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An Assessment of the Environmental Impacts of Urban Sprawl in Buffalo City Metropolitan Municipality, Eastern Cape Province

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Date: 6/02/2019

ABSTRACT

Large industrial and residential developments near towns and along highways associated with public policies have transformed the pattern of development over the recent years, creating a new urbanisation phenomenon; urban sprawl. Indiscriminate population densities, discontinuous and fragmented settlements, largely define urban sprawl. The progression of urban sprawl can be described by transformation in pattern over time, like proportional increase in built-up surface to population leading to rapid urban spatial expansion. Stemming an understanding from the processes, causes and patterns of urban sprawl, the consequences of sprawl on land and vegetation can be analysed.

Environmental impacts to both the rural and urban population emanate from such instances, creating an excessive liability to the government. With attention to this and recognising the lack of discussion on the matter, the research deliberates some of the impacts observed in Buffalo City Metropolitan Municipality, Eastern Cape, South Africa. The study makes use of Geographic Information Systems and Remote Sensing with the assistance of landscape metrics. The influence of urban sprawl in this municipality has revealed impacts on vegetation, green areas and land in general. The results disclose that urban sprawl is a multidimensional phenomenon that is better explained using various methods (indices). Buffalo City Metropolitan municipality is located in Eastern Cape amidst the thicket ecosystem, the municipality has grown and expanded over the recent past. The study spread over an 18-year period from 1994- 2012. Based on field surveys and SPOT imagery, built-up areas of BCMM was extracted for different periods. Data used for the study are census data for BCMM, 1994, 2000, 2006 and 2012 SPOT images, images of BCMM acquired from Google earth 2018. The rate of transformation of the area was calculated and it was higher compared to that of population growth. Based on this data urban growth are analysed with the assistance of landscape metrics that include Shannon entropy. The outcomes confirm that this metropolitan municipality has experienced sprawl and sprawl has done so at cumulative rate.

KEYWORDS AND PHRASES

Urban sprawl, Sprawl indices, urban planning, Entropy, RS

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ACRONYMS AND ABBREVIATIONS

AI	Aggregation Index
BCMM	Buffalo City Metropolitan Municipality
CBD	Central Business District
CD	Change Detection
CNES	Centre National d'Etudes Spatiales
DN	Digital Number
DOS	Dark Object Subtraction
ETM	Enhanced Thematic Mapper
FRAGSTATS	Fragmentation Statistics
GCP	Ground Control Point
GPS	Global Positioning System
GIS	Geographic Information System
HRV	High-Resolution Visible
HRVIR	High-Resolution Visible Infra-Red
ISODATA	Iterative Self Organizing Data Analysis Technique
LANDSAT	Land Satellite
LPI	Largest Patch Index
LULC	Land Use Land Cover
ML	Maximum Likelihood
MDG	Millennium Development Goals
MODIS	Moderate Resolution Imaging Spectroradiometer
PA	Producer’s Accuracy
PCA	Principal Component Analysis
PCC	Post- Classification Comparison
PDI	Patch Density Index
OA	Overall Accuracy
OBIA	Object-Based Image Analysis
ROI	Region Of Interest
SANBI	South Africa National Biodiversity Institute
SANSA	South African National Space Agency
SPOT	Satellite Pour l’Observation de la Terre
TID	Temporal-Image Differencing

TIR	Temporal-Image Rationing
WGS	World Geodetic System

CHAPTER 1: AN ASSESSMENT OF THE ENVIRONMENTAL IMPACTS OF URBAN SPRAWL IN BUFFALO CITY METROPOLITAN MUNICIPALITY, EASTERN CAPE PROVINCE

The ecosystem plays an intrinsic role on the planet; however, its worth is currently under threat due to degradation and advances of both agriculture and urban expansion. This, in turn, is heavily affecting biodiversity, as some of the world's species are now under threat and on the verge of extinction due to fragmentation and degradation. Development activities lead to habitat destruction and have been linked to the extremely high current species extinction rates that are being experienced worldwide, far exceeding historical global extinction rates by a factor as much as 10 000 (Wilson, 1992; UNEP, 2006). This unintended consequence, however, is unknown to most humans. Humans often do not understand, though, that the natural environment is also a kind of 'infrastructure'. It is more intricate and sophisticated than the built environment that we value so highly, and it is even more crucial to our survival.

