URBAN ECOSYSTEM SERVICES IN JOHANNESBURG, SOUTH AFRICA.

Veronika Bianca Els (540570)

Supervisor: Dr Ute Schwaibold

School of Animal, Plant and Environmental Sciences

A dissertation submitted to the Faculty of Science University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science

Johannesburg, 2018

Declaration

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

Signature of Candidate: ……………… ……...............................

………22nd… day of… February 2018.

Acknowledgements

I would like to thank my supervisor Dr Ute Schwaibold for her assistance throughout this dissertation. I would also like to thank Johannesburg City Parks and Gauteng Department of Agriculture and Rural Development for providing the information and documents used in my research.

I would also like to thank my father, Dirk Els, for his general advice and checking of my research and report; and my mother, Christiane Els, for her assistance in data collection. Lastly, I would like to thank my parents and brother for all their support and for assisting me with funding for my studies.

Abstract

Ecosystem services play a critical role in delivering goods and services to residents in urban areas. These urban ecosystem services are also able to mitigate climate change effects, which is becoming increasingly important in global change scenarios. However, few urban ecosystem services studies, particularly those relating to climate change, have been done in South Africa and Johannesburg. The aim of my study was to assess the current state of ecosystem services in the city of Johannesburg, South Africa, and their potential to mitigate possible climate change impacts. My objectives were to assess the state of three key urban ecosystem services, namely carbon sequestration, urban temperature regulation and water flow regulation and provision, to assess the distribution of ecosystem services in Johannesburg and the possible risks of their degradation, and to determine whether environmental policy protects and manages ecosystem services in Johannesburg. I selected 20 sites across Johannesburg that support different land use types and calculated the carbon sequestration capacity for each site, each land use type and for the entire Johannesburg area. I performed a variety of water quality tests in sites that contained water bodies. These tests included measuring water temperature, pH, conductivity, dissolved oxygen, water transparency and flow rate. I also measured air temperatures in spots under trees and in full sunlight at each site to determine the cooling effect of trees. ArcGIS was used to perform Euclidean distance and kernel density functions on land use, land type and natural feature data. This enabled me to assess the location of natural features that provide the three key services in Johannesburg, and therefore the potential degradation risks to these urban ecosystem services. Lastly, I interviewed Johannesburg City Parks about their environmental policies and analysed documents obtained from GDARD regarding what environmental and ecosystem services policies are implemented in Johannesburg.

My results showed that, in general, the measured ecosystem services in Johannesburg are in relatively good health, have good service provision and in some cases, have the potential to be improved. The distribution of Johannesburg's wetlands and protected areas provide no potential for connectivity and thus have limited resilience to disturbances. Rivers and roads have highly dispersed networks across the Johannesburg area, while wetlands, protected areas and rivers occur in close distances to highly urbanised areas. This proximity between natural and built-up features is one of the main risks to ecosystem degradation. Johannesburg's urban forest has a relatively high carbon storage value of 436 064.9 tonnes (compared to other local and national cities). All the tested water bodies are in good health with regards to the specific

tests conducted in this study. Only two of the water bodies (one being the Jukskei river) showed some concerning factors (regarding transparency, dissolved oxygen, and conductivity). Trees and vegetation provide critical cooling abilities in Johannesburg (of around 1 to 2°C), which can mitigate climate change effects (increased temperatures) and can reduce fossil fuel emissions through reduced energy requirements for cooling in buildings.

The measured ecosystem services are protected and managed through various national and provincial level policies and some city level general ecosystem protection policies in Johannesburg. The role of these ecosystem services in mitigating and helping cities adapt to climate change effects is very well understood and integrated into policies, particularity at a provincial and national level. With regards to climate change mitigation, the local governing body recognised the importance of trees in terms of carbon storage, but did not recognise their role in local climate cooling. However, the provincial level governing body does recognise the importance of trees in mitigating UHI effects and in general emphasises the importance of ecosystem services more than the Johannesburg city level governing body. National governing bodies need to integrate more ecosystem services into local governing body policies, and work with local authorities in terms of implementing long-term monitoring systems for ecosystems and ecosystem services. Therefore, more communication and collaboration between stakeholders from various disciplines and governing levels needs to occur to promote ecosystem services understanding, protection and management in Johannesburg.

Keywords: carbon sequestration; climate change; ecosystem services; temperature regulation; water provision

Table of Contents

List of Figures

List of Tables

Nomenclature

List of Symbols

r	Radius
Y	Biomass
π	pi = 3.14
a	constant = 0.1936
b	constant = 1.1654
CBH	circumference at breast height = 1.3m
DBH	diameter at breast height = 1.3m

Abbreviations

NEMA	National Environmental Management Act
GDARD	Gauteng Department of Agriculture and Rural Development
EISD	Environment and Infrastructure Services Department
IPCC	Intergovernmental Panel on Climate Change
TEEB	The Economics of Ecosystems and Biodiversity
GCRO	Gauteng City Region Observatory
SANBI	The South African National Biodiversity Institute
CBH	Circumference at Breast Height
DBH	Diameter at Breast Height
UNISA	University of South Africa
EIA	Environmental Impact Assessment
MOE	Municipal Owned Entity

1 Introduction

Natural ecosystems provide various resources, from food (agriculture and fishing) and fibre to wood and water. Complex processes underpin the functioning of these natural ecosystems, including the flow of energy and materials through organisms and the physical environment. These materials can include water, carbon and various chemicals and minerals that are found in abiotic systems such as water, soil, rocks and the atmosphere, and in biotic systems including microorganisms, plants and animals (Chapin *et al*., 2011).

Ecosystems are impacted by changes in the environment and organism activities. These can include changes in temperature, or changes in organism feeding patterns, competition, predation or even fire and soil, wind and water erosion. One major ecosystem disturbance is the presence of humans, as anthropogenic activities are seen to have a pervasive influence on these systems (Chapin *et al*., 2011). Humans have caused long-term changes to the natural environment, thereby impacting ecosystem equilibrium and resource supply. These disturbances can change ecosystem structures and functions by changing factors such as climate and biota, including the introduction of new species and the extinction of other species. These changes lead to the creation of novel conditions and therefore new types of ecosystems (Chapin *et al*., 2011).

1.1 Urbanisation and Ecosystems

The creation of these unique ecosystems can be seen in cities around the world. Urban ecosystems consist of built infrastructure, high human density as well as various natural features including plants, animals, rivers and open natural land (Carpenter *et al*., 2003). This mixture of built-up and natural features offers habitats for various species (McIntyre *et al*., 2000). However, high levels of urbanisation also bring various risks to the inhabitants of cities, including humans, plants and animals. Anthropogenic activities have transformed land surfaces, added and removed species and have altered biogeochemical cycles. Land has been transformed to produce food, fibre and other goods, which has also impacted on freshwater and marine ecosystems, as well as plant and animal populations. The burning of fossil fuels, the intensification of agriculture and the introduction of synthetic chemicals have altered the cycles of carbon, nitrogen, phosphorous, sulphur and water on a global scale, which severely affects ecosystem functions and contributes to the effects of climate change (Chapin *et al*., 2011). It has therefore become more vital to understand these urban ecosystems as the importance of the environment and ecosystems to society has become more recognised (McIntyre *et al*., 2000).

The impacts created by urbanisation can be reduced through ecosystem services, which contribute to the functionality of an ecosystem. Ecosystem services can be defined as the benefits that human populations obtain, either directly or indirectly, from ecosystem functions (Bolund and Hunhammar, 1999). These can be grouped into various categories. For the purpose of this study I followed the Millennium Ecosystem Assessment Framework's (2003) definition for ecosystem services. This includes four categories, namely provisioning services, which are the actual products obtained from ecosystems (food, fibre, water, fuelwood, biochemical and genetic resources), regulating services, which are benefits obtained from the regulation of ecosystem processes (climate, disease and water regulation, pollination and water purification), cultural services, which are nonmaterial benefits obtained from ecosystems (spiritual, religious, recreational, ecotourism, aesthetic, educational, sense of place and cultural heritage) and supporting services which are necessary for the production of all the other ecosystem services (soil formation, nutrient cycling and primary production) (Carpenter *et al*., 2003).

Urban regulating and supporting ecosystem services, which are deemed as important, include carbon sequestration, water production and regulation, urban temperature regulation, pollination, waste treatment and air purification (Gomez-Baggethun and Barton, 2013). Natural features such as trees, rivers and green spaces within urbanised areas are vital as they provide these ecosystem services that in turn can contribute to the resilience and protection of urban areas (Gomez-Baggethun and Barton, 2013). These urban ecosystem services can strengthen a city's resilience to various elements, including climate change impacts (Leichenko, 2011). The ecosystem services that play an important role in the face of climate change are urban temperature regulation, water flow regulation and production, runoff mitigation and carbon sequestration. They are directly impacted by climate change and can help a city to mitigate and adapt to climate change effects (Gomez-Baggethun *et al*., 2013). Temperature regulation helps counter urban heat islands by providing cooling through tree shading and evapotranspiration, while increased vegetated "green" areas decrease water runoff (and therefore flooding) and increase carbon storage potential (Whitehead *et. al*., 2009). Flooding, droughts and impacts on water quality and security of water supply are threats in various climate change scenarios, yet very few studies consider how climate change impacts urban ecosystem services and how these ecosystem services could mitigate climate change effects (Whitehead *et. al*., 2009).

1.2 Research Question

Urban ecosystem services are degrading at a fast pace due to anthropogenic activities. This makes it vitally important to protect them as they provide crucial benefits to cities, while simultaneously being able to provide protection against climate change impacts. There is a limited amount of urban ecosystem services research in South Africa and specifically relating to the greater Johannesburg area (see Le Maitre *et al*., 2007; Turpie *et al*., 2008; Egoh *et al*., 2009; Pejchar and Mooney, 2009; Egoh *et al*., 2010 and Schäffler and Swilling, 2013). Most existing research focuses on ecosystem services in more pristine areas across South Africa and not in urban environments. Urban ecosystem research can help urban planners and developers to understand the benefits of green spaces and ecosystem services in their cities to counter urban heat island effects, reduce flood risk, improve air quality and enhance habitat availability and connectivity. This is particularly important in more vulnerable areas in Johannesburg, such as the large informal settlements (Whitehead *et. al*., 2009). Given the lack of urban ecosystem services research in Johannesburg, and specifically those linked to climate change mitigation, I aimed to provide more information on the state of some of these ecosystem services, specifically carbon sequestration, urban temperature regulation and water flow regulation and provision.

1.3 Study Area

The study area for my research was the greater Johannesburg area (1 644.58km²) located in the province of Gauteng in South Africa. Johannesburg lies at an altitude of 1 753m (Kromberg *et al*., 2008) and is located in the Highveld of South Africa. Its natural vegetation is characterised by indigenous grassland (Mucina and Rutherford, 2006). Summer temperatures can reach an average maximum of 28ºC and minimum of 17ºC, while winter temperatures can reach a maximum of 19ºC and a minimum of 5ºC (The South African Weather Services, 2016). Johannesburg experiences summer rainfall, with an annual rainfall average of 713 mm (The South African Weather Services, 2016).

Johannesburg, which includes seven major regions, is the most populated city in South Africa with around 4.4 million people and has a high population growth rate (StatsSA, 2011). It is the provincial capital of Gauteng, the economic heartland for South Africa, and it contributes the highest percentage to South Africa's gross domestic product (Rogerson, 2002). The city includes scattered regions of residential, township, industrial and office developments, with 19% of Johannesburg's citizens living in informal settlements (African Green City Index, 2011). Due to the scattered and sprawling layout of the city, the density of Johannesburg is much lower (2 400 people per kilometre) than the average for other major African cities (African Green City Index, 2011). The city boasts a rich cultural diversity, including African, Asian and European residents, however, some races have been negatively affected by past inequalities due to the apartheid regime (Le Maitre *et al.*, 2007). Johannesburg contains the largest man-made forest in the world, with an estimated 10 million trees in the city (African Green City Index, 2011). The key natural landscape features of Johannesburg include rivers, wetlands, protected areas, parks and recreational areas, ridges, forest, grassland and bushland (City of Johannesburg, 2008).

1.4 Aim and Objectives

The aim of this study was to assess the current state of three key ecosystem services in the City of Johannesburg, South Africa, and their potential to mitigate possible climate change impacts.

The objectives were to 1) assess the quality of three key urban ecosystem services, namely carbon sequestration, urban temperature regulation and water flow regulation and production, 2) to assess the distribution of these ecosystem services in Johannesburg and the possible risks of their degradation, and 3) to determine whether environmental policy protects and manages ecosystem services in Johannesburg.

2 Literature Review

Urban ecology is the study of living organisms and how they interact with each other, their surroundings and humans in an urban environment (Endlicher *et al*., 2014). Urban ecology uses similar approaches to classic ecology and other disciplines within ecology. The key difference in urban ecology is mainly due to the presence and interactions of social and economic systems within urban ecosystems which are not as dominant in classic ecological studies (Liu *et al*., 2007). Originally ecological studies focused on areas with little to no human presence as they were seen as an agent of disturbance (Pickett *et al.,* 2008). An urban ecosystem can be defined as the interactions between plant and animal populations and their communities as well as their relationships to human influences (Endlicher *et al*., 2014). These urban ecosystems have been transformed and developed by humans for their purposes. They are different to more pristine ecosystems in terms of their development, influence and potential impacts on themselves and the environment (McIntyre *et al*., 2000). Only recently (from 2000 onwards) have urban ecology studies become more common as the importance of understanding how ecosystem structures and functions are shaped by urban development has grown (McIntyre *et al*., 2000).

Urban systems have unique ecological and socioeconomic structures and patterns compared to more pristine and rural areas (Liu *et al*., 2007). For example, society depends on the environment for the provision of food, water, oxygen, and various other raw materials, which are vital to survival and the functioning of societies and economies (Pickett *et al.,* 2008). Urban ecology research primarily focuses on social-ecological systems, which are becoming increasingly more important in urbanised areas. Factors such as global change, land use changes, increases in infrastructure and population growth rates all impact the environment (Ernstson *et al*., 2010). Global change (including climate change) affects weather patterns which may lead to increasing severity and frequency of extreme weather events. This is caused when a climate variable such as temperature or rainfall exceeds a certain threshold. Extreme weather events such as droughts, flooding, hurricanes and cyclones can disrupt ecological features and functions, for example processes such as soil formation and nitrogen cycles can be disrupted and destroyed by flooding (Linnenluecke and Griffiths, 2010). Population and economic growth rates increases the need for more space for industry, agriculture and housing (Ernstson *et al*., 2010).

2.1 Urbanisation

Throughout time, humans and the environment have had a complex but important relationship with one another (Pickett *et al.,* 2008). Evidence shows that humans are altering almost all the Earth's ecosystems through raw material extraction and land degradation by various anthropogenic activities (see McIntyre *et al*., 2000; Carpenter *et al*., 2003 and Wu, 2010). The extent and impacts of anthropogenic activities are most evident in urban areas such as cities due to the high concentration of residential and commercial developments. An urban environment can be defined as a built environment supporting a high human density, as well as various natural features, including plants, animals, rivers and open natural land (Carpenter *et al*., 2003). Cities are areas that have been highly urbanised by humans and can be described as a heterogeneous space that contains a mosaic of areas with different physical properties and uses. To construct and maintain urban infrastructure, these areas have high levels of energy use per year, mainly in the form of burning of fossil fuels (McIntyre *et al*., 2000).

Around 50% of the world's population live in cities, yet cities themselves only take up around 3% of the world's surface. One study has shown that urbanised areas account for 80% of the world's carbon emissions, 60% of residential water use and 80% of wood that is used for industrial purposes (Wu, 2010). Urban areas have significant impacts on the environment, while simultaneously relying on the environment for benefits such as water supply and other raw materials (Wu, 2010).

Various urbanisation characteristics can impact the natural environment. Built infrastructure, population growth, land cover changes and climate change are urbanisation features that will have large and uncertain impacts on the environment (Carpenter *et al*., 2003). Roads and buildings transform rural landscapes into residential, commercial and industrial areas. These changes increase the amount of impermeable surfaces, accumulate various toxic substances, increase the amount of domestic wastewater load and increase the demand for water due to larger populations living in these cities. The burning of fossil fuels increases the amount of nitrogen and sulphur deposition in and around industrial areas, which can increase the amount of nitrogen availability and lead to nitrification and nitrate leaching, causing air and water pollution (McIntyre *et al*., 2000). Urbanisation has various impacts on other features within cities, including plant and animal species, water bodies and water availability, soil health, human health and climate and temperature changes (see McIntyre *et al*., 2000; Hamel *et al*., 2013; Radhi *et al*., 2013; Concepcion *et al*., 2015). Native species can be driven away from areas and be susceptible to extinction due to habitat destruction, while exotic or invasive species can be introduced into new areas (Concepcion *et al*., 2015). More impermeable surfaces can increase the amount of storm water runoff, which in turn increases the risk of flooding, causing damage to infrastructure and posing a threat to human health and lives (Hamel *et al*., 2013).

However, urbanisation does bring some benefits to the environment; the spatial heterogeneity introduced through urbanisation can provide more diverse habitat niches which can attract more species and result in higher levels of biotic diversity. Non-native species increase a city's diversity and can thrive in these urban environments due to their high dispersal rates. Urban environments also tend to have greater primary productivity than surrounding areas, due to the addition of water, fertilizers and other limiting factors. City residents also provide additional food to animals through intentional seed provision or unintentional methods such as garbage and litter disposal (McKinney, 2008). When ecological functions and the way they are impacted and changed by anthropogenic activities are studied, it allows for an evaluation of ecological performances in various urban areas. This allows for a clearer and better understanding of how building density, city and building design, and the amount and type of green spaces influence a city's ecological performance, and therefore what changes can be made to existing cities around the world to make them more sustainable (Strohbach and Haase, 2012).

2.2 Urban Ecosystem Services

A variety of life and natural features occur in urban areas. It is important to recognise that urban environments need to be seen as ecosystems themselves as they include urban climate, hydrology and soils, as well as flora and fauna (Endlicher *et al*., 2014). These urban ecosystems comprise of suburban areas, exurbs (the region beyond the suburbs of a city), sparsely settled villages which are connected by commuting corridors or by utilities, and hinterlands that are directly managed or affected by the urban and suburban areas. The boundaries of urban ecosystems vary and are usually set by watersheds, air-sheds, commuting radii or convenience. Some examples of smaller urban ecosystems include street trees, lawns/parks, cultivated lands, urban forests, wetlands, lakes and streams (Pickett *et al*., 2008). However, these transformed landscapes often host exotic flora and fauna, which can result in an imbalance between biotic immigration and extinction rates of indigenous biota. Higher levels of air, water and soil pollution also tend to occur in more urbanised areas (McIntyre *et al*., 2000).

Plants and animals play an important role in cities, and allow for ecosystem services to thrive and environmental systems to survive (Bolund and Hunhammar, 1999). Animals and plants provide various benefits to urban environments such as amenity values (aesthetic enjoyment and recreational activities), environmental education (about species and conservation) and other ecosystem services (McKinney, 2008). Ecosystem services can be defined as the benefits that human populations obtain, either directly or indirectly, from ecosystem functions (Bolund and Hunhammar, 1999) and can be grouped into four categories: provisioning, regulating, supporting and cultural services (Carpenter *et al*., 2003). These ecosystem services convert energy flows and materials into critical products and services that are needed to sustain all populations (McIntyre *et al*., 2000). Ecosystem services are seen as the conditions and processes that produce the life support systems for ecosystems to survive and thrive (Fisher *et al*., 2007). The structure, components and pattern of an ecosystem determine its flows, functions and processes, which in turn result in the production of goods and services. These are very complex relationships which are difficult to determine and measure, making decisions on ecosystem services maintenance and trade-offs difficult (Fisher *et al*., 2007).

Ecosystem services deliver goods and services over various spatial and temporal scales. However, under large stresses (or high demands) these ecosystems can flip to undesirable states, changing the level of production of these services or even completely halting production (Costanza, 2000). An investigation done for the Millennium Ecosystem Assessment (MA) determined that globally 15 out of the 24 ecosystem services studied were in a state of decline (Fisher *et al*., 2007). The deterioration of ecosystem services such as water regulation and purification, which are seen in wetlands, can degrade the overall health of ecosystems as their infrastructure is declining (Fisher *et al*., 2007). The process of nutrient cycling, for example, can result in clean water, which plays an important role in ensuring good health and therefore the survival of various ecosystems. Water regulation leads to storm regulation and flood reductions which protect natural and human dominated systems (Fisher *et al*., 2007). Therefore, ecosystem services are vital for the protection and ultimately the survival of natural and urban systems (Fisher *et al*., 2007).

Ecosystem services can be impacted and therefore changed by various activities and drivers. The major drivers of ecosystem service changes include climate change, land use change, invasive species, overexploitation, pollution, population increase and economic growth. These drivers can cause changes in the supply of ecosystem services which can negatively impact society and the economy. When land use changes, for example by built infrastructure which transforms the land into a more homogenous structure, this can make ecosystem services more vulnerable. For example, if changes in the landscape directly impact on the hydrology in the area, it could later affect water supply or water quality. All of these drivers are linked to one another and with the environment, resulting in complex relationships, linkages and feedback mechanisms (Carpenter *et al.*, 2009). This can be illustrated by cultivated lands which provide additional services of crop production and yield more water than they would have in their natural state. However, the pesticides used on the crops can pollute this yielded water and affect river ecosystems, which in some cases can affect downstream ecosystems. This pollution can degrade river ecosystems and can result in a reduced service provision (Le Maitre *et al.*, 2007).

Despite its highly transformed and built up nature, cities still include remnants of natural land, rivers and streams, as well as established and cultivated green spaces. Some of the most common and important urban ecosystem services include food supply, water regulation (for example runoff mitigation), temperature regulation, carbon sequestration, air purification, noise reduction, waste treatment, pollination and recreation. These were established from various urban ecosystem services studies and are deemed as important as they provide critical products and services to urban environments and their citizens (Gomez-Baggethun and Barton, 2013). These ecosystem services therefore provide “free” benefits to society which, if lost, would result in additional expenses in order to build an alternative method to provide the same benefit. For example, some green spaces and wetlands can act as effective storm water attenuation systems which reduce the need to build new pipe and channel systems to transport storm water out of the city (Schäffler and Swilling, 2013). Vegetation in urban areas can reduce air temperature by intercepting solar radiation and can reduce pollution by removing pollutants including ozone, sulphur dioxide, nitrogen dioxide and carbon monoxide. This positively contributes to the health of the city residents (Gomez-Baggethun and Barton, 2013). In turn water provision from rivers, dams and wetlands is a vital resource to cities and to all parts of life, including humans and the environment (Kroll *et al.,* 2012). An ecosystem services study done in Stockholm, Sweden (Barthel *et al.,* 2010), provided evidence that urban gardens supported ecosystem services such as pollination, seed dispersal and pest regulation. It was further discovered that these urban gardens create strong social community relationships with gardening, which results from continuous management and community practices of gardening which helps strengthen a citizen's connection to nature. This in turn increases the public's ecological knowledge of urban ecosystem services, resulting in increased ecosystem devices protection and production in urban areas which helps to stop the further decline of these critical urban ecosystem services (Barthel *et al.,* 2010). This type of research is relatively easy and inexpensive to replicate as only interviews and surveys were conducted with members of the gardening community. (Barthel *et al.,* 2010). Therefore, urban ecosystems contribute to a city's and society's resilience and protects them against various elements such as flooding and increased temperatures (Gomez-Baggethun and Barton, 2013).

The majority of the human population lives in cities which makes urban regions the focal point of ecosystem service demands, as well as a major source of environmental impact. The fact that cities are expected to grow at rapid rates indicates that urban ecosystem services will face a high risk of degrading at a fast pace (Bolund and Hunhammar, 1999; Grimm *et al*., 2008). The urban ecosystem services provided by vegetation, trees, open spaces and water bodies are at high risk of being degraded and destroyed due to climate change and anthropogenic activities such as pollution and land use changes (space for more urbanisation or agriculture). For example, it is estimated that in China 300 million more people are likely to move into cities within the 21st century, which will place significant pressure on the environment and transform the urban landscape. Increased urbanisation can lead to inadequate sewage treatment, resulting in large nutrient loads in rivers and various water bodies, which degrades the world's most precious resource (Grimm *et al*., 2008). Therefore, ecosystem services need to be identified, assessed and protected in urban environments in order for them to provide ecosystem resilience and help reduce environmental degradation (Larondelle and Haase, 2013).

However, there is a lack of detailed information on ecosystem services in cities (Strohbach and Haase, 2012). This may be due to the various challenges regarding the application of ecosystem services assessments. Firstly, there are gaps in scientific knowledge in understanding and quantifying how ecosystems provide services. Secondly, in most cases there is a lack of policy-supporting tools for ecosystem services, making it difficult to include these studies in decision making, planning and management processes (de Groot *et al*., 2010).

It has been reported that the main causes of ecosystem services degradation include dysfunction of institutions and policy, gaps in scientific knowledge and unpredictable events which tie in with the challenges of assessing ecosystem services (Carpenter *et al.*, 2009). Often it is unknown whether or why policy instruments are successful or have failed in protecting ecosystem services. This is mainly due to the lack of "before" and "after" data evaluation systems in order to monitor and manage ecosystem services policies. The lack of monitoring for these policies therefore results in an inadequate protection of ecosystem services which can lead to ecosystem services degradation (Carpenter *et al.*, 2009).

2.3 Urban Ecosystems and Climate Change

As mentioned, ecosystem services can strengthen resilience to climate variability which are natural changes in temperature and rainfall variables, which includes various elements such as storms and El Nino Southern Oscillations. However, they are also able to strengthen a city's resilience to climate change. Climate change refers to a change in climate that is natural, or human induced which alters the composition of the global atmosphere and changes the frequency, intensity and persistence of extreme climate events such as droughts and flooding (McCarthy *et al.*, 2014).

Urban resilience can be defined as the ability of a city or urban system to absorb certain disturbances while still being able to retain its identity, structure and key processes (Leichenko, 2011). Climate change is a global threat and enhancement of resilience is seen as the key goal for mitigation and adaptation efforts in cities. Climate change has various impacts on cities and can alter ecosystem functions. This results in changes to temperature and precipitation regimes, evaporation, humidity, vegetation growth rates, soil moisture levels, water tables and aquifer levels and air quality. These changes can in turn affect the effectiveness of urban green spaces and infrastructure and therefore climate adaptation strategies in cities (Solecki and Marcotullio, 2013). More concerning is that climate change-related shocks usually occur in combination with other environmental, economic and political stresses, making climate change resilience extremely important (Leichenko, 2011). For example, climate change can result in more intense and frequent flooding and drought events which can threaten food security, which in developing countries can result in economic and social instability (McCarthy *et al.*, 2014). Research suggests that some of the key characteristics of resilient cities include diversity, flexibility, adaptive governance and the ability to learn and be innovative (Leichenko, 2011). Resilience and its numerous characteristics are generally measured by the ability of a city (including its environment, economic and social systems) to absorb shocks and disturbances (such as natural disasters) and return to an alternative stable state and growth rate of output, employment and population (Brand and Jax, 2007; Pike *et al.*, 2010). Resilient cities are therefore able to deliver ecosystem services over time, even in the face of various urban dynamics and disturbances (Ahern, 2013).

Ecosystem services that play an important role in the face of climate change include carbon sequestration, water flow regulation and provision, urban temperature regulation and runoff mitigation. Carbon sequestration occurs when trees absorb and store carbon as biomass which lessens the amount of greenhouse gases in cities and their atmosphere locally and regionally (Strohbach and Haase, 2012). Water flow regulation and production are an important local ecosystem service to monitor in the face of climate change as water is a scarce and precious resource that needs to be secured in order to meet the societal needs of cities (Gomez-Baggethun *et al.*, 2013). Urban temperature regulation refers to the regulation of local temperatures by buffering the effects of urban heat islands, which occurs through vegetation absorbing and reflecting heat energy, thereby changing local temperatures (Loughner *et al.*,2012). Runoff mitigation occurs when open green spaces, vegetation and wetlands help absorb rainwater runoff, which reduces the chances of local and regional flooding events which can be exacerbated due to more frequent storms linked to climate change (Gomez-Baggethun *et al.*, 2013).

Given the key attributes of ecosystem services, my study focused on an assessment of three ecosystem services, namely carbon sequestration, urban temperature regulation and water flow regulation and provision as these ecosystem services are directly impacted by climate change and play a role in helping to mitigate climate change effects.

2.4 Carbon Sequestration

A significant amount of carbon is stored in natural forests, with research estimating that around 45% of terrestrial carbon is stored in these forests. Importantly, 33% of anthropogenic carbon emissions from fossil fuels and land use changes are stored in forests. However, natural forests are being destroyed and cleared across the tropics worldwide. A high rate of 152 000 km² per year of forest clearing was recorded in the tropics in the 1990s (Bonan, 2008). With natural forests and areas becoming more degraded and with atmospheric carbon increasing by 2600 million metric tons per year, it is vital to incorporate natural features, such as trees, within urban areas (Nowak and Crane, 2002).

Urban forests are therefore important features as urban areas are seen as hotspots of global change. Urban forests can be defined as the "sum of all woody and associated vegetation in and around human settlements" (Strohbach and Haase, 2012). Urban forests in the USA, Germany, UK, Korea and Australia have been found to store significant amounts of carbon (Strohbach and Haase, 2012). Trees are able to fix carbon during the photosynthesis process and store the excess carbon as biomass (Nowak and Crane, 2002). Various factors can influence the amount of carbon urban forests store, which includes the age, composition and history of the urban trees. Urban areas are therefore becoming important areas for environmental features as these natural features can directly alleviate impacts from the area. However, being so close to anthropogenic activities can have negative impacts. Increasing human population sizes and density of cities have been seen to cause decreasing green space density and therefore less space for urban trees and other natural features (Strohbach and Haase, 2012).

