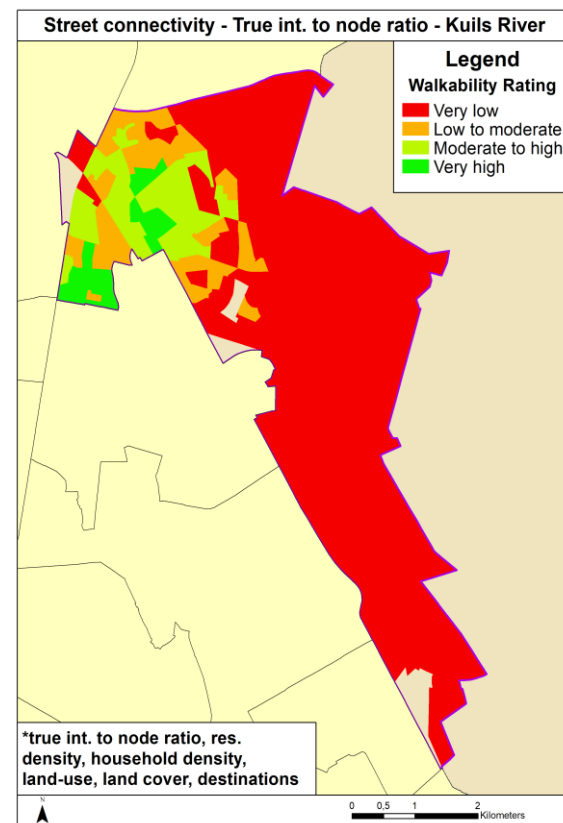
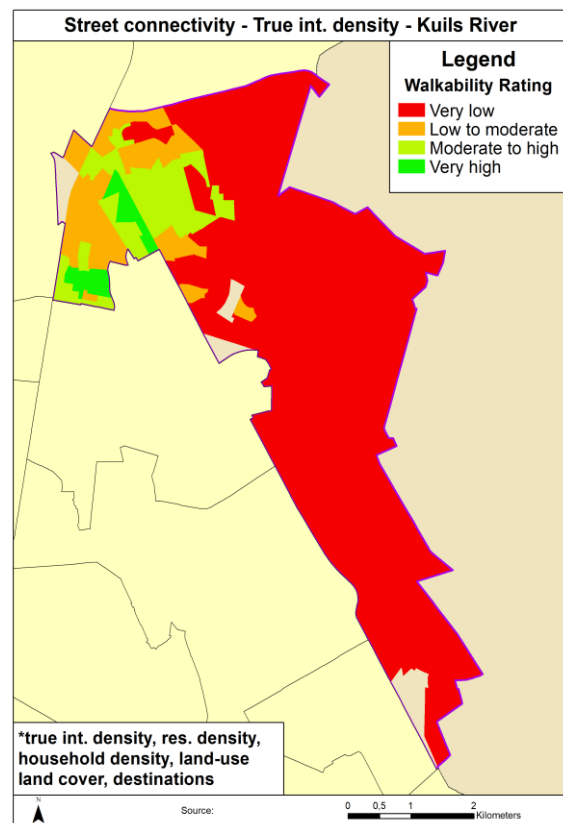


Figure 5.6: Street connectivity - Kuils River

Figure 5.8: Residential density - Kuils River

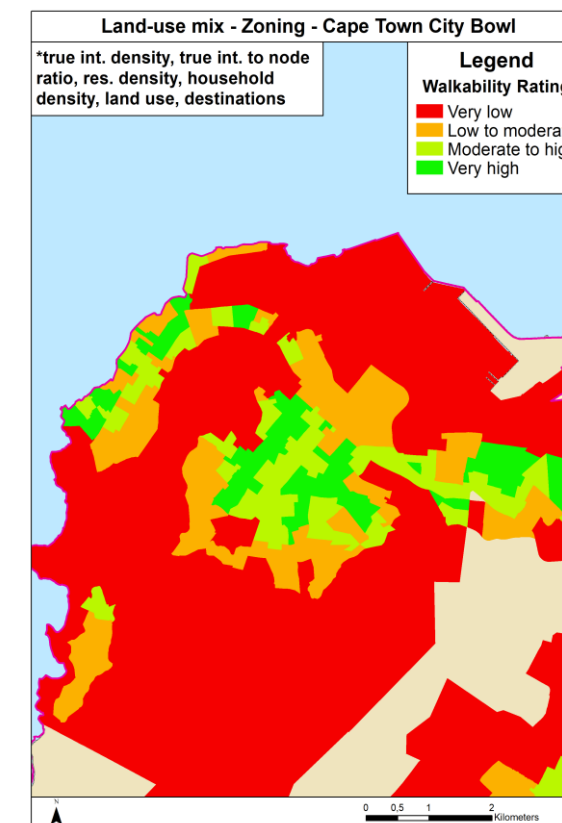
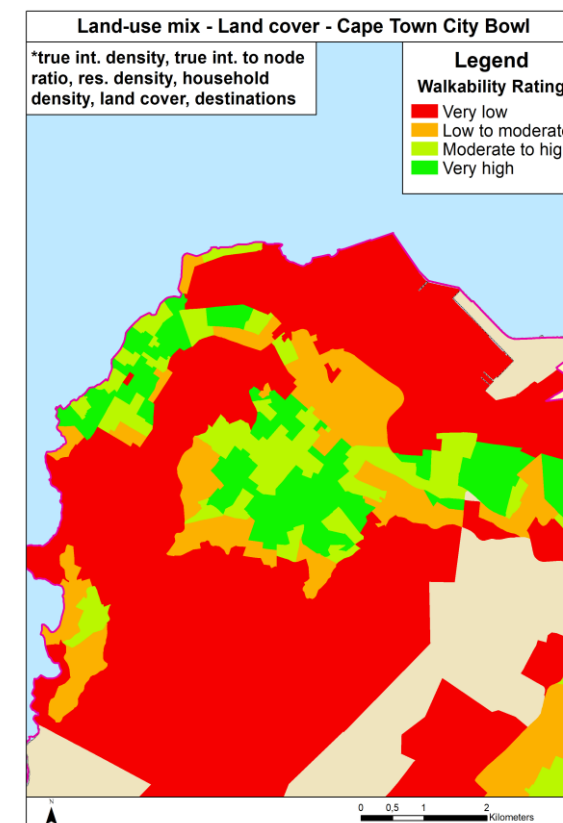
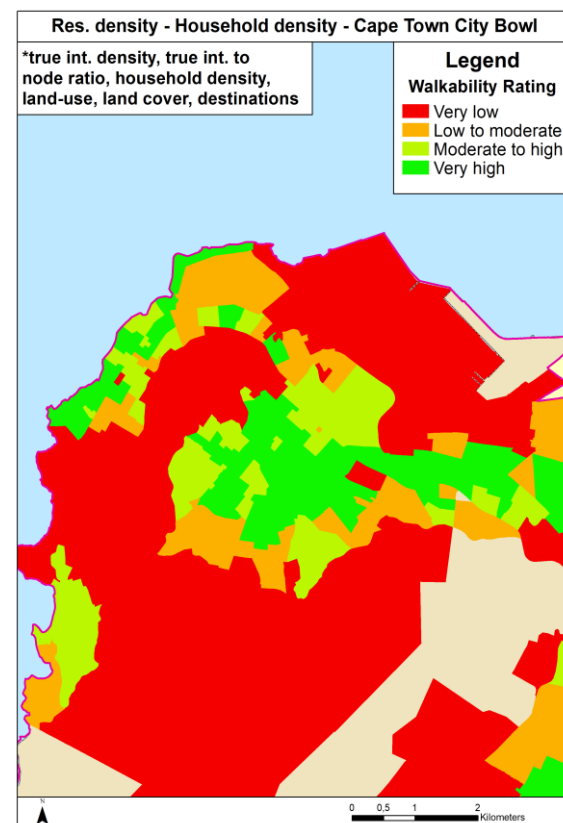
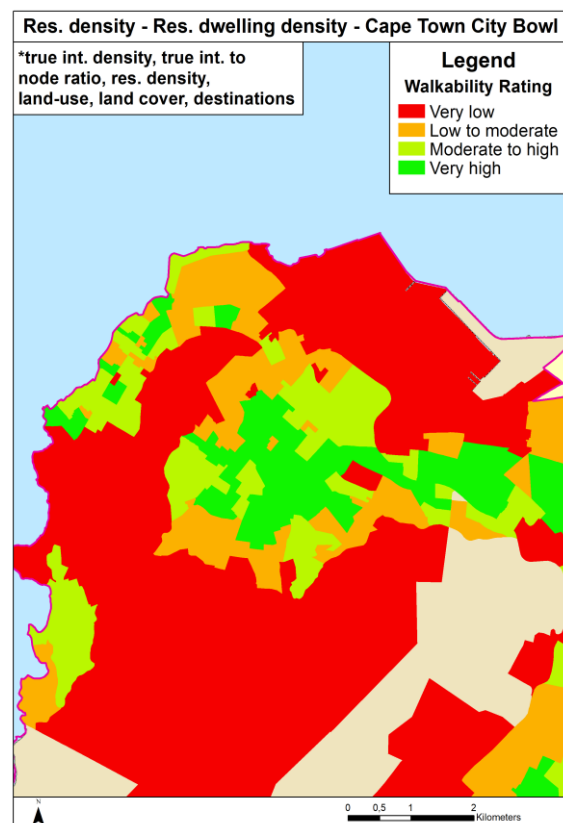


Figure 5.7: Residential density - Cape Town City Bowl

Figure 5.9: Land-use mix - Cape Town City Bowl

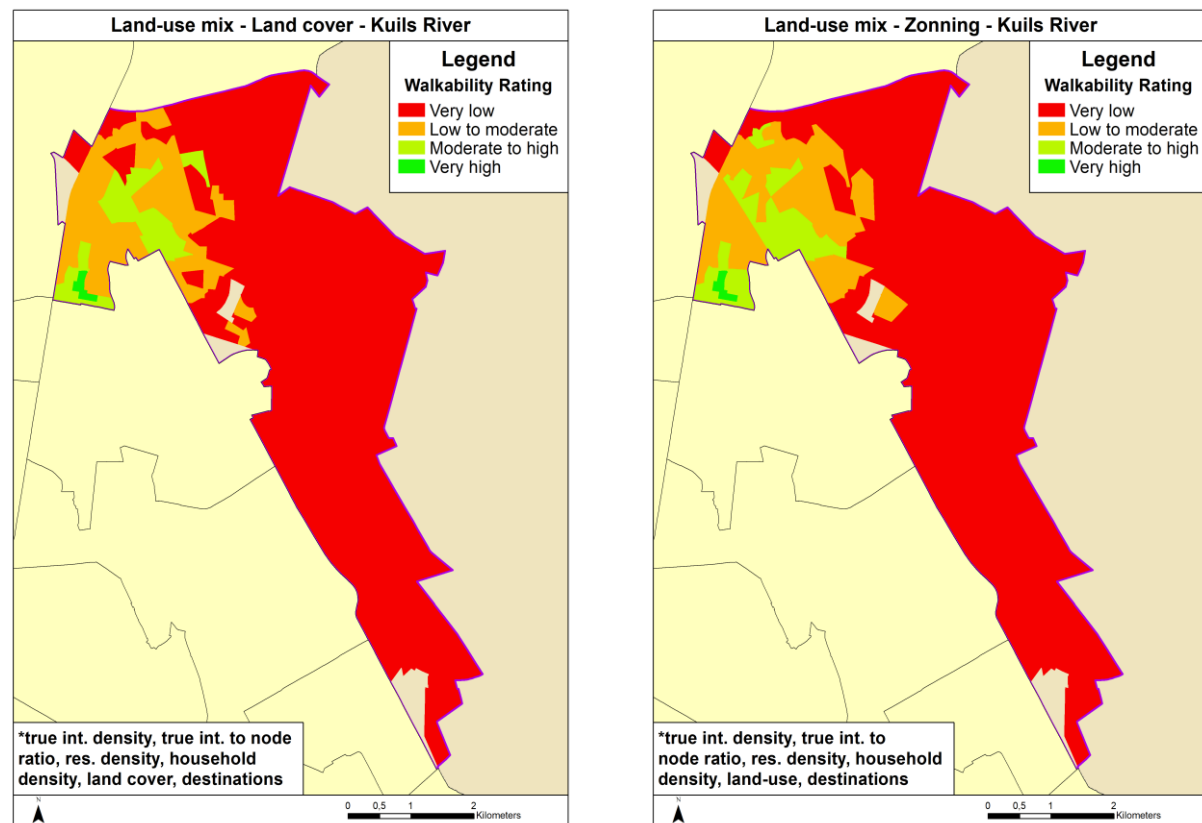


Figure 5.10: Land-use mix - Kuils River

### 5.3.3 Weighted walkability indices

The literature review revealed two distinct methods of calculating walkability indices. The first category refers to the weighting of measures in calculating walkability indices (Frank et al., 2005; Frank et al., 2006; Frank et al., 2010; Debesova and Krivka, 2012; Reyer et al., 2014; Luadsakul and Ratanvaraha, 2015; Adams et al., 2014 and de Sa and Arden, 2014; Jun and Hur, 2015). The second category is studies which do not assign any weights to the measures in calculating walkability indices (Leslie et al., 2005; Moudon et al., 2006; Leslie et al., 2007; Gebel et al., 2011; Leather et al., 2011; Giles-Corti et al., 2014; Murekatete and Bizimana, 2015; Stockton et al., 2016).