Urban sprawl that is the spreading out of urban areas because of development and expansion has been silently damaging the ecosystem at the expense of urbanisation. The development pattern is often unplanned and done in a haphazard way. According to Jain (2009), urban sprawl is a term that describes the perceived inefficiencies of development, including the disproportionate growth of urban areas and excessive leapfrog development. Sprawl is a cumulative result of many individual decisions and it requires not only an understanding of the factors that motivate an individual landowner to convert land but also an understanding of how these factors and individual land-use decisions aggregate over space. Some of the causes of urban sprawl include population growth, economy, proximity to resources and basic amenities. Population growth is a cause of concern for most African countries especially taking into account that most of these African countries are still third world countries, controlling growth and the natural increase is still a huge challenge. The global proportion of urbanites has increased from 28, 3% in 1950 to 50 % in 2010 (World Bank, 2011). Urban Sprawl in the context of the environment is the disturbance or destruction of the landscape and of ecosystems by spill over development of settlements, outside of closed built-up areas (ARL and YLP, 1999). The recognition of urban sprawl has initiated a debate on the effects of sprawl on the environment. Sprawl has been associated with many negative effects. The research seeks to identify variables contributing to urban sprawl and their effects on the environment. One of the most evident signs of urban sprawl is the encroachment of urban land onto farmland (Brueckner, 2000). This loss is evident since urban sprawl is characterised by expansion of urban acreage onto land previously used for agriculture. If growth persists at an excessive rate this means the urban area would have long commutes, which generate traffic congestion while causing air pollution.

Since sprawl has brought more harm than good to the environment, it is important to come up with ways and plans to control its adverse impacts. The spatial patterns of change caused by urban sprawl manifest in urban fringe zones or city peripheral boundaries than in the city centre. Thus, the monitoring of urban development to establish, amount and location of land conversion for future planning are important.

1.1 CONCEPT OF URBAN SPRAWL

Urban sprawl is one of the major reasons for rural push and the increasing of the city boundary towards its outskirts. Sprawl occurs at the borders of an urban area resulting in radial development or development along highways in a linear manner. Urban sprawl further results in the affection of urban core areas by such phenomena as massive congestion, insufficient public transport, poor sanitation, and other basic amenities. Its threat to the function of the environment best explains the necessity of this study. To achieve sustainability the examination of the spatial urban growth patterns and their successive impacts on the grassland ecosystem are of great importance.

South Africa's grassland biome is one of the most threatened ecosystems in the country and as such, there is a need for a sustainable management strategy. The threats posed by urban sprawl have significantly affected the fauna. Fragmentation of habitats into smaller units occurs at a higher rate. The degree and extent of damage are unaccounted and hence, this study seeks to examine the impacts with particular reference to BCMM found within one of South Africa's threatened provinces Eastern Cape, a home for quite a number of endangered species and a biological hotspot. Many scholars have researched the subject of urban sprawl and fragmentation. Pathan and Jothimani (1985) did some of the researches on monitoring and mapping of sprawl with the use of Landsat MSS data: Case studies of three major cities in Gujarat.

1.2 STATEMENT OF PROBLEM

South Africa's grassland savannah ecosystem is under threat mainly due to the rapid rate of land cover change being spiralled by either urbanisation or agriculture. However, little is documented on how and to what extent urban sprawl has contributed to both wildlife habitat loss and ecosystem destruction in South Africa. This is mainly due to the paucity of cost-effective and fast methods to differentiate and objectively quantify heterogeneous croplands and urban areas. Progressions in satellite remote sensing provide the opportunity of mapping urban areas and agricultural land. The mapping and collection of reliable, current, spatially accurate and high quality information inventories provide baselines on the current state of the grassland savannah ecosystem of Buffalo city metropolitan municipality, South Africa. Information about the past and present spatial distribution of these ecosystems is crucial to the understanding of the changes that may be occurring, whether positive or negative. Whether agriculture or urban expansion is contributing most to the obliteration of the ecosystem is unknown. Buffalo City metropolitan municipality was chosen for this particular study based on the booming size of its population that has been experienced over the recent years (Statistics South Africa, 2011). The environment of this municipality has been greatly affected largely due to the changes and transformations brought by urban growth and population increase as such service delivery has deteriorated and habitants have embarked on constructing informal settlements. These settlements do not have adequate and standard ablution facilities and have been greatly polluting the environment. Moreover, urban expansion has led to the reduction in natural and pristine areas that act as carbon sinks and this has further contributed to climate change.

1.3 AIMS AND OBJECTIVES

The goal of the dissertation is to examine urban sprawl and land conversion impacts on the grassland savannah ecosystem. The use of Remote sensing methods for the production of maps indicating spatio-temporal patterns of urban sprawl that have led to habitat fragmentation shall be implored for the purpose of conservation management within the South African Grassland Savannah.

The objectives are:

- To investigate and quantify the urban sprawl over Buffalo City metropolitan municipality based on the analysis of temporal satellite imagery to detect change of land use and land cover patterns.
- Identify and measure urban sprawl using Landscape Metrics that include Shannon Entropy the renowned urban sprawl index.
- Analyse the major impacts of urban sprawl on the vegetation, land present in Buffalo City Metropolitan municipality in order to improve the understanding of the dynamics of the relationship between urban land use and the environment in order to allow for improved environmental and land use planning.