2.5 Water Provision and Regulation

Water is an important and vital commodity anywhere in the world (McIntyre *et al*., 2000). It is uncertain as to how climate change and temperature changes will impact precipitation, evaporation and hydrology at regional scales. This uncertainty places even greater importance on water and climate change research, especially in water scarce and third-world countries. However, only a few studies have researched how climate variability (natural fluctuations in temperature and rainfall variable) and climate change (change in climate that is natural or human induced that alters the composition of the global atmosphere and changes the frequency, intensity and persistence of extreme climate events such as droughts and flooding) might impact water quality and quantity in urban areas (Whitehead *et al*., 2009).

The combination of climate change and climate variability is expected to impact river regimes, flow velocity, hydraulic characteristics, water levels, inundation patterns, residence time, habitat availability and connectivity across habitats. Climate change will have different impacts in different regions across the globe. For example, Whitehead *et al.* (2009) suggest that in the UK winter rainfall could increase by 10-20% in low-emission scenarios, and by

15-35% in high-emission scenarios, while other countries can experience drier and hotter summer periods, droughts or even flooding events. China has already experienced various climate extremes such as the great flood of 1998, which resulted in an economic loss of 20 billion US dollars through inundating 21 million hectares of land and destroying five million houses (Piao *et al*., 2010). These different impacts can result in additional effects. For example, lower flow rates in rivers result in less dilution ability and therefore higher concentrations of pollutants (Whitehead *et al*., 2009). Increased storm events can result in flooding or sewer overflows, discharging highly polluted waters into river systems, while severe flooding can destroy crops and impact food security (Whitehead *et al*., 2009 and Piao *et al*., 2010).

Climate change is also expected to change air and water body temperatures. Research indicates that river temperatures are in close equilibrium with air temperatures as water can be warmed up through higher air temperatures and can lose their heat through the air. Water temperature will therefore be expected to increase or decrease with increasing air temperature due to climate change effects. For example, large European rivers have experienced a temperature increase of around 1-3°C over the past 100 years (Whitehead *et al*., 2009). According to Goldenberg *et al*. (2001) a fivefold increase in hurricanes has been seen in the Caribbean between the mid 90's and early 2000 period. The increase of these hurricanes is due to increased sea-surface temperatures caused by climate change and are expected to persist for an additional 10 to 40 years (Goldenberg *et al*., 2001). Changes in water temperature and dissolved oxygen levels can impact aquatic organisms' life cycles, which in turn affects the overall quality and health of the water, which can impact human water usage as well (van Vliet *et al.,* 2013). However, there is uncertainty as to how water temperature will impact water quality due to changes in regional precipitation and extreme events, which will also play a role (Whitehead *et al*., 2009).

2.6 Urban Temperature Regulation

Urbanisation is increasing across the world, especially in developing countries (Peng *et al*., 2012). Importantly, urbanisation alters local climate which can result in urban heat islands (UHI's). Urban heat islands occur when there is an increase in impervious urban surfaces, which in turn increases water runoff, decreases evapotranspiration and increases solar radiation absorption. These effects, combined with additional releases of anthropogenic heat, change the near-surface air temperature, humidity, wind speeds and precipitation in urban areas (Loughner *et al*., 2012). This creates a difference in temperature between urban and the surrounding non-urban areas, thereby creating an "urban heat island" (Imhoff *et al.,* 2010). The Intergovernmental Panel on Climate Change (IPCC) has reported that global and mean temperatures have increased by 0.84°C plus/minus 0.37°C since the industrial revolution, while the warm night frequency has also increased due to UHI's (Peng *et al*., 2012).

Urban heat islands strengthen as city size and building density increases, due to the increases in solar radiation absorption and decrease in evapotranspiration (Loughner *et al*., 2012). They can also occur at any latitude and either during the day or night as a function of the local thermal balance (Akbari *et al*., 2016). These urban heat islands can have negative effects on human health due to higher temperatures and occurrences of heat waves, which can lead to heat stress and exhaustion, and increase the number of sick leave days, which can hamper economic growth in certain industries (Kikegawa *et al*., 2006). Urban heat islands also aggravate air pollution by modifying the distribution and availability of pollutants in cities, which negatively affects human health and worsens climate change impacts (Sarrat *et al.,* 2006 and Loughner *et al*., 2012).

Within recent times there has been an increase in research and understanding of urban heat islands, their environmental effects, health impacts and development of measures to mitigate UHI's and the introduction of policies and programmes to help cool UHI's (Akbari *et al*., 2016). Features that were identified as reducing UHI effects included cool roofs, cool pavements, urban vegetation, trees and reflective urban building material (Akbari *et al*., 2016). Therefore, research indicates that urban trees have the potential to lessen urban heat island effects and decrease near-surface temperatures through their shading (intercepting heat waves) and evaporative cooling abilities. An added benefit of urban trees is their ability to improve air quality by decreasing air temperatures and increasing the removal rate of pollutants from the atmosphere (Loughner *et. al*., 2012).

2.7 Socio-ecological Relationships

Ecosystem services studies should include social, economic, and ecological aspects in order to gain a full understanding of the processes, drivers and stakeholders of ecosystem services (James *et al*., 2009). For the purpose of this study I have mainly focused on the socio-ecological relationship of urban ecology and ecosystem services with a specific focus on the ecological health of ecosystem services and the governmental policies and planning regarding ecosystem services. Policies and guidelines play an important role in the protection of environmental features such as ecosystem services. Therefore, analysing these policies and the health of ecosystem services will shed light on whether these ecosystem services are being protected, whether they are in good health and provide reasons for these results (James *et al*., 2009). The reasons why the social and ecological relationship of ecosystem services is so important is discussed below in this section and the following section.

Both ecological and social systems are open and adaptive systems that interact with their environment which results in feedback mechanisms that can impact on and change the other (Yli-Pelkonen and Niemela, 2005). These systems are mediated by factors such as urban form, built infrastructure and the location and consumption preferences of heterogeneous households and businesses (Liu *et al*., 2007). In South Africa it is believed that environmental issues are seen as important to only the wealthy or white communities predominantly, which could result in the poorer previously disadvantaged communities not wanting to conserve the environment or that they are not benefiting from the environment due to their rural and more bare locations (Le Maitre *et al*., 2007). Research has shown that society can benefit from the environment as green spaces were shown to reduce crime, violence and stress (Tidball and Krasny, 2007).

Society has a significant impact on the environment through its activities and ecological footprint which causes land use change and environmental degradation (Yli-Pelkonen and Niemela, 2005). However, it is important to note that society and government are key drivers of urban growth innovation that can help make cities sustainable in the face of climate and global change, using new ideas and green technologies. Governing bodies, for example, play an important role in protecting the environment through creating and implementing environmental laws and policies. It is therefore vital that there is an open line of communication (and sharing of information) and collaboration between ecologists, governmental bodies, and society (including decision makers) to implement sustainability ideas and technologies (Yli-Pelkonen and Niemela, 2005).

Inadequacies in communication between stakeholders have led to the development and implementation of the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES), where South Africa is part of the international panel (Department of Environmental Affairs, 2012). This platform was developed to promote collaboration by making scientific research and data more relevant and accessible to policy makers, and to create more awareness in the scientific community about policy needs and processes (Larigauderie and Mooney, 2010). However, the implementation of “green policies” in planning and management of urban green spaces is a challenge in developing countries, including South Africa, which calls for urgent attention (Cilliers *et al*., 2013). Governmental organisations have a critical role to play to protect and maintain biodiversity and ecosystem services by implementing policies that adhere to the various stakeholders’ needs (Perrings *et al*., 2011).

2.8 South African and Johannesburg Studies and Governmental Policies

Studies concerning ecosystem services in South Africa have been done, but primarily on pristine systems and not urban ones, while to my knowledge very few studies have been conducted in the Johannesburg area (see Le Maitre *et al*., 2007; Turpie *et al*., 2008; Egoh *et al*., 2009; Pejchar and Mooney, 2009; Egoh *et al*., 2010 and Schäffler and Swilling, 2013). Most ecosystem services research to date has focused on the fynbos biome, with a few on specific areas of the savanna and thicket biomes, and estuarine and coastal fisheries (see Le Maitre *et al.,* 2007; Turpie *et al*., 2008; Egoh *et al*., 2009 and Pejchar and Mooney, 2009). One paper suggests that research generally focuses on woodlands and forests, as there is more interest in the goods and raw materials that are harvested from these areas (see Le Maitre *et al*., 2007).

Some researchers regard the city of eThekwini (previously known as Durban) as the leader in South Africa in terms of open space planning in biodiversity protection, resulting in the city shifting their focus from conservation to sustainable development (see Environmental Planning and Climate Protection Department, 2009; Roberts, 2010 and Cilliers *et al*., 2013). eThekwini focused on the importance of the goods and services provided by open spaces in meeting peoples basic needs and improving their quality of life, which differs from other conservation projects that solely focus on animal and plant requirements. This lead to developing monetary values for biodiversity and the valuation of ecosystem services (Cilliers, 2010). eThekwini protects their open spaces and ecosystem goods and services through property rate rebates, environmental charges, zoning regulations, land acquisition and environmental servitudes. For example, a servitude area will remain in the ownership of the land owner and can be used for passive recreational activities that do not compromise the natural environment within this area (Environmental Planning and Climate Protection Department, 2009). The City of Cape Town has their own assessment methods to identify any areas where ecosystem services are degrading (Cilliers *et al.*, 2013). A project called "the Cape Flats Nature Initiative" bridges the gap between biodiversity conservation and poverty alleviation (Cilliers, 2010). The initiative employs urban township residents to run biodiversity monitoring and management efforts which contributes information to ecosystem services studies (Tidball and Krasny, 2007). The aim of this initiative is to create a forum for the communication of conservation issues for various stakeholders and show policy makers that making Cape Town more resilient will protect the city and themselves from unforeseen disasters (Tidball and Krasny, 2007). The participation of various stakeholders (such as the local government, non-governmental organisations and bioregional planning and funding agents) in decision making processes contributes to the success of this initiative (Cilliers, 2010).

Johannesburg contains many natural features and green spaces; however, they are impacted by continuous urban development. The African Green City Index (2011) reported that Johannesburg has 231 square metres of green space per person, which is the second highest out of all the African cities that were included in this study. The protection of green spaces as well as sensitive areas such as wetlands is becoming increasingly difficult due to the high demands and pressures for new housing to accommodate the increasing population moving into the city (African Green City Index, 2011). The State of the Environment Report (City of Johannesburg, 2008) reported that the city has undergone a significant number of land use changes and development due to anthropogenic activities such as mining and construction. Most of the land cover in Johannesburg has been transformed due to private and public development, resulting in the loss of open spaces. Land degradation has taken place mainly through past and current mining activities and the destruction of natural areas through agriculture. The loss of natural space and the ongoing urban development places concerns on future climate change impacts on the city and its residents (City of Johannesburg, 2008). However, Johannesburg still contains the largest man-made forest in the world, and these trees can provide various climate change resilience and mitigation effects such as carbon sequestration and urban temperature regulation (African Green City Index, 2011).

The Department of Environmental Affairs of the Republic of South Africa is responsible for creating and implementing the various environmental laws, regulations, policies and guidelines. NEMA (National Environmental Management Act No. 107 of 1998) is the current national environmental act to govern environmental decisions. It covers aspects regarding protected areas, waste and biodiversity management, conservation, air quality, recycling and environmental impact assessments (Department of Environmental Affairs, 2017). The Department has issued various guidelines and policies for environmental issues that governmental bodies, businesses and stakeholders can use to follow and integrate in an urban environment. These include information on biodiversity, energy usage and reporting, waste and water management and air quality (Department of Environmental Affairs, 2017). There is a large number of various environmental acts and regulations in South Africa which are constantly being updated and added to. The National Environmental Management: Protected Areas Act (No.57 of 2003) provides protection for various national parks and ecosystems, including marine ecosystems. The National Environmental Management: Biodiversity Act (No.10 of 2004) provides regulations for threatened and protected species, marine species, hunting activities, bio-prospecting, access and sharing and regulations for alien and invasive species. The National Environmental Management: Air Quality Act (No. 39 of 2004) covers air quality regulations, invasive and alien species, pollution and dust prevention and greenhouse gas emission reporting regulations. The National Environmental Management: Waste Act (No. 59 of 2008) deals with all waste management and disposal regulations and laws, while the Environmental Conservation Amendment Act (No. 79 of 1992) and National Water Act (No. 36 of 1998) deal with general conservation and water supply, quality and protection laws and regulations respectively (Department of Environmental Affairs, 2017).

The Department has a separate branch dedicated to climate change and air quality research, and they have a National Climate Change Response White Paper (published in 2011). This branch, called the Climate Change and Air Quality branch, is involved in climate change adaptation research, covering many topics such as the effects of climate change on urban and rural areas, climate change impacts on food security, biodiversity and water, and climate change risk management and policy making (Department of Environmental Affairs, 2017; *National Climate Change Response White Paper*- The Department of Environmental Affairs, 2011). Johannesburg also has various development planning policies and strategies to ensure environmental protection in urban areas. These policies broadly include land use management as well as building and planning control and Environmental Impact Assessments (EIA's) in order to reduce urban sprawl and promote sustainability (Department of Environmental Affairs, 2017).

3 Methods

I followed The Economics of Ecosystems and Biodiversity (TEEB) manual for cities' guidelines on how to manage ecosystem services in urban areas (TEEB, 2011) to assess the ecosystem services within the City of Johannesburg. This includes six steps to guide cities in including ecosystem services in their decision making and policies. The six steps are as follows: 1) specify and agree on the problem or policy issue with stakeholders, 2) identify the most relevant ecosystem services that can help solve the problem or policy issue, 3) determine what information is needed and select assessment methods, 4) assess ecosystem services, 5) identify and compare management/policy options, and 6) assess the impact of the policy options on range of stakeholders (TEEB, 2011). For this study, I only followed the specific steps that are most relevant to my research and to my aim and objectives, which were steps 2, 3 4 and 5. This allowed me to identify the three ecosystem services I assessed (carbon sequestration, water provision and regulation and temperature cooling), find the appropriate methods to assess them and evaluate whether policies are in place to protect them in Johannesburg.

I used Google Earth Pro (2015) to randomly select 20 one km² sites (see Figures 3.1 and 3.2). The Johannesburg boundary within which I selected the sites was available as a layer called "borders" in Google Earth Pro (2015). This layer represents the entire Johannesburg area and is 1 644.58km² in size. I overlaid one km² grid lines over this Johannesburg area using the MGRS GridLines feature on Google Earth Pro (2015). A semi-random sampling method was used to select my sites; I used a random number generator to randomly select the initial 20 1km² quadrants (quadrants are from this point onwards referred to as sites). Google Earth Pro (2015) and Gauteng City Region Observatory (GCRO) maps allowed me to identify land cover types and therefore the possible ecosystem services generated within the 20 sites to ensure that the selected sites represented a wide variety of land cover types across the entire Johannesburg area, which included nature reserves, residential areas, core city areas, water bodies and open green spaces. A re-selection of some sites was done to ensure that all land use types were represented across the sites.

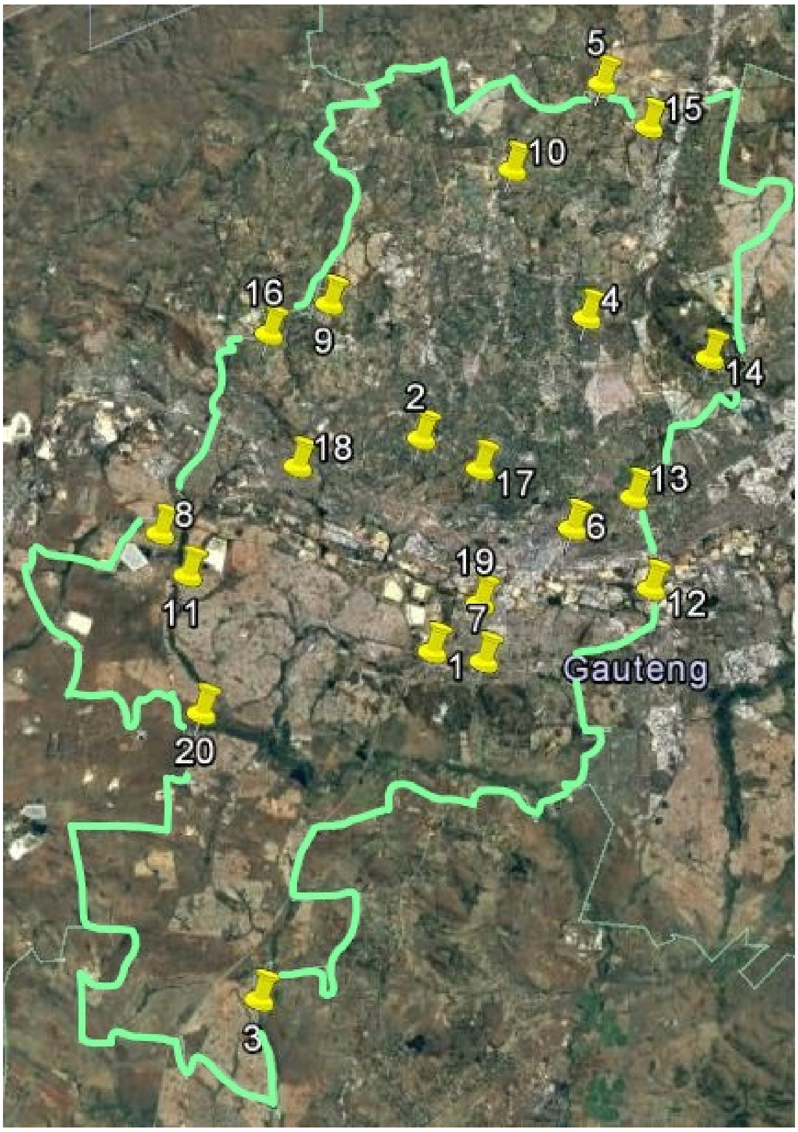


Figure 3.1 Locations of the 20 sites across Johannesburg (Google Earth Pro 2015)

Figure 3.2 Example of the entire quadrant size for sites 3 and 16 (Google Earth Pro 2015)

3.1 Mapping and Spatial Analysis

I assessed the land cover and land use of the greater Johannesburg area as part of my urban ecosystem services analysis. This included an assessment of the distribution of ecological features such as trees and water bodies, and analysing their distances to other features such as rivers, wetlands, protected areas, roads, and built-up areas. I obtained Gauteng land cover maps from The South Africa National Biodiversity Institute (SANBI) (2012) which included the following land cover types:

- cultivated: temporary-commercial dryland
- cultivated: temporary-commercial irrigated
- forest and woodland
- forest plantations
- improved grassland
- mines and quarries
- thicket and bushland
- unimproved (natural) grassland
- urban/built-up land: commercial
- urban/built-up land: industrial/transport
- urban/built-up land: residential
- urban/built-up land: residential (smallholdings: grassland)
- water bodies
- wetlands

Land use maps were also provided by the Gauteng City Region Observatory (GCRO) (2013) which included the following land use types:

- built-up
- commercial
- industrial
- informal
- residential
- school and sport grounds
- smallholding
- sport and golf
- township

Additional shapefiles, which included conservancies, rivers, wetlands, and protected areas, were obtained from the Gauteng Department of Agriculture and Rural Development (GDARD) C-Plan 2 (2013). All maps and shapefiles were projected into the same co-ordinate system before any analyses were done.

I mapped the overall study area and included land use, land cover, protected areas, river network, road network and wetlands overlays. I then used spatial analysis in ArcMAP (version 10.3.1) to analyse these maps, using the ESRI ArcGIS guide to determine which analyses to use (McCoy *et al*., 2002). I used the Euclidean distance function to create protected areas and wetland distance maps which project the relative distances of these features to one another. These distance maps also show whether any linkages or corridors exist between these natural features and how they are distributed across Johannesburg. The density (kernel) function was used to create river and road density maps which show the areas where these features are most concentrated or occur most frequently across Johannesburg (McCoy *et al*., 2002). This gave an idea of where high priority areas of conservation (containing a high number of rivers) or degradation/disturbances (containing high number of roads) are located in Johannesburg.

I chose to assess carbon sequestration, water provision and regulation and local temperature regulation (cooling) ecosystem services. Gomez-Baggethun and Barton (2013) consider these to be important urban ecosystem services, especially in terms of climate change mitigation, and they are easy to assess. To assess threats to these ecosystem services I focused on the location of water bodies (rivers and wetlands) and trees (which are found in all land use types including protected areas, residential and natural land cover types). The most pertinent threats to natural features are land use changes and anthropogenic activities. Therefore, analyses of the location of these natural features relative to built-up areas gave an indication of the level of potential threats to these ecosystem services within Johannesburg. I created a separate 150m buffer for wetlands, protected areas and rivers and determined how many and what type of land use (built-up) features fell within these buffers. A 150m buffer was used as this is the standard buffer size that is used in C-Plan analyses methods (C-Plan 2013). I also created a 150m zone for roads and determined how many rivers, wetlands and protected areas fell within this zone. These buffers and road zone were created to determine whether any natural features are in close proximity to built-up areas (which includes industry, commercial, residential, township, school, sport and recreational areas) which increases their risk of degradation.

3.2 Site Assessments

3.2.1. Carbon Sequestration

Two different approaches were used to calculate carbon storage potential within the sites as well as for the entire Johannesburg area, in order to provide a higher confidence level for the results. The first method, as applied by Lembani (2015), involved taking basic tree measurements from five randomly selected trees at every 100m point along a 1km transect across each of the 20 sites. I measured each tree's circumference (in cm) at breast height (CBH, at 1.3 m) using a measuring tape. The CBH was chosen instead of the diameter at breast height (DBH) as it is a more accurate measurement for irregular shaped stems, as their diameters are not a consistent value throughout the stem and will therefore not provide an accurate value (Tietema, 1993). For each site, I calculated the average tree circumference. To extrapolate these data across the entire site, I counted the number of trees at each site using an aerial image from Google Earth Pro (2015). Trees could be identified as dark green circular shapes in the sites.

I used allometric equations (given below) to estimate the DBH (in cm), then the radius (r) of the tree stem (cm), then the above ground biomass (Y) in kilograms, and then finally the amount of above-ground carbon stored in kilograms for each tree (Tietema, 1993). For the stored carbon equation, it was assumed that 45% is the average carbon content value for dry terrestrial biomass (as per Thomas and Malczewski, 2007). I calculated DBH, radius, above ground biomass, and stored carbon value for one tree in each site using the average tree size/circumference value. I then multiplied the average stored carbon value for one tree by the total number of trees in each site to obtain the total stored carbon for the entire site.

The estimation calculations for method one are as follows:

$$DBH = \frac{CBH}{\pi}$$

$$r = \frac{DBH}{2}$$

$$Y = a(\pi r^2)^b$$

where a (constant)= 0.1936, b (constant) =1.1654 and π (pi) =3.142

$$\text{Stored carbon} = Y \times 45\%$$

To extrapolate these data to the entire Johannesburg area I used the following equation adapted (using kilometres instead of hectares) from Schäffler and Swilling (2013):

$$X = \frac{Total\ size\ of\ JHB}{Total\ size\ of\ sites}$$

$$Total\ stored\ carbon\ in\ JHB \\ = X * the\ total\ stored\ carbon\ value\ for\ all\ the\ sites\ combined$$

where the total size of Johannesburg (including urban and suburban land, based on the municipal area/boundary) = 1 644.58 km².

The estimation calculations to determine stored carbon are general allometric equations: these were specifically chosen as they can be used for various tree species, as I did not specify the tree species in my sites (as suggested by Lembani, 2015). It is important to note that these allometric equations only provided an estimation of the final carbon storage, since I did not use the various specific equations for each different tree species. However, this equation was appropriate for my study as it has been developed from and validated for 14 different species, found around the world and South Africa, and often yields reliable biomass estimations for different species (Tietema, 1993; Zianis and Mencuccini, 2004).

Tree height was not measured as the used allometric equation estimated tree biomass from a variable other than tree height. Evidence has shown a relationship between the stem basal area or diameter of a tree and the total biomass of a tree (Tietema, 1993; Lembani, 2015).

The second carbon storage calculation method followed that of Schäffler and Swilling (2013) and was done for ten of the 20 sites. Here I once again measured five randomly selected trees at every 100m point along a 1km transect across the ten sites. However, in addition to measuring the trees circumference (in cm) at breast height (CBH, at 1.3 m), I also measured each tree's stem length to main branches (m) (the length of the trees stem/trunk from the ground to where the main branches start to branch out) and estimated the percentage (%) of the branch volume as a proportion of the total tree volume (B) (for example 70%= 0.7). This allowed me to calculate the diameter at breast height (DBH), the basal area, stem volume, total tree volume, the biomass and then the stored carbon using the average tree circumference, stem length and branch volume values for each site. I then multiplied the average estimated stored carbon value for one tree by the total number of trees in each site to obtain the total stored carbon (in kilograms) for the entire site.

The estimation calculations for method two are as follows:

$$DBH = \frac{CBH}{\pi}$$

$$Basel\ area\ (BA) = \frac{\pi * DBH * DBH}{40000}$$

$$Stem\ volume = BA * stem\ length * 0.7$$

$$Total\ tree\ volume = \frac{Stem\ volume}{(1 - B)}$$

$$Biomass = Tree\ volume * 0.7$$

$$Stored\ carbon = Biomass \times 45\%$$

To extrapolate the stored carbon to the entire Johannesburg I followed the same method applied by Schäffler and Swilling (2013), and I applied an additional extrapolation method using the adapted extrapolation calculations from method one. First a 50m by 50m area (in one of the sites) was used to extrapolate to the entire Johannesburg area. The total tree biomass of the 50m by 50m area was obtained by adding the individual biomasses (in kilograms) of all the trees in this area to then calculate the volume per hectare (kg/ha), the biomass per hectare (kg/ha), the carbon stock per hectare (kg/ha) and finally the total carbon stock (kg) for Johannesburg. The following equations were used:

$$Total\ tree\ biomass\ in\ area = Sum\ of\ all\ the\ individual\ tree\ biomasses\ in\ area$$

$$Volume\ per\ hectare = \frac{Biomass}{0.25}$$

$$Biomass\ per\ hectare = Volume\ per\ ha * 0.7$$

$$Carbon\ stock\ = Biomass\ per\ ha * 0.5$$

$$\begin{aligned} &Carbon\ stock\ of\ entire\ Johannebsurg\ area \\ &\qquad = Carbon\ stock\ per\ ha * total\ Johannesburg\ ha \end{aligned}$$

where the total Johannesburg area (including urban and suburban land, based on the municipal area/boundary) = 164458 ha.

To extrapolate these data to all of Johannesburg following method one, the following equations were used:

$$X = \frac{Total\ size\ of\ JHB}{Total\ size\ of\ the\ 10\ sites}$$

$$Total\ stored\ carbon\ in\ JHB$$
$$= X * the\ total\ stored\ carbon\ value\ for\ all\ the\ sites\ combine$$

A second extrapolation method was used due to the accuracy uncertainty of method two's extrapolation from a single 50m by 50m area. It is unlikely that a small 50m by 50m area can represent all the different land use types found in a large area such as Johannesburg.

3.2.2. Water Regulation and Provision

I tested water quality in my sites that contained water bodies to assess water provision as an ecosystem service. Specific water tests were conducted in two areas (where possible) along the water bodies in each site. These tests were conducted during the winter season along with the carbon storage measurements, as the waters are less turbulent (due to less rain and therefore, flooding) and there are less temperature fluctuations (UNESCO/WHO/UNEP, 1996). The water quality tests were chosen by following the World Health Organisation and United Nations Environment Programme water quality assessment and environmental monitoring guide (UNICEF, 2008).

Water temperature, pH, conductivity and dissolved oxygen (DO) were all measured using a YSI device submerged 10cm into the water. Measurements were taken twice along the water bodies, once near the start of the site and once further downstream at the opposite side of the site.

Water transparency was measured by filling a transparency tube and holding it up to the sun; the black disc inside the tube was then slowly moved away towards the top of the tube until it was only just visible. This reading on the tube was then recorded as the transparency depth.

The velocity/flow rate of the water was measured using a flow meter, which was placed at three points across a transect of the body of water. The instrument was held half way between the surface and the bottom of the water body, therefore depths varied according to each water body. Flow rate and water transparency were also measured twice along the water bodies, once near the start of the site and once further downstream at the opposite side of the site.

In addition to these water quality tests I also conducted a visual assessment of the water bodies and their immediate surroundings. I visually estimated the percentage of vegetation that was present around the water source (ground cover) using the Braun-Blanquet method and a 1x1m quadrant (Poore, 1955; Janos, 2006). The quadrant was tossed randomly five times to determine how many times out of the five throws vegetation occurs in the quadrant. Percentage of ground cover was then estimated using the Braun-Blanquet scale (Poore, 1955; Janos, 2006). If vegetation occurred only once in the quadrant out of the five tosses, then cover was estimated as <5%; twice cover was determined as 5-25%; three times cover was 25-50%; four times cover was 50-75%; and five times cover was 75-100%. The abundance and types of rocks in the water were visually estimated (also using the Braun-Blanquet method, 1x1m quadrant and five tosses), where boulders were stones >25cm; pebbles were stones between 2-25cm; gravel was stones <2cm; sand was grains <2cm in diameter and mud, silt, and clay: <0.06mm in diameter. Any disturbances in and around the water body were recorded, which included sand mining, presence of animals (as areas such as the Klipriviersberg Nature Reserve contains water holes and animals) and flood damage. General observations of the water source were also recorded, including the smell and colour of the water, the presence of any litter and any other factors (for example, petroleum and dead fish). Finally, a general description of the site, the riparian land use and weather conditions were noted (as per Dickens and Graham, 2002)

3.2.3. Temperature Regulation- Cooling

I took temperature measurements under five trees and in one spot with direct sunlight in each of the 20 sampling sites to get an understanding of how vegetation, and specifically trees, might play a role in cooling. These measurements were taken in summer as this is the hottest time of the year, which more accurately reflects the effects of tree cooling on air temperature. My methods were based on a study done by Shashua-Bar and Hoffman (2000).