Studies weighting measurements within a walkability index decide on the weighting of measurements through a process of trial and error (Frank et al., 2005; Adams et al., 2014; de Sa and Arden, 2014). Other studies do not provide a justification for assigning weights and simply reference the weighting methods used in previous studies (Dobesova and Krivka, 2012; Reyer et al., 2014). Studies calculating walkability indices through the summation of equally weighted measurements also do not provide an explanation of why this method was used. However, Murekatete and Bizimana (2015) noted that the measurements in their study were not weighted due to the limited availability of data.

This subsection will examine how the weighting of measures affects a walkability index through comparing a series of differently weighted walkability indices. The weighted walkability indices presented in this subsection will draw on the weighting as assigned in previous studies as well as experimental weightings. Cluster analyses were done on each of the experimental weightings. The cluster analysis provides a simplified version of the walkability index results and presents a clear spatial representation of spatial clusters of the walkability of Small Areas.

The first experimental weighting was an equally weighted walkability index. This walkability index was composed to set a baseline for comparison. An equally weighted index is in line with previous studies using the equally weighted methodology (Leslie et al., 2007; Murekatete and Bizimana, 2015). The equation of the equally weighted walkability index is:

$$\text{True intersection to node ratio} + \text{Household density} + \text{Land-use mix} + \text{Destinations}$$

Figure 5.11 represents the spatial clusters of Small Areas with high and low walkability ratings for the equally weighted walkability index. From figure 5.11 Small Areas with high walkability ratings (shaded in red) are clustered toward the central business district of Cape Town and the metro southeast. Small

Areas with a low walkability rating (shaded in blue) are located toward the periphery of the metropolitan area (Figure 6.11).

The second of the weighted walkability indices are based on the walkability index equation of Reyer et al. (2014) which is:

$$(2*\text{Intersection density}) + \text{Land-use mix} + \text{Floor area ratio} + \text{Household density}$$

This walkability index weights street connectivity double as much as the other measures. The reason for the weighting is based on the assumption that a high degree of street connectivity encourages walking. The second experimental walkability index weights the intersection to node ratio twice as much as the other measurements and is stated as:

$$(2*\text{True intersection to node ratio} + \text{Household density} + \text{Land-use mix} + \text{Destinations})$$

This equation differs from the study by Reyer et al. (2014) in three ways. The first difference is that this study uses the true intersection to node ratio as the measure of street connectivity. Secondly, this study excludes a measure of floor area ratio. The third difference is this study including a measure of walkable destinations. The cluster analysis of the second experimental walkability index is presented in figure 5.12. The spatial clusters are similar to the spatial pattern of clusters observed in the results of the first experimental weighting. This illustrates that a change in the true intersection to node ratio has little effect on the results on the walkability index.

The third of the weighted walkability indices is based on the walkability index equation of Frank et al. (2005), which is:

$$\text{Intersection density} + \text{Residential density} + (6*\text{Land-use mix})$$

This walkability index weights the land-use mix index six times more than the other measurements. The reason for the weighting is based on the assumption that a high degree of land-use mix encourages walking (Frank et al., 2005). The third experimental walkability index weights the land-use mix measurement six times that of the other measurements and is stated as:

$$\text{True intersection to node ratio} + \text{Household density} + (6*\text{Land-use mix}) + \text{Destinations}$$

This equation differs from the Frank et al. (2005), as it includes the true intersection to node ratio variable and a measure of walkable destinations. The cluster analysis of the third experimental walkability index is presented in figure 5.13. These cluster analysis results indicate a stark decrease in the cluster of both Small Areas with a high and a low walkability rating. The fewer high and low walkability clusters within this weighted walkability index indicate an inverse relationship between Land-use mix and the other measurements of walkability.

The fourth of the weighted walkability indices are based on the walkability index equation of de Sa and Arden (2014) which is:

$$\text{Intersection density} + \text{Net residential density} + (3*\text{Land-use mix})$$

This walkability index weights the land-use mix index three times more than the other measurements. De Sa and Arden (2014) reference the Frank et al. (2005) study as justification for this weighting of the land-use mix. The fourth experimental walkability index weights the land-use mix three times more than that of the other measurements and is stated as:

$$\text{True intersection to node ratio} + \text{Household density} + (3*\text{Land-use mix}) + \text{Destinations}$$

This equation differs from de Sa and Arden (2014) as it includes the true intersection to node ratio and a measure of walkable destinations. The cluster analysis of fourth experimental walkability index is presented in figure 5.14. The cluster analysis closely relates to the clusters displayed in the third weighted walkability index. This was expected as both these walkability indices weight land-use mix heavier than the other three measures. Evident from figure 5.13 and 5.14 is a shift in the cluster of highly walkable Small Areas further to the southeast and toward the northwest of the metropolitan area.

The fifth weighted walkability index is based on the studies validating the walkability rating of Walk Score (Carr, Dunsiger and Marcus, 2011; Duncan et al., 2011; Nykiforuk et al., 2016; Koschinsky et al., 2017). Walk Score emphasises the importance of a mix and density of destinations in encouraging walkability. These studies all validate, to varying degrees, Walk Score ratings as an effective measurement of walkability. Therefore the fifth weighted walkability index weighted the destinations measure six times more than that the other measures and can be stated as:

$$\text{True intersection to node ratio} + \text{Household density} + \text{Land-use mix} + (6*\text{Destinations})$$

Figure 5.15 displays the cluster analysis results of the destinations weighted walkability index. The spatial clustering of highly walkable Small Areas is markedly different from the previous weighted indices. Highly walkable areas cluster in a linear pattern extending from the central business district toward the south, southeast and west of the metropolitan area. Small Areas with a low walkability rating are concentrated toward the periphery and few low walkable environments are located in the centre of the metropolitan.

The last of the weighted walkability index weights street connectivity and destinations, each, three times more than the other two measures. The equation can be stated as:

$$(3*\text{True intersection to node ratio}) + \text{Household density} + \text{Land-use mix} + (3*\text{Destinations})$$

This walkability index was not based on any previous study's methodology. The equation weights measures of connectivity (street connectivity) and accessibility (destinations) as these two measures of walkability are interrelated. Destinations tend to locate in areas with a high degree of connectivity increasing the accessibility of a destination. Figure 5.16 presents the cluster analysis results of the walkability index weighted toward street connectivity and destinations. The results are similar to the previous weighted walkability index. However, there is not any clear linear distribution in the clustering of the highly walkable areas. The cluster analysis of the walkability index shows distinct clusters of highly walkable Small Areas in the central business district, the south, the southeast and the northeast of the metropolitan area.

The cluster analysis results presented in this subsection display a strong spatial correlation of highly walkable Small Areas based on the results of the weighted walkability indices. However, the two walkability indices weighted toward land-use mix differs the most from the other four indices. After considering the results of weighted walkability indices this study will utilise the walkability index weighting the destinations measure six times more than the other three measures. This was decided as firstly, the land-use mix does not necessarily indicate whether there are places to walk to in an area. Secondly, household density was not considered as the data range produced z-scores larger than 3 and less than -3, which already skews the final walkability rating. Thirdly, street connectivity is a measure of design, which can facilitate walking but is not a predetermining factor to walking behaviour. Fourthly, the positive validation of destination based walkability indices necessitated the inclusion of the measure within the final walkability index. Lastly, the destinations measure is based on network-based walking

distances which provide an indication of the walkability of an area. The following section presents the final walkability index and validates the index through presenting streetscapes.