1.4 RESEARCH DESIGN

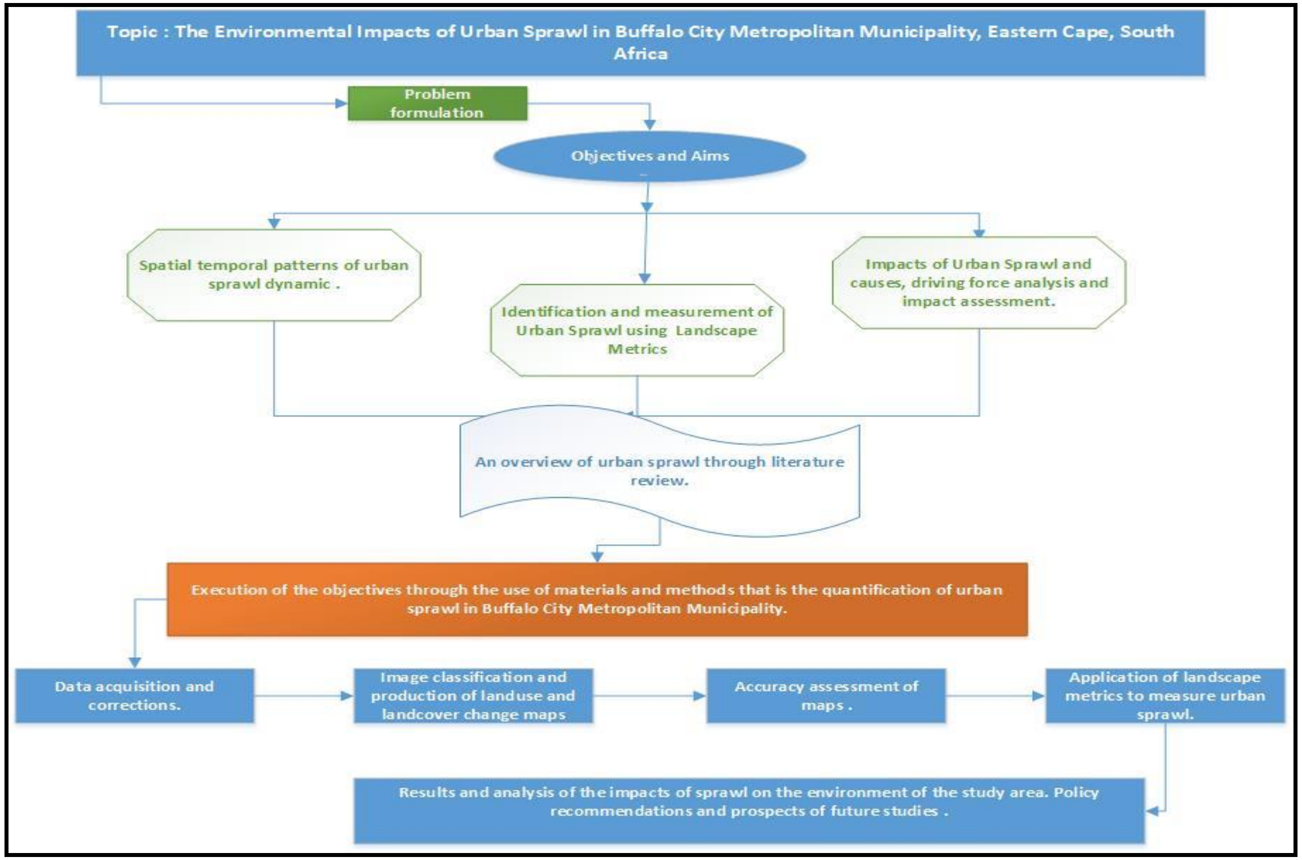

Figure 1-1 Research Framework

The research is a descriptive study, which is going to use a quantitative strategy to study the environmental impacts of urban sprawl. Acknowledging past studies on urban sprawl, the pattern of urban sprawl is characterised by the use of spatial metrics built on the extent of developed areas (paved surfaces at times). The process that describes the phenomenon centres on the change in pattern over time, which is the increase of the urbanised areas in proportion to the number of people there. This change in pattern is driven by certain factors that cause sprawl. The concept of sprawl is driven by a multitude of factors involving dynamics of population, activities of the economy, on-going and future prospects in development (Sudhira, 2008). The understanding of causes, patterns, processes can assist us in examining the impacts of urban sprawl which are in most cases negative (that is consequences). Urban sprawl is a potential threat to the achievement of sustainability and as such should be controlled. The research framework attempts to explain the way the research shall be conducted and the main thrust of strategies adopted.