Within each study site I measured the air temperature, using a digital thermometer, under five trees that were not more than 20 metres apart. These measurements were all taken between 11:00 am and 14:00 pm for every site. A reference point was then chosen for each site where an additional temperature reading was taken. This reference point was close to the five original temperature points (50 to 100 meters from it), had no trees and received full sun for most of the day. No measurements were taken on windy or overcast days (wind velocity did not exceed 10 kilometres per hour, or 5 knots).

3.2.4. Site Access Analysis

I also assessed access to the ecosystem services for each site, using a classification method based on Fisher *et al*. (2007). I used Google Earth Pro (2015) features such as the borders and labels, local place names, parks/recreational areas, water body outlines, place categories and place icons to obtain information about the features within each site. Physical site visits and additional research determined whether the natural features providing the ecosystem services were on privately owned land or public/governmental owned land. Private land is land owned privately which were generally residential houses and smallholdings, private businesses, sport grounds and some schools. Public land is land owned by the government which were generally public parks and spaces, municipal land, public schools and roads/sidewalks. Access control to these ecosystem services is an important aspect with regards to the protection and maintenance of the areas containing ecosystem services. However, access control does vary from place to place, as private areas such as private schools still have large volumes of people that have access to it making it less "private" than residential areas. This will also impact the protection and maintenance of ecosystems services found in these areas.

3.3 Statistical Analysis

The statistical programme Statistica (version 13.2; 2016) was used to perform all the statistical analyses. Significance was set at $p<0.05$ for all tests.

A t-test was done to identify any significant differences between the carbon storage values between the land use types. A general linear model (GLM) was performed on the carbon storage values. This determined any differences between the sites' carbon storage values based on each site's land use types and proximity to natural features (including: rivers/dams, wetlands, protected areas and parks/recreational areas). A Fisher post-hoc test was then performed on these results to determine which of these differences were significant. A paired t-test was done to identify any significant differences between the carbon storage values for the two different sampling methods.

A paired t-test was done to identify any significant differences between the reference temperatures and the shade temperatures. A GLM was also performed to determine any differences between the cooling values (reference temperature minus the shading temperature) for each site based on land use type and proximities to natural features (including: rivers/dams, wetlands, protected areas and parks/recreational areas). Once again, a Fisher post-hoc test was performed on these results.

A multiple regression was performed on the water data to determine whether the sites distances to various natural features had any influence on the water quality of the water bodies. I also identified and graphed the important and key trends found in the water data.

3.4 Integration of Ecosystem Services Protection within the Regulatory Environment.

In order to gain an understanding of how ecosystem services are represented within Johannesburg and Gauteng laws I obtained and analysed various forms of information regarding ecosystem services laws and regulations, using methodologies such as policy document analysis and interviews as appropriate. I looked for information regarding what types of laws are in place for ecosystem services protection and management, whether governmental bodies recognise the importance of certain ecosystem services in climate change mitigation and adaptation, what the future plans are regarding the protection and management of ecosystems services and what the challenges are for creating and implementing environmental policies in Johannesburg and Gauteng.

I interviewed the Johannesburg City Parks to assess whether and how ecosystem services are protected in the City of Johannesburg. Here I obtained ethics clearance (H17/02/08) from the Human Non-Medical Ethics Committee of the University of the Witwatersrand. Interviews were conducted with two available members of the governmental body Johannesburg City Parks, that are involved in open space, water and pollution management as well as environmental and conservation projects. Initially four members were to be interviewed, however only two were interviewed as the others were not available. Although this reduced the sample size and analyses potential, the collected data were still included.

The interview schedule contained questions that allowed for a deeper understanding of how Johannesburg utilises ecosystem services in urban planning and management, what environmental policies are in place to protect and maintain ecosystem services and whether this governmental organisation recognises the role of ecosystem services in protecting the city from climate change impacts (see Appendix I for the questionnaire).

Additional interviews were requested with members from The Gauteng Department of Agriculture and Rural Development (GDARD) and The City of Johannesburg's Environmental and Infrastructure Services Department (EISD). Interviews were not granted from these departments, however GDARD sent nine official governmental documents related to natural features and ecosystem services within the Gauteng province. I did a review of these policy documents, focussing on how ecosystem services are protected and managed in Johannesburg and Gauteng and I used the questionnaire from the Johannesburg City Parks interview to identify what type of information to look for in the documents in order to identify any ecosystem services policies in place in Gauteng, whether ecosystem services protection policies exist in Johannesburg and whether the role of ecosystem services in climate change mitigation and adaptation is recognised at a provincial level.

These departments were chosen because GDARD develops environmental policies and strategies for the Gauteng province, while Johannesburg City Parks implements and monitors these as well as the national environmental policies, with a specific focus on parks and nature reserves (City of Johannesburg, 2013).

4 Results

4.1 Spatial Analysis

A relatively low percentage of built-up features fell within a 150m buffer for wetlands, protected areas, and rivers (Figure 4.1). Compared to wetlands and protected areas, a substantially higher percentage of built-up features fell within the rivers' buffer zones. Wetlands and protected areas were generally seen to be further away from heavily built-up areas such as schools, sports grounds, industrial, commercial and residential areas.

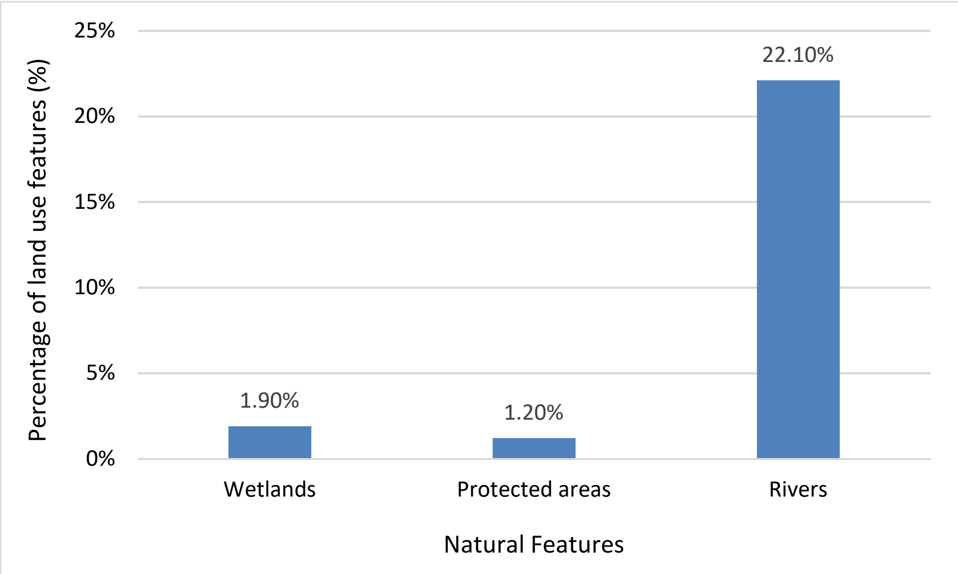


Figure 4.1 Percentage of built-up features that fell within a 150m buffer of wetlands, protected areas and rivers

A relatively high percentage of natural features fell within a 150m road zone (Figure 4.2). All protected areas fell within the road zone. Around 60% of rivers and wetlands fell within the road zone.

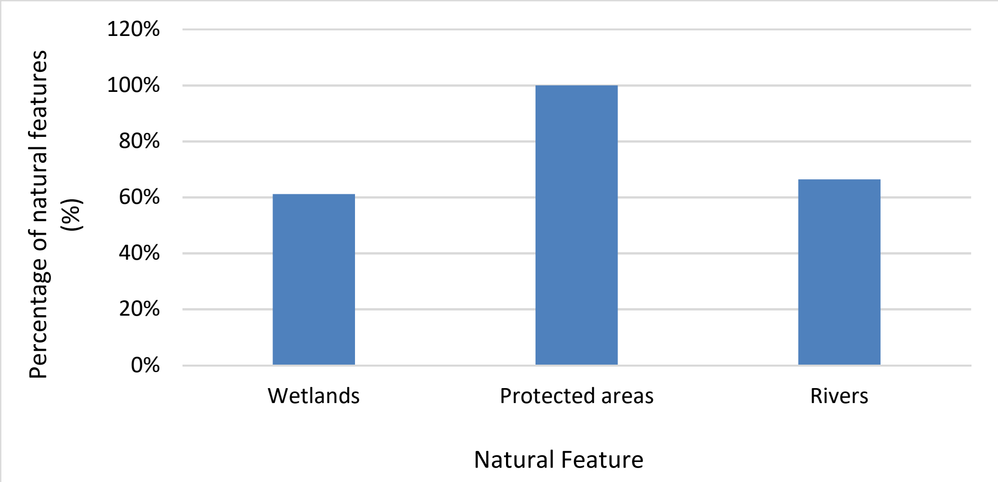


Figure 4.2 Percentage of wetlands, protected areas and rivers within 150m road zone

The most dominant land use features in Johannesburg were residential and township areas (Figure 4.3, national map provided by GCRO, I created map for JHB). This was also reflected in the land cover map, where urban built-up residential land (seen in dark blue) was a key feature (Figure 4.4, national map provided by SANBI, I created map for JHB). Therefore, the majority of land in Johannesburg was used for housing. Unimproved grassland (natural and untreated grasslands containing sensitive native species) was the most dominant natural feature in the land cover map.

Very few and only small protected areas occurred in Johannesburg (Figure 4.5, national map provided by GCRO, I created map for JHB). The majority of the protected areas were concentrated in the northern and central area of Johannesburg (Figure 4.5). These small protected areas were located considerably far away from one another indicated by distance circles on the map (Figure 4.6, created myself). When the maps were superimposed over the land cover and land use maps, the protected areas occurred in various land covers, including grassland, thicket and bushveld.

The distribution of wetlands was concentrated in the southern and central areas of Johannesburg (Figure 4.7, shapefile proved by GDARD, I created map for JHB). These wetlands occurred relatively close to one another in the lower half of Johannesburg, and are stretched across a large portion of the city's lower width (Figure 4.8, created myself). These wetlands occurred in grassland and cultivated dryland areas, and were in close proximity to townships, residential and golf and sport land use areas.

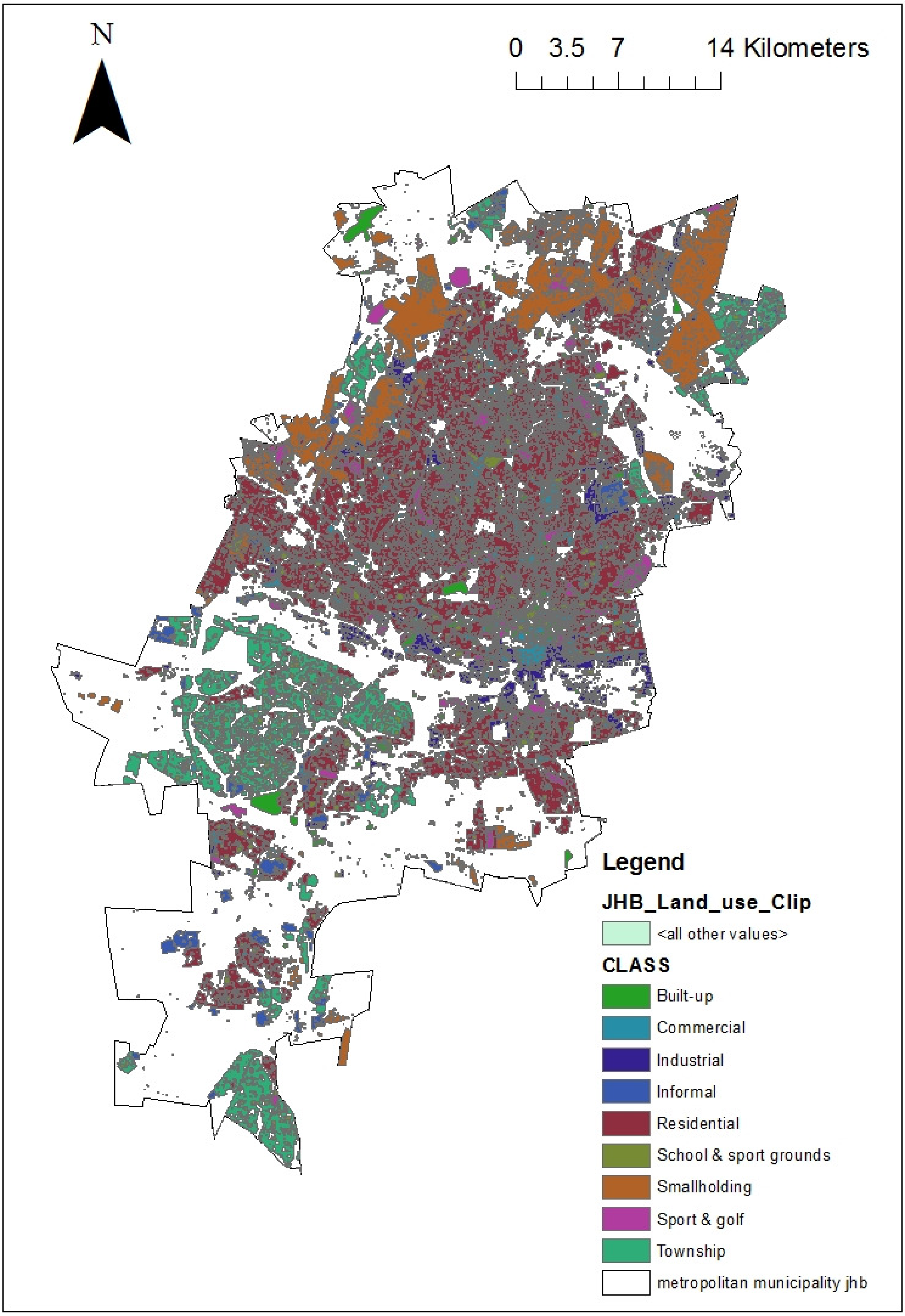


Figure 4.3 Land use map, Johannesburg, South Africa (GCRO, 2013)

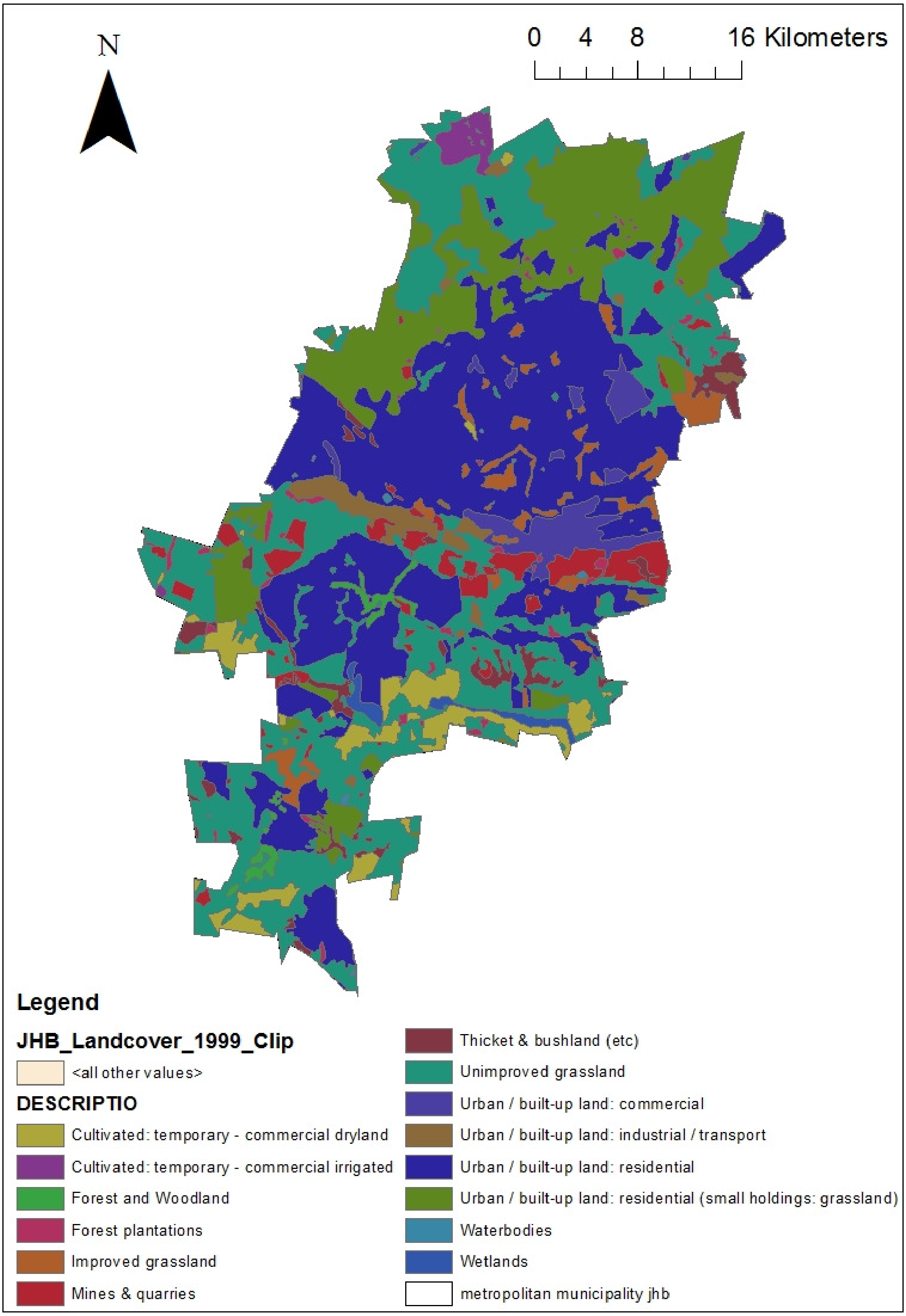


Figure 4.4 Land cover map of Johannesburg, South Africa (SANBI, 2012)

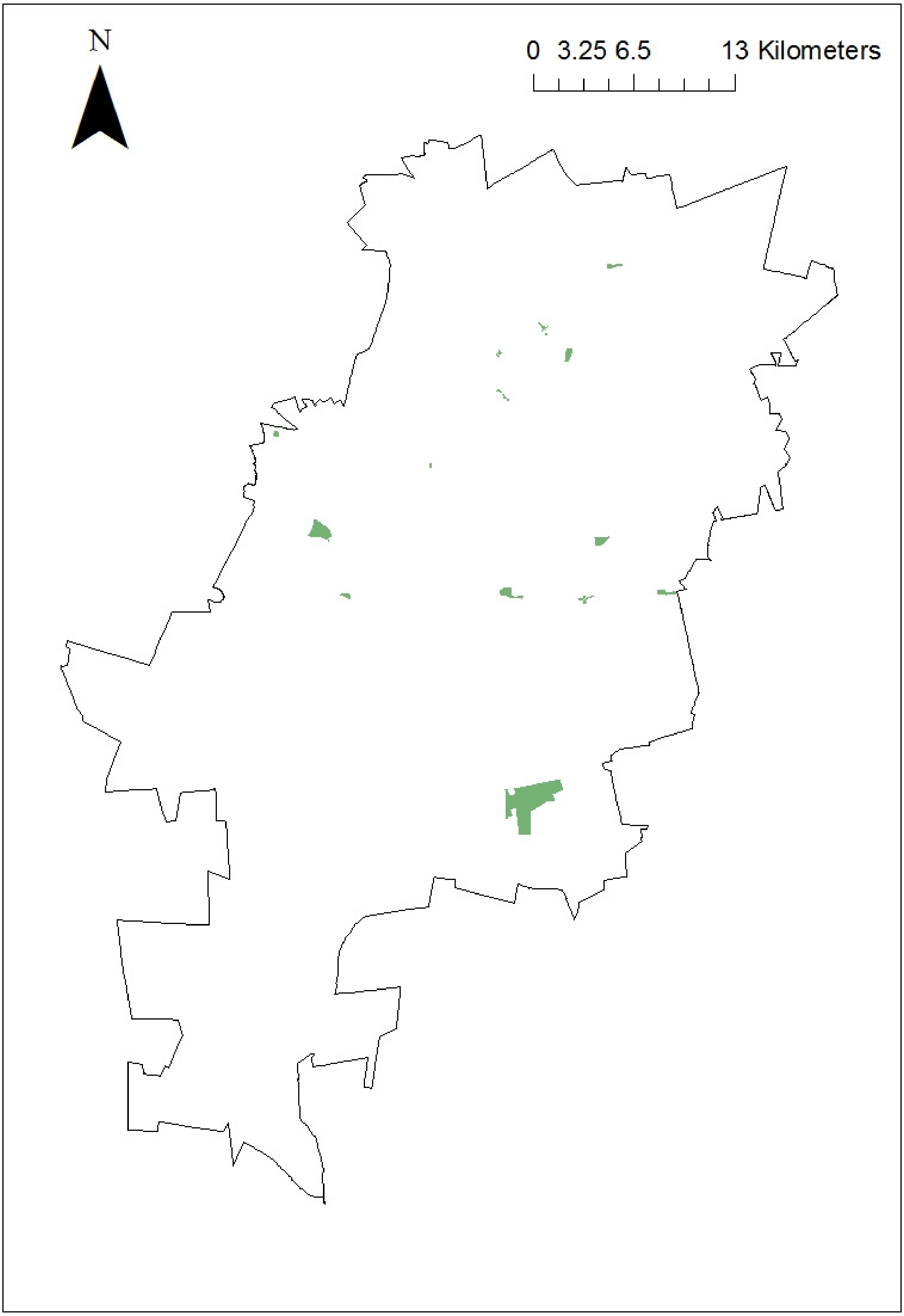


Figure 4.5 Protected areas, Johannesburg, South Africa (GDARD, 2013)

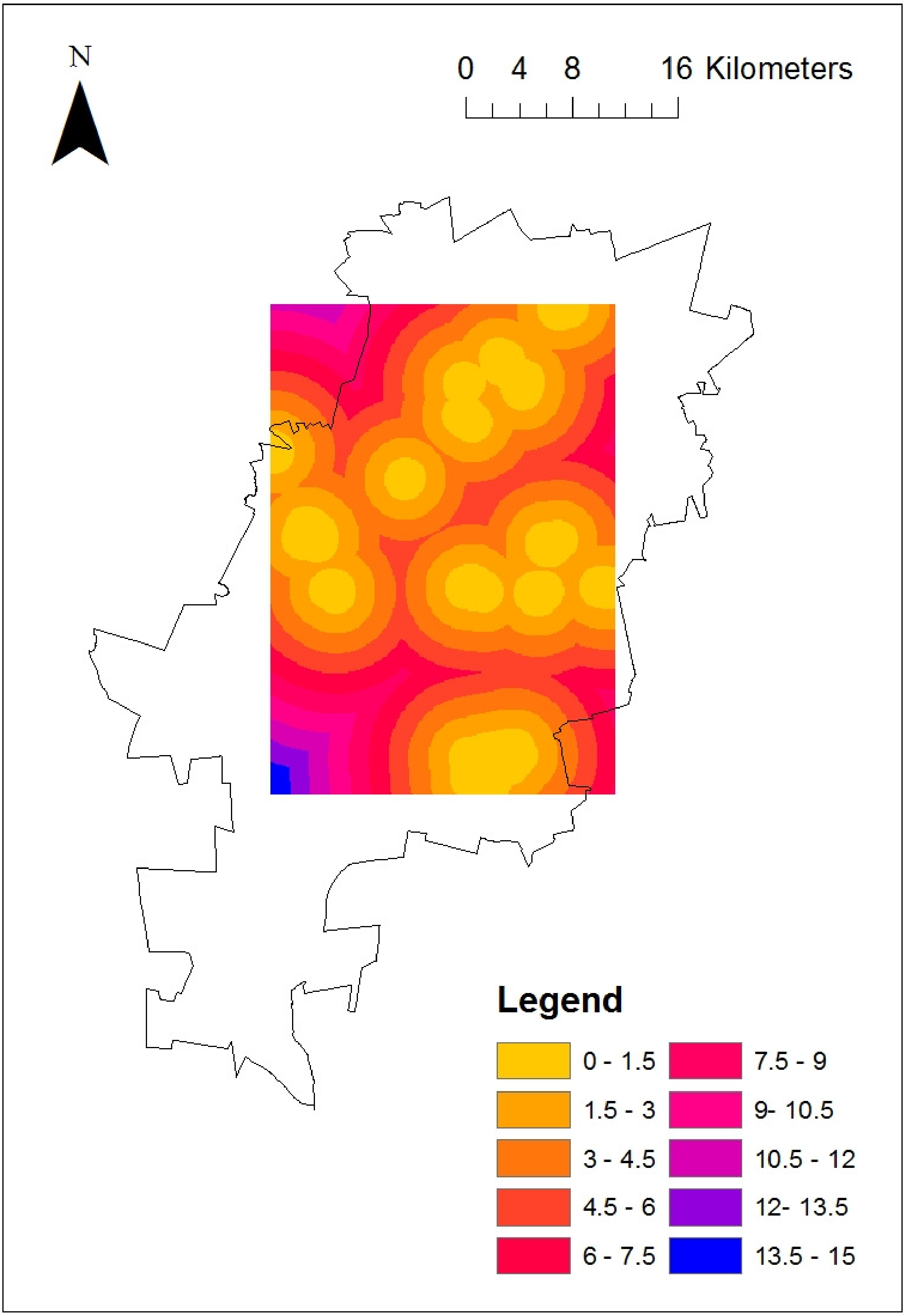


Figure 4.6 Protected area distances from one another (km), Johannesburg, South Africa

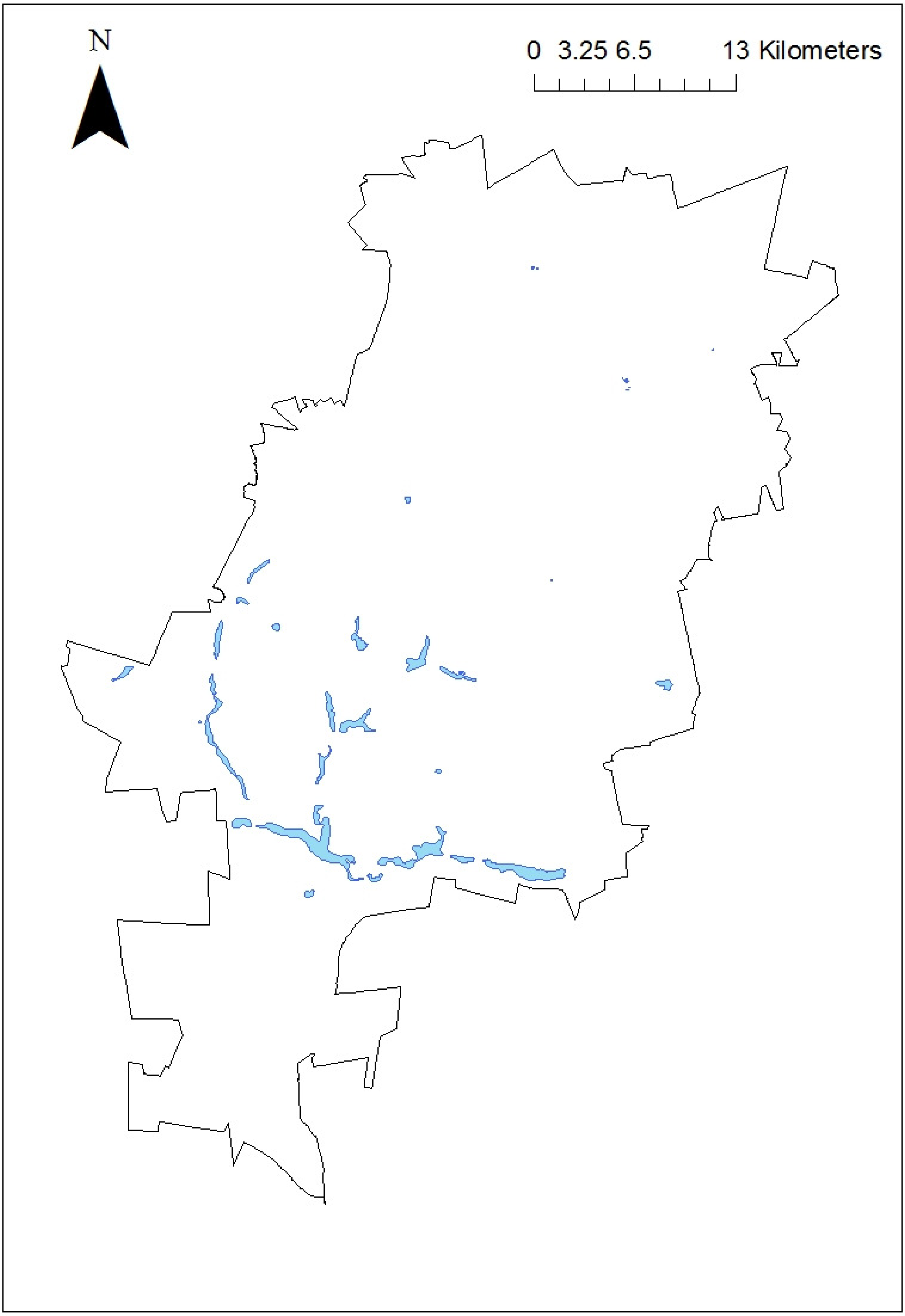


Figure 4.7 Wetlands in Johannesburg, South Africa (GDARD, 2013)

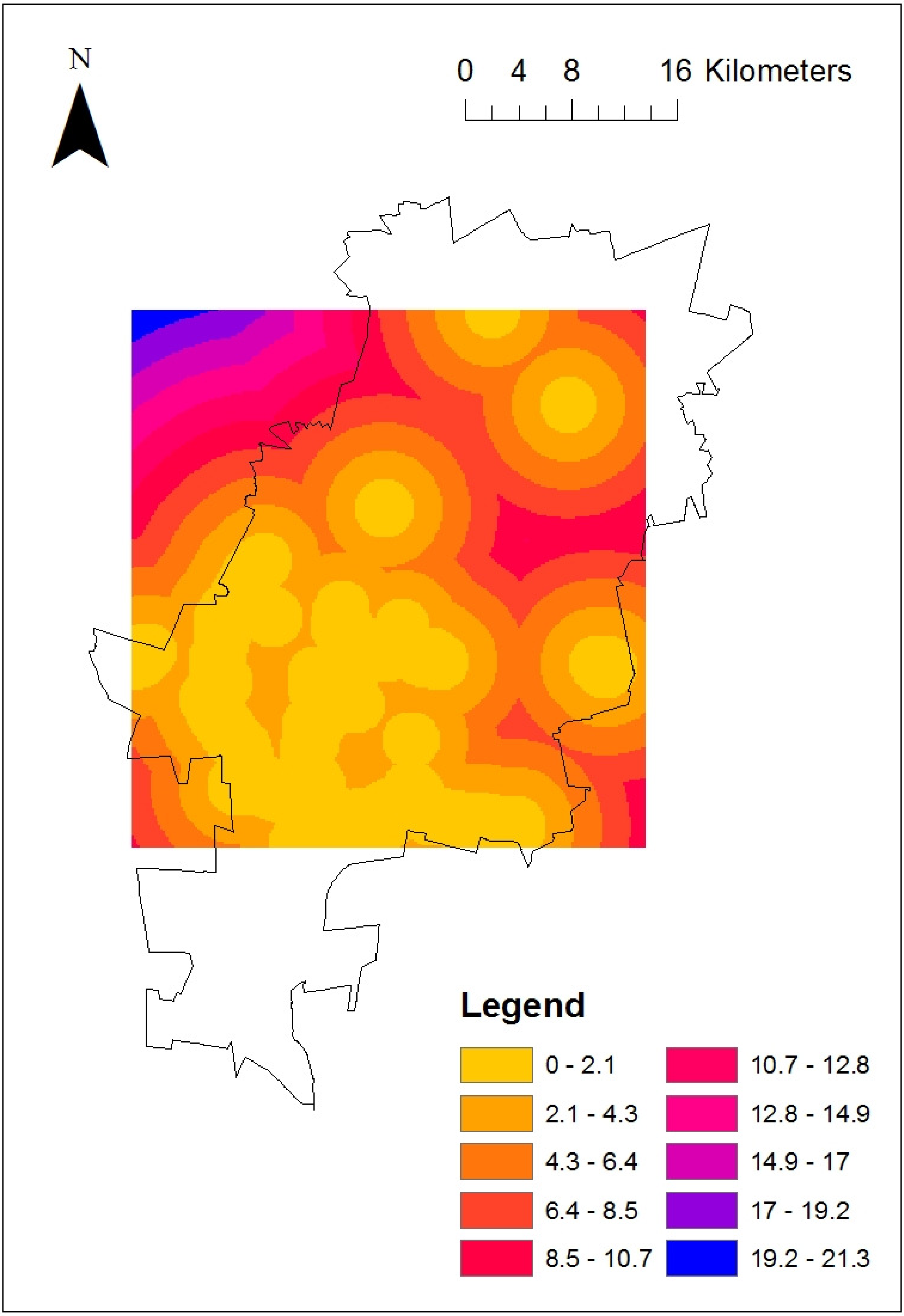


Figure 4.8 Wetland distances from one another (km), Johannesburg, South Africa

A large network of rivers occurred in Johannesburg (Figure 4.9, shapefile provided by GDARD, I created JHB map). This river network had a relatively even distribution across the entire Johannesburg. The highest concentration of rivers occurred in the northern and southern-central areas of the city (Figure 4.10, created myself). Notable areas of the lowest river density were seen in the central and most southern parts of Johannesburg, which are highly built-up (residential) areas and townships respectively. No natural features were identified in the most southern tip of Johannesburg.