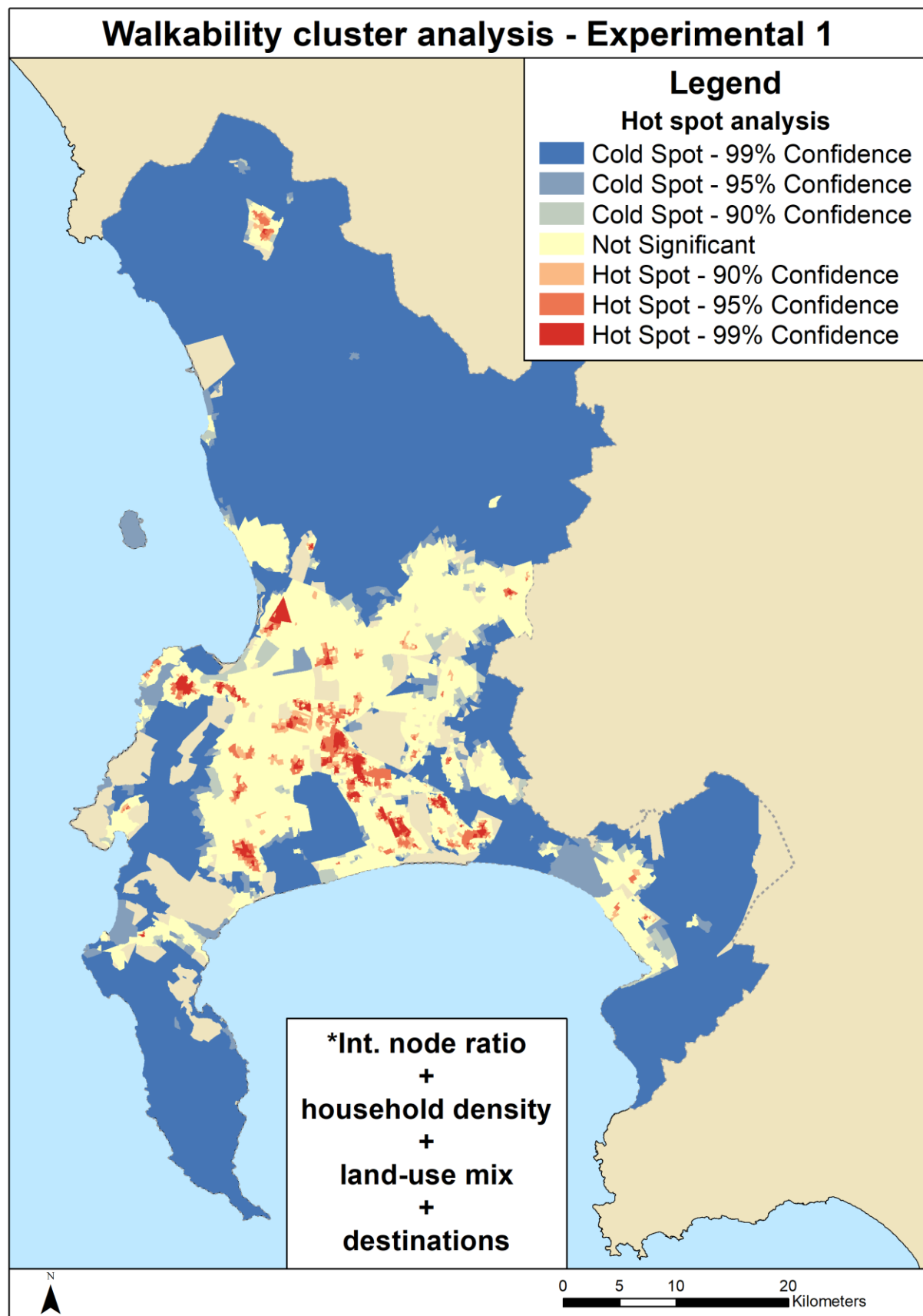


Figure 5.11: Walkability cluster analysis 1

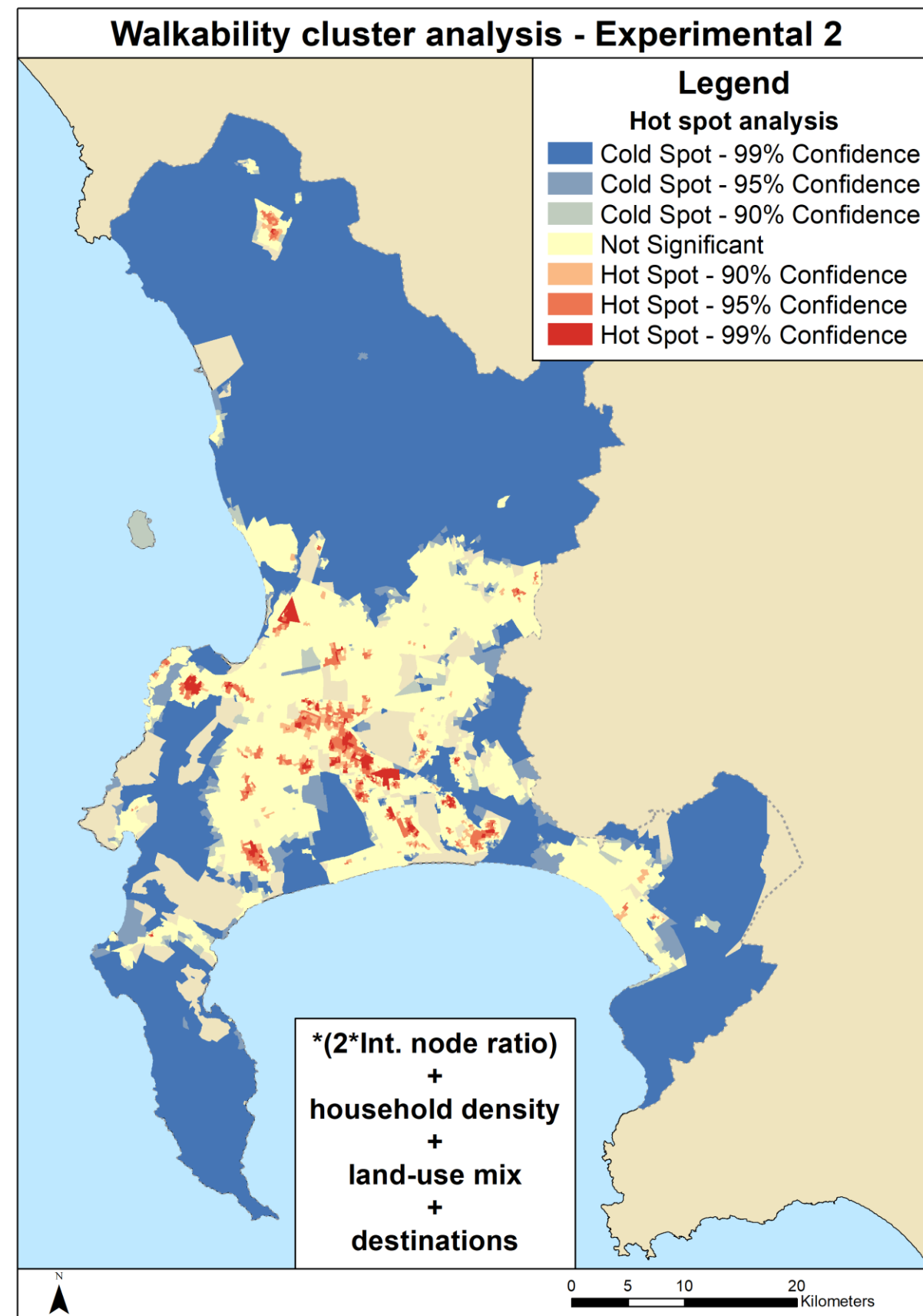


Figure 5.12: Walkability cluster analysis 2

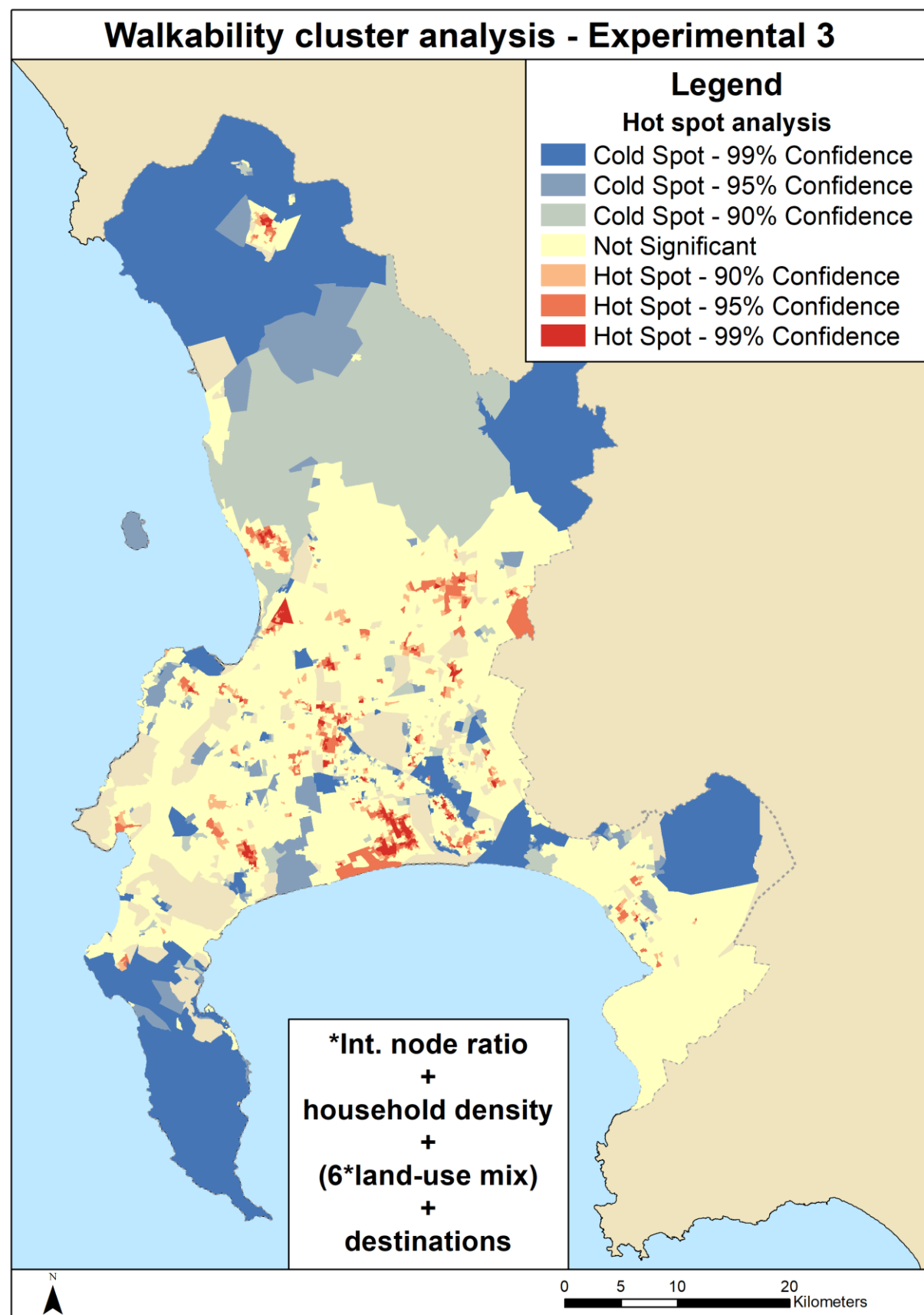


Figure 5.13: Walkability cluster analysis 3

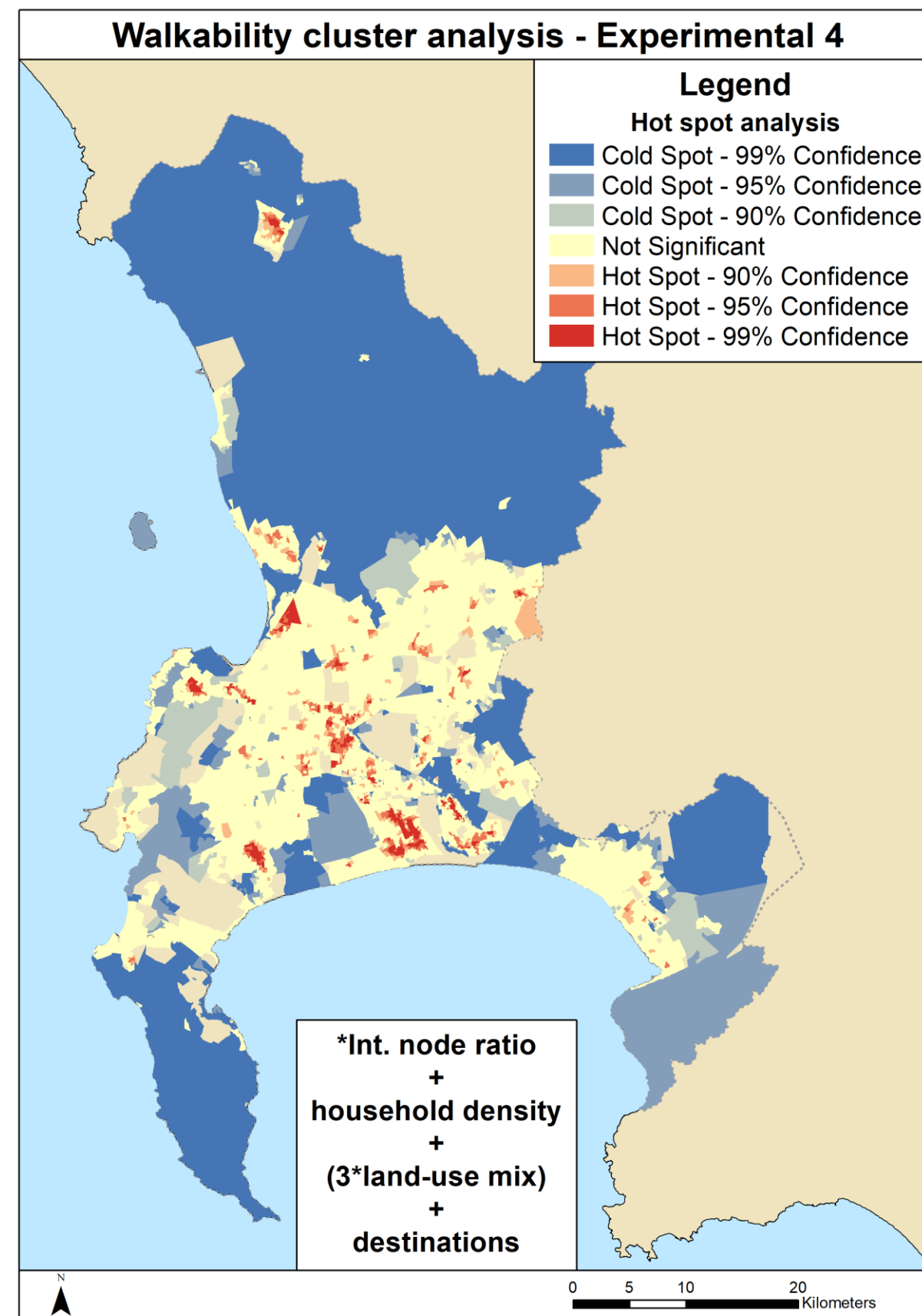


Figure 5.14: Walkability cluster analysis 4

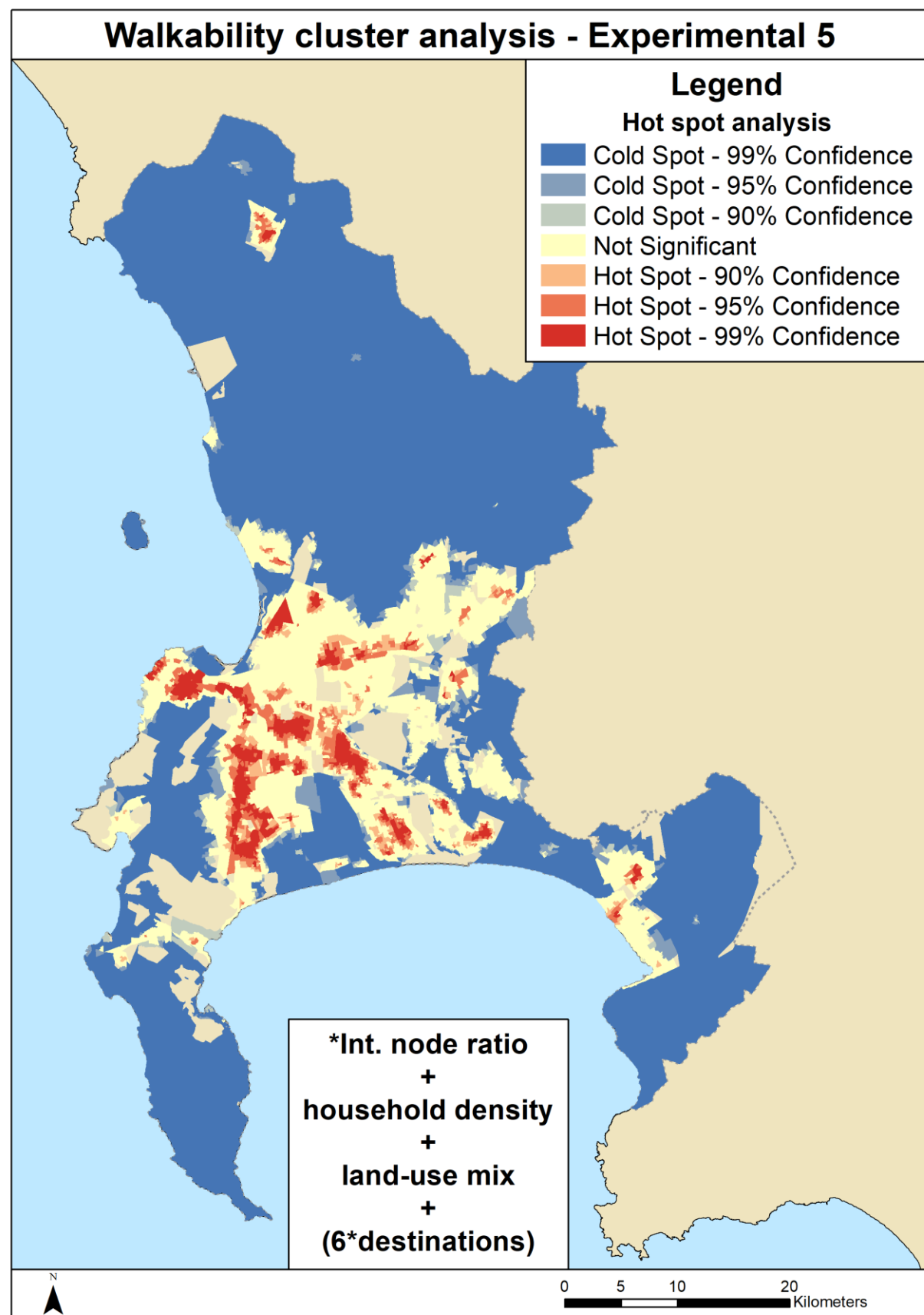


Figure 5.15: Walkability cluster analysis 5

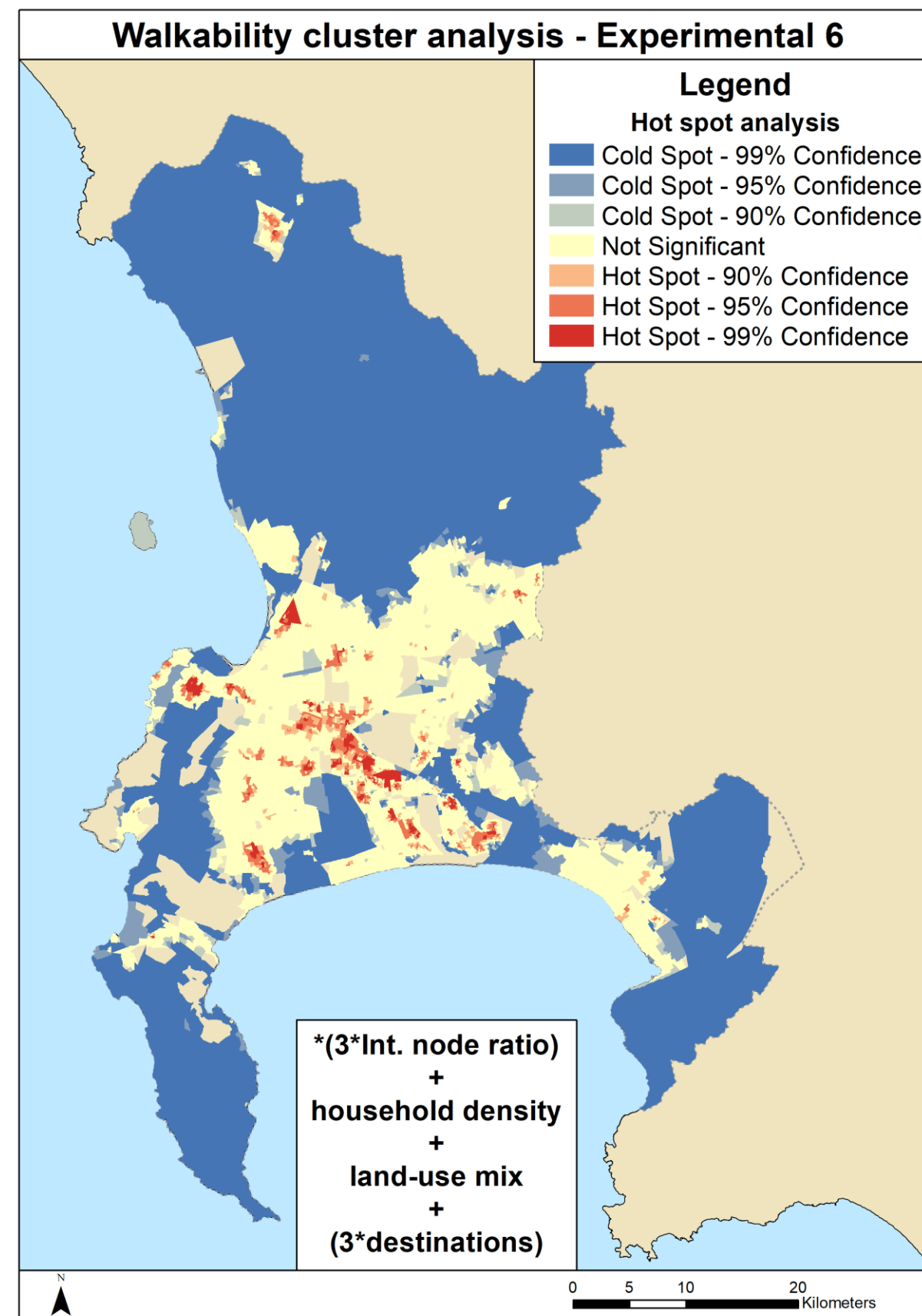


Figure 5.16: Walkability cluster analysis 6

### 5.3.4 Final walkability index and validation

This subsection presents the final walkability rating for the CCT along with field validations. The walkability ratings are displayed in figure 5.17. The ratings were categorised into five quintiles, with Small Areas with a “Very low” rating coloured in red and Small Areas with a “Very high” rating coloured in dark green. The spatial distribution of different categories is consistent with the cluster analysis presented in the previous subsection. To determine how the results of the walkability index relate to reality 40 field validation points were taken. The validation points were taken within the Cape Town City Bowl area and Kuils River (Figure 5.18 and 5.19). Four field validation points were selected at random per walkability rating for the two areas under investigation. The streetscapes are presented in figures 5.20 to 5.59.

The field validation points were taken within the Cape Town City Bowl and Kuils River with a “Very high” walkability rating and are displayed in figures 5.20 to 5.23 and figures 5.24 to 5.27, respectively. The streetscapes within the Cape Town City Bowl contain both built environment features and street design elements contributing to walkability. From figures 5.20 to 5.22 it is evident that the areas are dense with multi-storeyed buildings or buildings located in close proximity to each other. The street design elements are observed in figures 5.20 to 5.23, these elements are sidewalk space, ramped street curbs, green street furnishings, active building frontages and street lights. The streetscapes of Kuils River also display built environment features and street design elements contributing to walkability. Figures 5.24 to 5.26 display the importance of public and commercial destinations. The street design elements for Kuils River include sidewalks, ramped curbs, and pedestrian crossing islands. Field validation points within the Cape Town City Bowl and Kuils River with a “High” walkability rating are presented in figures 5.28 to 5.31 and figure 5.32 to 5.35, respectively. The streetscapes in figures 5.28 to 5.31 contain more street design elements contributing to walkability than built environment features. Only figures 5.28 and 5.29 display densities and destinations enhancing the walkability of an area. In figures 5.32 and 5.33 educational and community destinations are present along with street design elements which increase the walkability of an area. Figures 5.34 and 5.35 contain fewer built environment features contributing to the walkability of the areas. However, street design elements facilitating walking are still present (Figure 5.34 and 5.35).