1.5 SIGNIFICANCE OF STUDY

It is of importance to understand the operations within an ecosystem, to comprehend fully the functioning of a particular ecosystem. Due to the increase of human interaction with the smooth functioning of the ecosystem, the study seeks to establish the degree of damage caused by agricultural activity and urbanisation in terms of ecosystem obliteration. This is critical for land use planning and conservation purposes in spaces regarded as biological diversity hot spots such as South Africa's ecological grassland savannah ecosystems. As agricultural fields increase and urban areas expand, the quality and quantity of wildlife habitat deteriorate, because of fragmentation into small patches (Osborn & Parker, 2003; Templeton, *et al.*, 1990). Species extinction rate is potentially going to increase because of habitat fragmentation (MacArthur & Wilson, 2002). Fragmentation involves restricting wildlife species into havens in small islands of habitats. This affects their distribution across space and decreases their reproductive attainment. In this regard, it is important to apprehend fragmentation and spatial extent of its damage due to urban expansion and how all this affects the ecosystem and its immediate beneficiaries. It is vital to identify which grassland communities face the problem of fragmentation because that information will add to our understanding of grassland sustainability. This improves the ability to manage particular grassland communities to achieve sustainability (Burkhard, *et al.*, 2009; Kienast, *et al.*, 2009). Understanding the consequences of urban sprawl would help policymakers, city planners and all stakeholders associated to plan, eradicate and understand the problems associated with increased populations and urban area. The research intends to illustrate the problems faced by the ecosystems of Buffalo City Metropolitan Municipality at the expense of urban sprawl. The research will also provide a point of reference for future studies on the impacts of urban sprawl in developing countries in Africa.

1.6 CHAPTER OUTLINE

Chapter one provides a brief background on fragmentation, urban sprawl and its impacts on ecosystems that largely contribute to environmental damage. The identification of the research problem, study's objectives, the significance and scope.

Literature review presented in chapter two discusses the spatio-temporal configurations of urban sprawl and how their effects on the environment. A review on the common methods used to compute urban sprawl and the global trends of urban sprawl, and the impacts that result from this transformation.

Materials and methods used to collect; process and analyse data pertaining to urban sprawl are shown in chapter three. Spatial patterns of urban sprawl in BCMM. Spatial patterns of urban sprawl identification, with satellite imagery. Achieved, through the extraction of built-up areas, for the period under investigation.

Chapter four presents the results and discussion on the quantification of urban sprawl in BCMM. Accomplished, through the computation of classification and landscape metrics. Analysis of results on the impacts of urban sprawl on the ecosystem and environment.

General conclusions and recommendations, drawn from the measurement of urban sprawl in Buffalo City Metropolitan Municipality are formulated in chapter five.

CHAPTER 2: LITERATURE REVIEW

Urban sprawl is difficult to define as many scholars have different views as to what sprawl is, urban sprawl means different things to different people (Brueckner, 2000). Characterisation of urban sprawl is often descriptive with strong differences of opinion as to how urban sprawl manifests itself on the ground (Torrens, 2008). Urban sprawl has become an intricate area of research in academic spheres across the world. Urban areas continue to expand outwards thus instigating the expansion of the urban perimeter. Land in the peripheral zone of the city emerges as built-up land.

Often natural pristine forests are at risk of facing this untimed conversion (Galster, *et al*., 2001). Because of its disorganised use of land resources and encroachment on agricultural land and natural environments, urban sprawl is worth criticizing strongly. Literature suggests that urban sprawl is a type of urban growth since there is no clear distinction between the two terms. Urban expansion often ignores the importance of other land uses (Ewing, *et al*., 2003). Although the definition of urban sprawl is debated, a common agreement is that urban sprawl is regarded as an unplanned and uneven pattern of growth driven by a combination of processes that result in inefficient resource use (Bhatta, 2010). In developing countries urban sprawl is often the result of surpassing of urbanization from urban planning, inappropriate national policies (housing and land), rural-urban migration and the need by citizens to find affordable housing (Deng & Huang, 2004; Menon, 2004a) .

Why so much disagreement on the issue of urban sprawl from various scholars? Professional views of what sprawl suggests, give different expert and disciplinary orientations, and this is a contributing factor. Each discipline has its own “language” of sprawl. Various professionals from diverse disciplines shed light on various aspects of urban sprawl, the variance in language and perceptions (e.g. architects, planners, real estate agents, bankers, land-use regulators) adds to the lack of a cohesive and holistic definition (Osborn & Parker, 2003). This vagueness negatively affects what data to be used , what method should be made use of , what technology should be used, and what concerns of urban sprawl might be projected and lessened in advance (Batisani & Yarnal, 2009).