Johannesburg had a large and highly dispersed network of roads (Figure 4.11, shapefile provided by GDARD, I created JHB map). High road density areas occurred in the more central parts of Johannesburg, which is a highly urbanised area with high levels of commercial and residential development (Figure 4.12, created myself). When comparing the river and road density maps of Johannesburg (Figures 4.9 and 4.10, respectively), an overlapping of high road and river density areas is noticed. Lower levels of road networks were seen in the most southern tip of Johannesburg, once again in conjunction with the poorer areas of Johannesburg, which in this case is the area of Orange Farm.

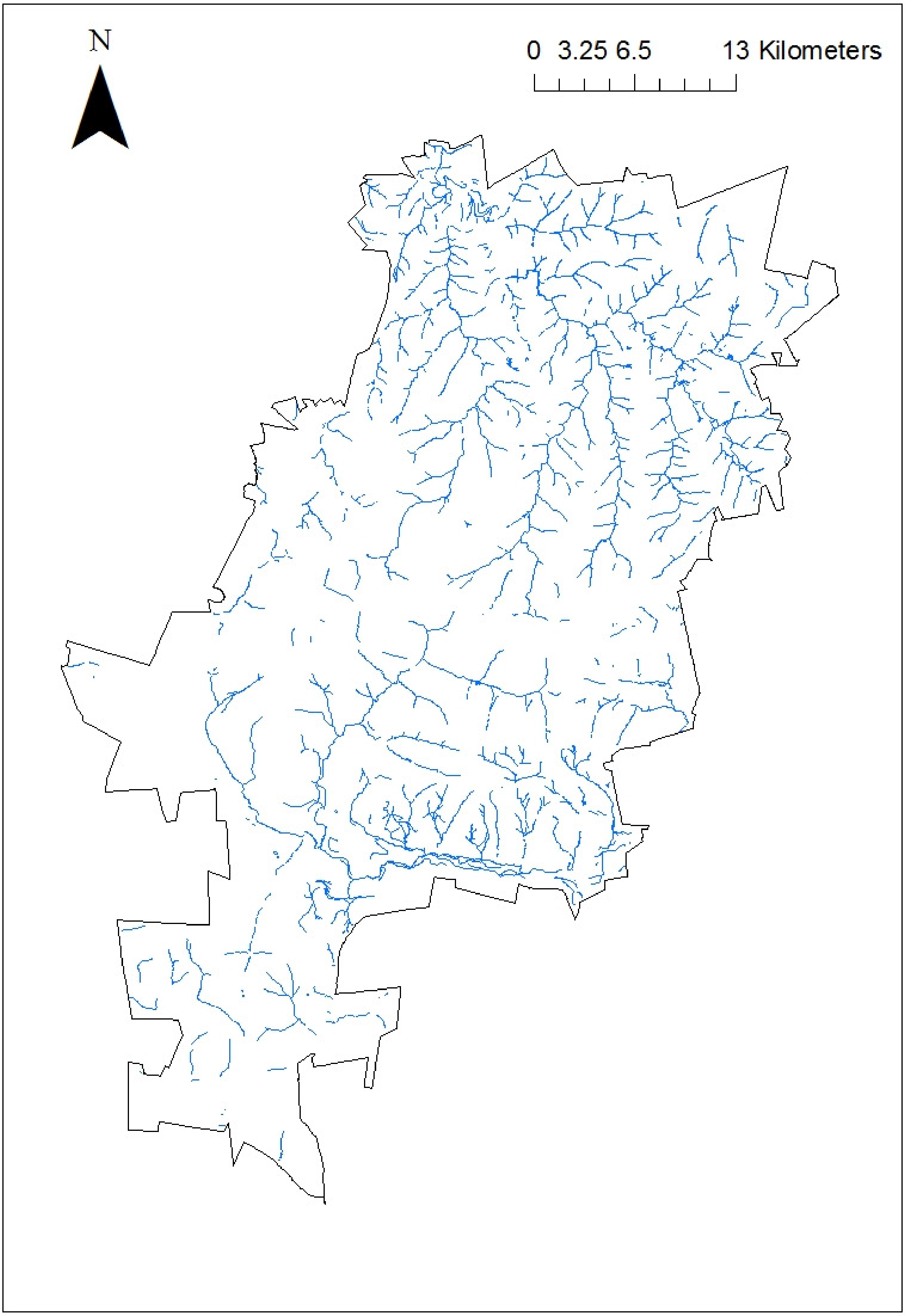


Figure 4.9 River networks in Johannesburg, South Africa (GDARD, 2013)

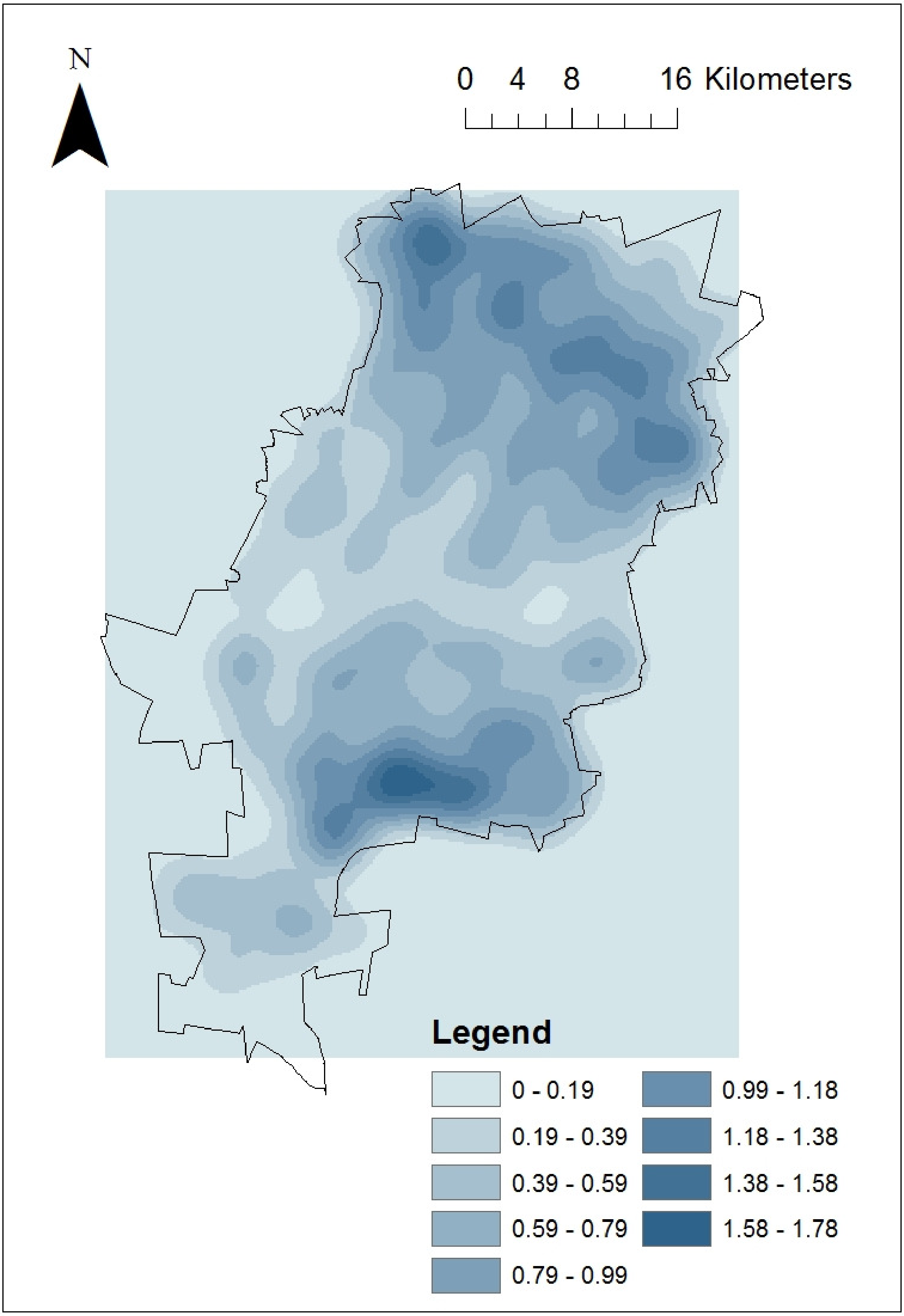


Figure 4.10 River density (squared km) in Johannesburg, South Africa

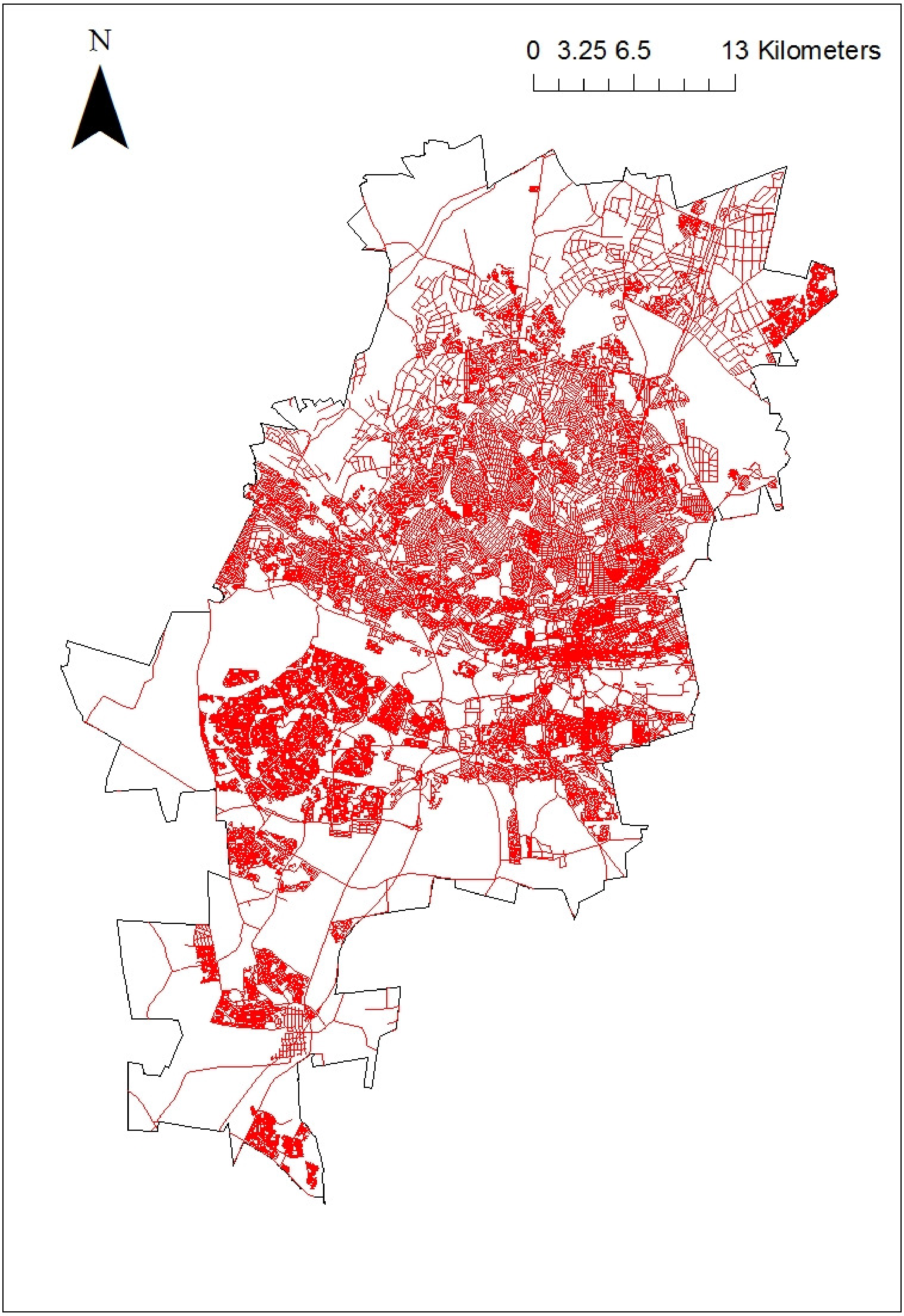


Figure 4.11 Road network in Johannesburg, South Africa (GDARD, 2013)

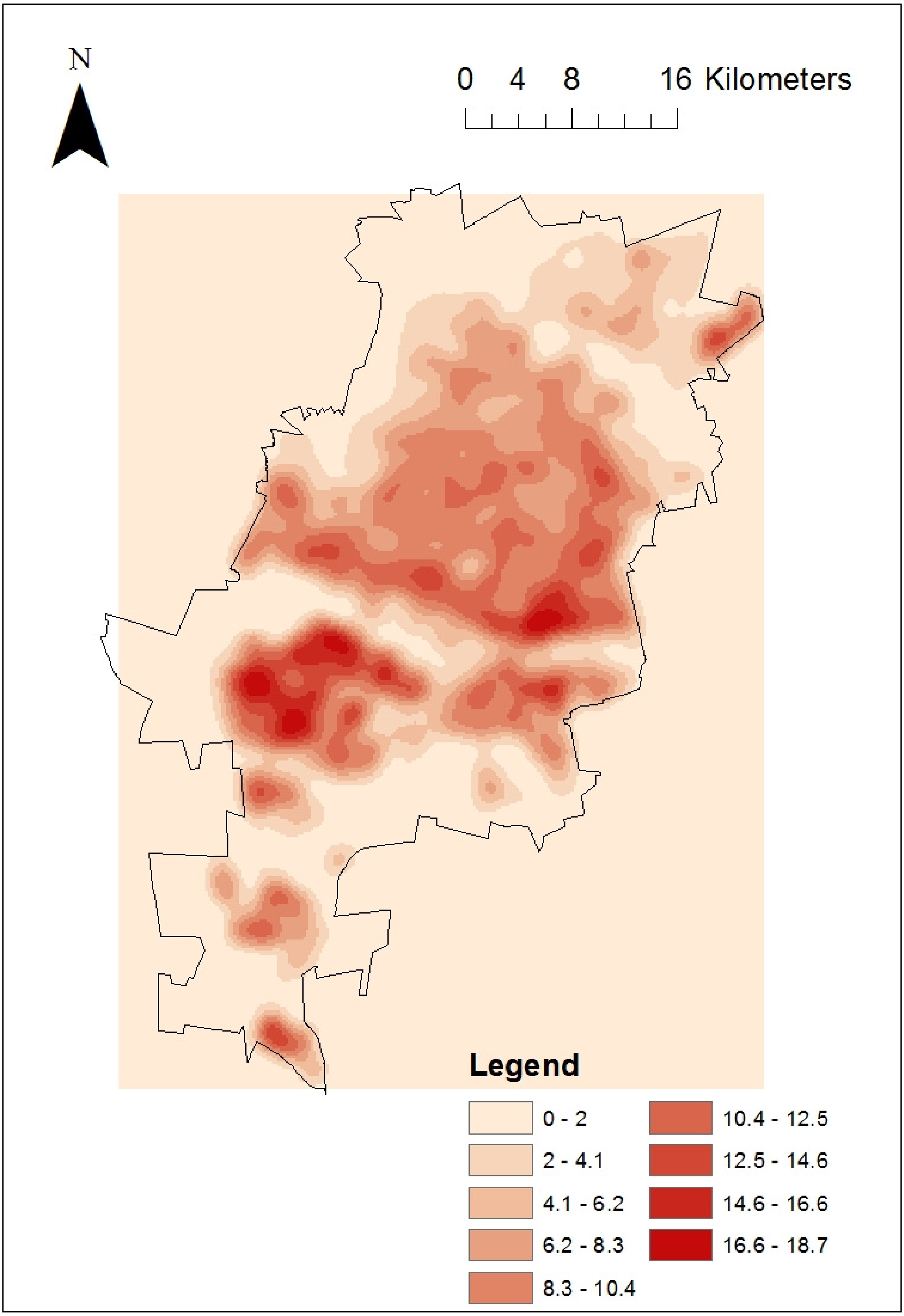


Figure 4.12 Road density (squared km) in Johannesburg, South Africa

4.2 Carbon Sequestration

The first method used to determine carbon storage measured tree circumference at breast height and then used various allometric equations to determine carbon storage (as per Lembani, 2015).

Residential sites had the highest carbon storage values in Johannesburg (Figure 4.13). Townships had the lowest stored carbon, followed by nature reserves and smallholdings. Residential areas were seen to have a high number of large trees, while nature reserves had a high number of much smaller trees. Important to note is that the industrial land use value is not included in the graph, as only one out of the 20 sites sampled were industrial, making it an extremely small sample size. A value of 511.12 t per squared kilometre was calculated for industrial areas, however this is not an accurate representation of all industrial areas. This particular site contained a factory park and an old mine that were situated near a residential area. When the carbon storage values were extrapolated to the entire greater Johannesburg area, the total stored carbon for Johannesburg was determined to be 436 064.9 t (Appendix II).

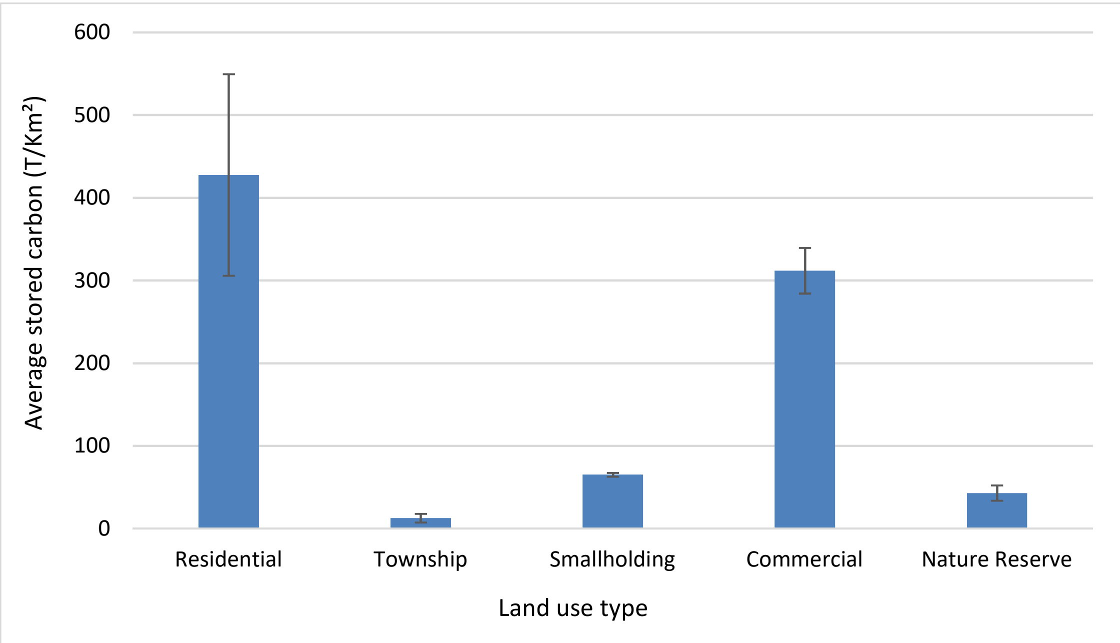


Figure 4.13 Average stored carbon (t) per squared kilometer per land use type

Statistical tests were only performed on the following grouped land use types due to the low number of samples for land use types: Reserves/smallholdings; residential and commercial. A t-test determined no significant difference in carbon storage between the grouped land use types (T_2=2.9; p>0.05). A general linear model (GLM) revealed no significant differences between the sites, various land use types or proximity to key features (F_1=1.11; p>0.05).

The second method used to determine carbon storage measured tree circumference at breast height, stem length to main branches and percentage of branch volume, and then used various allometric equations to calculate carbon storage (Schäffler and Swilling, 2013). This second method was only tested on 10 of the 20 sites.

Differences were found in the stored carbon values between the first and the second method for the ten sites (Figure 4.14). Some of the observed differences were relatively small, for example site 1 only had a difference of 6.7 t between the two methods. However, large differences were found in the other sites. For example, method one yielded almost double the amount of stored carbon than method two in site 2, while a difference of 358.8 t was seen in site 9. Method 1 yielded higher stored carbon values compared to method 2, except in sites 1 and 5.

A paired t-test determined that the carbon storage values from the two different methods were significantly different (T_9=2.75; p<0.05). At a 95% confidence level, the upper limit is 235.75 t and the lower limit is 22.99 t. This is a significantly wide range (possibly due to a small sample size) and indicates low confidence in the results and the conclusion is less certain, suggesting that the carbon values calculated in this study are a less precise estimate of their true value and should be used as a guideline measure. In other words, the carbon storage value for a 1km² area in Johannesburg can range between 22.99 t and 235.75 t, which is very variable and does not give a definite/accurate value. A reason for this inaccuracy could be due to the general allometric equations used, as these equations can be used for various tree species and are not tailored to individual tree species. The two different methods used to calculate the stored carbon use very different variables and equations which could also contribute to the large differences in carbon storage values.

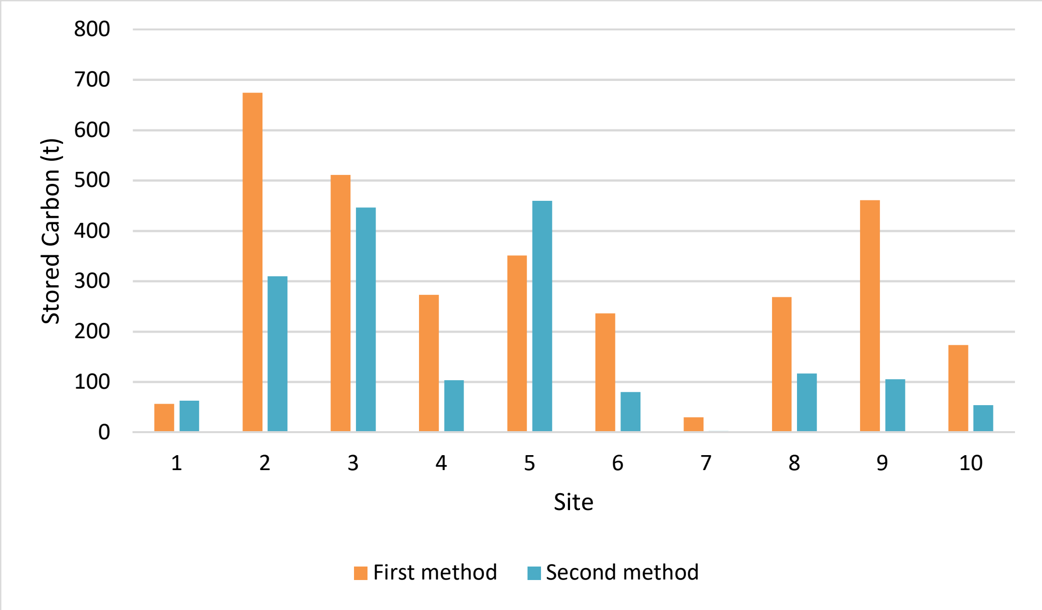


Figure 4.14 Comparison between the first and second carbon storage method values

Schäffler and Swilling (2013) calculated the total stored carbon value of Johannesburg by only extrapolating a small measured area of 50m by 50m. Therefore, to replicate this, only one 50m by 50m area of one site in this study was used to extrapolate to the size of Johannesburg. However, depending on which site was used to extrapolate, very different final carbon values for Johannesburg were obtained. When site 3 was used, the total stored carbon value for Johannesburg came to 1 334 639.9 t, however, when site 2 was used the total stored carbon value was 4 193 673.2 t.

However, if the carbon values are extrapolated using method 2 in the same manner as done in method 1 (by dividing the size of Johannesburg by the total size of the ten sites and then multiplying the value with the total stored carbon for the ten sites) a total stored carbon value of 286 225.2 t is obtained.

4.3 Water Regulation and Provision

Water bodies occurred in various land cover and land use areas across Johannesburg (Table 4.1). This included residential areas, open areas, nature reserves and recreational parks. These differences contributed to the various disturbances in each site. In almost all the assessed sites litter was found in and around the water. Notably, small amounts of litter were found in the nature reserve. However, the nature reserves are open to citizens for recreational activities such as walking and hiking. The sites with the highest amount of litter and strong sewage smells were both in/next to residential areas (sites 10 and 13). Most water bodies had high levels of vegetation cover around them, with site 4, the recreational park, having the lowest of 50%. The water bodies all had different types and abundances of rocks, which was expected as each site has different landscapes and riparian land uses.