The field validation points for the Cape Town City Bowl and Kuils River taken within Small Areas with a “Moderate” walkability rating are shown in figures 5.36 to 5.39 and 5.40 to 5.43, respectively. Figures 5.36 to 5.39 show a clear decrease in walkability. The figures show dense urban environments; however, the street design elements decrease the walkability of the areas. In the streetscapes these are a general

decrease in the space for sidewalks (Figures 5.36, 5.37 and 5.39), a reduction in active frontages (Figures 5.37 to 5.39), obstructive sidewalk features (5.37 and 5.38), and building heights beyond the suggested human scale of three storeys (Figure 5.37 and 5.38). For Kuils River, figures 5.40 and 5.41 display limited urban environmental features and street design elements positively influencing the walkability the areas. Both figures display low densities and no planned pedestrian infrastructure. Figures 5.42 and 5.43 also display low densities; however, the figures show the presence of planned sidewalks which increase the walkability of an area.

The field validation points selected within the Cape Town City Bowl and Kuils River with a “Low” walkability rating are presented in figures 5.44 to 5.47 and 5.48 to 5.51, respectively. Figures 5.45 to 5.47 display a lack of density and street design elements decreasing the walkability of the areas. In the three figures, sidewalks are narrow with cars encroaching on the space (Figure 5.46) or non-existent (Figure 5.45 and 5.45). Figure 5.44 represents an area with appropriate densities and street design elements. Yet the area has a low walkability rating. This was further investigated and it was found that the area had a negative destinations z-score. Thus the area might have pedestrian infrastructure but no destinations are within a comfortable walking distance. Figures 5.48 to 5.51 present streetscapes for Kuils River displaying low walkability both for built environment features and street design elements. The built environment on display is of a low density containing gated communities and cul-de-sacs (Figure 5.48). None of the figures indicate the presence of pedestrian infrastructure (Figures 5.48 to 5.51). Field validation points in areas with “Very low” walkability ratings for the Cape Town City Bowl and Kuils River are shown in figures 5.52 to 5.55 and 5.56 to 5.59, respectively. The type of streetscape displayed in figures 5.52 to 5.59 corresponds with one another. The only difference between streetscapes of the Cape Town City Bowl and Kuils River is context. Figures 5.52 to 5.55 represent industrial areas (Figure 5.52 and 5.54) and are reserved for transport use (Figure 5.53 and 5.55). The streetscapes taken in Kuils River display peripheral areas under construction (Figure 5.56, 5.57 and 5.59) or transport routes (Figure 5.58).

Based on the validation points the walkability index is a good measure of walkability. The walkability index results most strongly correlates with reality within the rating categories of “Very high”, “Low” and “Very low”. No clear distinction in walkability was observed within areas rated as “High” and “Moderate”. However, the differences are largely subjective and in general, the walkability index performs satisfactorily. The following chapter considers the possible applications of the walkability index.