It is therefore important to discuss some of the definitions brought forward by scholars and come up with a definition that suits the purpose of this research. Definitions under discussion, share facts and differ in details and situations. According to the Centre for Advanced Spatial Analysis (2002) urban sprawl is a general term encompassing a variety of urban forms, sprawl occurs on the urban margin in fast growing areas. Sprawl signifies landscapes with far-reaching areas of single farming homes on large pieces of land and commercial ribbons with large parking spaces. Cars provide the only commonly used means of transportation in these areas (Gillham, 2008). Burchell (2003) supports the definition propounded by (Brown, *et al*., 1997) that urban sprawl is a form of low-density occupation, leapfrog growth characterized by unlimited expanses.

Basing relevant arguments on accounts of conditions characterized in literature, intensified by experience and observation an abstract definition of sprawl would be the pattern of land use in an urban area. It reveals low levels of a combination of a number of distinct dimensions clustering, density, centrality, continuity, concentration, proximity, mixed uses and nucleation (Galster, *et al*., 2001)

Leapfrog land use patterns, low-density single-use developments and strip commercial development all characterize the presence of urban sprawl (Ewing, 1997). What is considered sprawl ranges from compactness to completely dispersed development and hence it is a measure of to what degree is it sprawled and not an obsolete form. Leapfrog and scattered development can stretch beyond the urban fringe creating built-up areas that are isolated from the city by areas of natural pristine land. Urban sprawl presents problems to researchers, as there is no common ground as to what it is really. The common question though is; where does sprawl end and acceptable city growth begin? Sprawl disturbs just about every aspect of sustainability that an urban area could attain. Due to its encroaching nature on environmentally sensitive areas, urban sprawl has caused damage. Owing to its piecemeal nature of development on the urban fringe, areas found at a distance from the urban core show signs of urban sprawl. Concerns of the future of urban areas in various nations have grown over the years and hence the implementation of the growth management legislation in some of the nations.

Not all scholars have condemned the concept of urban sprawl. Kahn (2001) explored one potential advantage of urban sprawl, greater fairness of housing opportunity across racial divides and increased housing affordability. A number of scholars reviewed the definition of sprawl and found out that urban sprawl can simultaneously or alternatively mean (i) certain outlines of land use, (ii) land development processes, (iii)results of specific land use behaviours (Johnson, 2001; Sudhira & Ramachandra, 2007; Galster, *et al*., 2000). Scholars reviewed many various definitions of Sprawl. Their conclusions were that urban sprawl is best defined judging from the perspectives of the one who presents it. Defining urban sprawl is also dependant on location. Differences are witnessed between geography, history, politics, and current town planning, per place and per country. Researchers and Scholars in the USA might define suburban sprawl areas in Europe as urban, as they observe lower densities in their suburban areas (Besussi, Chin, Batty, & Longley, 2010)

In the context of South Africa's Buffalo City Metropolitan Municipality urban sprawl is development taking place in a radial manner or in any direction around an established urban area along the roads over a stated period. It includes edge-growth with low-densities or the development of college towns or industrial zones in a leapfrog manner. This development is at the expense of the natural surrounding pristine areas and farmlands. The importance of green space in an urban environment is that it provides opportunities for urban beautification, outdoor recreation, groundwater recharge, wildlife habitat, pollutant filtering, and improved environmental condition (Stephenson & Stoel, 1999).

2.1 TYPES OF URBAN SPRAWL

The complexity of the nature of urban sprawl compels one to look at its forms. To understand it better it is wise to classify the different types of urban sprawl, urban development in this context is the density of urban areas and type of physical form (Batty, Besussi, & Chin, 2003). There are a number of forms taken by urban sprawl, these include:

Contiguous compact development: gradually forms around the urban area, does not create patches, and mainly has high density that is the nature of this sprawl.

Linear or Strip development: the nature of urban expansion is along rivers, or infrastructural works or, growth is continuous but scattered, leaving natural and agricultural land undeveloped.

Poly-nucleated development: Agglomerations of numerous smaller towns, the urban sprawl is much lower density than traditional settlement, physically separated from the urban city and discontinuous of which it is sprawled. Creation of new large agglomeration of townships disjointed from each other (Batty, Besussi, & Chin, 2003; Weijers, 2012).

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Scattered development: Discontinuous, uncoordinated development separated from the common historic central core that creates vulnerable and vacant land between new and developed areas. Areas of development are interfused with vacant land.

Leapfrogging development: Is the expansion that barricades and leapfrogs over existing barriers (Batty, Besussi, & Chin, 2003; Weijers, 2012).