Table 4.1: Visual observations of the water sources within each site

Site	7	8	18	10	4	13
Description	Nature Reserve	Near mine dump	Recreational Area Dam	Open Land Next to urban development	Recreational Park	Residential Area
General Observations	< 1% litter Weak sewage smell Quiet, secluded area	< 1% litter	Slightly murky water < 2% litter	Strong sewage smell High levels of litter >50%	< 1% litter Storm water waste Light sewage smell	Dirty, murky water High levels of litter (>60%) Strong sewage smell
Riparian land use	Natural area	Natural area Near gold mine dump	Recreational area Fishing	Light recreational usage	Formal recreational park	Open land, semi-park Urban area
Percentage vegetation around water (%)	100	100 Reed beds and grass	100	75-100	50	75-100
Abundance and types of rocks	50-75% sand 5-25% pebbles	75-100% sand	75-100% sand	25-50% boulders 25-50% sand	50-75% boulders 5-25% pebbles	50-75% boulders 5-25% sand

Site	7	8	18	10	4	13
	5-25% boulders	5-25% silt and mud	5-25% silt and mud 5025% boulders	5-25% silt and mud	5-25% gravel 5-25% sand	5-25% silt and mud
Disturbances	Visitors Possible water source for reserve animals	Near mine dump Near township	Human activities Fishing Ducks	High levels of litter and dumping Recreational activities	Recreational activities Storm water waste	Litter, dumping Presence of sewage

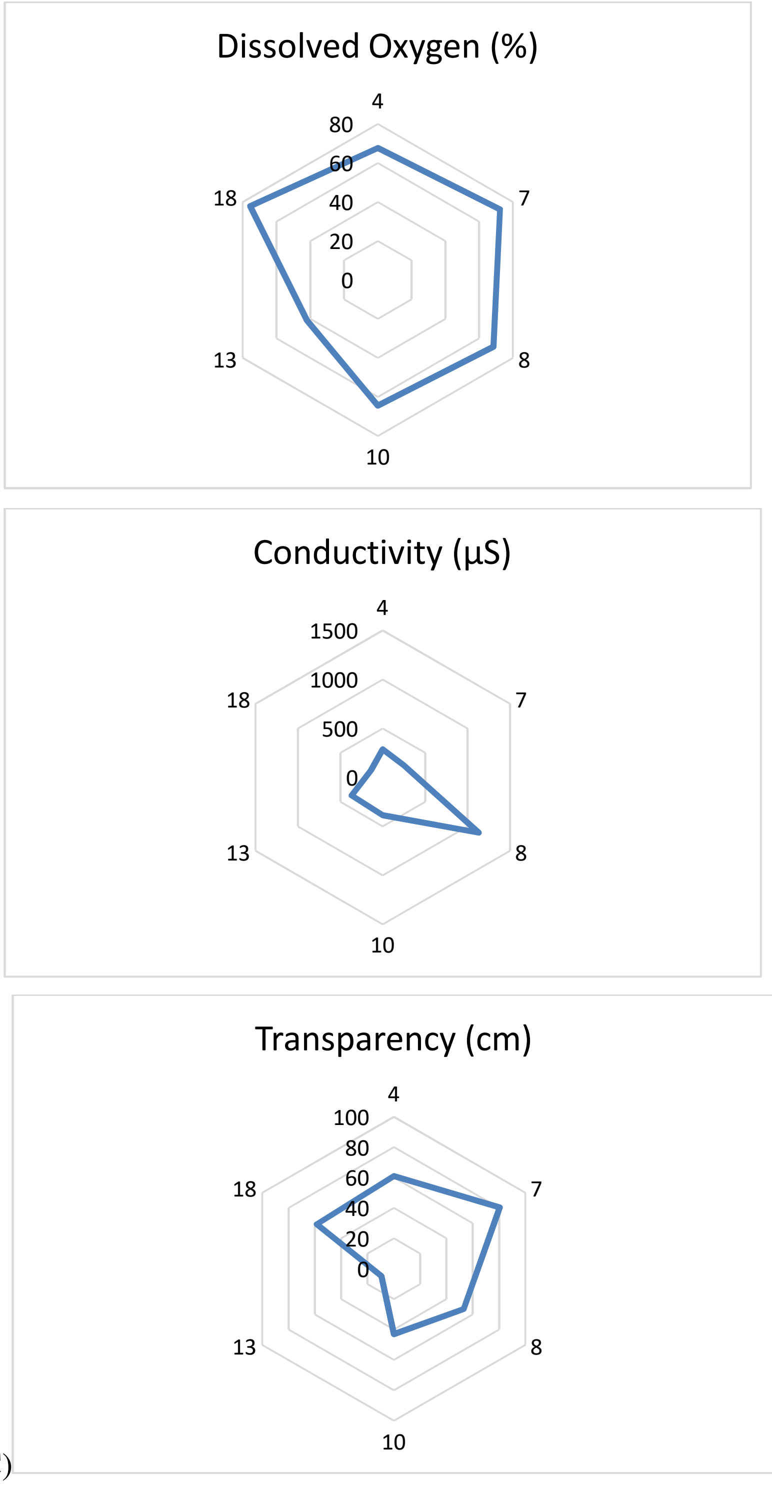
The physical water measurements differed from site to site (Table 4.2). The same tests that were conducted twice within the same sites (but at difference spots) however yielded similar results. Therefore, only the average was reported. Water temperatures were generally quite low, between 8-15°C (measurements taken in winter). Most of the pH measurements were between 7 and 8 for all the sites. Dissolved oxygen readings were between 60% to 70%, except for site 13 (commercial area), which had a low dissolved oxygen reading of 41.9% (Figure 4.15 A). The conductivity reading for the township area, site 8, was extremely high (on average 1130.5µS) compared to those from the other sites, which ranged between 100µS and 400µS (Figure 4.15 B). Transparency also varied between sites, generally between 40cm to 80cm. Most notably site 13 had an extremely low transparency reading of 9.5cm, while the natural reserve, site 7, had the highest reading of 80.5cm (Figure 4.15 C). Flow rates were relatively low for all water bodies, ranging from 0 to 0.4 meters per second. Site 18 (residential) had a flow rate of 0, due to it being a dam. The nature reserve and residential sites (7 and 4 respectively) had the highest flow rates of 0.4 meters per second.

A multiple regression determined that the water bodies' distances to various natural features (or distance to highly urbanised areas) did not appear to be related to the quality of water as no pattern or correlation was found between water quality parameters and distances to various natural features; including the water temperature ($R^2{}_3$=0.69; p>0.05), pH ($R^2{}_3$=0.16; p>0.05), dissolved oxygen ($R^2{}_3$=0.03; p>0.05), conductivity ($R^2{}_3$=15.59; p>0.05), transparency ($R^2{}_3$=0.04; p>0.05) or flow velocity ($R^2{}_3$=0.44; p>0.05).

Table 4.2 Physical water measurements at each site

Site	Land type	Temperature (°C)	pH	Dissolved Oxygen (%)	Conductivity (µS)	Trans-parency (cm)	Flow (m/s)
7	Nature reserve	13.2	7.1	72.4	247.7	80.5	0.4
8	Township	9.2	7.5	68.6	1 130.5	53.0	0.1
18	Residential	10.7	8.5	75.6	139.8	58.5	0
10	Small-holding	11.1	7.9	64.5	387.1	42.0	0.2
4	Residential	12.1	8.1	67.7	286.2	61.0	0.4
13	Commercial	15.5	7.9	41.9	367.8	9.5	0.2

The dissolved oxygen, conductivity and transparency measurements highlighted two areas that scored extremely low in these tests. Site 13 had extremely low dissolved oxygen and transparency values compared to the other water bodies (Figure 4.15 A and C). Site 8 had very high conductivity levels compared to the other water bodies (Figure 4.15 B).



A)

B)

C)

Figure 4.15 Radar charts, A) Dissolved Oxygen (%), B) Conductivity (µS), and C) Transparency (cm) for the sites

4.4 Temperature Regulation-Cooling

On average, there was a 1 to 2°C difference between the reference and shade temperatures in the sites (Figure 4.16). A paired t-test showed a significant difference between the reference and shade temperatures (T_{19}=13.02; p<0.05).

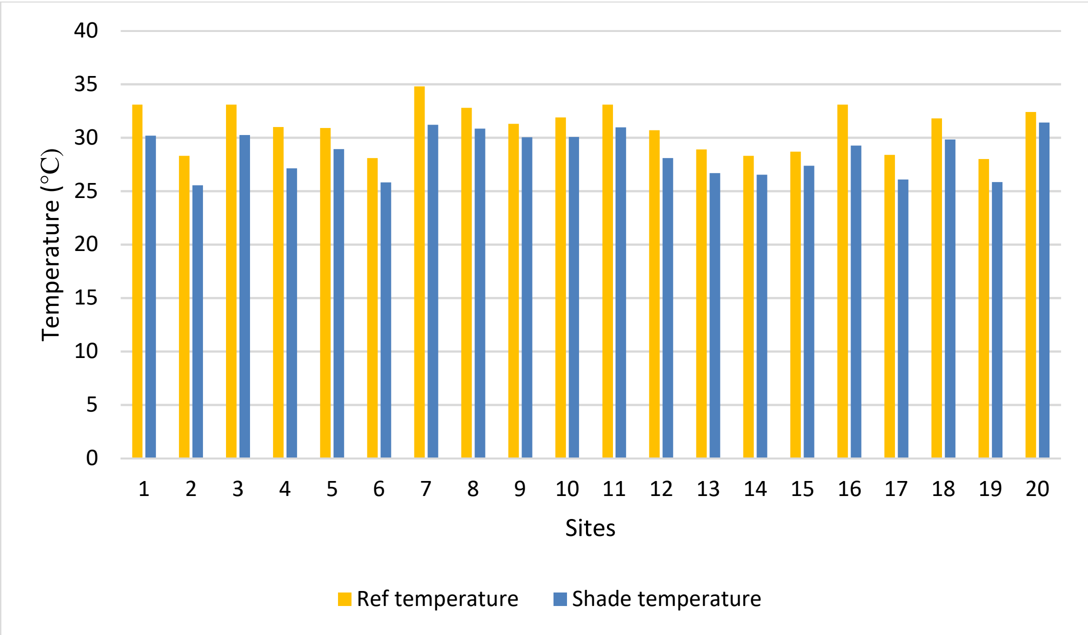


Figure 4.16 Reference and Shade temperatures per site

The mean value for the reference temperature was around 30.9°C, while for the shade temperature was around 28.6°C (Figure 4.17). The standard error is 0.5°C.

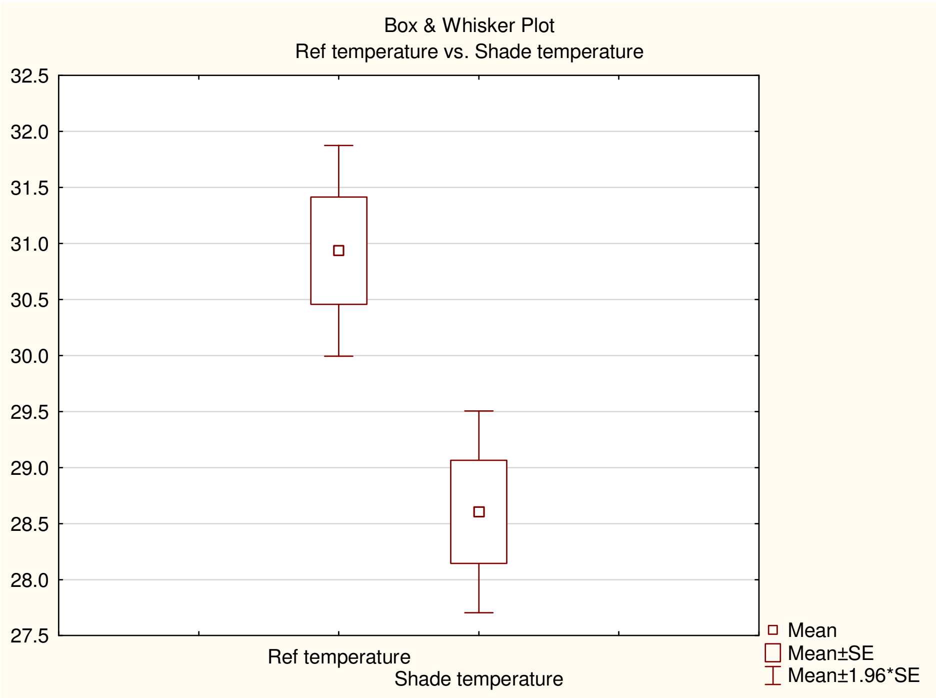


Figure 4.17 Box and Whisker plot: reference and shade temperatures, with mean and standard error values

A general linear model (GLM) revealed no significant differences between the sites, various land use types or proximity to key features (F_1=0.004; p>0.05).

Although no significant difference in cooling was found between the land use types, some differences should be highlighted (Figure 4.18). Nature reserves had the highest cooling effect of 2.9°C, with the lowest effect being seen in smallholdings. Most of the land use types had similar cooling effects to one another.

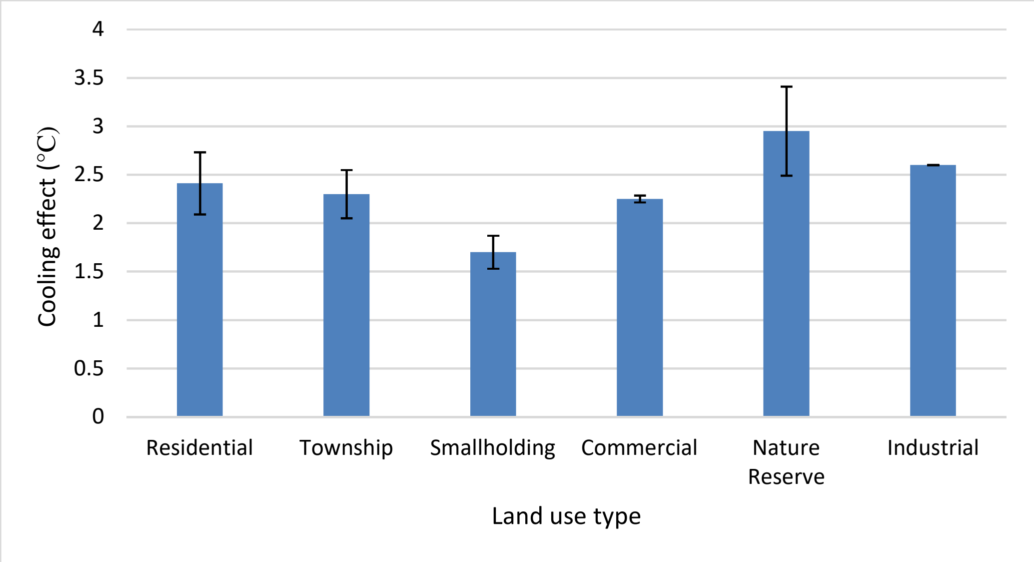


Figure 4.18 Average cooling effect of trees per land use type, Johannesburg, South Africa

4.5 Private versus Public access to Land

There was a mixture of privately and publicly owned land across the 20 sites, with eight being private and 12 having a mixture of both private and public access. A large portion of the sites was residential and therefore private land, which restricts the access to the ecological features providing the urban ecosystem services in these areas. However, access restriction to these features does not mean that the benefit of the ecosystem service is also restricted (for example oxygen production by trees is a benefit that reaches beyond its specific location). Most of the public areas are found around and in-between private land, resulting in all the public spaces being mixed with private areas in the sites. Therefore, Johannesburg has a large mixture and distribution of land types with different access control.

4.6 Ecosystem Services Policy Analysis

Interviews were conducted with environmental specialists from Johannesburg City Parks. Interviewees were chosen based on their willingness and availability to be interviewed. Various GDARD environmental documents were also analysed, which included: The Ridges Guidelines (2006); Biodiversity Assessment Guidelines (2014); Gauteng Conservation Plan Version 3.3 (2011); The Gauteng Pollution buffer zone Guidelines (2017); The Gauteng Sustainable Development Guideline (2017); The Environmental Management Framework Report (2014); Gauteng Provincial Environmental Management Framework Standards

(2017); The EMF Revised Section B- Environmental Management Zones (2017); and The Biodiversity Mainstreaming Toolbox for Land-use Planning and Development in Gauteng (2014). The policy documents were reviewed by reading them and extracting any information relating to ecosystem services, how they are protected and managed in Johannesburg and Gauteng and their role in climate change mitigation and adaptation. The main findings from the interviews and document analyses are summarised below.

Both City Parks and GDARD implement various policies and programmes regarding the protection and maintenance of ecosystems such as rivers, wetlands, dams, protected areas, parks and street trees. Johannesburg City Parks' main policy for protecting these ecosystems is the Open Space Management policy, which also includes the protection of sensitive ecosystems such as wetlands. GDARD policies implement buffers for sensitive species, wetlands, rivers and ridges in order to ensure that the ecological integrity of these features is protected against urban development and land use changes. The size of these buffers are as follows: sensitive species 200m; wetlands 30m (in urban area) and 50m (outside urban area); rivers 32m (in urban area) and 100m (outside urban area); and ridges 200m. Policies are also in place to rehabilitate wetlands, buffers and corridors when they are impacted by development or mining processes and that where possible natural trees that are growing on sites should be maintained. The majority of the policies mentioned above help protect wetland, river and open space ecosystem services however they do not specifically mention ecosystem services in the documents. However, The Biodiversity Mainstreaming Toolbox for Land-use Planning and Development in Gauteng (2014) defines ecosystem services and green infrastructure and conveys their importance for maintaining biodiversity and mitigating and adapting to climate change effects in Gauteng and Johannesburg.

Both City of Johannesburg and GDARD recognise the role of trees and carbon sequestration in climate change mitigation. Various well-established studies and programmes exist with regards to Johannesburg's urban forest and carbon sequestration opportunities. These studies have been done in collaboration with the University of South Africa (UNISA) and include research on tree inventories across Johannesburg, tree canopy cover measurements, tree diversity and species catalogues, tree valuation methods, tree carbon storage and sequestration calculations and community involvement. Based on all these carbon sequestration studies and information gathered during the interviews and document analysis, carbon sequestration is seen as the most important ecosystem service to mitigate and adapt to climate change in Johannesburg. City Parks conducted studies on how to prevent carbon release back into the atmosphere and has implemented tree planting schemes, such as the Soweto Greening programme. GDARD has developed and created GIS input layers for wooded areas across Gauteng which can be used to help measure carbon sequestration potential.

During the interviews with Johannesburg City Parks no mention was made to trees and their role in cooling local temperatures, reducing urban heat islands and how this can help mitigate higher temperatures, caused by climate change. A possible reason for this could be due to limited education and research on this ecosystem service in South Africa and particularly in Johannesburg, which makes it difficult to implement programmes and policies for its protection and maintenance (Le Maitre *et al.*, 2007). However, the documents provided by GDARD recognises the importance of trees and their role in reducing the Urban Heat Island (UHI) effect. This includes research on how climate and wind direction impacts UHI in cities and how albedo also plays a role in increasing temperatures in urban environments. These documents illustrate how biodiversity features such as wetlands and trees play an important role in helping urban cities adapt to and mitigate climate change effects through reducing flood risks, reducing UHI effects and increasing carbon sequestration. They also place importance on conserving urban parks and open spaces in order to protect and maintain these ecosystem services in cities. Landscape planning and building guidelines also promote the inclusion of trees in landscape designs to help reduce UHI effects. GDARD also recognises the importance of water efficiency in the face of climate change and has various policies and guidelines regarding water drainage, rain water harvesting and re-using grey water. For example, total sealing of paved areas should be avoided, and natural drainage systems should be maximised to help combat surface storm water runoff.

Ecosystem connectivity seems to be well integrated in various policies and programmes for all types of ecosystems across Johannesburg. These include the Catchment Management policy, the Integrated Development Plans and Environmental Impact Assessment (EIA) regulations. GDARD documents show that important species and climate change corridors are protected in development plans and that connectivity between biodiversity in urban planning is ensured. This also includes protecting ridge, river and wetland buffers as they act as wildlife corridors. Johannesburg City Park's goals for climate change mitigation and adaptation mainly lie in the urban forest management policies (which includes further research programmes and creating more parks within the city) and sustainability in capital development, which was only vaguely mentioned during the interview. No new future programmes are in place with regards to ecosystem services protection and maintenance, as the current policies and programmes will be kept and used. This inadequate monitoring of ecosystem services has been seen throughout history, whereby society uses ecosystem processes and products for their own benefit but do not consider any appropriate and long-term monitoring programmes (van Jaarsveld *et al.*, 2005). The maintenance and monitoring of certain ecosystem services is crucial for the production and protection of other ecosystem services (such as freshwater ecosystems impacting flood control and regulation as well as food and fuel production) making ecosystem service monitoring a critical role in their protection (van Jaarsveld *et al.*, 2005). GDARD's main focus regarding climate change mitigation and adaptation include increasing carbon sequestration potential and moving towards alternative energy sources such as renewable energy. GDARD also places importance on green infrastructure in cities as they recognise that natural features within urban built-up environments can create resilient cities and help reduce flooding, fire risks and heat waves.

Research on ecosystem service valuation has been done by City Parks in collaboration with GCRO in 2015. GDARD emphasis that ecosystem service valuation is important and should be understood by stakeholders in order to integrate valuation into land use planning and decision making. Documents provided by GDARD provides users with example projects and tools to help with ecosystem service valuation. These included the GCRO Green Assets and Infrastructure project done in 2015, the National Biodiversity Assessment project and the TEEB guideline document. However, no plans for further research or actual implementation of these ecosystem service evaluation methods and projects were mentioned in the interview or provided documents. Important to note is that Johannesburg City Parks are not responsible for the creation of their environmental policies and therefore only implement the policies that are passed by governing bodies at national and provincial level. When asked about possible ecosystem degradation risks that are present in the city, only storm water discharge was brought up. Documents from GDARD cite human activities such as urban development and mining as the biggest ecosystem degradation risks. The City has plans and tools in place to reduce the impacts of increased population and development on ecosystems. These include site development plans, flood lines, buffer zones and EIA's. Flood lines and buffer zones for features such as rivers, wetlands, ridges and protected areas ensure that no development occurs within a certain distance of these natural features. EIA's ensure that the correct protocols are followed during the development process and that environmental impact is considered and reduced.

5 Discussion

The main aim of this study was to assess the current state and possible risks of degradation of three key ecosystem services in Johannesburg, namely carbon sequestration, water flow regulation and provision and urban temperature regulation. I also gathered and analysed information about ecosystem services policies from Johannesburg City Parks and GDARD.

5.1 Spatial Analysis

Unimproved grasslands (natural grasslands for agriculture and grazing) were the most dominant natural land cover in Johannesburg. Unimproved grasslands provide habitat for various native flora and fauna species which in turn helps support a wide range of biodiversity such as insects, small mammals and birds (Greyling, 2000). This biodiversity helps to maintain ecosystem structure and function which in turn maintains and protects ecosystem service provision (Chapin *et al*., 2011).

Rivers are the ecological feature that had the highest amount of built-up features fall within their buffer (22.1%), while 66% of rivers fell within the 150m road zone. Due to this close proximity between rivers and highly urbanised features rivers have a high risk of being degraded through anthropogenic activities such illegal dumping, construction activities, storm water run-off and pollution through littering and fertilisers (Lehner and Grill, 2013). This is confirmed by the collected data and map analyses that show that the rivers within Johannesburg cut across residential and built-up areas. The large dispersion of Johannesburg's river network could make it difficult to successfully implement and maintain protection policies over such a large area. However, such a large network of rivers also has benefits. More rivers result in more water for, and quicker access to, anthropogenic and biodiversity uses (such as habitats, connectivity and water supply) (Lehner and Grill, 2013). The South African National Water Act (No. 36 of 1998) aims to ensure that the country's water resources are protected, conserved, sustainably used, developed, managed and controlled. Therefore, this Act should play an important role in ensuring that large river networks, such as those found in Johannesburg, are monitored and protected using laws and policies backed by National Government (National Water Act, 1998). GDARD also conducts river health biomonitoring projects to detect any changes in river conditions across Gauteng.

The road network within Johannesburg also has a large distribution extent over the city which, when compared to the rivers network, has a similar pattern, creating many overlapping points between rivers and roads. This once again emphasises how close natural and built-up features are to one another in the city. A study done in the United States determined that their roads approximate their streams in terms of systemic presence in ecosystems (Riiters and Wickham, 2003). Some of the major impacts roads have on aquatic and terrestrial ecosystems include disruption of wildlife movement, habitat modifications, alteration of water drainage patterns, the introduction of exotic species, modifications of microclimates and chemical cycles, and increasing noise levels. It has been reported that these effects can extend to hundreds of meters from roads. However, one positive impact of high road dispersal is the easy access to rivers and other natural features, which makes monitoring them easier (Riiters and Wickham, 2003).

Protected areas occurred in small patches that were all located relatively far from one another. These patches provide very little potential for a corridor to be created between these protected areas. Corridors and patches of green areas and sensitive natural features such as protected areas are very important in building ecosystem resilience. Resilience helps protect and conserve habitats and ecosystem services that occur within them by absorbing stress and disturbances, thereby allowing the system to remain in a stable state (Carpenter *et al*., 2006). For example, if disturbances to an ecosystem occur in only one part of the landscape, the other undisturbed patches help build resilience by maintaining the essential processes and functions while allowing the degraded essential processes to be re-established, which allows the ecosystem to stay in a stable state (Carpenter *et al*., 2006). Therefore, the lack of linkages or corridors between protected areas in Johannesburg increases their risk of degradation. However, the land cover types found in these protected areas (grassland, thicket and bushveld) are able to provide vital habitat, resources and protection to the biodiversity found in the area, which helps strengthen ecosystem functionality and ecosystem services provision (Elmqvist *et al*., 2013). These protected area patches are dispersed across Johannesburg which makes them more difficult to protect as they occur in different land use types. Some research has indicated that the amount of urban land near protected areas will increase, on average, by more than 3 times between the years 2000 and 2030 and will be transformed into urbanised areas such as housing to accommodate the increasing population size (Elmqvist *et al*., 2013). Specifically, around 25% of the World's protected areas will be within 15km of a city of at least 50 000 people by 2030 (Elmqvist *et al*., 2013). However, in my study I found that built-up features already occur within 150m of protected areas, which is expected to increase as population sizes increase.

All protected areas fell within a 150m road buffer, while only 1.2% of built-up features fell within the 150m protected area buffer. It was expected that roads would occur in close proximity to protected areas as these protected areas occur near urbanised areas, and roads provide people and cars access into these protected areas and nature reserves. While a low number of built-up features occur in the protected areas buffer, it is important to note that this includes a variety of features such as schools, sporting grounds, as well as industrial, commercial, residential, township and recreational areas. From the above it seems as though roads are the most dominant feature to occur near protected areas and therefore could result in the largest degradation risk. The low number of other built-up features near protected areas may be attributed to the country's and city's policies regarding protected areas. Increasing urban expansion can increase fragmentation to a point that further isolation between patches and reduction in patch sizes will occur that alters connectivity and ecosystem service flows (Elmqvist *et al*., 2013). Therefore, future policies regarding the protection of these areas will play an important role. The Johannesburg City Parks have various tools in place to help mitigate increased population and urban development impacts on the environment. These include site development plans, 1-in-100-year flood lines and Environmental Impact Assessments, that provide the environment some level of protection against growing anthropogenic activities. This should also in turn protect the ecosystem services found in protected and green areas, such as local temperature cooling and carbon sequestration, which help mitigate climate change effects such as temperature increase and the level of greenhouse gases in the atmosphere (Loughner *et al*., 2012; Strohbach and Haase, 2012). However, these plans and tools to mitigate increased population and urban development impacts on the environment might not be successfully being implemented or monitored, which means that ecosystem services protection might not be occurring as hoped. (Loughner *et al*., 2012; Strohbach and Haase, 2012). Monitoring of these tools and ecosystem services is still a developing concept in South Africa and could possibly be hindered by limited resources such as money and time available for environmental protection (van Jaarsveld *et al*., 2005). The limited research and knowledge on ecosystem services and their management also plays a big role in the inadequate planning and monitoring of them within South Africa (van Jaarsveld *et al*., 2005).

Wetlands occurred slightly closer to one another and featured most dominantly across the southern-central area of Johannesburg. A potential for corridors between wetlands might be more feasible than between protected areas, however this is unlikely due to the built-up features occurring between the wetlands. GDARD and Johannesburg City Parks stated that they take all ecosystem connectivity into consideration in urban and open space planning. They integrate and implement connectivity into their catchment management policies and integrated developments plan, by using GIS techniques, and have various policies for the protection of species and climate change corridors as well as natural feature buffers. However, a clear lack of ecosystem connectivity was found for protected areas and wetlands. The grassland and cultivated drylands in which most of the wetlands are located offer undisturbed and natural substrate for wetland biota to use in their dispersal movements within wetlands. This dispersal ability will influence the composition and functioning of the wetland ecosystem. The physical and social processes of wetlands are connected over a much wider territory, which makes the conservation of these wetlands extremely important (Amezaga *et al*., 2002). Evidence has shown that conservation and management need to focus on a rich distribution of wetlands in space and not just on maintaining the quality of the sites (Amezaga *et al*., 2002). Therefore, the distribution of wetlands in Johannesburg does not offer much protection and resilience to anthropogenic degradation and climate change effects as they are only located along one end (southern to central side) of the city. However, it is also important to keep in mind that high connectivity between natural features such as wetlands can increase the chances of spreading invasive species, which can be detrimental to wetland functions such as flood prevention and water purification. Johannesburg City Parks and GDARD recognises the detrimental effects of invasive species and as a result implements various projects to remove and monitor alien invasive plants around water sources. Around 850 hectares of alien invasive plants have been cleared by the city in 2016-2017 (Johannesburg City Parks and Johannesburg Zoo, 2017).

Wetlands were found near townships in Johannesburg, residential areas and golf and sport areas. A significantly higher number of wetlands (61%) fell within the 150m road zone, while only 1.9% of built-up features fell in the wetland 150m buffer. This exposes the wetlands to higher levels of pollution and anthropogenic activities such as land use changes and infrastructure construction (Amezaga *et al*., 2002). Research suggests that, in the United States, housing development will impact around one third of wetlands by 2050, due to increases in wetland vulnerability from increased run-off, sedimentation and habitat loss.