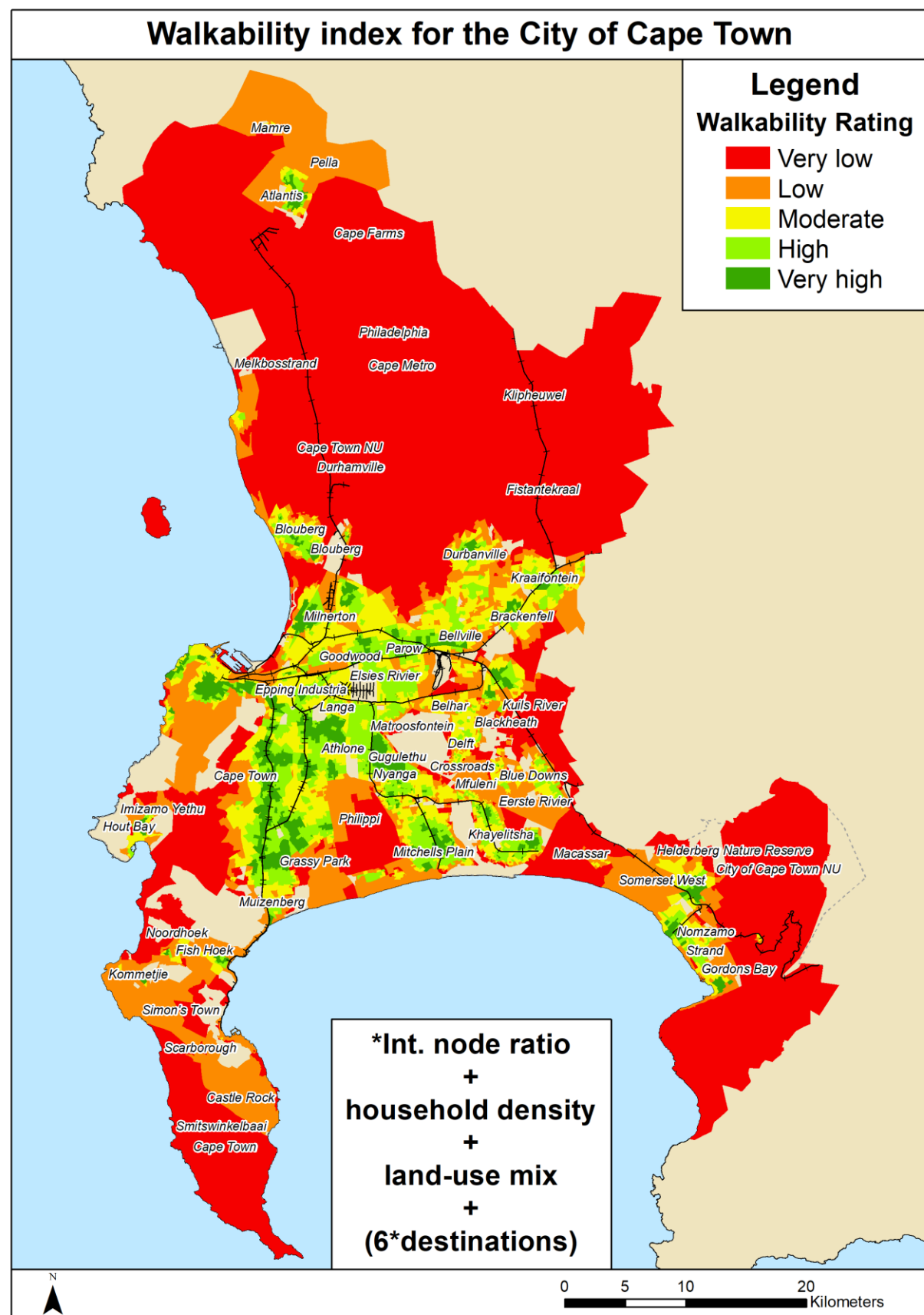


Figure 5.17: Walkability index for the CCT

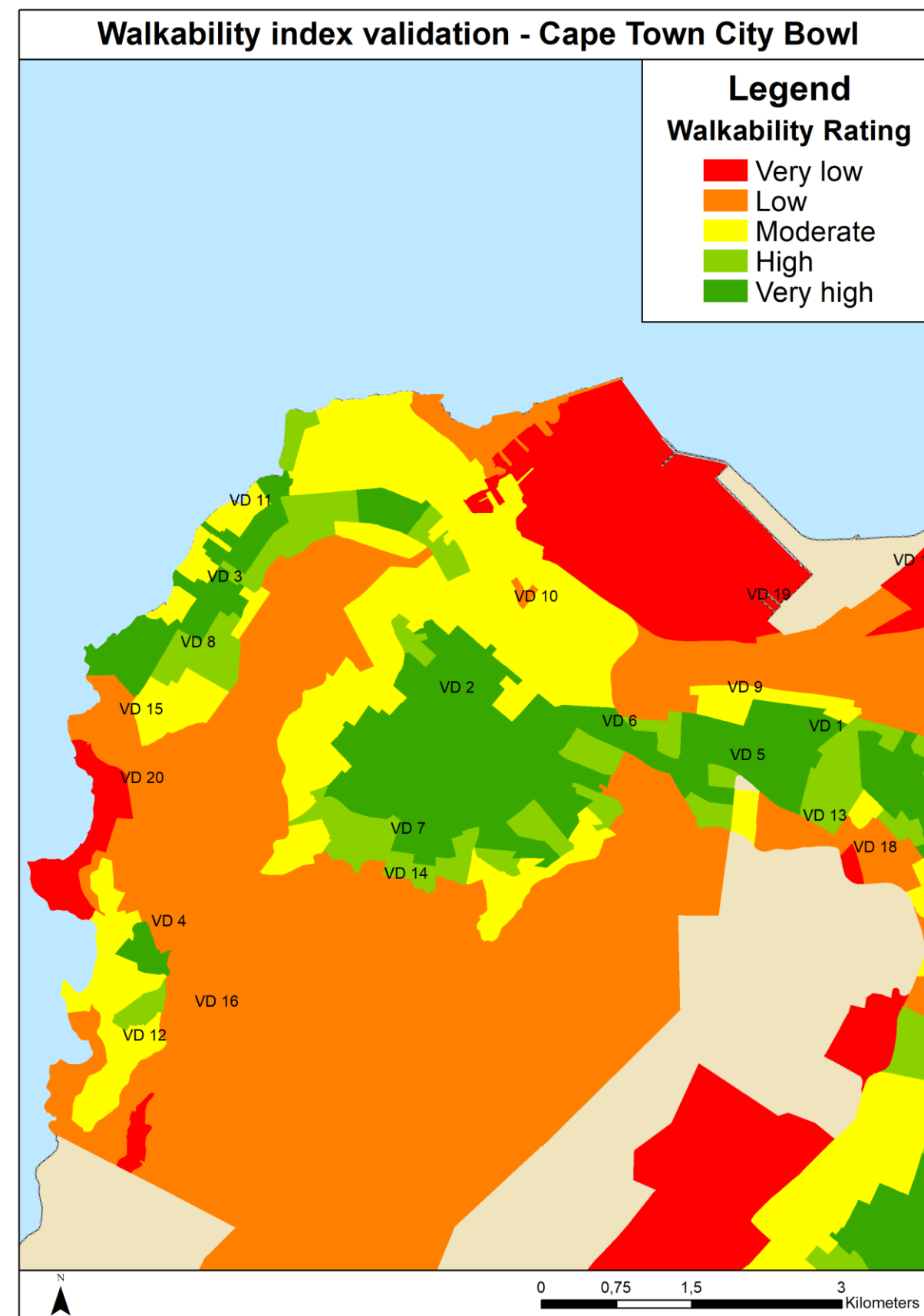


Figure 5.18: Walkability index validation - Cape Town City Bowl

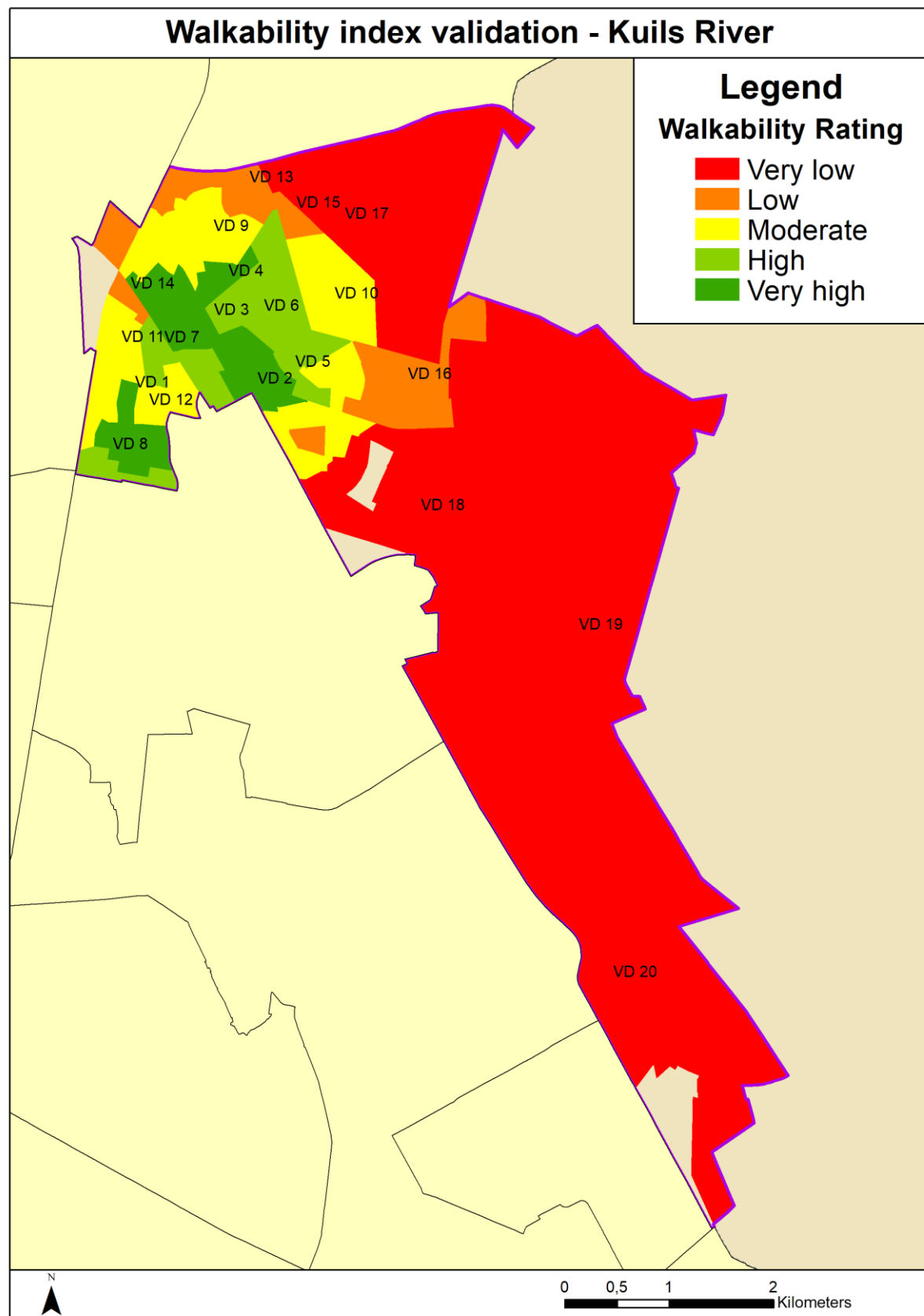


Figure 5.19: Walkability index validation - Kuils River

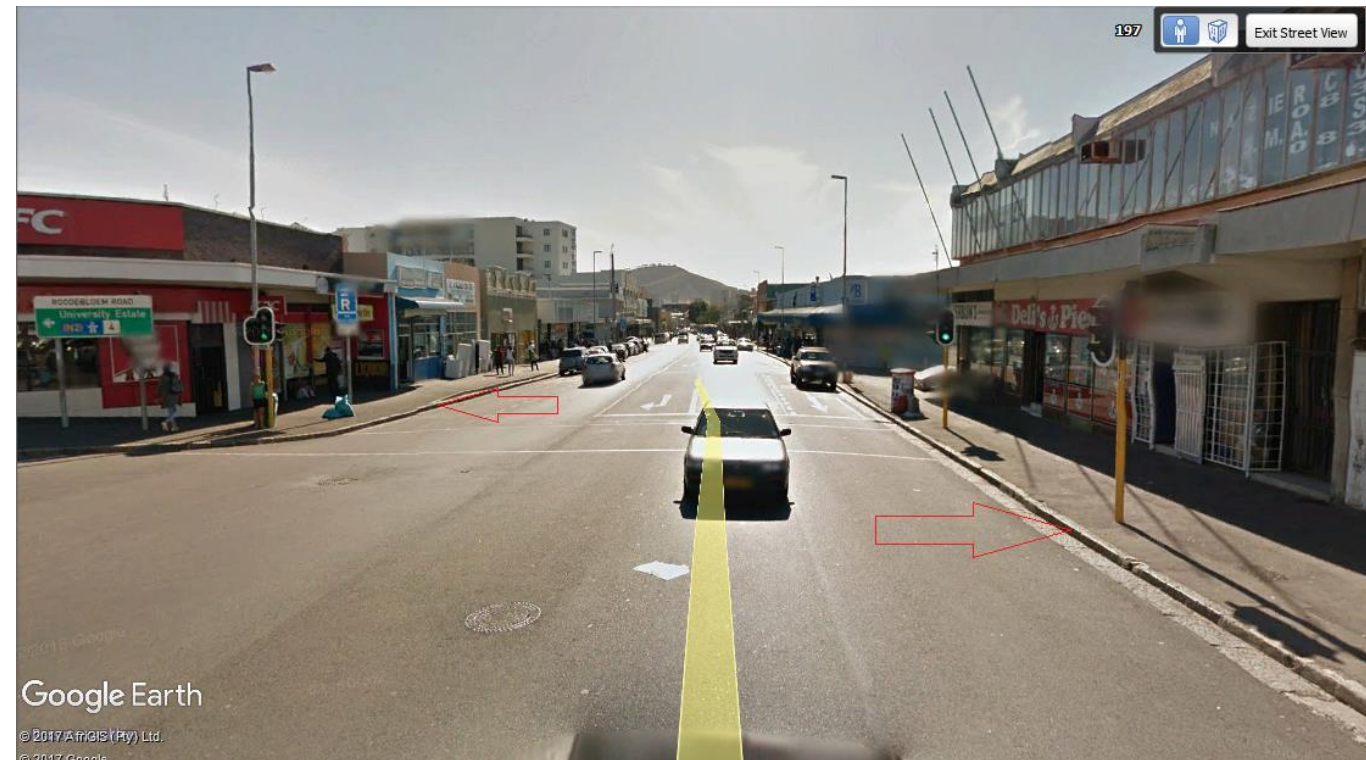


Figure 5.20: Validation point 1 - Cape Town City Bowl (“Very high” rating)



Figure 5.21: Validation point 2 - Cape Town City Bowl (“Very high” rating)

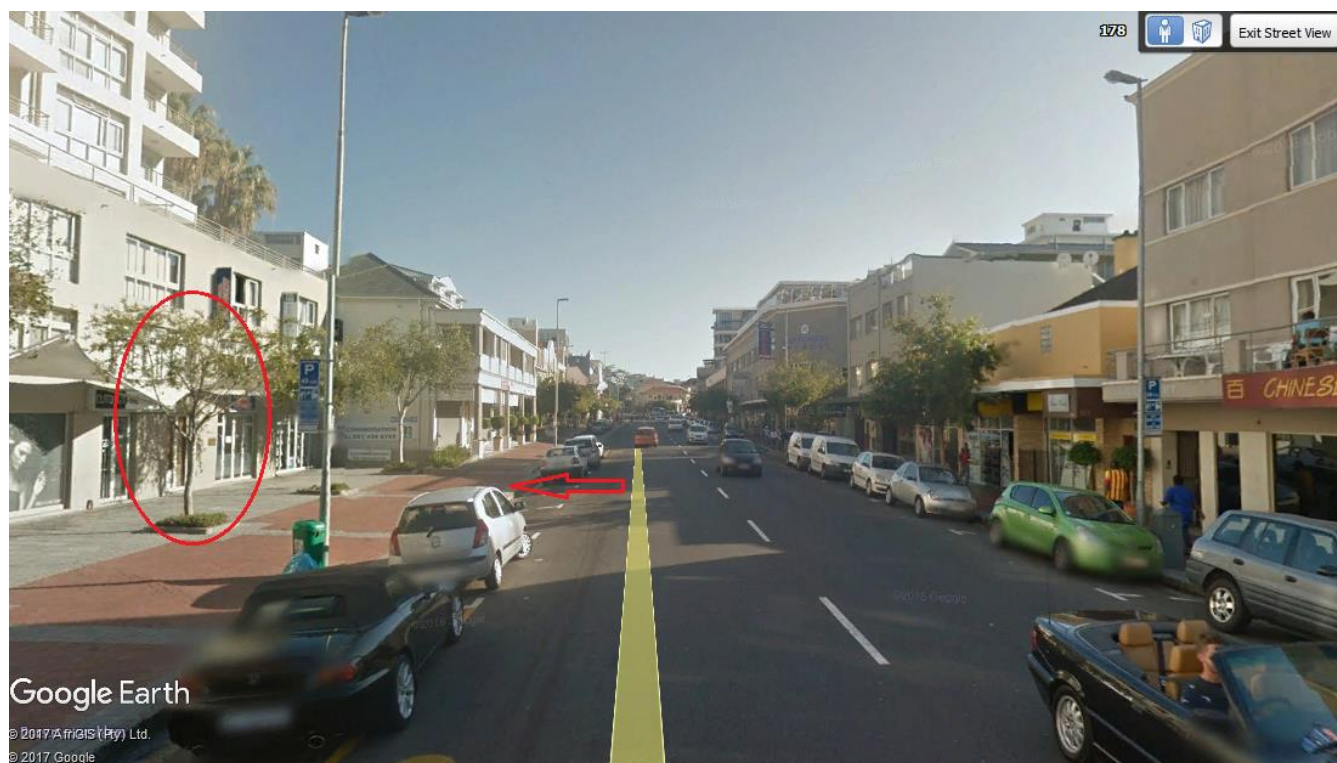


Figure 5.22: Validation point 3 - Cape Town City Bowl (“Very high” rating)



Figure 5.24: Validation point 1 - Kuils River (“Very high” rating)



Figure 5.23: Validation point 4 - Cape Town City Bowl (“Very high” rating)



Figure 5.25: Validation point 2 - Kuils River (“Very high” rating)



Figure 5.26: Validation point 3 - Kuils River (“Very high” rating)



Figure 5.28: Validation point 5 - Cape Town City Bowl (“High” rating)



Figure 5.27: Validation point 4 - Kuils River (“Very high” rating)