The definitions and descriptions given on the above developments have one problem, diverse developments like compact contiguous and scattered are both categorised as urban sprawl, though the resultant impacts and forms are very unalike. Literature reveals a diverse phenomenon of urban sprawl or none at all and this creates challenges when assessing the effects of metropolitan sprawl. It is therefore wiser to express the phenomenon not as a complete form but rather as a continuum of advance and growth from compact to scattered.

The figure below describes the various developments discussed above in pictures attempting to show the pattern of urban sprawl:

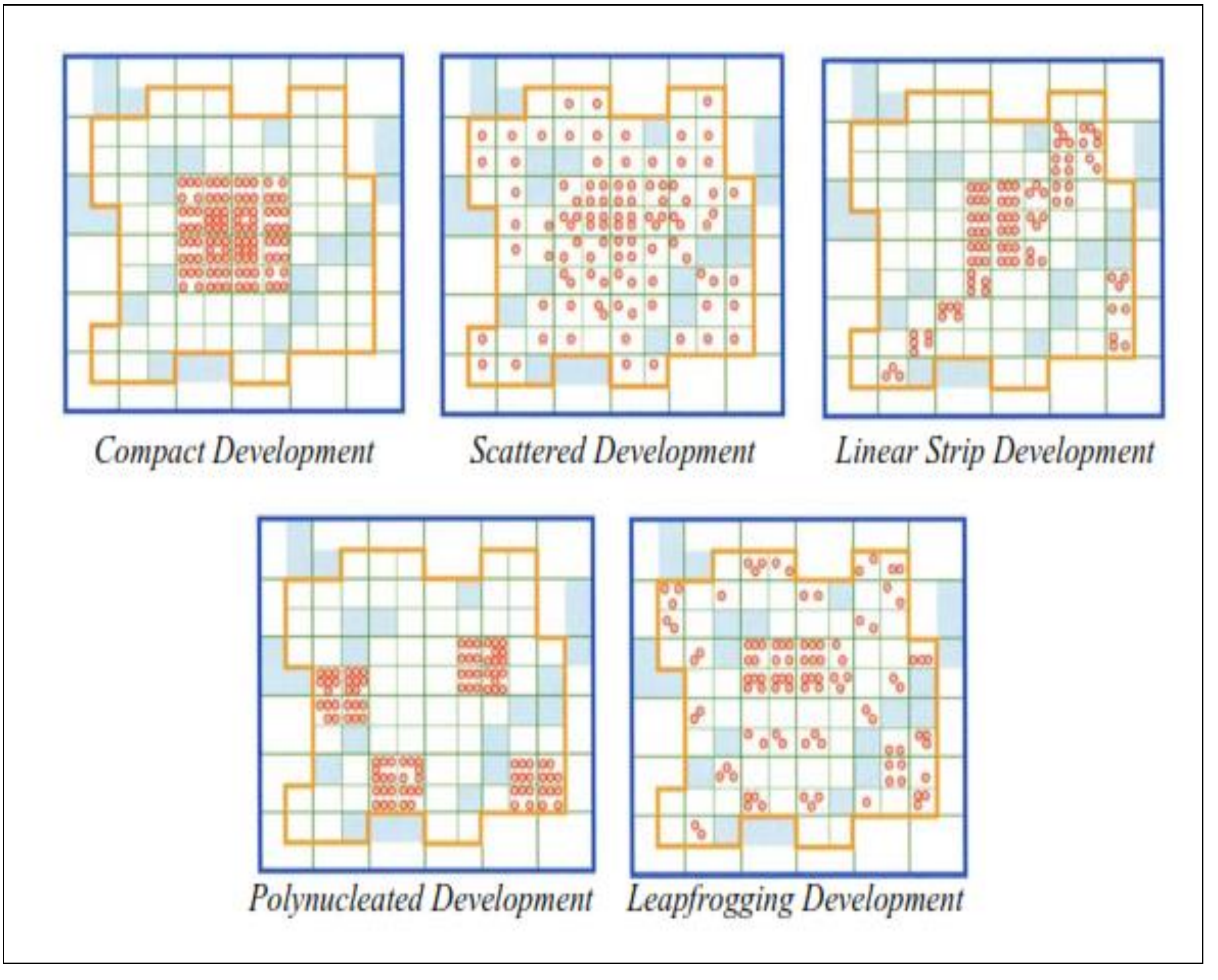

Figure 2-1 Diagram showing physical patterns of Urban Sprawl (adapted from Galster *et al*. 2001)

2.2 TRENDS IN URBAN SPRAWL

History of humanity has proven that for most of the years on earth humans have been residing in rural areas. Urbanization changed this trend in the 1st decade of the 20th century. The world is still experiencing urbanization as people migrate to cities in search of employment and better living standards. Since World War II, urban sprawl has gradually became one of the dominant urban spatial expansion patterns throughout the world, with the difference in date, time, causes and consequences (Ewing, *et al*., 2003a; EEA, 2006; Gill, 2008). Conclusions are drawn however on the definition and most scholars agree that urban sprawl depends on culture, politics and geographical location for a sound definition. Urban sprawl is an inefficient form of urban growth characterised by uniform low densities. Urban sprawl consumes resource land and agricultural land. Ecological disturbance through habitat fragmentation and destruction is linked to urban sprawl.