Housing development in South Africa has a high potential to increase over time due to high population growth rates in the country (Elmqvist *et al*., 2013). Wetlands are very sensitive ecosystems, therefore even small changes in water composition, from distant sources, can severely affect the viability of a wetland. Therefore, it is important to conserve wetlands to the whole catchment and beyond to ensure complete protection. However, this is difficult to achieve in terms of implementing the correct environmental policies, which include all stakeholders' needs and interests (Amezaga *et al*., 2002). Firstly, environmental problems are usually very complex, multiscale and affect multiple actors and agencies, making it difficult to guarantee that the selected policy will be successful when implemented. Secondly, due to the multiple number of stakeholders that are involved and affected by environmental policy implementation, it is difficult to ensure that all parties' needs and interests are catered for. Stakeholders such as government, policy makers, non-profit organisations and private companies all require different land and water use rights for wetlands or natural features, so not all stakeholders' needs will be met, or the conservation of the entire area might not be viable in all cases (Reed, 2008). Another pattern which is seen to arise numerous times in this study is that fewer natural features (including rivers, wetlands, protected areas and general green areas), and therefore fewer ecosystem services, seem to occur in the most southern tip of Johannesburg. These areas, namely Soweto, Lenasia and Orange Farm, are associated with high levels of economic deprivation and low urban development. Fewer ecosystem services in these areas can result in these already poor and vulnerable communities being more susceptible to climate change impacts (Gill *et al*., 2007).

Johannesburg has a much more sprawling layout than other major cities across Africa (African Green City Index, 2011). There has been much debate over the "compact city" paradigm in literature (Tratalos *et al*., 2007). Some have argued that reducing urban sprawl and urban land will provide various long-term social and ecological benefits, as more space will be available for green space/infrastructure (Tratalos *et al*., 2007). However, some doubts have been placed on whether compact cities will be able to maintain areas of natural habitat that are able to provide useful levels of ecosystem services (such as run-off mitigation and carbon sequestration), as there will be little space and natural features left within, between and in close proximity to highly urbanised areas (Tratalos *et al*., 2007). It has also been argued that increased urban density can lead to the deterioration of ecosystem services provision due to a decline in urban biodiversity and quality of life in urban areas (Tratalos *et al*., 2007). According to the extensive research done by Tratalos *et al*. (2007) high density urban development is generally associated with poor environmental performance as there is less space for green infrastructure and more impact on natural features from anthropogenic activities. Therefore, the sprawling layout of Johannesburg should have a much more positive effect on the environment and lower certain risks in ecosystem services degradation as more space between buildings will be available for green infrastructure. Densely urbanised areas and compact cities have been seen to have less coverage by green spaces and smaller habitat sizes, which has resulted in the prediction of higher rain water run-off, higher maximum temperatures and lower carbon storage (Tratalos *et al.*, 2007). Therefore, it seems that it is more important to incorporate green spaces between and within urban areas than having separate larger green spaces further away from urbanised areas. Urban and green spaces mixing is needed in order for city residents to receive the benefits and climate change mitigation from the various urban ecosystem services.

5.2 Carbon Sequestration

Cities might appear to be lifeless (limited natural fauna and flora), highly built-up areas; however, they can contain and support diverse ecosystems (Strohbach and Haase, 2012). Cities around the world contain rich ecosystems such as parks, recreational areas and urban forests (Strohbach and Haase, 2012). As mentioned earlier, these urban forests have been shown to store significant amounts of carbon in cities in the USA, Germany, Korea, Spain, the UK and Australia. Carbon storage in trees helps to reduce the amount of greenhouse gases in the atmosphere which greatly reduces climate change effects (Nowak and Crane, 2002).

The twenty sites across Johannesburg all had different carbon storage values, even though they were not significantly different from one another when grouped into the different land use types. Sites that are classified as poor areas with high levels of social inequality (this includes the township areas of Soweto and Orange farm) had the lowest amount of stored carbon and the lowest number of trees. The same pattern has been found in numerous studies where social inequity is matched with inequity in the environmental quality of the landscape (see Tratalos *et al.*, 2007; Kuruneri-Chitepo and Shackleton, 2011; Schäffler and Swilling, 2012). Due to past inequalities caused by Apartheid, majority groups were forced to live in these areas, which were never upgraded or properly developed or maintained. This has led to a poor quality of life and very little environmental protection, leading to a lack of ecosystem services that can help mitigate climate change effects (Schäffler and Swilling, 2012). A lack of environmental protection in these economically deprived areas provides opportunities for tree planting initiatives in townships in Johannesburg and across South Africa (Stoffberg *et al.*, 2010) A study conducted in the Eastern Cape in South Africa found notable differences in tree density and species richness in different neighbourhoods, with the lowest being recorded in low income and township areas (Kuruneri-Chitepo and Shackleton, 2011). The Johannesburg City Parks have recognised this inequality and have implemented programmes in economically deprived areas. The Greening Soweto programme (started around 10 years ago) has resulted in the planting of around one million trees in Soweto, in order to increase the amount of carbon sequestration. Various environmental education programmes are held in these areas to increase the residents and youths understanding and appreciation of the environment. These programmes include the snare initiative project whereby residents are taught about the dangers of snare trapping and participate in removing snares in their local areas and water testing class projects where the youth in deprived areas are taught how to test for clean healthy water and how alien plants affect water supply in South Africa.

In comparison to the economically deprived areas of Soweto and Orange Farm, the residential areas in Johannesburg had the second highest amount of stored carbon and a high density of tress within the sites. These residential areas are occupied by middle to higher income classes, which has been seen to have a greater ecological performance in terms of carbon sequestration and tree cover than lower income and social groups (Tratalos *et al.*, 2007). It is important to note that high carbon storage and high population density are not mutually exclusive, therefore providing support for the high levels of carbon storage found in high density and populated Johannesburg residential areas (Strohbach and Haase, 2012). Highly compacted housing can leave more open space for vegetation such as grass and trees in gardens, increasing the provision of various ecosystem services and climate change mitigation measures in these areas (Strohbach and Haase, 2012).

Nature reserves were seen to store the second lowest amount of carbon. Nature reserves in Johannesburg contain high numbers of much smaller, indigenous trees that are not seen in the more residential and urbanised areas. Evidence shows that large trees can store approximately 1000 times more carbon than small trees. This is a possible reason why the nature reserve sites have such low carbon storage values (Nowak and Crane, 2002). However, it is important to note that grasses are also able to store significant amounts of carbon, which is dominantly present in open land and nature reserve sites across Johannesburg. A study done in South

Africa determined that grasslands store the fifth highest amount of above-ground carbon out of 16 land use types (Mills *et al.,* 2005).

Differences in carbon storage across land use and cover classes was also seen in the urban forest in Leipzig, Germany (Strohbach and Haase, 2012). However, very few or no trees are found in some of Leipzig's industrial and commercial areas (Strohbach and Haase, 2012). This was not the case in Johannesburg, where the industrial site and commercial sites had the first and third highest carbon storage values, respectively. As discussed before this is not an accurate representation of all industrial areas as only one industrial site was sampled in my study. This site was also located near a residential area and therefore contained more trees than other industrial areas across Johannesburg. Johannesburg does contain the largest man-made forest in the world and therefore a high number of trees are located across most of Johannesburg, especially in residential and suburban areas. However, tree distribution across Johannesburg does still vary, where trees cover around 24.2% of northern Johannesburg and only around 6.7% of the poorer southern areas of Johannesburg such as Soweto, Lenasia and Orange Farm (Schäffler and Swilling, 2012).

The method 1 results calculated that the city of Johannesburg has a carbon storage of around 436 065 metric tonnes (t). A study done by Schäffler and Swilling (2012) (which my method 2 was based on) calculated a value of 5.3 million tonnes, which is exponentially higher. The carbon storage values obtained by using the same methods from Schäffler and Swilling (2012), ranged from 1 to 4 million tonnes, depending on which sites were used to extrapolate from. These values are so variable that it places doubts on the accuracy of this extrapolation method as well as the results of the study done by Schäffler and Swilling (2012). An entire city's carbon storage capacity should therefore not be extrapolated from one small area, which in this case was a 50m by 50m area, as it does not represent all different land use types found across Johannesburg. Schäffler and Swilling (2012) suggested that Johannesburg City Park's GIS database is incomplete and lacks data for open spaces and ecological networks. Furthermore, the City has not undertaken any efforts to calculate the carbon storage potential of Johannesburg. According to the document analysis done GDARD has created GIS input layers for wooded areas in Gauteng which can be used to calculate potential carbon sequestration, but they themselves have not conducted any studies to measure the actual carbon storage value of Johannesburg. However, since then Johannesburg City Parks have done studies to determine which tree species have the greatest potential to sequester carbon and investigated methods to prevent the release of sequestered carbon back into the atmosphere (Johannesburg City Parks and Johannesburg Zoo, 2015). Due to the lack of carbon storage studies in Johannesburg, specifically urban/city studies, a comparison to other South African and international studies is discussed below.

A study done in Tshwane (Pretoria) determined a total stored carbon potential of 200 492 tonnes, based on the additional planting of 115 200 trees as per the City of Tshwane Metropolitan Municipality 2002 strategy (Stoffberg *et al.*, 2010). Nowak and Crane (2002) calculated the carbon storage for various USA cities. These values ranged from 19 300 tonnes (for Jersey City) to 1 225 200 tonnes (New York). New York City has the highest percentage of open space in comparison to other US cities, which may certainly explain their high carbon sequestration potential (Elmqvist *et al.*, 2013). Philadelphia had the most similar carbon storage value to Johannesburg, of 481 000 tonnes (Nowak and Crane, 2002). This study estimated that around 2.1 million trees exist in Philadelphia, where Johannesburg is recorded to have around 6 to 10 million trees in the city (African Green City Index, 2011). However, aspects such as tree age and composition as well as soil composition, climate zones and size and structure of cities influence carbon storage, which differs between and within cities. It is also difficult to directly compare carbon storage values between cities as different studies use different methodologies to calculate stored carbon (Strohbach and Haase, 2012). It is important to note that the stored carbon values in my study could not accurately reflect the true value as only above-ground tree biomass was measured. It has been suggested that soils can store up to 60 percent of the total carbon in forests, making it an important factor to take into account when reporting on carbon storage capacities (Nowak and Crane, 2002).

Urban forests are generally overlooked, with more attention and conservation efforts being placed on natural forests. Although natural forests can store around 45% of terrestrial carbon, these forests are undergoing rapid transformations due to anthropogenic activities such as land cover changes and deforestation (Bonan, 2008). Urban forest areas contain about a half of the tree density found in natural forest stands (Nowak and Crane, 2002). However, evidence suggests that individual urban trees contain four times more carbon than individual trees in natural forests, due to larger tree diameters in urban forests. Larger tree diameters mean these urban trees have more biomass which can therefore store more carbon than the smaller stemmed trees found in natural areas (Nowak and Crane, 2002). Urban trees therefore have a greater impact per area of tree canopy cover than natural forests as they have faster growth rates, increased proportions of large tress and other secondary effects including reduced building energy usage (air temperature cooling) and therefore reduced fossil fuel emissions. However, according to Stoffberg *et al*. (2010) only 50% of urban trees in the UK survive after a 30-year period. Factors such as competition between trees for space, water and soil, anthropogenic clearing of trees and environmental factors such as wind and fires contribute to the high mortality rates of younger trees (Perry, 1978). To ensure the survival of urban forests municipalities need to plant long living, fast growing and low maintenance trees; minimize the amount of fossil fuels emitted from tree management activities; use dead tree wood for energy purposes and plant trees in energy-saving locations (Nowak *et al*., 2002).

5.3 Water Quality

Water bodies are located across various land use types in Johannesburg, indicating a high level of mixing between built-up and natural features in the city. Most of the water bodies in the sites had high levels of vegetation ground cover (80-100%) around them, except in the recreational park site which only had 40-50% cover. Vegetation around water provides various advantages to the ecosystem around the water. High amounts of vegetation reduce the amount of runoff in high rainfall and flooding periods. More vegetation results in more evapotranspiration and therefore cooling of the immediate surrounding air and water. These two aspects will become important during climate change impacts, where flooding and increased temperatures will become more frequent and intense (Williams *et al.,* 2012). Riparian vegetation also provides habitat protection and increases connectivity to other green spaces. This ensures habitat and ecosystem protection and resilience to environmental, anthropogenic and climate change impacts (Elmqvist *et al*., 2013). The river within the park had less vegetation as large boulders, instead of vegetation, surrounded the river where data were collected. The park management might remove overgrown vegetation as part of their maintenance and management plan. A wide variety and abundance of rocks were found in each water body due to the different land uses and typographies of the sites. The different rocks provide habitats for a range of aquatic organisms such as micro and macro-invertebrates, algae and fish. This improves overall quality of the water and provides habitat complexity and strengthens ecosystem structure (Kiffney et al., 2006).

Physical water measurements provide vital information about the health of the water bodies. All the water bodies had normal pH levels which ranged from 6-8 (Phiri *et al*., 2005). These pH levels allow for normal chemical and biological processes to occur and do not negatively affect the health of the organisms living in the water bodies (Kannel *et al*., 2007). Healthy bodies of water have dissolved oxygen levels between 80% to 120% (Ogbeibu and Oribhabor, 2002). Water in the sites across Johannesburg all had oxygen levels below 80% (between 60% and 70%). Site 13, a commercial land use site, had extremely low levels of around 41%. High oxygen levels are needed in order for aquatic life to thrive and are a key element in river health (Kannel *et al*., 2007). Dissolved oxygen is also an index of water quality to estimate the effects of industrial and municipal effluents on water (Kannel *et al*. 2007). High levels of organic and nutrient pollution can lower dissolved oxygen levels in rivers (Kannel *et al*. 2007). This is very plausible as high levels of litter (>70%) as well as a strong odour of sewage were present at this site. Dissolved oxygen levels in rivers in Benin, Nigeria ranged from 60.18% to 173.29% (Ogbeibu and Oribhabor, 2002). While the lower side of the range was seen in Johannesburg, the highest dissolved oxygen level found in my study was only 72.4%, which is significantly lower than the rivers tested in the study. However, dissolved oxygen levels above 110% can be harmful to certain fish, as the excess oxygen can block blood flow in blood vessels (Ogbeibu and Oribhabor, 2002; Jones, 2011). The slightly lower than "healthy" dissolved oxygen levels found in my study can be due to pollution (as litter was found at almost all water sites) including sewage and run-off, which is more likely in Johannesburg due to the river's close proximity to urbanised areas.

One important aspect to take into consideration is that the river present in site 13 leads out of the Bruma Lake Park. Historically Bruma Lake contained a high degree of bacteria, germs and pathogens, with high levels of litter and sewage present in the lake (City of Johannesburg, 2012). A lack of monitoring in conjunction with decaying infrastructure, increased water flow and a lack of vegetation around the lake has led to the erosion of the riverbanks and an overall decline in the lakes quality of water. Toxic spills have often been noted to flow into Bruma Lake from surrounding areas and industries (City of Johannesburg, 2012). Chemical cleaning projects have been implemented in Bruma Lake since 2007, however doubts have been placed on the success of these programmes. Due to continuous failed clean up attempts, Bruma Lake was redeveloped into Bruma Lake Park in 2016. This included completely draining the lake, re-establishing a channel for the Jukskei river to flow through and creating more green space surrounding the new channel (Johannesburg Development Agency, 2016). However, given the quality of water from the river passing through the new channel, problems still seem to persist. Interviews with the Johannesburg City Parks revealed that there were various monitoring points for Bruma Lake and its connected river systems in the past. However, currently they do not monitor the sites anymore as it is not part of their current targets and therefore do not know whether water quality has improved in river systems flowing through Bruma. The City perhaps does not monitor Bruma anymore as they believe their remediation plans were successful and are therefore unaware that the water quality has declined again. This could indicate a barrier in effective environmental monitoring in Johannesburg as the City either does not have enough funding or staff to conduct the monitoring evaluations or they do not believe that long term monitoring is needed. In the supplied integrated catchment management midterm report for 2016-2017, it is stated that an R800 000 litter trap project was implemented in the Jukskei river and Bruma area, yet the river still contained high levels of litter and intense sewage odours (Johannesburg City Parks and Johannesburg Zoo, 2017).

Water transparency plays an important role in aquatic plants and organisms survival. The commercial land use area (site 13) also had the lowest transparency (9.5 cm) which can be due to suspended solids from sewage and industrial wastes. Low transparency results in less sunlight being able to reach any bottom dwelling plants, which can kill these plants and create a higher demand for oxygen through decomposition by bacteria (Kannel *et al*, 2007). Transparency levels from rivers around the city of Benin, Nigeria ranged between 56 to 103cm (Ogbeibu and Oribhabor, 2002). According to the South African Quality Guidelines transparency can reach low levels such as 2mm to 5cm (Department of Water Affairs and Forestry, 1996). Therefore, a transparency level of 9.5cm is considered low, and is not fit for aquatic life and recreational usage. The nature reserve site had the highest transparency measurements (of 80cm, the highest level in the transparency tube), one of the highest oxygen levels (72.4%, which is considered “acceptable”) as well as general good levels for all other water quality parameters. The nature reserve also had the lowest amount of litter around the river, as well as low levels of disturbances. This suggests that policies regarding the protection and maintenance of nature reserves appear to be successfully implemented and monitored in Johannesburg.

Freshwater streams should ideally have a conductivity range between 150 to 500 µS (Behar, 1997); all the measured sites, besides one, fell into this range. The site located in the Township had a conductivity level of around 1100 µS. This high reading indicates the presence of high levels of salts and mineral acids, which can be harmful to aquatic organisms (Kannel *et al*., 2007). These high levels can be caused by increased surface runoff that can bring in ionic substances such as nitrates and phosphates from fertilizers (Phiri *et al*., 2005). However, in this case a more probable cause is the presence of an old mine dump which is situated near the site, with the stream passing through it. Although these conductivity levels are not ideal, most streams have conductivity levels ranging between 50 to 1500 µS (Behar, 1997). A study conducted by Phiri *et al*. (2005) found conductivity levels of 1700 µS in sites that were affected by effluents from an industry not far from the study area. A study conducted on the Fuji river basin in Japan recorded water conductivity levels between 50 and 300 µS (Shrestha and Kazama, 2007). These fall into similar ranges found in Johannesburg rivers. The Fuji river basin flows through a much more natural setting, and therefore has low levels of anthropogenic disturbances, unlike Johannesburg rivers which are found predominantly in highly urbanised areas.

The flow of a river is an important indicator of a river's health. The flow of water within a river can provide various benefits for downstream human usages (for irrigation, industrial processing or hydropower), public water supply and diluting pollution (Acreman and Dunbar, 2004). In order for a river to maintain a pristine natural ecosystem, its flow rate needs to be very close to its natural flow regime. However, a river's natural flow regime is based on various factors, including the size of the river, its natural state or perceived sensitivity and a combination of the desired state of the river and the uses to which it is put. Therefore, the complexities of natural systems make it difficult to define thresholds at which flow regimes will maintain a river's desired state or condition (Acreman and Dunbar, 2004). The rivers assessed in this study had relatively low flow rates between 0 to 0.4 meters per second. The width of all these rivers were relatively small (never more than 2 to 3m wide), and the low velocity could be attributed to the fact that data collection was done in winter, which is the dry season in Johannesburg. However, it is important to note that natural water flow fluctuations are necessary in some ecosystems, where extreme natural events (such as droughts and flooding) help reset or alter conditions that underpin the long-term development of biotic communities. For example, floods and droughts interact with the underlying geology of a river to shape the river's physical and chemical templates and therefore impact the sites on which biotic communities develop over long term periods. If rivers do not go through this natural process of flow extremes, it can upset patterns of material transport, resource availability, plant mortality and succession and the composition of biological communities. Importantly, the lack of natural flow fluctuations can lead to the deterioration of river ecosystem services such as water purification and recreational services, as the sediments and organic materials in the river can be substantially modified (Naiman *et al*., 2008). Complex modelling systems, such as the Pitman hydrological model, can be used to determine how development and climate change may impact river flow and therefore the benefits of these waters (Andersson et al., 2006), however this was outside the scope of this study.

As discussed, it is difficult to predict exactly how climate change will impact the different water parameters and overall quality. A study conducted on European rivers recorded a 1 to 3°C increase in water temperatures, which impacts chemical reactions, biological processes and fish and insect lifecycle stages (Whitehead *et al*., 2009). The water temperature measurements from the tested rivers in Johannesburg are normal (between 9 and 15°C) for winter. Similar temperatures were seen in other rivers across South Africa, including the Western Cape, Eastern Cape, Limpopo, Mpumalanga and KwaZulu-Natal. My temperature readings did not fall more than 2 or 10°C out of these ranges, thereby classifying them as normal (Dallas, 2008). Some common anthropogenic factors that change water temperature can include thermal discharge, flow modification, inter-basin water transfer, modification to riparian vegetation and climate change. However, water temperature measurements need to be done over long periods, during different seasons and at different spots throughout the rivers length, in order to monitor changes in river temperatures and climate change impacts (Dallas, 2008).

Climate change may reduce water availability and cause shifts in precipitation levels (Elmqvist *et al*., 2013). Future climate change models have shown that higher carbon dioxide levels in the atmosphere could result in increased flooding events in Australia (Whitehead *et al*., 2009). Similar climate models were done for South Africa and results showed that in the projected climate change scenarios there could be a general increase in extreme rainfall and flooding events across South Africa (Engelbrecht *et al*., 2012). Increased precipitation within Johannesburg could result in disastrous flooding events as they could impact and destroy infrastructure (such as roads, buildings and built-up areas), potentially cause human injury and death in some cases and even impact natural areas and green infrastructure (Chapin *et al*., 2011). A severe case of flooding occurred on the major highways in Johannesburg in November 2016, which resulted in six deaths due to drowning and cars being swept into rivers (The Citizen, 2016) Impacts of flash flooding have already been seen in Johannesburg, as well as severe thunderstorms and hailstorms, which severely impacts the informal settlements (Murray, 2009; Pijoos, 2016). A study done by Fatti (2014) shows that periodic flooding has occurred in Ekurhuleni (East Rand region of Gauteng) since 2006. Flooding occurs along the eastern banks of the Atlas Spruit which floods open park space and nearby roads and houses, causing severe property damage which take months to repair (Fatti, 2014). Droughts have affected most of South Africa, including Gauteng and most recently the Western Cape. This has severely impacted water availability and in combination with an increase in debilitating fires due to drier and hotter conditions have led to the destruction of countless homes, infrastructure, crops and vegetation (Murray, 2009; The South African Weather Service, 2017).

Increased water demand and climate change impacts will place high stresses on our already scarce water ecosystems. Therefore, it is critical that our aquatic ecosystems are correctly protected and maintained (Dallas, 2008). Water sources will be vital to conserve in times of drought as they can bring important relief in water stressed areas (Elmqvist *et al*., 2013). Alternatively, water sources can also cool local temperatures by evaporation, absorbing heat and transporting heat out of an area (through a river). One study has shown that water has a cooling effect of 1 to 3°C, to an extent of 30 to 35 meters (Kleerekoper *et al*., 2012).

According to Johannesburg City Parks and the integrated catchment management mid-term report for 2016-2017, all their water quality targets for the quarter were met. This included the maintenance of 172 ha of river trails, 3 wetlands, 2 dams, and various areas (over 800 ha) being cleared of alien invasive plants. Various clean up and litter trap operations were run around Johannesburg water bodies. Therefore, the City officials stated that Johannesburg's rivers and wetlands are in good condition as all their targets were met. According to the analysis done on the GDARD documents most rivers in Gauteng are largely or seriously/critically modified, with virtually no rivers remaining natural/unmodified and few rivers being moderately modified. Although none of the measured water bodies were in extremely poor conditions, two water bodies (from site 13, which is the Jukskei river flowing out of Bruma, and site 8, near the township) are concerning, due to their low dissolved oxygen and transparency readings, and high conductivity levels, respectively. Both the interviewees and the integrated catchment management mid-term report said that the main challenges in keeping Johannesburg's rivers and wetlands in good condition include meeting the public's demands for water usage, staff challenges, alien invasive plants and displaced people residing and sorting waste material along water sources. According to GDARD their main challenge in keeping rivers in good condition is high storm water runoff that flushes polluted water from urban areas and road networks into the rivers. This causes stress on the river systems as it brings in sewage, pesticides and effluents from mining activities and heavy industries. The City has come up with various plans to overcome these challenges in the future. Interviews with Johannesburg City Parks made it clear that they just implement the policies that are provided from a national level, and therefore do not participate in policy creation. When asked why, they responded that that is how policy creation and implementation work in South Africa, however GDARD stated that the City of Johannesburg can implement their own policies and guidelines that GDARD are not aware of. Water quality measurements also fall under another municipal owned entity (MOE) and not with City Parks according to the interviewee. There therefore seems to be a disconnect between the various MOEs in Johannesburg (such as Johannesburg Water and Johannesburg City Parks and Johannesburg Zoo) and a low level of communication between local and national governmental bodies. National bodies need to obtain feedback from local municipal bodies in order to be able to change and adapt their policies to be more successful.

5.4 Temperature Cooling

Cooling from trees was observed in every site. An average of around 1 to 2 °C of cooling was found under trees (28.6°C) compared to areas exposed to direct sunlight (30.9°C). This is also reflected in a study done by Gill *et al.* (2007) where, by adding 10 percent of green cover surface temperature was decreased by around 2°C. An average temperature cooling of 0.94°C was reported from studies conducted around the world (from the USA, Botswana and various European and Asian countries) (Bowler *et al*., 2010). My results fall within the range of these studies. It was recorded that urban trees lower temperatures by 0.7 to 1.3°C in urban areas in Washington DC in the United States, but mature trees can lower air temperatures by 2.2 to 3.3°C (Loughner *et al*., 2012). Therefore, mature trees play a critical role in temperature cooling and should be preserved in urban areas. One study even suggests that mature trees are able to cool ground surface temperatures by as much as 15.6°C, however this high level of cooling was not found in Johannesburg. A reason for this could be that only air temperature was measured in my study and not ground surface temperature, which could yield different results, and therefore, should be included in future studies to better our understanding about urban heat island mitigation (Gill *et al*., 2007).

An energy exchange and surface runoff modelling exercise determined that, if no changes in surface cover occur by 2080, an increase of 1.7°C to 3.7°C in temperature will occur in Manchester, in the United Kingdom. The modelling exercise used the energy exchange model with surface cover type, air temperature, building mass per unit of land and an energy balance equation as inputs; and the surface runoff model with surface cover type, precipitation, antecedent moisture conditions and hydrologic soil type as inputs to determine changes in surface temperature (Gill *et al*., 2007). This indicates the level of importance that vegetation and trees play in urban areas. An increase in temperatures will be exacerbated even more in climate change scenarios, impacting both natural features and human health. It is important to keep in mind that the magnitude of an urban heat island effect varies in time and space due to the different meteorological, locational and urban characteristics that it experiences (Gill *et al*., 2007). However, in all cases trees and vegetation are able to lower air temperatures in urban areas.

Areas that experience the highest temperatures usually have the lowest tree populations, and therefore the lowest amount of cooling, are generally found in socio-economic disadvantaged areas (Gill *et al.*, 2007). This was confirmed in my study, as the township areas had the second lowest cooling effect and was the land use type with the least number of trees and green ground cover. Residents in these areas are therefore more vulnerable to climate change impacts (such as increased temperatures) as they may benefit less from ecosystem services and tend to lack the resources and finances to mitigate and adapt to these climate change effects (Gill *et al*., 2007).

We now know that trees are able to lower local temperatures. However, the location of these trees might also play a role. Bowler *et al*.'s (2010) research suggests that the value of adding street trees may differ, depending on the areas specific urban topography. A study conducted in New York found cooling effects of 0.05°C to 1.54°C depending on the location of the city and the presence of open space planting, street trees, green roofs and urban forests (Rosenzweig *et al*., 2009). Areas with high building density may also provide shade in addition to the shade provided by trees, as cooling is seen to be a factor from both shading and evapotranspiration (Shashua-Bar and Hoffman, 2000). This doesn't seem to support my results, as commercial areas (containing high building density) had the second lowest cooling effect. The area under clusters of trees are also seen to have lower air temperatures compared to those under individual trees, as the nature reserve sites (which has a high density of clumped trees) had the highest amount of cooling out of all the land use types. This could be due to the fact that a larger distribution of trees (clusters of trees over a large area) are able to produce a greater general cooling effect in the area, due to a higher level of shading present, and not just localised cooling resulting from fewer individual trees (Bowler *et al*., 2010).

Ground cover, however, also plays a part in cooling. Grass and other smaller vegetation are able to intercept solar radiation and lower ambient air temperatures (Getter and Rowe, 2006). This could be an attribute as to why nature reserves have such a higher cooling effect than other sites. Commercial and residential areas have a higher amount of impervious surfaces due to more houses, buildings, roads and parking lots, while townships have low green cover and more bare ground. These surfaces absorb the incoming solar radiation and transform it into sensible heat (Getter and Rowe, 2006). This therefore increases the air temperatures in these areas, thereby lowering the overall cooling abilities of the trees in the residential, commercial and township sites. However, green roofs (containing grass and small vegetation such as shrubs and herbs) can be implemented in more built-up and bare areas to increase green ground cover. These provide greater cooling per unit areas than impervious surfaces (Rosenzweig *et al.*, 2009) and offer high insulation, keeping buildings warm in winter and keeping heat outside in summer, with a cooling ability of 0.2 to 1.2 °C and an energy saving of 4% to 40% (Kleerekoper *et al.*, 2012). However, some research indicates that street trees are still the most effective in terms of cooling, as they offer more cooling per unit area (Rosenzweig *et al.*, 2009). Therefore, it is important to recognise that different green spaces and different layouts will alter the amount of cooling that can occur in urban areas. This relationship should be explored and analysed in future studies in order to implement the most effective green spaces in urban areas. Each city will have different mitigation strategies that will be the most effective for temperature cooling in their own layout and scenario.