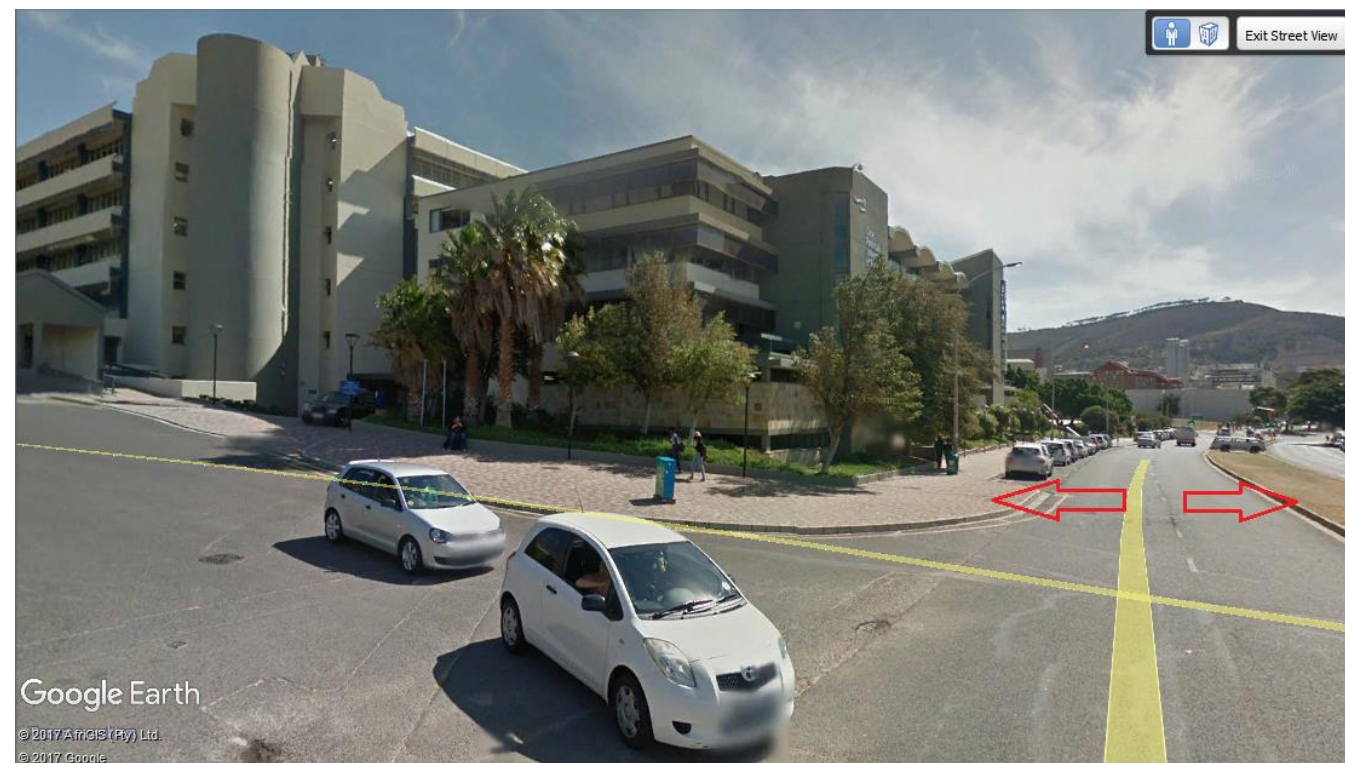


Figure 5.29: Validation point 6 - Cape Town City Bowl (“High” rating)



Figure 5.30: Validation point 7 - Cape Town City Bowl (“High” rating)



Figure 5.32: Validation point 5 - Kuils River (“High” rating)



Figure 5.31: Validation point 8 - Cape Town City Bowl (“High” rating)



Figure 5.33: Validation point 6 - Kuils River (“High” rating)



Figure 5.34: Validation point 7 - Kuils River (“High” rating)



Figure 5.36: Validation point 9 - Cape Town City Bowl (“Moderate” rating)



Figure 5.35: Validation point 8 - Kuils River (“High” rating)

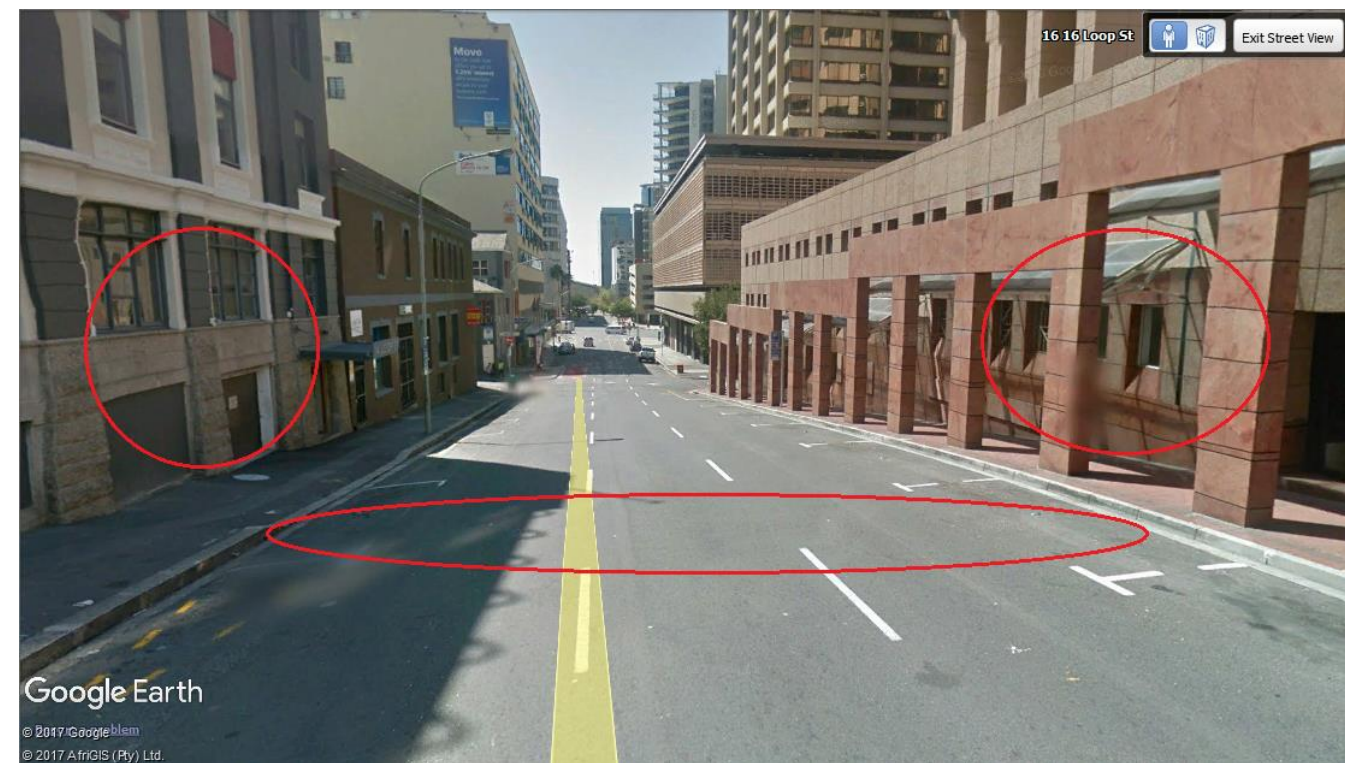


Figure 5.37: Validation point 10 - Cape Town City Bowl (“Moderate” rating)



Figure 5.38: Validation point 11 - Cape Town City Bowl (“Moderate” rating)



Figure 5.40: Validation point 9 - Kuils River (“Moderate” rating)



Figure 5.39: Validation point 12 - Cape Town City Bowl (“Moderate” rating)



Figure 5.41: Validation point 10 - Kuils River (“Moderate” rating)



Figure 5.42: Validation point 11 - Kuils River (“Moderate” rating)



Figure 5.44: Validation point 13 - Cape Town City Bowl (“Low” rating)



Figure 5.43: Validation point 12 - Kuils River (“Moderate” rating)



Figure 5.45: Validation point 14 - Cape Town City Bowl (“Low” rating)



Figure 5.46: Validation point 15 - Cape Town City Bowl (“Low” rating)



Figure 5.48: Validation point 13 - Kuils River (“Low” rating)



Figure 5.47: Validation point 16 - Cape Town City Bowl (“Low” rating)



Figure 5.49: Validation point 14 - Kuils River (“Low” rating)



Figure 5.50: Validation point 15 - Kuils River (“Low” rating)



Figure 5.52: Validation point 17 - Cape Town City Bowl (“Very low” rating)



Figure 5.51: Validation point 16 - Kuils River (“Low” rating)



Figure 5.53: Validation point 18 - Cape Town City Bowl (“Very low” rating)

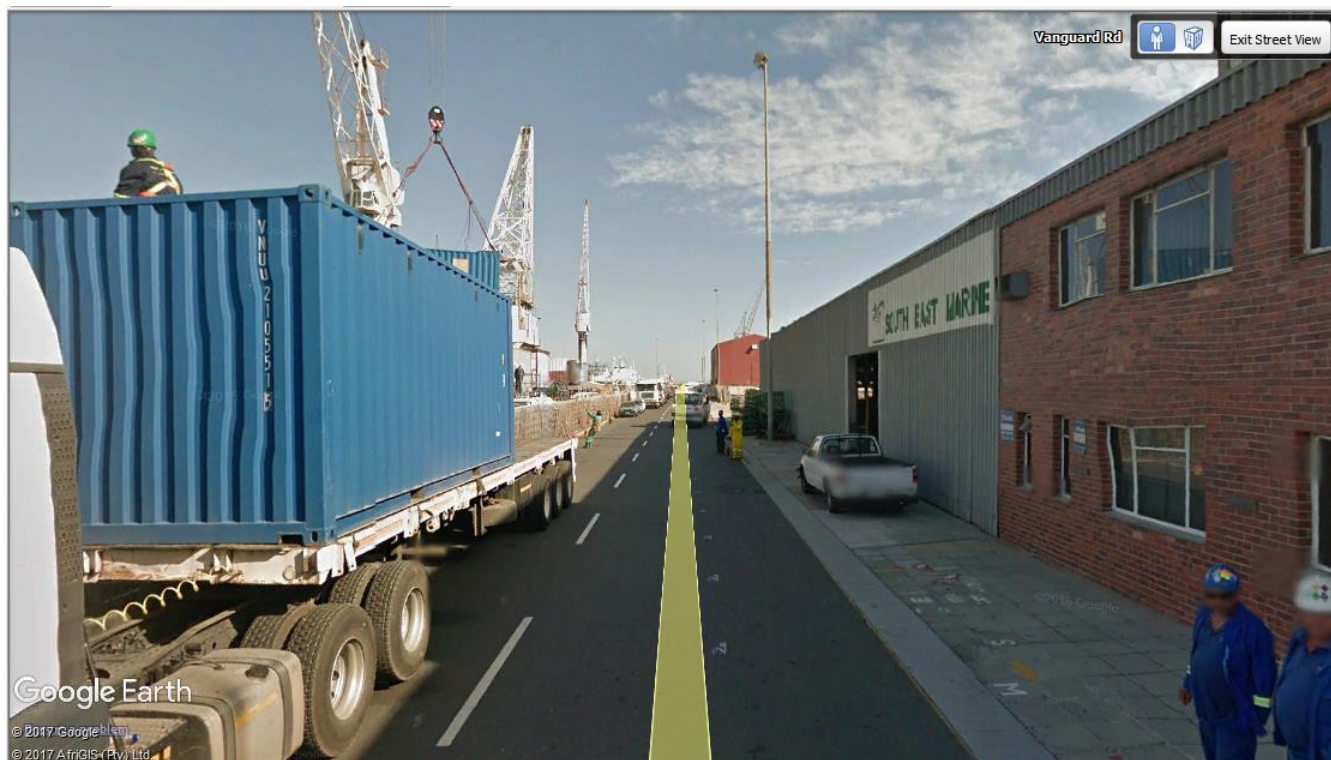


Figure 5.54: Validation point 19 - Cape Town City Bowl (“Very low” rating)



Figure 5.56: Validation point 17 - Kuils River (“Very low” rating)



Figure 5.55: Validation point 20 - Cape Town City Bowl (“Very low” rating)



Figure 5.57: Validation point 18 - Kuils River (“Very low” rating)



Figure 5.58: Validation point 19 - Kuils River (“Very low” rating)



Figure 5.59: Validation point 20 - Kuils River (“Very low” rating)

## 6. Planning for walkability

The penultimate chapter of this study investigates how a walkability index can aid in urban planning and decision making. The chapter has two sections; the first section reviews the NMT strategy of the CCT with aim of identifying areas where a walkability index could be of value. The second section illustrates practically how the use of a walkability index could alter NMT planning. This chapter is an important step in the research process as it illustrates the real world application value of a walkability index to urban planning. Based on the literature review, there is not much previous research dealing specifically with how walkability indices relate to urban planning. This chapter thus aims to shed some light on this research topic and also contribute to the overall body of research.

### 6.1 Applying the walkability index within the City of Cape Town

The CCT has a detailed non-motorised transportation plan which spans two volumes. Volume 1 is a status quo report and sets the context which the NMT strategy needs to address. Volume 2 presents the policy, strategies and spatial plan of the non-motorised transportation strategy. Both volumes contain all the elements necessary in fostering pedestrian-friendly urban environments as referred to in chapters two and three. Therefore this section highlights how the walkability index created during the research project could be applied in future NMT planning in the CCT. A non-policy based application is also mentioned, which describes how the walkability index methodology could be used in the assessment of public transport interchanges.

Volume 1 makes reference to the identification of strategic locations/areas for NMT interventions. Volume 1 refers to these strategic areas as areas with high concentration of people and the areas surrounding schools. In this regard, the walkability index presented in chapter five is well suited to identify these strategic areas. This study's walkability index includes both a measure of household densities and the walkable areas surrounding schools. The walkability index could easily be altered to assign a higher weight to walkable areas around schools, which would further facilitate the identification of strategic locations/areas.

Volume 1 states that NMT priority areas should be based on the location of transit, educational, commercial and recreational destinations. The weighting of the destinations measure of the walkability index fits this description almost perfectly and can spatially denote these areas at a Small Area level. Focus areas are described as areas with a high concentration of people but are lacking in walkability. The walkability index could also easily identify focus areas, through a simple search by attribute whereby

Small Areas with a high household density and a low walkability rating are selected and then spatially displayed. An important goal of Volume 1 is the creation of non-motorised linkages in the process of developing a non-motorised transportation network. Locating areas with a high, moderate and low walkability rating enables planners to identify and draw linkages between areas of similar or differing walkability ratings.