2.2.1 Global trends of urban sprawl

Prior studies conducted in previous years have fixated on the negative aspect of urban sprawl. The distinction of urban growth from urbanisation has resulted in many viewpoints from various authors. Migration is a key part in the process of urbanisation. The increase in the proportion of the total population, residing in towns and the emergence of infrastructure initiatives result in the growth of villages into towns, towns into cities and cities into megacities (Sudhira, 2008).

A number of authors mainly in the western context (Transportation Research Board, 1998, 2002; Sierra Club, 1998) have conducted studies on urban sprawl and its implications. According to the TRB (2002), urban sprawl is the spread-out development that consumes significant amounts of both natural and synthetic resources. The European Environment Agency (2011) defines sprawl as the physical pattern of low-density expansion of large areas, under market conditions, mainly into the surrounding agricultural areas. Correspondingly, the Swiss FOEN uses the term uncontrolled spread of towns and villages into undeveloped areas (FOEN, 2015). Population increases in developing countries have since taken a new trend now more than any other time in history. Population increases coupled with migration lead to development correlates to land consumption and conversions. Masser and Cheng (2000) suggest that the coming two decades will be filled with urban growth and expansion, with reference to developing nations and less developed countries.

Coincidentally, the urban sprawl phenomenon is a global concern, not only witnessed in the developed world but also in developing countries. It is important to note however that the dynamics of urban sprawl in the two contexts (developing and developed) are quite different (Menon, 2004a).

Urban sprawl as a conventional development pattern is an observation from the perspectives of a developed nation (Adaku, 2014). Definitions and descriptions of urban sprawl follow the context of developed nations. Conversely, the displays, causes and impacts of the phenomenon have points of dissimilarity from developed nations (Menon, 2004a). Analytically looking at urban sprawl from the viewpoints of developing nations hold the answer to dealing with the phenomenon practically in developing countries (Adaku, 2014).

Adopting policies of dealing with the problem of sprawl from western countries is not an issue. Nonetheless, it is the question of whether the adopted policies can solve urban sprawl in developing countries. The rate of population growth combined with the socio-economic situations in urban areas (cities and towns) governs the changes in urban sprawl in both developed and developing nations. In most developing nations in Africa, a considerable size of population growth in urban areas is a result of rural-urban migration (Adaku, 2014). The nature of this occurrence is fostered by the urban primacy nature of development and growth, a common characteristic of African developing nations. In these countries a few cities are developed and served with decent infrastructure. These primate cities and urban areas become the most attractive destinations for rural folk. This results in an influx of population at major centres of development, raising concerns on urban space and density (Menon, 2004a). Movement of people to the urban fringe (suburbs) in the developing world context is due to the lack of space in the urban core rather than the need for luxurious space in developed nations (Menon, 2004a).

In the western context urban sprawl has been experienced through the dispersal of population from the compact core centre to the dispersed peripheries. Urban dispersion is a form of urban sprawl that has become a global trend producing a simultaneously a negative perception (Bengston, *et al*., 2005). Many cities in the west experienced strong rates of growth between the 1950s and the 1980s (Catalan, *et al*., 2007). Urban sprawl in the western context is not only a product of population increase, instead, the need for lavish lifestyles that consume more natural space left as environmental sinks and regulators. As such it is easy to note that urban sprawl has increased even in regions and sections of the city or town with volatile or decreasing population growth.

The basic human need for shelter drives rural immigrants to squat on vacant government land in form of slums and squatter camps in both the urban core and fringe, indirectly forcing any new developments to the peripheries (Adaku, 2014). This is a common thing in developing nations in Africa like South Africa, Zimbabwe, Tanzania and other countries like Brazil and India. This, however, is not the case with developed nations (Catalan, *et al*., 2007).

There is a global fight against unsustainable development that has taken a toll due to an increase in population size. Globally, developing countries are at the forefront in terms of unprecedented urban growth. Some developed countries have adopted smart growth policies to control urban expansion and have managed to contain the growth of their cities and towns. At the sustainable development summit held at the UN headquarters (New York) in 2015, one hundred and ninety-three nations agreed to adopt seventeen global goals (SDG's). Of the seventeen goals, goal number eleven was set to address the issue of cities, the aim of the goal is to make cities sustainable for all, and access to housing and decent shelter to all (UNDP, 2015). Though some nations were already adhering to the issue of sustainability in the city the majority had not done anything to control and manage growth.