Urban heat island (UHI) effects are a complex science. Although UHIs increase the local temperatures, they do not directly cause climate changes as they do not alter hemispheric or global temperatures (Elmqvist *et al.*, 2013). However, it has been determined by Elmqvist *et al.* (2013) that UHI effects worsen under climate change effects. Local temperatures will further increase and can affect humidity, clouds and storms and therefore alter precipitation levels. Elmqvist *et al.* (2013) have shown that cities receive different amounts of precipitation compared to areas of lower population and building density. These urban areas have been seen to receive heavier and more frequent rain events than areas that are just outside of urbanization but still occur in the same region. If cities increase in size and number, the effects of UHI can start playing a role in regional climate. Therefore, combating UHI effects can mitigate climate change effects such as increased local temperatures and extreme local precipitation events (Elmqvist *et al.*, 2013).

5.5 Private versus Public Access

Most sites were either privately owned or have a mixture of both private and public ownership. While green spaces in public areas are maintained and managed through policies at local authority level, those in private land are completely managed by the owners and residents of that land (Tratalos *et al.*, 2007). It has been shown that a resident's economic constraint and cultural ideas affect how they manage their land (Tratalos *et al.*, 2007). For example, some individuals have been influenced by their cultural backgrounds and social histories to prefer a certain type of landscape that can include more or less vegetation cover or flowering plants. Also, residents from different economic statuses have different resources to devote to ecological features within their gardens and neighbourhoods (Kinzig *et al.*, 2005). Such a pattern was seen by Kinzig *et al.* (2005), where residents of lower socioeconomic status had less diverse plant and bird communities in their areas. This could have significant impacts on the ecosystem services within these private lands, with higher degradation risk, land use changes or poor ecosystem service management. Therefore, these residents should be informed of the benefits they can receive from ecosystem services on their land (Turpie *et al*., 2008).

One of the main risks to ecosystem services degradation, especially in private unprotected land, is overexploitation (Carpenter *et al*., 2006). Provisioning services are at a high risk of being overexploited, especially in conjunction with the exponential rise in urban populations. Once provisioning ecosystem services are overexploited (through the extraction of natural features such as trees and water) it can lead to the degradation of important regulating services such as carbon sequestration, temperature cooling and water provision (Carpenter *et al*., 2006). Within smaller urban areas ecosystem service trade-offs could result in the degradation of particular ecosystem services and therefore, poses challenges in maintaining and protecting these ecosystem services (Carpenter *et al*., 2006). For example, food production/agriculture is deemed as an important ecosystem service, however converting other land types into agricultural land in urban areas can result in a trade-off in another ecosystem service such as carbon sequestration, as trees can be cleared to provide space for agricultural land (Carpenter *et al*., 2006). However, Carpenter *et al*. (2006) determined that trade-offs are difficult to analyse and to anticipate, which makes it difficult to make decisions on ecosystem services trade-offs. For example, the planting of more trees will increase the ecosystem service of carbon sequestration and local temperature cooling. However, more trees require more water, which can place additional stresses on our scarce water sources, and can possibly lead to a reduction in water ecosystem services (Carpenter *et al*., 2006).

If governmental bodies and private companies work together with non-profit organisations (NGOs) to create environmental awareness, environmental educational projects and public participation, they can motivate residents to protect green spaces, specifically in their privately-owned space (Elmqvist *et al*., 2013). This is particularly important in South Africa, as only around 6% of land falls within protected areas (Turpie *et al*., 2008). Therefore, a staggering 94% of land is susceptible to degradation, where there has been a reported lack of support from Government to conserve these unprotected areas (Turpie *et al*., 2008). However, there is national protection for ecological features such as biodiversity, protected areas and water sources in South Africa, even if they are located on private land. These include the Biodiversity Act, Protected Areas Act and the Water Act, which consist of binding requirements to protect water and biodiversity ecosystem services as well as natural features such as trees within protected areas across South Africa (Le Maitre *et al*., 2007). For example, in some cases legal mechanisms can be put in place whereby biodiversity on private land needs to be conserved by limiting certain land use activities. This is called a green servitude. A biodiversity stewardship can also occur when a voluntary agreement between Government and private and communal landowners is made in order to protect biodiversity priority areas (Biodiversity Mainstreaming Toolbox, 2014). However, in other cases natural features such as trees (and their ecosystem services) do not have this level of national protection on private lands. This makes carbon sequestration and urban temperature regulation susceptible to degradation and land use changes in private areas. Further details regarding ecosystem services policies are discussed in the next section.

Government should assist residents by setting base-line requirements for green management or possibly offer some type of incentive (Elmqvist *et al*., 2013). However, some schemes have been developed to help conserve water in South Africa, most notably the Working for Water programme. This scheme involves using the local community to clear invasive alien plants, which impact the country’s scarce water resources, thereby creating jobs and conserving water ecosystem services in the same process. It has been recorded that 66% of the Working for Water activities have occurred outside of conservation and protected areas, thereby contributing to the protection of water resources in unprotected and private lands (Turpie *et al*., 2008). Another programme developed in South Africa are the Payments for Ecosystem Services (PES) schemes, which involve voluntary payments for well-defined ecosystem services that are conditional on service delivery (Turpie *et al.,* 2008). These PES schemes therefore offer an incentive to private lands to conserve their ecosystem services. Therefore, if residents help to maintain and preserve green spaces within their areas it can result in a decrease in public spending on environmental maintenance (Elmqvist *et al*., 2013). When designing and planning urban areas, it is important to include clusters of different types of public and private patches with high ecosystem connectivity and that contain key ecosystem services. This will ensure that these ecosystem services are protected and can therefore help play a part in climate change mitigation (Elmqvist *et al*., 2013).

5.6 Governmental Policies and their Role in Ecosystem Protection

Through the interviews with City Parks, it was seen that ecosystem services are protected and maintained mainly through the Open Space Management strategy and the Catchment Management policy. These policies protect sensitive ecosystems such as wetlands, other water bodies and Johannesburg's urban forest. GDARD policies implements buffers for sensitive species, wetlands, rivers and ridges in order to ensure that the ecological integrity of these features is protected against urban development and land use changes. It appears that ecosystem services are not directly mentioned or have their own policies, but rather fall under a broader overall ecosystem and species protection. These policies are therefore able to protect ecosystem services such as pollination as they become protected through the protection of areas containing this service (Le Maitre *et al*., 2007). The Biodiversity Mainstreaming Toolbox for land use planning and development in Gauteng (2014) document does define ecosystem services and conveys their importance for maintaining biodiversity and mitigating and adapting to climate change effects in Gauteng and Johannesburg.

On a national level ecosystem services are acknowledged in the Biodiversity Act and the Water Act, but not by most of the sectoral programmes (Le Maitre *et al*., 2007). There are various international frameworks relating to biodiversity that South Africa is party to. These include: Convention on Biological Diversity (CBD); Convention on the conservation of Migratory Species of Wild Animals (CMS); Convention of Wetlands of International Importance (Ramsar Convention); World Heritage Convention; Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); Convention to Combat Desertification (UNCCD); and Framework Convention on Climate Change (UNFCCC) (Biodiversity Mainstreaming Toolbox, 2014). The protection of particular ecosystem services will fall under these international frameworks South Africa is part of. Various environmental legislation and guidelines in South Africa also cover ecosystem services protection. The National Framework for Sustainable Development (2008), The National Water Act (No.36 of 1998), The National Environmental Management Act (No. 107 of 1998), The National Environmental Management: Protected Areas Act (No. 57 of 2003) and the National Environmental Management: Biodiversity Act (No. 10 of 2004) provide protection for various ecosystems and biodiversity in South Africa which does offer protection to certain ecosystem services such as water regulation and production, pollination, carbon storage and temperature regulation (through tree protection) to name a few. The White paper on the Conservation and Sustainable Use of South Africa’s Biological Diversity (1997) specifically highlights the important role of biodiversity and ecosystems in providing ecosystem services to South Africa. Finally, various guidelines for development and planning exist such as the environmental impact assessment (EIA), an IDP, The Gauteng Conservation Plan and The National Freshwater Ecosystem Priority Areas (NFEPA) in order to minimise environmental impacts and to protect and maintain ecological features and ecosystem services. However, it has been reported that impacts on biodiversity and ecosystem services are rarely sufficiently considered during the EIA process, which places doubts on the success of these various guidelines and policies in South Africa (Biodiversity Mainstreaming Toolbox, 2014).

The integration of ecosystem services into policies has been seen in The European Union (EU) over the last couple of years (Maes *et al.*, 2012). It has become more evident to policy makers in the EU that nature-based solutions (such as water purification and carbon storage) are more cost-effective than technical infrastructure. Therefore, ecosystem approaches are now being integrated into their planning and policies. This is seen in the EUs common agriculture policy where preserving and restoring ecosystem services is one of the six priorities identified by the rural development pillar (Maes *et al.*, 2012). The importance of investing in nature as a source of economic development has also been recognised in the EU’s regional and cohesion policy (Maes *et al.*, 2012). In the United States, national laws such as the Clean Water Act and Clean Air Act, imposes binding requirements to US cities to protect water and air quality ecosystem services, with similar sections seen in NEMA, and South Africa’s Water Act and Air Quality Act (Le Maitre *et al*., 2007; Hansen *et al.,* 2015).

A significant amount of research has been done on Johannesburg’s urban forest and its role in climate change mitigation, and has led to the development of a tree census and tree by-laws. This includes research on a tree inventory, tree canopy cover, tree species and diversity, the values of trees and community involvement. Collaboration work has been done between Johannesburg City Parks and UNISA (Johannesburg City Parks and Johannesburg Zoo, 2015). City Parks only links carbon sequestration to climate change mitigation and did not mention and recognise the role of trees cooling local temperatures. A disadvantage of this is that tree planting schemes will possibly not be implemented in areas with high building densities, which as discussed earlier provides shading to buildings, which lowers energy usages, costs and fossil fuel emissions. However, GDARD recognises and highlights the importance of trees and their role in reducing the Urban Heat Island (UHI) effect in various of their provided documents. Like GDARD, New York City recognises the critical role carbon sequestration plays in climate change mitigation in cities. However, unlike the city of Johannesburg they realise that higher air temperatures in urban areas (the urban heat island effect) is an important issue that requires further research, as it can increase ozone concentrations, decrease air quality and lead to heat-related illnesses and deaths (Department of Environmental Conservation, 2016). The fact that the importance of trees in combating UHI's is recognised at a provincial level in Gauteng but not at a city level provides evidence that a lack of communication between different levels of governmental organisations occurs.

City Parks said that their main climate change mitigation and adaptation plans involve urban tree and park management and sustainability in capital development (to support low carbon and resource efficient development). On a provincial level GDARD's main focus regarding climate change mitigation and adaptation include increasing carbon sequestration potential, moving towards alternative energy sources and incorporating green infrastructure within cities. Therefore, the provincial government places importance on numerous ecosystem services and recognises their role in climate change mitigation and adaptation, which seems to be lacking from Johannesburg City Parks. When asked about the possible ecosystem degradation risks in Johannesburg, only storm water discharge was mentioned from Johannesburg City Parks, while GDARD includes human activities such as urban development and mining as the biggest risks. However, online reports such as the Infrastructure Planning and Storm Water Management Plans, provide additional threats (as well as opportunities in these scenarios) to ecosystems, such as climate change, urban growth and development and land use changes, and discusses how climate change will impact water resources and other environmental structures (City of Johannesburg, 2014). New York City's Department of Environmental Conservation has various guidelines and policies regarding climate change and a variety of ecosystems, biodiversity and natural features (Department of

Environmental Conservation, 2016). The local government recognises that the community and New York's natural systems are at risk of climate change and have incorporated climate change considerations into all aspects of the City's activities (Department of Environmental Conservation, 2016). Some of New York's ecosystem services policies include the New York Storm-water Management Plan and the New York's PlaNYC (Hansen *et al.,* 2015). Similar policies are implemented in South Africa, however on a national scale, which includes The White paper on the Conservation and Sustainable Use of South Africa's Biological Diversity (1997), The National Environmental Management Act (1998) and The National Climate Change Response White Paper (2011) which provide protection to various ecosystems and biodiversity and provide policies regarding climate change.

The city of Munich in Germany integrates urban ecosystem services protection in their policies by imposing fees for rainwater runoff in order to try to mitigate its effects (Aevermann and Schmude, 2015). Ecosystem services are implemented in legal frameworks around the world such as the Berlin's Biodiversity Strategy and Urban Development Plan Climate and Seattle's Open Space 2100 plan (Hansen *et al.,* 2015). Research and implementation of ecosystem services valuation and monetisation have been done in the cities of Berlin, Seattle and New York. These have been implemented by planners and various stakeholders within each city (Hansen *et al.,* 2015). The city of Munich uses municipal accounting to monetise their ecosystem services and follows the European Union Emissions Trading Scheme (EU ETS) to valuate carbon sequestration and storage (Aevermann and Schmude, 2015).

Research on ecosystem services valuation has been done by City Parks and GCRO in 2015, as well as in documents such as The Economics of Ecosystems and Biodiversity (TEEB) and through the National Biodiversity Assessment (Biodiversity Mainstreaming Toolbox, 2014). However, no further action or implementation of actual policies has occurred since then. A valuation exercise was done on green open spaces that are under the control of City Parks within the city of Johannesburg. This value was then extrapolated to the entire size of Johannesburg to try to estimate the value of ecosystem services in Johannesburg (Schäffler *et al.,* 2013). It has been recommended by Schäffler *et al.* (2013) that further long term and more robust research should be done in valuating ecosystem services in Johannesburg, as it can lead to informed decision-making and management processes. This research done by City Parks and GCRO also highlights that government needs to incorporate green infrastructure in budgeting and planning processes, and need to invest more in urban ecosystems. Therefore, the national government needs to encourage more urban ecosystem services research and support local governments in these initiatives (Schäffler *et al.,* 2013).

No future plans have been developed with regards to ecosystem service protection and maintenance, with City Parks saying that they will be using their current policies and strategies. This might not be the best course of action, as continuous monitoring and updating of strategies and policies should be done to ensure successful ecosystem protection and maintenance. With constantly changing population levels and urban development impacts and demands, policies will eventually become outdated and will therefore need to be changed to suit the current conditions. It is important to update the knowledge we have about environmental systems and their health and how this will influence the success of current policy implementation. Obsolete policies can also do more harm than good in some instances where environmental factors have changed but go unnoticed as they have not been monitored (Rive *et al*., 2006). The inadequate long-term monitoring and maintenance of ecosystem services in South Africa calls for an immediate need to evaluate and develop monitoring programmes in collaboration with governmental, private and community bodies (see Balmford *et al*., 2005; Ahern *et al*., 2014).

One important aspect regarding environmental policies is that they include all stakeholders' needs. Stakeholders will come from various disciplines, including social, ecological and governmental realms (James *et al*., 2009). The various documents provided GDARD states that they ensure that international approaches and views of stakeholders have been considered in the development of environmental guidelines. City Parks maintains that there is constant collaboration and communication between the Department of Environmental Affairs (DEA), GDARD, and local level authorities (such as themselves). However, the final say in policies remains with the national government. No mention was made about stakeholders such as the community, businesses, NGO's and scientific research councils in the Johannesburg City Parks interview and their role in creating and implementing environmental policies in Johannesburg. Documents from GDARD recognises the importance of stakeholder collaboration but admit that the biodiversity sector struggles to communicate with other sectors and stakeholders. Therefore, they have initiated a campaign to increase communication, education and public awareness regarding environmental issues in South Africa (Biodiversity Mainstreaming Toolbox, 2014). In New York City, a variety of stakeholders are involved with ecosystem services protection and management (with some even designing policies and planning efforts). These include governing bodies, partnerships, non-profit organizations, Universities and local community groups (McPhearson *et al*., 2014). Collaboration across various disciplines is important as various stakeholders will be impacted by changes in environmental policies and ecosystem health, and can contribute different information and opinions on ecosystem service protection and maintenance policies. Therefore, stakeholders and experts from different fields across Johannesburg, Gauteng and South Africa need to collaborate and communicate with each other to successfully implement ecosystem services policies within Johannesburg that will protect and enhance the benefits provided by them (Carpenter *et al*., 2009).

6 Conclusion

Johannesburg is a highly urbanised city, however it still contains a variety of natural features. In general, the measured ecosystem services in Johannesburg appear to be in good health and have good service provision, based on the specific tests measured in this study. The distribution of Johannesburg's wetlands and protected areas provides little to no connectivity potential between the ecosystems, thereby decreasing their resilience to disturbances. Rivers and roads have highly dispersed networks across the Johannesburg area, while wetlands, protected areas and rivers occur in close distances to highly urbanised areas. This proximity between natural and built-up features is one of the main risks to ecosystem degradation, which was also found in the literature review of this paper (Carpenter *et al*., 2003). Therefore, these ecosystem services need to be monitored over a long period of time to ensure that successful protection and monitoring systems are in place. Long term monitoring will also determine whether these ecosystem services are declining as was initiating reported by the Millennium Ecosystem Assessment (Fisher *et al*., 2007). Local governing bodies in collaboration with other governmental, private and community bodies need to implement long-term ecosystem service monitoring programmes through careful planning and implementation as this seems to be limited in the City of Johannesburg (van Jaarsveld *et al*., 2005).

Johannesburg's urban forest has a relatively high carbon storage value (compared to other local and national cities), and has the potential to increase. Preference should be given to underdeveloped areas in Johannesburg as highlighted by this study. All the tested water bodies are in relatively good health, with only two of the water bodies showing some concerning factors (regarding transparency, dissolved oxygen, and conductivity). However, these can be easily remediated through implementing clean-up projects and proper monitoring systems. Trees and vegetation provide critical cooling abilities in Johannesburg, which can mitigate climate change effects (increased temperatures) and can reduce fossil fuel emissions by reducing energy needs within buildings. Therefore, these urban ecosystem services do play an important role in climate change mitigation and adaptation as initially stated in the literature review of this paper (see Laughner *et al*., 2012; Strohbach and Haase, 2012; Gomez-Baggethun *et al*., 2013).

Ecosystem services in Johannesburg are protected and managed through numerous national level and some local level ecosystem protection policies and are included in climate change mitigation and adaptation policies. The majority of these policies provide general biodiversity and ecosystem protection (which provides protection to ecosystem services as a result of overall ecosystem protection), with only some policies and guidelines specifically focusing on and mentioning ecosystem services. These ecosystem services specific policies and plans are lacking at a city level in Johannesburg compared to South Africa's country level policies and other international cities. Johannesburg's local governing body recognises the importance of trees in terms of carbon storage, but does not recognise their role in local climate cooling, while it is recognised at a provincial and national level. This provides evidence of some discrepancies and miscommunications between local, provincial and national level governmental bodies. It is important to note that the environmental features measured in this study suggest that the environmental policies within Johannesburg are successful. However, this does not mean that they are successfully implemented across the entire city or with regards to other environmental features not measured in this study. National governing bodies therefore need to integrate more ecosystem services into city-level policies, and work with local authorities in terms of implementing correct monitoring systems for ecosystems and ecosystem services. This lack of policy supporting tools for ecosystem services can make it difficult to include ecosystem services in decision making, planning and management processes (de Groot *et al*., 2010). Collaboration and communication between all stakeholders from different industries and governmental levels need to occur, so that ecosystem services protection and management can be understood by everyone and be successfully implemented within Johannesburg.

The limitations of my study are that the carbon storage value only includes above ground tree biomass. Future studies should therefore include below ground biomass in its total carbon storage potential, and ideally as well as carbon stored by soils and other above ground vegetation such as grasses. This will provide a better indication of the entire carbon storage potential of Johannesburg. Another limiting factor to my study was the bias in land use types sample sizes. Increasing the number of sites and the amount of different land use types within these studies will provide more robust and accurate results. For example, including the same number of land use covers sites (in other words to not over represent one land use cover and under represent others) will improve the accuracy of the study's results. The last limiting factor of my study is only having interviewed one local governing body and analysed one provincial level governing body's various documents. It will be beneficial to interview more local and national governing bodies as it will provide a clearer picture of the level of ecosystem services protection and maintenance in Johannesburg and South Africa.

Future studies regarding trees roles in local temperature cooling should also measure land surface temperatures in conjunction with air temperatures. This will provide additional information about how land surface features are impacted by sunlight and how trees and other vegetation (which should also be considered in the future studies) will lower this impact. It will also be beneficial to determine exactly what building and vegetation layout and types will offer the best cooling potential for the city of Johannesburg. This research will be able to be applied in the real world and should result in great cooling impacts in Johannesburg. Furthermore, any future studies regarding ecosystem services should try to include more than three ecosystem services, as done in this study, if the appropriate time, resources, and funding is available.

7 References

Acreman, M., Dunbar, M.J., 2004. Defining environmental river flow requirements-a review. *Hydrology and Earth System Sciences*, 8, 861-876.

Aevermann, T. and Schmude, J., 2015. Quantification and monetary valuation of urban ecosystem services in Munich, Germany. *Zeitschrift fur Wirtschaftsgeographie*, 3, 188-200.

African Green City Index, 2011. Assessing the environmental performance of Africa's major cities. Economist Intelligence Unit, Siemens AG, Munich, Germany.

Ahern, J., 2013. Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design. *Landscape Ecology*, 28, 1203-1212.

Ahern, J., Cilliers, S., Niemela, J., 2014. The concept of ecosystem services in adaptive urban planning and design: a framework for supporting innovation. *Landscape and Urban Planning*, 125, 254-259.

Air Quality Act, 2004. The South African National Environmental Management: Air Quality Act No. 39 of 2004. Government Gazette, Cape Town, Republic of South Africa.

Akbari, H., Cartalis, C., Kolokotsa, D., Muscio, A., Pisello, A. L., Rossi, F., Santamouris, M., Synnefa, A., Wong, N. H., Zinzi, M., 2016. Local climate change and urban heat island mitigation techniques-the state of the art. Journal of Civil Engineering and Management, 22, 1-16.

Amezaga, J.M., Santamaria, L., Green, A.J., 2002. Biotic wetland connectivity-supporting a new approach for wetland policy. *Acta Oecologica*, 23, 213-222.

Andersson, L., Wilk, J., Todd, M., Hughes, D.A., Earle, A., Kniveton, D., Layberry, R., Savenije, H. H. G., 2006. Impact of climate change and development scenarios on flow patterns in the Okavango River. *Journal of Hydrology*, 331, 43-57.

Balmford, A., Bennun, L., Brink, B. T., Cooper, D., Côté, I. M., Crane, P., Dobson, A., Dudley, N., Dutton, I., Green, R. E., Gregory, R. D., Harrison, J., Kennedy, E. T., Kremen, C., Leader-Williams, N., Lovejoy, T. E., Mace, G., May, R., Mayaux, P., Morling, P., Phillips, J., Redford, K., Ricketts, T. H., Rodriguez, J. P., Sanjayan, M., Schei, P. J., van Jaarsveld, A. S., Walther, B. A., 2005. The convention on Biological Diversity's 2010 target. *Science*, 307, 212-213.

Barthel, S., Folke, C., Colding, J., 2010. Social-ecological memory in urban gardens-retaining the capacity for management of ecosystem services. *Global Environmental Change,* 20, 255-265.

Behar, S., 1997. Definition of water quality parameters, in *Testing the waters: chemical and physical vital signs of a river.* River Watch Network, Montpelier, Vermont, USA.

Biodiversity Act, 2004. The South African National Environmental Management: Biodiversity Act No. 10 of 2004. Government Gazette, Cape Town, Republic of South Africa.

Bolund, P., Hunhammar, S., 1999. Ecosystem services in urban areas. *Ecological Economics*, 29, 293-301.

Bonan, G. B., 2008. Forests and climate change: forcings, feedbacks and the climate benefits of forests. *Science*, 320, 1444-1449.

Bowler, D. E., Buyung-Ali, L., Knight, T. M., Pullin, A. S., 2010. Urban greening to cool towns and cities: a systematic review of the empirical evidence. *Landscape and Urban Planning*, 97, 147-155.

Brand, F. S., Jax, K., 2007. Focusing the meaning(s) of resilience: resilience as a descriptive concept and a boundary object. *Ecology and Society*, 12, 1-10.

Carpenter, S. R., Castilla, J. C., Choo, P. S., de Groot, R., Mooney, H. A., Naeem, S., Noble, I., Zhiyun, O., Reid, W. V., Turpie, J. K., Williams, M., Shidong, Z., 2003. Ecosystems and their services, in Gallopin, G., Kasperson, R., Munasinghe, M., Olive, L., Padoch, C., Romm, J., Vessuri, H. (Eds.), *Millennium ecosystem assessment: Ecosystems and human well-being: a framework for assessment*. Island Press, Washington, D.C., USA, pp. 49-71.

Carpenter, S. R., Bennett, E. M., Peterson, G. D., 2006. Scenarios for ecosystem services: an overview. *Ecology and Society*, 11, 1-14.

Carpenter, S. R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Diaz, S., Dietz, T., Duraiappah, A. K., Oteng-Yeboah, A., Pereira, H. M., Perrings, C., Reid, W. V., Sarukhan, J., Scholes, R. J., Whyte, A., 2009. Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment. *PNAS,* 106, 1305-1312.

Chapin, F. S., Matson, P. A., Mooney, H. A., 2011. *Principles of terrestrial ecosystem ecology*. Springer Publishing, New York, USA.

Cilliers, S., 2010. Social aspects of urban biodiversity- an overview, in Muller, N., Werner, P., Kelcey, J. G. (Eds.), *Urban Biodiversity and Design*. Wiley's and Sons Ltd, West Sussex, United Kingdom, pp. 81-98.

Cilliers, S., Cilliers, J., Lubbe, R., Siebert, S., 2013. Ecosystem services of urban green spaces in African countries- perspectives and challenges. *Urban Ecosystems,* 16, 681-702.

City of Johannesburg, 2008. State of the Environment Report. Department of Environmental Affairs, Johannesburg, South Africa.

City of Johannesburg, 2012. Bruma Lake gets a dose of cleanliness. *City of Johannesburg* 28 June (http://www.joburg.org.za/index.php?option=com_content&view=article&id=1278:bruma-lake-clean-up-under-way&catid=120:environment&Itemid=201). Accessed 3 March 2017.

City of Johannesburg, 2013. Department of environment and infrastructures services. *City of Johannesburg* 18 January (http://joburg.org.za/index.php?option=com_content&view=article&id=7644:department-of-environment-infrastructure-and-services&catid=138:environment&Itemid=78). Accessed 7 June 2016.

City of Johannesburg, 2014. Infrastructure Planning and Storm Water Management Plans. *City of Johannesburg* 15 April (https://joburg.org.za/images/October/1d.pdf). Accessed 24 May 2017.

Concepcion, E. D., Moretti, M., Altermatt, F., Nobis, M. P., Obrist, M. K., 2015. Impacts of urbanisation on biodiversity: the role of species mobility, degree of specialisation and spatial scale. *Oikos*, 124, 1571-1582.

Costanza, R., 2000. Social goals and the valuation of ecosystem services. *Ecosystems*, 3, 4-10.

Dallas, H., 2008. Water temperature and riverine ecosystems: An overview of knowledge and approaches for assessing biotic responses, with special reference to South Africa. *Water South Africa*, 34, 393-404.

de Groot, R. S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, 7, 260-272.

Department of Environmental Affairs, 2012. Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (https://www.environment.gov.za/projectsprogrammes/ipbes). Accessed 13 May 2016.

Department of Environmental Affairs, 2017. Acts and Regulations (https://www.environment.gov.za/legislation/actsregulations). Accessed 10 June 2017.

Department of Environmental Conservation, 2016. Guidance and Policy Documents (http://www.dec.ny.gov/regulations/397.html). Accessed 25 May 2017.

Department of Water Affairs and Forestry, 1996. South African Water Quality Guidelines (second edition). Volume 2: Recreational use. CSIR Environmental Services, Pretoria, South Africa.

Dickens, C. W. S., Graham, P. M., 2002. The South African Scoring System (SASS) version 5 rapid bio-assessment method for rivers. *African Journal of Aquatic Science*, 27, 1-10.

Egoh, B., Reyers, B., Carwardine, J., Bode, M., O'Farrell, P. J., Wilson, K. A., Possingham, H. P., Rouget, M., De Lange, W., Richardson, D. M., Cowling, R. M., 2010. Safeguarding biodiversity and ecosystem services in the Little Karoo, South Africa. *Conservation Biology*, 24, 1021-1030.

Egoh, B., Reyers, B., Rouget, M., Bode, M., Richardson, D. M., 2009. Spatial congruence between biodiversity and ecosystem services in South Africa. *Biological Conservation*, 142, 553-562.

Elmqvist, T., Fragkias, M., Goodnes, J., Guneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schwewenius, M., Sendstad, M., Seto, K. C., Wilkinson, C., 2013. *Urbanisation, Biodiversity and Ecosystem Services: Challenges and Opportunities.* Springer, Dordrecht, Netherlands.

Endlicher, W., Langner, M., Hesse, M., Mieg, H. A., Kowarik, I., Hostert, P., Kulke, E., Nutzmann, G., Schulz, M., van der Meer, E., Wessolek, G., Wiegand, C., 2014. Urban ecology- definitions and concepts, in Langner, M. and Endlicher, W. (Eds.), *Shrinking cities: effects on urban ecology and challenges for urban development*. Peter Lang Press, Frankfurt, Germany, pp. 1-15.

Engelbrecht, C. J., Engelbrecht, F. A., Dyson, L. L., 2012. High-resolution model-projected changes in mid-tropospheric closed-lows and extreme rainfall events over southern Africa. *International Journal of Climatology*, 33, 173-187.

Environmental Conservation Act, 1992. The South African Environmental Conservation Act No. 79 of 1992. Government Gazette, Cape Town, Republic of South Africa.

Environmental Planning and Climate Protection Department, 2009. The value of Durban's biological diversity. eTthekwini municipality environmental management department, Durban, South Africa.

Ernstson, H., van der Leeuw, S. E., Redman, C. L., Meffert, D. J., Davis, G., Alfsen, C., Elmqvist, T., 2010. Urban transitions: on urban resilience and human-dominated ecosystems. *AMBIO a Journal of the Human Environment,* 1-22.