Volume 1 outlines key issues hindering the development of an NMT network based on the contextual analysis. Key issue one relates to a lack of land-use diversity which in turn extends daily commutes (City of Cape Town, 2005a). This walkability index could aid the identification of areas with a low level of land use heterogeneity through the entropy index results. Furthermore, the walkability index could provide an integrated insight which relates land-use mix to other measures of walkability. Volume 1 presents the various locational data on separate layers from page 38 to 44 (City of Cape Town, 2005a). The walkability index presented in chapter five integrates all of the data mentioned in Volume 1, thus presenting results that take into account all locational data considerations simultaneously.

Volume 2 of the NMT strategy makes reference to the specific strategies and policies aimed at developing an NMT network. Volume 2 also explains the methodology used in the drafting of the NMT strategy. The methodology consists of a four-step process; the steps are the statement of a vision and objectives, problem statement, policy formulation and finally strategic intervention (City of Cape Town, 2005b). A walkability index would be well suited to bridge the non-spatial nature of policy statements and strategic interventions in Volume 2.

The walkability index developed in this study can directly assist in four strategic interventions as outlined in Volume 2. Strategies 6.1 and 6.3 refer to investments in NMT infrastructure and community facilities, respectively (city of Cape Town, 2005b). Limited reference is made as to where or how these areas of intervention will be identified. The walkability index can narrow the search for areas of interventions through identifying areas with a low walkability rating requiring infrastructure or facility investment. Strategy 6.5 addresses aspects of public awareness campaigns to encourage using walking as a mode of transport or educating communities on the benefits of NMT (City of Cape Town, 2005b). The walkability index allows for the spatial targeting of awareness campaigns. Strategy 6.6 relates to the aspect of the integrated sustainable development of urban environments through non-motorised transportation (City of Cape Town, 2005b). The walkability index compiled in this research presents an integrated decision-making tool through incorporating different measures of walkability. The integrated

nature of the walkability index could be further enhanced through incorporating perceived measures of walkability.

The walkability index can also assist in the design of an NMT network presented in Volume 2. The walkability index allows for a more precise definition of NMT priority areas. This is stated as the walkability index includes more factors affecting NMT planning. The non-motorised transportation plan is conceptual, whereas the walkability index allows for the actual identification of statistically significant clusters of high or low walkability areas.

A non-policy based application relates to the assessment of public transport interchanges. Public transport interchanges are focal points of transport orientated development. Park (2008) notes the importance of the critical walking distance around public transport interchanges. The critical walking distance is also known as the last mile problem in transportation planning. The last mile (1,6 km) problem refers to the final leg of a commute which should be completed by walking. Walkability within the critical walking distance could be assessed done through drawing a one-mile (1,6 km) ring or network buffer around public transport interchanges. These buffer areas replace the census tracts as the enumeration areas for the walkability assessment. The walkability assessment would follow the methodology described in chapters four and five to measure the walkability within the last mile of public transport interchanges. Such a walkability assessment could locate public transport interchanges with poor walkability ratings as well as identify the exact measure hindering the walkability around public transport interchanges.

The section clearly illustrates the application value of the walkability index for the NMT planning in the CCT. The main benefit of the index is the spatial component, as it allows authorities to identify areas with existing or latent walkability potential. The following section provides examples of how the walkability index could facility NMT planning in the CCT.

## **6.2 Comparing different approaches to non-motorised transportation planning**

The section above clearly details the potential of a walkability index for NMT planning the CCT. This section illustrates this point through providing two examples of how the walkability index could be applied in NMT planning. These examples are presented against the backdrop of two examples illustrating the CCT's NMT strategy of identifying NMT priority areas/nodes. These examples demonstrate how incorporating different locational features influence the identification of NMT

corridors, priority areas, and priority nodes. The two examples represent NMT planning at metropolitan and local scales.

### **6.2.1 Metropolitan scale application**

The NMT strategy for CCT identifies NMT priority areas or nodes based on the spatial distribution of population density and the location of public transport interchanges, schools, commercial nodes, community facilities and tourist attraction. Figure 6.1 represents the household density, the location of public transport interchanges and railway lines in the CCT. It was attempted to add the other destinations to the map; however, the large number of points made the map illegible. Therefore only household density and public transport interchanges were considered for the metro-scale investigation.

Figure 6.1 indicates that the majority of households are concentrated to the southeast of the metropolitan. In accordance with the City's NMT strategy, public transport interchanges located in close proximity to areas with a high household density were marked as priority nodes. This data presentation provides limited insight into the presence of any possible NMT corridors of metropolitan significance. Further, this methodology of NMT planning does not underline the importance of NMT investment for the entire metropolitan. If this methodology was followed, various areas to the northwest, north, northeast and east of the south-eastern cluster will be largely disregarded (Figure 6.1).

Figure 6.2 presents how the walkability index can be incorporated into NMT planning at a metropolitan scale. The map identifies NMT priority nodes and corridors based on the walkability ratings of Small Areas and the location of public transport interchanges (Figure 6.2). Priority nodes are highly walkable areas around public transport interchanges. NMT corridors are delineated based on the linear distribution of walkable and highly walkable Small Areas. NMT planning within priority nodes necessitates infrastructure investment that increases the connectivity between public transport interchanges and adjacent walkable Small Areas. The NMT corridors should focus on the creation and maintenance of linkages to and between public transport interchanges.

Figure 6.2 differs from figure 6.1 in two key aspects. The first difference is in the distribution of priority nodes. Figure 6.1 concentrates priority nodes to the southeast, whilst figure 6.2 indicates the location of various possible priority nodes across the metropolitan area. The second difference is the clear formation of corridors at a metropolitan scale in figure 6.2. Areas identified as NMT corridors should be targeted for NMT network development. One example of a planning intervention facilitating NMT networks is

deprioritising car use within these areas through street design and traffic calming. Another would be an intensification of land use and densities around transit stations.

### 6.2.2 Local-scale application

At a local scale, it is possible to include all of the destinations referred to in the City's NMT strategy. The area under investigation is the Voortrekker Corridor Central Improvement District (VCCID), which the CCT classifies as a special rates area. The Voortrekker Corridor is also an area of interest for the CCT's long-term urban development plans. This area was thus chosen to demonstrate the difference in NMT planning based on the two different approaches.

Figure 6.3 displays the household densities, commercial destinations, community centres, public schools and public transport interchanges in the VCCID. Figure 6.3 indicates that few of the Small Areas in and around the VCCID have high household densities. The map identifies NMT priority areas based on the location of household densities and the collection of destinations as figure 6.3 displays. This method only identifies a few NMT priority areas specifically as public transport interchanges. Other destinations are located within Small Areas with household densities ranging from "Moderate" to "Very low" (Figure 6.3). Figure 6.3 does not indicate the occurrence of either clusters or corridors for NMT investment.

Figure 6.4 presents the walkability ratings and the destinations of interest, as mentioned in the above paragraph, in the VCCID. Areas with "Moderate" to "Very high" walkability ratings cluster along the Voortrekker Road. NMT priority areas are identified as areas where highly walkable areas are spatially clustered along with the destinations of interest. Mapping the spatial distribution of walkable Small Areas allows for the recognition of possible NMT interlinkages (displayed in pink) and linkages (displayed in purple) (Figure 6.4). Interlinkages refer to routes connecting NMT priority areas. Linkages are feeder routes for NMT interlinkages. Interlinkages should encourage modes of NMT and public transport. NMT linkages should prioritise the use of NMT modes whilst allowing restricted access to private motor vehicles.

Figure 6.4 differs from figure 6.3, as figure 6.4 allows for the identification the latent walkability of areas and potential NMT links at a local scale. The map displayed in figure 6.3 only communicates the location of density (households) and destinations. This is only two of the five D's of walkability, the other three being diversity (land-use mix), design (street connectivity) and distance to transit. The walkability index results present an integrated version of all the D's contributing to walkability. Therefore, the map in figure 6.4 indicates not only existing walkable environments but also areas with a

high potential for walkability. The data displayed in figure 6.3 does not provide much clarity as to where NMT links should be placed. Figure 6.4, on the other hand, indicates west to east (along Voortrekker Road) NMT interlinkages as well as areas suitable to act as feeder linkages to the VCCID.

The above section displayed and described the difference a walkability index can make in NMT planning at a metropolitan and local scale. At a metropolitan scale, the walkability index allows for the identification of significant NMT corridors and priority nodes across the city. At a local scale, the walkability index facilitates a nuanced approach to NMT planning, through incorporating walkability ratings. This allows for the drawing of NMT linkages between and toward priority areas. A walkability index can make an invaluable contribution to NMT planning methodology when considering the current methodology of the city's NMT strategy. The following chapter reflects on the research process and concludes the dissertation.

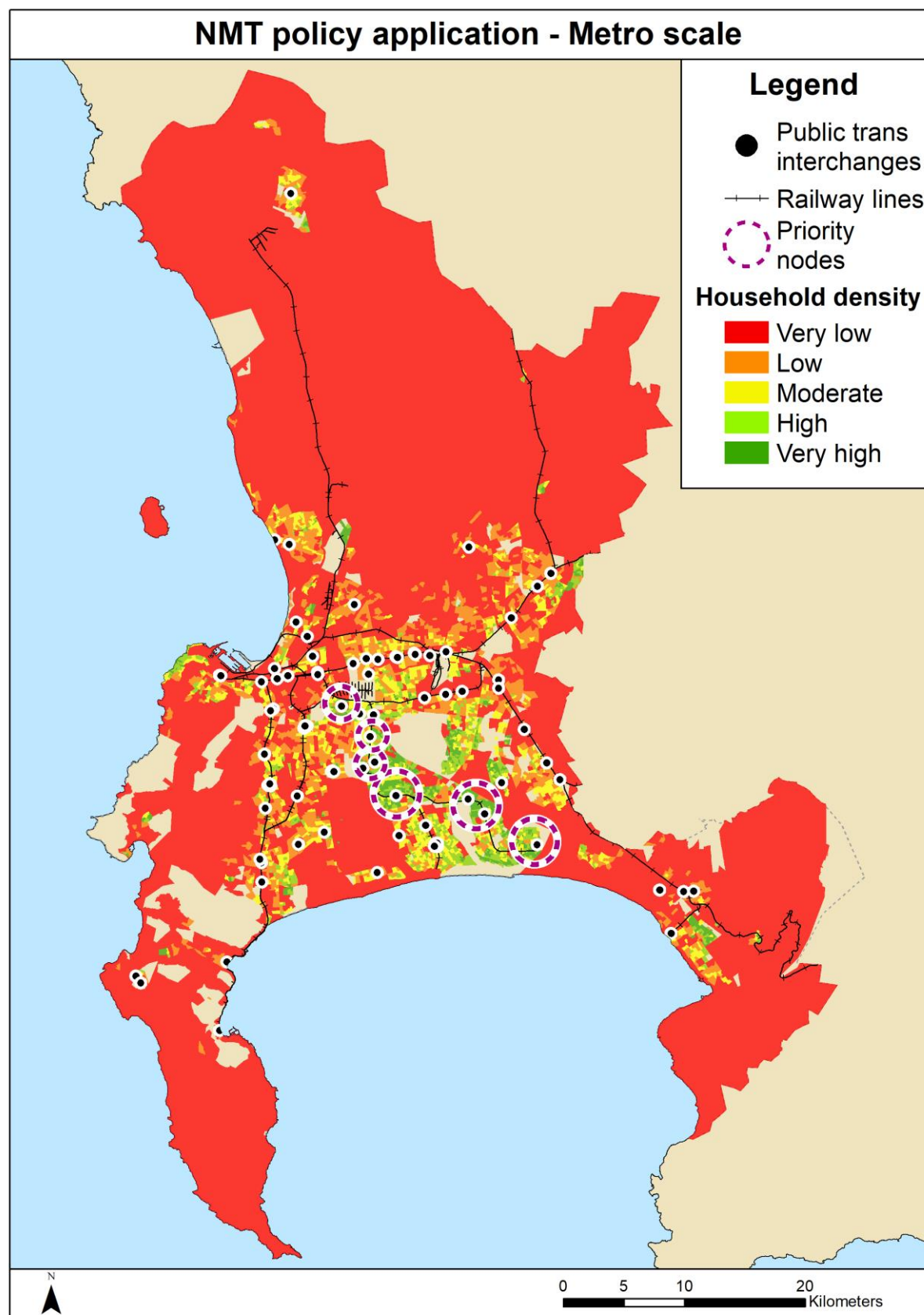


Figure 6.1: CCT NMT policy application - Metro scale

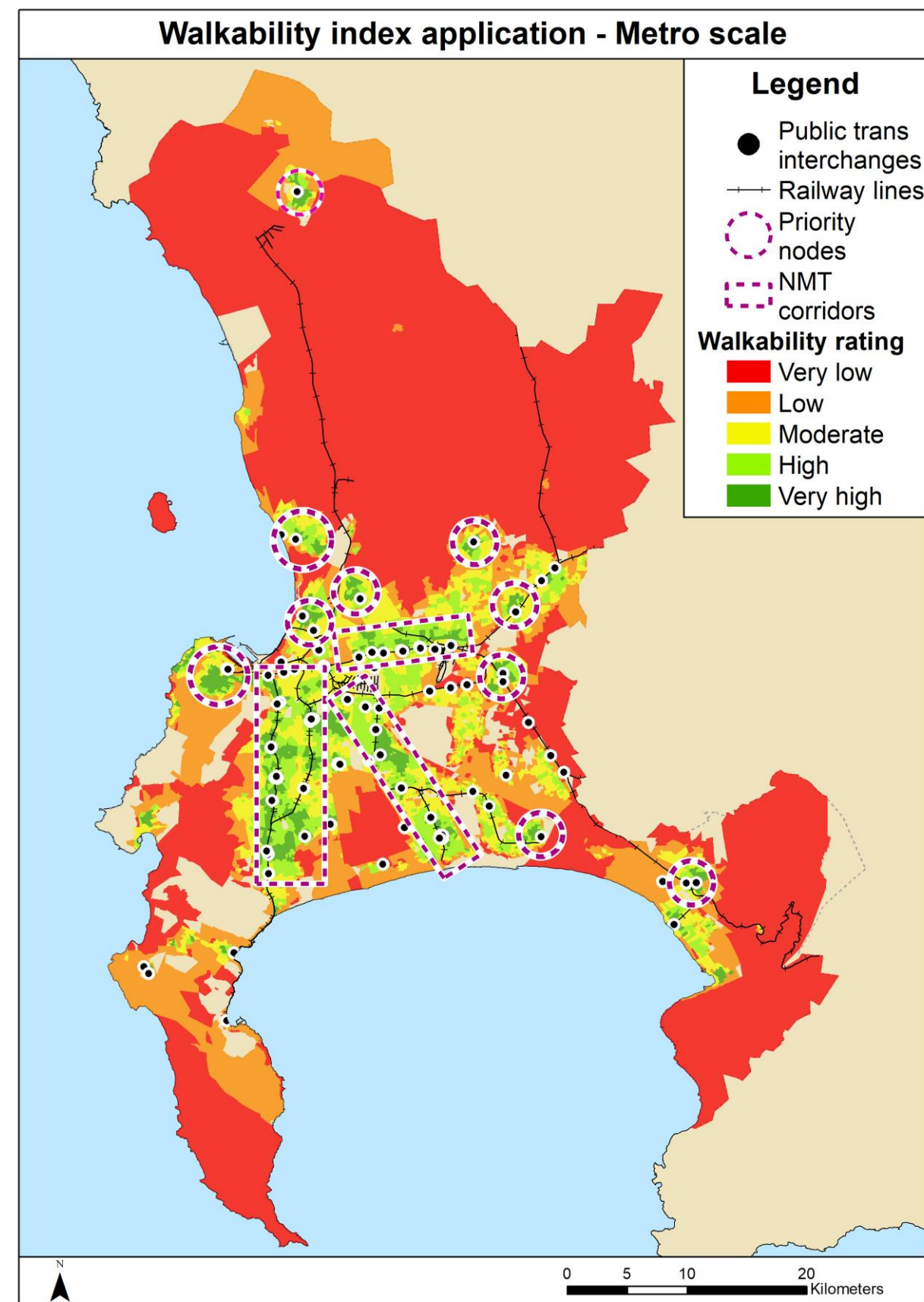


Figure 6.2: Walkability index application - Metro scale

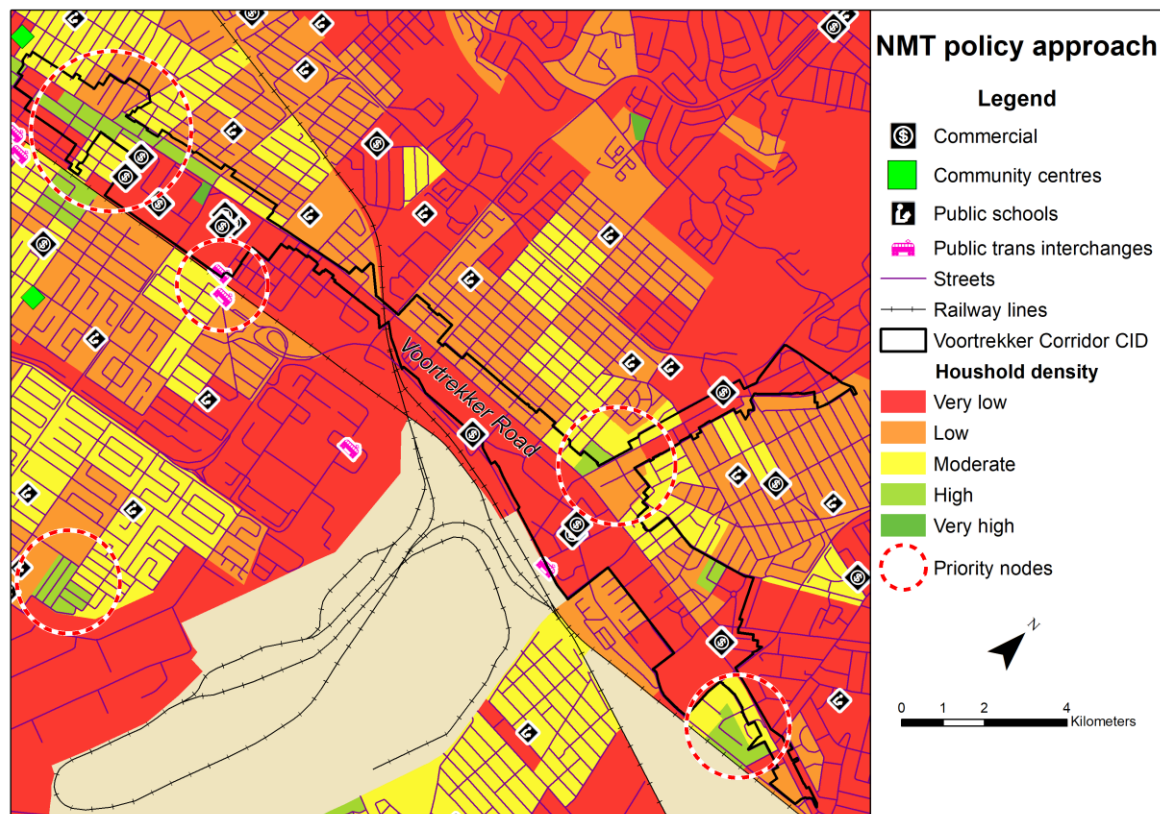


Figure 6.3: CCT NMT policy application - Local scale

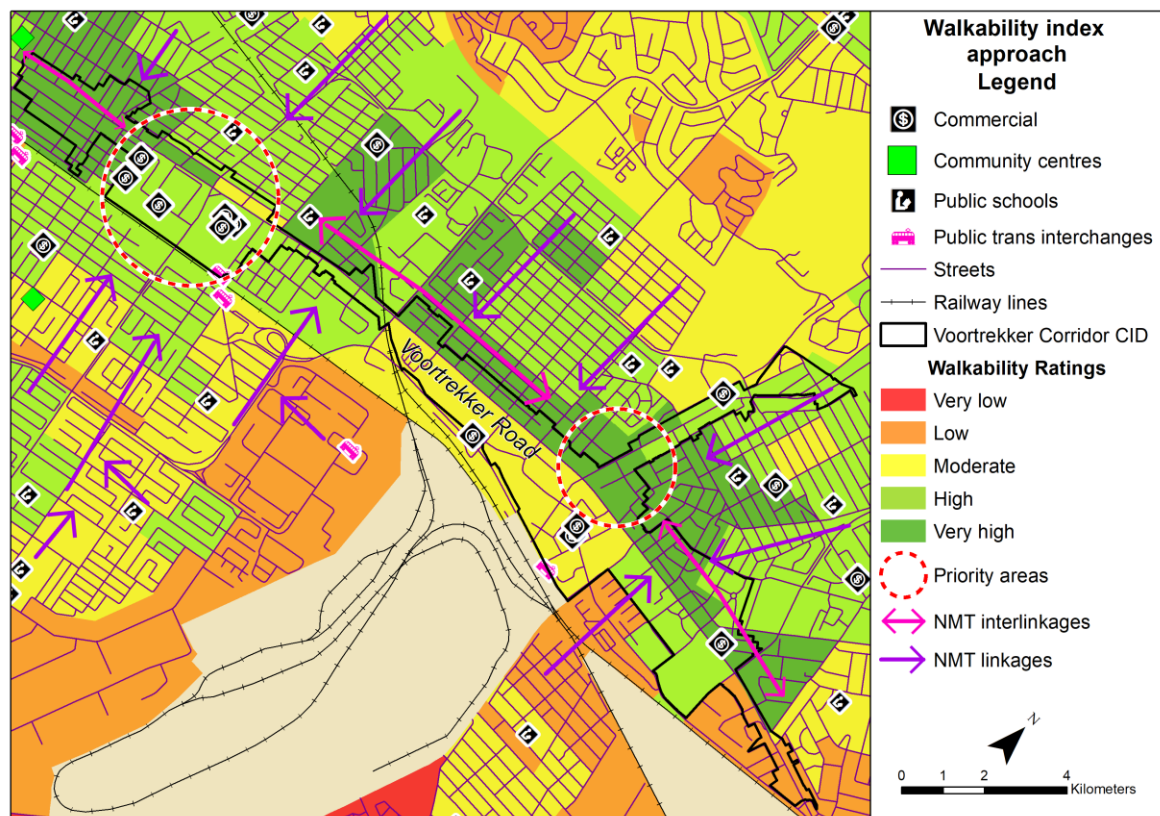


Figure 6.4: Walkability index application - Local scale

## 7. Walking ahead: recommendations, future research and conclusion

The final section presents some recommendations, identifies possible avenues of future research and concludes with a summary of the research process. The first recommendation for the study is the inclusion of informal destinations and land uses within the index. The walkability index calculated for this study utilised the spatial data which is in essence only represents formal land uses and some informal destinations. Informal land uses and destinations refer to the informal use of land and unregistered commercial destinations. This study did include the location of informal trading bays and minibus taxi ranks as provided by the open data portal of the CCT. However, including more informal urban aspects would be of great worth given the large proportion of people involved in informal economic activities in South Africa. The second recommendation relates to the validation process of the study. A more thorough validation process would refine the results of the walkability index. However, the time available for conducting research during the year was insufficient to conduct a thorough validation process. The final recommendation is to include the walkability index or a refined version thereof in the NMT policy for the CCT. The current NMT strategy lacks a clear spatial definition of areas where policy interventions are most needed or could result in the greatest net benefits to a community, neighbourhood or the city as a whole.

This research addresses a gap in the literature, as it is one of the few walkability assessments based within an African and South Africa context. The first future research suggestion resulting from the research is extending the scope of the research to other cities within South Africa. Walkability research focussed on other South African cities could identify similarities or highlight differences in walkability results. The literature review mentioned various groupings of walkability research related to how walkability affects property values, the physical activity of people, and the environment. Research into these relationships was constrained by a lack of the availability of an objective measure of walkability for Cape Town. The creation of the walkability index thus allows for future research into what the relationship is between walkability and the mentioned areas of study. Such research is relevant to urban planning as well to academic disciplines such as medicine, property studies and environmental science. The final suggestion for future research relates to composing a walkability index which includes both objective and perceived measures of walkability. Although the current index provides a good indication of the physical features contributing to walkability, it lacks nuance which can only be obtained through perceived measures of walkability.

This research project aimed to create a GIS-based walkability index for the CCT. Based on the research findings and the research product, it is stated that the research aim and objectives were successfully achieved. The following paragraph describes how the main and sub-research questions were answered. Chapter six answers the main research question, which is “Can a walkability index assist future NMT planning in Cape Town?” Chapter six explains how a walkability index could assist in future NMT planning through providing a spatial component to NMT policy statements and interventions. Further, the walkability index can assist in the identification of NMT priority areas, nodes and corridors. Through a thorough review of the literature, the three main urban environmental features influencing walkability were identified as street connectivity, residential density, and land-use mix. The research methodology used within this research project drew heavily on the experience of previous research. The research methodology also allowed the study to identify the most suitable variables for the measures of street connectivity (true intersection to node ratio), residential density (household density), and land-use mix (based on zoning data) within GIS. The measure of destinations is unique to this walkability study as a weighted overlay method is a novel approach to evaluating destination proximity. These measures of walkability were all included in the final walkability index which weighted the measure of destinations six times more than the other measures. This weighting also differs from previous studies which weight the measure of the land-use mix more than other measures. The destinations layer presented the realistic walkable areas around destinations in Cape Town and therefore this layer was weighted the most. The result of the walkability index was validated through field validation points. The streetscapes of the validation points revealed a strong correlation between the walkability index results and presence of pedestrian-friendly design features contributing to the walkability of an area. Based on the above the research aims and objectives were achieved and the research questions were answered. The research can now conclude through reflecting on the research journey.

In conclusion, this study provides a quantitative assessment of walkability in the CCT. Because it only considered features from the built environment which could be quantified and mapped, the results presented in this dissertation could differ from the real world pedestrian experience. However, this research demonstrates how a walkability index can assist future NMT planning from a methodological and an implementation point of view. It presents a maiden attempt at compiling a metropolitan-wide walkability index for the CCT and South Africa. This research project should thus serve as a gateway to further research to encourage active transportation within South Africa.

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## Appendix A

### Transit:

Formal	Informal
MyCiti stops	Minibus taxi ranks
Public transport interchanges	Minibus taxi holding areas
Metrorail stations	

### Education:

Formal	Informal
Early childhood development	
Primary schools	
Secondary schools	
Universities	
Technical and Vocational Education and Training	
Adult Basic Education and Training centres	

### Healthcare:

Hospitals	Informal
Clinics	

### Community:

Formal	Informal
Community centres	
Places of worship	
Libraries	

### Entertainment:

Formal	Informal
Art centres	
Bars	
Cafes	
Cinemas	
Nightclubs	
Pubs	
Restaurants	
Theatres	

### Parks:

Formal	Informal
Community Parks	
District Parks	

### Commercial:

Formal	Informal
Butcheries	Informal trading bays
Clothes stores	
Convenience stores	
Department stores	
Department stores	