European Union, 2014. Mapping and Assessment of ecosystems and their services. European Commission, Ispra, Italy.

Fatti, C., 2014. Community adaptation and mitigation of storm and flood risk: the influence of knowledge and community perceptions in the case study of Ekurhuleni. MSc thesis, University of the Witwatersrand, Johannesburg, South Africa.

Fisher, B., Costanza, R., Turner, R. K., Morling, P., 2007. Defining and classifying ecosystem services for decision making. Working paper, Centre for Social and Economic Research on the Global Environment (CSERGE), University of East Anglia, Norwich, United Kingdom.

GCRO, 2013. *Land use map of South Africa*. Gauteng City-Region Observatory, Gauteng, South Africa.

GDARD, 2013. *Conservation Plan 2 for South Africa*. Gauteng Department of Agriculture and Rural Development, Gauteng, South Africa.

GDARD, 2013. *Protected areas map of South Africa*. Gauteng Department of Agriculture and Rural Development, Gauteng, South Africa.

GDARD, 2013. *Wetlands map of South Africa*. Gauteng Department of Agriculture and Rural Development, Gauteng, South Africa.

GDARD, 2013. *River network map of South Africa*. Gauteng Department of Agriculture and Rural Development, Gauteng, South Africa.

GDARD, 2013. *Road network map of South Africa*. Gauteng Department of Agriculture and Rural Development, Gauteng, South Africa.

GDARD, 2006. *Ridges Guidelines*. Gauteng Department of Agriculture and Rural Development, Gauteng, South Africa, viewed 9 October 2017, (https://mail.google.com/mail/u/0/#inbox/15ef1af9b11286fa?projector=1).

GDARD, 2014. *Requirements for Biodiversity Assessments*. Department of Agriculture and Rural Development, Gauteng, South Africa, viewed 9 October 2017, (https://mail.google.com/mail/u/0/#inbox/15ef1af9b11286fa?projector=1).

GDARD, 2011. *Gauteng Conservation Plan version 3.3*. Department of Agriculture and Rural Development, Gauteng, South Africa, viewed 9 October 2017, (http://gekco.co.za/wp-content/uploads/2013/07/Gauteng_Cplan33.pdf).

GDARD, 2017. *The Gauteng Pollution Buffer Zone guidelines*. Department of Agriculture and Rural Development, Gauteng, South Africa, viewed 9 October 2017, (http://www.gauteng.gov.za/media/Pages/Publications.aspx).

GDARD, 2014. *The Environmental Management Framework Report*. Department of Agriculture and Rural Development, Gauteng, South Africa, viewed 9 October 2017, (http://www.gdard.gpg.gov.za/Pages/Gauteng-Provincial-EMF.aspx).

GDARD, 2017. *The Gauteng Sustainable Development Guideline.* Department of Agriculture and Rural Development, Gauteng, South Africa, viewed 9 October 2017, (http://www.gauteng.gov.za/Pages/Home.aspx).

GDARD, 2017. *The Gauteng Provincial Environmental Management Framework Standards*. Department of Agriculture and Rural Development, Gauteng, South Africa, viewed 9 October 2017, (http://www.gdard.gpg.gov.za/Pages/Gauteng-Provincial-EMF.aspx).

GDARD, 2017. *The EMF Revised Section B- Environmental Management Zones*. Department of Agriculture and Rural Development, Gauteng, South Africa, viewed 9 October 2017, (http://www.gauteng.gov.za/Pages/Home.aspx).

Getter, K. L., Rowe, D.B., 2006. The role of extensive green roofs in sustainable development. *The American Society for Horticultural Science*, 41, 1276-1285.

Gill, S. E., Handley, J. F., Ennos, A. R., Pauleit, S., 2007. Adapting cities for climate change: the role of the green infrastructure. *Built Environment*, 33, 115-133.

Goldenberg, S. B., Landsea, C. W., Mestas-Nunez, A. M., Gray, W. M., 2001. The recent increase in Atlantic hurricane activity: causes and implications. *Science*, 293, 474-479.

Gomez-Baggethun, E., Barton, D. N., 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, 86, 235-245.

Gomez-Baggethun, E., Gren, A., Barton, D. N., Langemeyer, J., McPhearson, T., O'Farrell, P., Andersson, E., Hamstead, Z., Kremer, P., 2013. Urban ecosystem services, in Elmqvist, T., Goodness, J., Marcotullio, P. J., Parnell, S., Sendstad, M., Wilkinson, C., Fragkias, M., Guneralp, B., McDonald, R. I., Schewenius, M. and Seto, K. C. (Eds.), *Urbanization, biodiversity and ecosystem services: challenges and opportunities*. Springer, Dordrecht, Netherlands, pp. 175-251.

Greyling, L. M., 2000. Hawks, habitats and humans: aspects of land transformation and raptor conservation in South Africa. MSc thesis, University of Cape Town, Cape Town, South Africa.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., Briggs, J. M., 2008. Global change and the ecology of cities. *Science,* 319, 756-760.

Hamel, P., Daly, E., Fletcher, T. D., 2013. Source-control stormwater management for mitigating the impacts of urbanisation on baseflow: a review. *Journal of Hydrology*, 485, 201-211.

Hansen, R., Frantzeskaki, N., McPhearson, T., Rall, E., Kabisch, N., Kaczorowska, A., Kain, J. H., Artmann, M., Pauleit, S., 2015. The uptake of the ecosystem services concept in planning discourses of European and American cities. *Ecosystem Services*, 12, 228-246.

Imhoff, M. L., Zhang, P., Wolfe, R. E., Bounoua, L., 2010. Remote sensing of the urban heat island effect across biomes in the continental USA. *Remote Sensing of Environment*, 114, 504-513.

James, P., Tzoulas, K., Adams, M. D., Barber, A., Box, J., Breuste, J., Elmqvist, T., Frith, M., Gordon, C., Greening, K. L., Handley, J., Haworth, S., Kazmierczak, A. E., Johnston, M., Korpela, K., Moretti, M., Niemela, J., Pauleit, S., Roe, M. H., Sadler, J.P., Thompson, C. W., 2009. Towards an integrated understanding of green space in European built environment. *Urban Forestry and Urban Greening*, 8, 65-75.

Janos, P., 2006. Braun-Blanquet's legacy and data analysis in vegetation science. *Journal of Vegetation Science*, 17, 113-117.

Johannesburg City Parks and Johannesburg Zoo, 2015. Trees that sequester carbon dioxide and ways to prevent sequestered carbon dioxide to be released back into the atmosphere. Johannesburg City Parks and Johannesburg Zoo, Johannesburg, South Africa.

Johannesburg City Parks and Johannesburg Zoo, 2017. Integrated Catchment Management report 2017. Johannesburg City Parks and Johannesburg Zoo, Johannesburg, South Africa.

Johannesburg Development Agency, 2016. Johannesburg Development Agency: Building a better city (http://www.jda.org.za/index.php/latest-news/1821-new-look-bruma-lake-set-to-bring-in-major-investment). Accessed 21 June 2017.

Jones, B., 2011. Oxygen- The most important water quality parameter? *Water Column*, 23, 1-5 (http://www.indiana.edu/~clp/documents/water_column/Water_Col_V23N1.pdf). Accessed 20 June 2017.

Kannel, P. R., Lee, S., Lee, Y. S., Kanel, S. R., Khan, S. P., 2007. Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment. *Environmental Monitoring and Assessment*, 132, 93-110.

Kiffney, P.M., Greene, C.M., Hall, J.E, Davies, J.R., 2006. Tributary streams cause spatial discontinuities in habitat, biological productivity, and diversity in mainstream rivers. *Canadian Journal of Fisheries and Aquatic Sciences*, 63, 2518-2530.

Kikegawa, Y., Genchi, Y., Kondo, H., Hanaki, K., 2006. Impacts of city-block-scale countermeasures against urban heat-island phenomena upon a building's energy-consumption for air-conditioning. *Applied Energy*, 83, 649-668.

Kinzig, A. P., Warren, P., Martin, C., Hope, D., Katti, M., 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. *Ecology and Society*, 10, 1-13.

Kleerekoper, L., van Esch, M., Salcedo, T.B., 2012. How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling*, 64, 30-38.

Kroll, F., Muller, F., Haase, D., Fohrer, N., 2012. Rural-urban gradient analysis of ecosystem services supply and demand dynamics. *Land Use Policy*, 29, 521-535.

Kromberg, J. G., Castle, D., Zwane, E. M., Jenkins, T., 2008. Albinism and skin cancer in Southern Africa. *Clinical Genetics*, 36, 43-52.

Kuruneri-Chitepo, C. and Shackleton, C. M., 2011. The distribution, abundance and composition of street trees in selected towns of the Eastern Cape, South Africa. *Urban Forestry and Urban Greening*, 10, 247-254.

Larondelle, N., Haase, D., 2013. Urban ecosystem service assessment along a rural-urban gradient: a cross-analysis of European cities. *Ecological Indicators*, 29, 179-190.

Larigauderie, A., Mooney, H. A., 2010. The Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services: moving a step closer to an IPCC-like mechanism for biodiversity. *Current Opinion in Environmental Sustainability*, 2, 1-6.

Lehner, B. and Grill, G., 2013. Global river hydrography and network routing: baseline data and new approaches to study the worlds large river systems. *Hydrological Processes*, 27, 2171-2186.

Leichenko, R., 2011. Climate change and urban resilience. *Current Opinion in Environmental Sustainability*, 3, 164-168.

Le Maitre, D. C., O'Farrell, P. J., Reyers, B., 2007. Ecosystem services in South Africa: a research theme that can engage environmental, economic and social scientists in the development of sustainability science? *South African Journal of Science*, 103, 367-376.

Lembani, R. L., 2015. Greening Soweto: calculating above-ground tree biomass, stored carbon and net economic value. MSc thesis, University of the Witwatersrand, Johannesburg, South Africa.

Linnenluecke, M. and Griffiths, A., 2010. Beyond adaptation: resilience for business in light of climate change and weather extremes. *Business and Society*, 49, 477-511.

Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., Pell, A. N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C. L., Schneider, S. H., Taylor, W. W., 2007. Complexity of coupled human and natural systems. *Science*, 317, 1513-1516.

Lougner, C. P, Allen, D. J., Zhang, D., Pickering, K. E., Dickerson, R. R., Landry, L., 2012. Roles of urban tree canopy and buildings in urban heat island effects: parameterization and preliminary results. *Journal of Applied Meteorology and Climatology*, 51, 1775-1793.

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schagner, J. P., Grizzetti, B., Drakou, E. G., La Notte, A., Zulian, G., Bouraoui, F., Paracchini, M. L., Braat, L., Bidoglio, G., 2012. Mapping ecosystem services for policy support and decision making in the European Union. *Ecosystem Services*, 1: 31-39.

McCarthy, J. J., Canziana, O. F., Leary, N. A., Dokken, D. J., White, K. S., 2014. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. The Press Syndicate of the University of Cambridge, Cambridge, United Kingdom.

McCoy, J., Johnston, K., Kopp, S., Borup, B., Willison, J., Payne, B., 2002. ArcGIS 9. Using ArcGIS Spatial Analyst. ESRI, California, United States of America.

McIntyre, N. E., Knowles-Yanez, K., Hope, D., 2000. Urban ecology as an interdisciplinary field: differences in the use of "urban" between social and natural sciences. *Urban Ecosystems*, 4, 5-24.

McKinney, M.L., 2008. Effects of urbanisation on species richness: A review of plants and animals. *Urban Ecosystem*, 11, 161-176.

McPhearson, T., Hamstead, Z. A., Kremer, P., 2014. Urban ecosystem services for resilience planning and management in New York City. *Ambio*, 43, 502-515.

Millennium Ecosystem Assessment, 2003. Ecosystems and their services, in *Ecosystems and human well-being: a framework for assessment*. Island Press, Washington, D.C., USA, pp. 49-71.

Mills, A.J., O'Connor, T.G., Donaldson, J.S., Fey, M.V., Skowno, A.L., Segwela, A.M., Lechmere-Oertel, R.G., Bosenberg, J.D., 2005. Ecosystem carbon storage under different land uses in three semi-arid shrublands and a mesic grassland in South Africa. *South African Journal of Plant and Soil*, 22, 183-190.

Mucina, L. and Rutherford, M. C. (Eds.), 2006. *The vegetation of South Africa, Lesotho and Swaziland*. Strelitzia, South African National Biodiversity Institute, Pretoria, South Africa.

Murray, M. J., 2009. Fire and ice: unnatural disasters and the disposable urban poor in post-apartheid Johannesburg. *International Journal of Urban and Regional Research*, 33, 165-192.

Naiman, R.J., Latterell, J.J., Pettit, N. E., Olden, J.D., 2008. Flow variability and the biophysical vitality of river systems. *Comptes Rendus Geosciences*, 340, 629-643.

National Water Act, 1998. The South African National Water Act No. 36 of 1998. Government Gazette, Cape Town, Republic of South Africa.

NEMA, 1998. The South African National Environmental Management Act No. 107 of 1998. Government Gazette, Cape Town, Republic of South Africa.

Nowak, D. J. and Crane, D. E., 2002. Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution*, 116, 381-389.

Nowak, D.J., Stevens, J.C., Sisinni, S.M., Luley, C.J., 2002. Effects of urban tree management and species selection on atmospheric carbon dioxide. *Journal of Arboriculture*, 28, 113- 122.

Ogbeibu, A. E. and Oribhabor, B. J., 2002. Ecological impact of river impoundment using benthic macro-invertebrates as indicators. *Water Research*, 36, 2427-2436.

Pejchar, L., Mooney, H. A., 2009. Invasive species, ecosystem services and human well-being. *Trends in Ecology and Evolution*, 24, 497-504.

Peng, S., Piao, S., Ciaia, P., Friedlingstein, P., Ottle, C., Bre, F., Nan, H., Zhou, L., Myneni, R. B., 2012. Surface urban heat island across 419 global big cities. *Environmental Science and Technology*, 46, 696-703.

Perrings, C., Duraiappah, A., Larigauderie, A., Mooney, H., 2011. The biodiversity and ecosystem services science-policy interface. *Science*, 331, 1139-1140.

Perry, T. O., 1978. Trees and their typical ages and growth rates. *METRIA Proceedings*, 1, 1-12.

Phiri, O., Mumba, P., Moyo, B. H. Z., Kadewa, W., 2005. Assessment of the impact of industrial effluents on water quality of receiving rivers in urban areas of Malawi. *International Journal of Environmental Science and Technology*, 3, 237-244.

Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., Li, J., Zhou, L., Liu, H., Ma, Y., Ding, Y., Friedlingstein, P., Liu, C., Tan, K., Yu, Y., Zhang, T., Fang, J., 2010. The impacts of climate change on water resources and agriculture in China. *Nature*, 467, 43-51.

Pickett, S. T. A., Cadenasso, M. L., Grove, Groffman, P. M., Band, L. E., Boone, C. G., Burch, W. R., Grimmond, C. S. B., Hom, J., Jenkins, J. C., Law, N. L., Nilon, C. H., Pouyat, R. V., Szlavecz, K., Warren, P. S., Wilson, M. A., 2008. Beyond urban legends: an emerging framework of urban ecology, as illustrated by the Baltimore ecosystem study. *BioScience*, 58, 139-150.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., Costanza, R., 2008. Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Urban Ecology*, 99-122.

Pike, A., Dawley, S., Tomaney, J., 2010. Resilience, adaptation and adaptability. *Cambridge Journal of Regions, Economy and Society*, 3, 59-70.

Pijoos, I., 2016. Conflicting reports over death toll in Johannesburg flash floods. News24 10 November (http://www.news24.com/SouthAfrica/News/conflicting-reports-over-death-toll-in-johannesburg-flash-floods-20161110). Accessed 1 June 2017.

Poore, M.E.D., 1955. The use of phytosociological methods in ecological investigations: I. The Braun-Blanquet System. *Journal of Ecology*, 43, 226-244.

Protected Areas Act, 2003. The South African National Environmental Management: Protected Areas Act No. 57 of 2003. Government Gazette, Cape Town, Republic of South Africa.

Radhi, H., Fikry, F., Sharples, S., 2013. Impacts of urbanisation on the thermal behaviour of new built up environments: a scoping study of the urban heat island in Bahrain. *Landscape and Urban Planning*, 113, 47-61.

Reed, M. S., 2008. Stakeholder participation for environmental management: a literature review. *Biological Conservation*, 141, 2417-2431.

Riiters, K. H. and Wickham, J. D., 2003. How far to the nearest road? *Frontiers in Ecology and the Environment,* 1, 125-129.

Rive, N., Torvanger, A., Fuglestvedt, J.S., 2006. Climate agreements based on responsibility on global warming: periodic updating, policy choices, and regional costs. *Global Environmental Change*, 16, 182-194.

Roberts, D., 2010. Prioritising climate change adaptation and local level resilience in Durban, South Africa. *Environment and Urbanisation*, 22, 397-413.

Rogerson, C.M., 2002. Urban tourism in the developing world: The case of Johannesburg. *Development South Africa*, 19, 169-190.

Rosenzweig, C., Solecki, W., Parshall, L., Gaffin, S., Lynn, B., Goldberg, R., Cox, J., Hodges, S., 2009. Mitigating New York City's heat island with urban forestry, living roofs and light surfaces. *American Meteorology Society*, 23, 1297-1312.

SANBI, 2012. *Land cover map of South Africa*. The South African National Biodiversity Institute, South Africa.

SANBI, 2014. *Biodiversity Mainstreaming Toolbox for Land-use Planning and Development in Gauteng*. The South African National Biodiversity Institute, South Africa, viewed 9 October 2017, (http://biodiversityadvisor.sanbi.org/wp-content/uploads/2014/12/Gauteng-Biodiversity-Mainstreaming-Toolbox_final.pdf).

Sarrat, C., Lemonsu, A., Masson, V., Guedalia, D., 2006. Impact of urban heat island on regional atmospheric pollution. *Atmospheric Environment*, 40, 1743-1758.

Schäffler, A., Swilling, M., 2013. Valuing green infrastructure in an urban environment under pressure-the Johannesburg case. *Ecological Economics*, 86, 246-257.

Schäffler, A., Bobbins, K., Nhlozi, M. W., Otto, E., de Wit, M., van Zyl, H., Crookes, D. J., 2013. State of green infrastructure in the Gauteng city-region. *Gauteng City-Region Observatory,* Johannesburg, South Africa.

Shashua- Bar, L., Hoffman, M. E., 2000. Vegetation as a climatic component in the design of an urban street: an empirical model for predicting the cooling effect of urban green areas with trees. *Energy and Building*, 31, 221-235.

Shrestha, S., Kazama, F., 2007. Assessment of surface water quality using multivariate statistical techniques: a case study of the Fuji river basin, Japan. *Environmental Modelling and Software*, 22, 464-475.

Solecki, W. and Marcotullio, P.J., 2013. Climate change and urban biodiversity vulnerability, in Elmqvist, T., Fragkia, M., Goodness, J., Guneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C., Wilkinson, C. (Eds.), *Urbanisation, Biodiversity and Ecosystem Services: Challenge and Opportunities*. Springer, New York, USA, pp.485-504.

StatsSA, 2011. City of Johannesburg Census. *Statistics South Africa* (http://www.statssa.gov.za/?page_id=993&id=city-of-johannesburg-municipality). Accessed 20 June 2017.

Stoffberg, G.H., van Rooyen, M.W., van der Linde, M.J., Groenewald, H.T., 2010. Carbon sequestration estimates of indigenous street trees in the city of Tshwane, South Africa. *Urban Forestry and Urban Greening*, 9, 9-14.

Strohbach, M. W. and Haase, D., 2012. Above-ground storage by urban trees in Leipzig, Germany: analysis of patterns in a European city. *Landscape and Urban Planning*, 104, 95-104.

TEEB- The economics of ecosystems and biodiversity. 2011. TEEB manual for cities: ecosystem services in urban management (http://www.teebweb.org/). Accessed 21 March 2016.

The Citizen, 2016. Flood cause mayhem, leave six dead in Ekurhuleni. The Citizen 10 November (https://citizen.co.za/news/south-africa/1341092/floods-cause-mayhem-leave-six-dead-in-ekurhuleni-2/). Accessed 30 November 2017.

The National Framework for Sustainable Development, 2008. The South African National Framework for Sustainable Development. Government Gazette, Cape Town, Republic of South Africa.

The *National Climate Change Response White Paper*- The Department of Environmental Affairs (published in 2011). Government Gazette, Cape Town, Republic of South Africa.

The South African Weather Service, 2016. Johannesburg temperature records. The South African Weather Service: WeatherSA (http://www.weathersa.co.za/climate/historical-rain-maps). Accessed 13 April 2016.

The South African Weather Service, 2017. Warning Reports. The South African Weather Service: WeatherSA (http://www.weathersa.co.za/warnings?region=rsa). Accessed 22 June 2017.

The *White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity* (published in 1997). Government Gazette, Cape Town, Republic of South Africa.

Thomas, S.C., Malczewski, G., 2007. Wood carbon content of tree species in eastern China: Interspecific variability and the importance of the volatile fraction. *Journal of Environmental Management*, 85, 659-662.

Tidball, K. G., Krasny, M. E., 2007. From risk to resilience: what role for community greening and civic ecology in cities?, in Arjen, W. (Eds.), *Social learning towards a more sustainable world.* Wageningen Academic Publishers, Wageningen, the Netherlands, pp. 149-164.

Tietema, T., 1993. Biomass determination of fuelwood trees and bushes of Botswana, Southern Africa. *Forest Ecology and Management*, 60, 257-269.

Tratalos, J., Fuller, R. A., Warren, P. H., Davie, R. G., Gaston, K. J., 2007. Urban form, biodiversity potential and ecosystem services. *Landscape and Urban Planning*, 83, 308-317.

Turpie, J. K., Marais, C., Blignaut, J. N., 2008. The working for water programme: evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. *Ecological Economics*, 65, 788-798.

UNESCO/WHO/UNEP, 1996. *Water quality assessments: a guide to use biota, sediments and water in environmental monitoring*, second edition, Chapman, D (Eds.), E and EF Spon, University Press, Cambridge, Great Britain.

UNICEF, 2008. *UNICEF Handbook on water quality*, United Nations Children Fund, New York, USA.

van Jaarsveld, A. S., Biggs, R., Scholes, R. J., Bohensky, E., Reyers, B., Lynam, T., Musvoto, C., Fabricius, C., 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAfMA) experience. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 360, 425-441.

Van Vliet, M. T. H., Franssen, W. H. P., Yearsley, J. R., Ludwig, F., Haddeland, I., Lettenmaier, D. P., Kabat, P., 2013. Global river discharge and water temperature under climate change. *Global Environmental Change*, 23, 450-464.

Waste Act, 2008. Th South African National Environmental Management: Waste Act No. 59 of 2008. Government Gazette, Cape Town, Republic of South Africa.

Williams, C.A., Reichstein, M., Buchmann, N., Baldocchi, D., Beer, C., Schwalm, C., Wohlfahrt, G., Hasler, N., Bernhofer, C., Foken, T., Papale, D., Schymanski, S., Schaefer, K., 2012. Climate and vegetation controls on the surface water balance: Synthesis of evapotranspiration measured across a global network of flux towers. *Water Resources Research*, 48, 1-13.

Whitehead, P. G., Wilby, R. L., Battarbee, R. W., Kernan, M., Wade, A. J., 2009. A review of the potential impacts of climate change on surface water quality. *Hydrological Sciences Journal des Sciences Hydrologiques*, 54, 101-123.

Wu, J., 2010. Urban sustainability: an inevitable goal of landscape research. *Landscape Ecology*, 25, 1-4.

Yli-Pelkonen, V., Niemela, J., 2005. Linking ecological and social systems in cities: urban planning in Finland as a case. *Biodiversity and Conservation*, 14, 1947-1967.

Zianis, D., Mencuccini, M., 2004. On simplifying allometric analyses of forest biomass. *Forest Ecology Management*, 187, 311-332.

8 Appendices

Appendix I: Questionnaire

Interviewee´s particulars

Organization: Interviewee (code):

Position at organization: Department:

<u>Questions:</u>

1) What are the main challenges in creating and implementing environmental policies within Johannesburg?

2) Does Johannesburg have specific environmental policies to protect urban ecosystem services?

3) Are ecosystem services protection and maintenance considered in Johannesburg’s “open space management” strategy? If yes, please elaborate. If not, please explain why.

4) Can you please elaborate on the City's "maintenance and management of the urban forest" programme? Specifically progress on the tree census and tree by-laws?

5) Does the city recognise the various benefits that trees provide in terms of carbon storage and local temperature cooling?

6) How would you describe the link between urban ecosystem services and climate change mitigation and adaptation?

7) Is ecosystem connectivity considered in urban and open space planning? If so, please elaborate. If not, please explain why.

8) How would you describe the current health of Johannesburg's rivers and wetlands?

____

____

9) What are the main challenges in keeping Johannesburg's rivers and wetlands in good condition?

____

____

10) What possible ecosystem degradation risks are present in Johannesburg?

____

____

11) Can you please discuss some of the city's future plans regarding the protection and maintenance urban ecosystem services?

____

____

12) What plans are in place to reduce the impacts of increased population and urban development on the environment and ecosystems?

____

____

13) What is the city's main focus and goals in their climate change mitigation and adaptation plans?

____

____

14) Are there any future plans in the pipeline regarding the valuing of ecosystem services within the city of Johannesburg?

____

____

Appendix II: Carbon Storage Calculations

Carbon Method 1:

Site		Average tree size	Number of trees in site		DBH	radius	Y	Stored carbon	Total stored carbon
7		31.8	3874		10.12225438	5.06112719	32.1916553	14.49	56119.71
1		118.6	2165		37.7515525	18.87577625	692.0903131	311.44	674268.99
19		92	1006		29.28450953	14.64225476	382.8977774	172.30	173337.82
16		74.3	1873		23.65042454	11.82521227	232.6949212	104.71	196126.91
9		47	1905		14.96056465	7.480282325	80.02245386	36.01	68599.25
2		67.5	2820		21.48591732	10.74295866	186.0490305	83.72	236096.22
18		134.8	1098		42.90817266	21.45408633	932.7545542	419.74	460874.03
8		9.4	401		2.99211293	1.496056465	1.879544353	0.85	339.16
10		45.6	2009		14.51493081	7.257465405	74.57640305	33.56	67420.80
4		72.4	2726		23.04563576	11.52281788	219.0608798	98.58	268721.98
13		94.4	1918		30.04845326	15.02422663	406.5845782	182.96	350923.15
12		88.7	3230		28.2340869	14.11704345	351.6467035	158.24	511118.48
14		156.8	2289		49.91099015	24.95549508	1326.779554	597.05	1366649.28
15		69.9	2027		22.24986104	11.12493052	201.8336521	90.83	184102.57
5		53.4	1226		16.99774792	8.498873961	107.7554734	48.49	59448.69
6		115.7	928		36.82845383	18.41422692	653.2863297	293.98	272812.37
3		26.1	1807		8.307888029	4.153944015	20.31383273	9.14	16518.19
20		116.5	965		37.08310174	18.54155087	663.8632753	298.74	288282.63
11		51.8	473		16.4884521	8.244226052	100.3797204	45.17	21365.82
17		28.7	2624		9.135493733	4.567746867	25.34645941	11.41	29929.10

Method 1: extrapolation:

	JHB size	Sites size		Total carbon for 20 sites
	1644.58	20		5303055.16
	82.229			
Total carbon for JHB	436064922.8			

Carbon Method 2:

Number of trees	Site	Average tree circumference	Average height	Average volume
3874	Klipriviersberg	46.558	1.1118	0.71
2165	Meredale	115.248	1.3822	0.75
3230	Elandspark	107.5433	1.347	0.78
928	Ellis Park	100.4842	1.53052	0.73
1918	Kengsington	144.05833	1.65833	0.72
2820	Northcliffe	72.7	0.91	0.67
2624	Melville	18.04	0.72	0.51
2726	Morningside	71.93	1.36	0.68
1098	Quentin	114.86	1.34	0.64
1006	Robertsham	88	1.46	0.59

DBH	sqm Basal Area	Stem Volume	Total tree volume	Biomass	Stored Carbon	Total stored carbon
14.81987168	0.01724959	0.013424666	0.04629195	0.032404365	0.016202183	62.76725564
36.68457776	0.105695605	0.102264726	0.409058904	0.286341233	0.143170617	309.9643848
34.23209558	0.092035813	0.086780568	0.394457128	0.27611999	0.138059995	445.9337834
31.98511427	0.080349965	0.08608406	0.318829853	0.223180897	0.111590449	103.5559364
45.85519063	0.165145555	0.191706079	0.684664569	0.479265198	0.239632599	459.6153251
23.14112873	0.042059001	0.026791584	0.081186618	0.056830633	0.028415316	80.13119193
5.742310347	0.002589782	0.00130525	0.002663776	0.001864643	0.000932322	2.446411637
22.89603011	0.041172786	0.039196492	0.122489039	0.085742327	0.042871164	116.8667919
36.56107353	0.104985123	0.098476045	0.27354457	0.191481199	0.095740599	105.1231781
28.01126998	0.061624794	0.062980539	0.153611072	0.10752775	0.053763875	54.08645838

Method 2: Extrapolation:

Using site 2: Total Biomass	Volume per H	Biomass per H	Carbon stock per H	Carbon stock for JHB
18.2142606	72.8570424	50.99992968	25.49996484	4193673.218

Using site 3: Total Biomass	Volume per H	Biomass per H	Carbon stock per H	Carbon stock for JHB
5.796703578	23.18681431	16.23077002	8.115385009	1334639.988

Method 2: Extrapolation using Method 1:

	Size of JHB	total carbon for 10 sites	Size of sites
	1644.5	1740.5	10
	164.45		
Total Carbon for JHB	286225.225		