Several studies exist that examine the impact of urbanization on the environment in China, for example, changes emanating from erosion, sedimentation and heavy metal concentrations in soils, ecological footprint evaluation, impacts on the ecosystem in terms of water quality and resources (Ren *et al.*, 2003).

2.2.2 Urban sprawl in South Africa

South Africa is no exception to the ills of urban sprawl, its former capital Johannesburg suffers from the aftermath of the phenomenon. Most of its major cities and towns are also sprawling and this has negatively affected the environment. Research towards this phenomenon is not as pronounced as it is in the west. South Africa's urbanisation growth rate has increased within the past two decades and continues to do so if not controlled.

Le Roux (2012) researched on quantifying the spatial implications of future land-use policies in South Africa and the focus was on how policies have affected and might affect the growth and development of the city of Johannesburg. Many developing cities lack the necessary resources to adequately manage landuse (UN-HABITAT, 2009) and although some countries have attempted to balance socio-economic development and environmental issues, evidence suggests that such efforts have been futile (Klosterman, 2001).

Johannesburg is the largest city in South Africa, a metropolitan municipality, under apartheid urban growth was controlled, and the city was racially controlled. After independence, the post-apartheid era patterns of urban growth began to break. Spatial change has been swift and this has spread out to neighbouring towns and cities in South Africa. The emergence of new suburban nodes and edge cities gated settlements, which are sprawling as each day passes.

It is difficult to examine developing nations like South Africa with one parameter, because population growth is increasing and this is leading to significant urbanisation rates. There is a need to assess pattern, causes, processes, and consequences when relating to urban sprawl. Most of the institutional structures of local government are inappropriate for dealing with high rates of urban growth because they were established during colonial times and consequently designed to deal with predominantly rural and agriculture societies (WCED, 1987).

At a local scale, other drivers such as resource extraction, urbanisation, and altered fire regimes are likely to play a role in thicket degradation, though not much exists in literature about their examination. The majority of research done is on private lands or state conservation areas. Commonage tenure holds a small but undetermined proportion of the thicket biome. These are areas adjacent to urban nodes (the central point from which lines branch or intersect) that are owned by the state and administered by municipal authorities for the benefit of urban settlements (Martens, 2011).

South African urban sprawl is the disorderly development of the urban expansion zone when compared to western countries. Indicators of urban sprawl in South Africa base from the western context, which is not ideally suitable in the African context. South African urban sprawl is different from Western urban sprawl, but there are common characteristics shared. As a result, most of the indicators proposed by western scholars, specifically urban form indicators can be used as references. Research on measuring the impacts of urban sprawl is insufficient where indicators are not involved .Western scholars proposed indicators summarised below:

Table 2.1 Indicators of urban sprawl

Sprawl indicators	**Source**
• Area or shape of urban expansion	Fan *et al*. (1997)
• Shape index • Fractal dimension • Isolation index	Zhang , Wu, & Zhen, (2004) Zhu & Wang, (2005) Yang , Jiang , & Su, (2005)
• The density of the built-up area	Huang *et al*. (2007)

• Area • Shape • Discontinuous development • Strip development • Agriculture impact • Open space impact • Traffic impact • Planning inconsistency	Siedentop & Fina, 2010) Sudhira, Ramachandra , & Jagadish, (2004) Jiang (2007)

Studies done in Cape Town and Johannesburg South Africa on Urban Sprawl have used both quantitative and qualitative approaches. However, there is still a need for more research on this aspect.

Study done in Rustenburg using SPOT 5 imagery, GIS and Remote Sensing techniques monitored urban growth (Mudau *et al.*, 2014). Observations revealed that Rustenburg was growing and expanding. They used post-classification change detection technique. Du Plessis and Boonzaaier (2015) recognized the absence of compendious cross city correlative empirical evidence to examine the transformations of South Africa's city of Johannesburg's form since 1994 to permit a critical reflection on the effects of new age spatial planning and policy methods. Future of Cape Town, (2013) assessed the impacts of sprawl in Cape Town, and noted the growth that had occurred in the city since apartheid (from 1985-2005 the built-up area had increased by up to forty per cent.

Yusuf and Allopi (2010) used a survey questionnaire and on sight investigation assessment to measure urban sprawl and its impacts on the inhabitants of Ethekwini Municipality in Durban, the results obtained from the survey proved that urban sprawl was prevalent in Ethekwini municipality. Though most cities and municipalities in South Africa are growing and sprawling at the same time not much has been researched on the phenomenon of urban sprawl, there is still need for more research and recommendations as to how it can be controlled.

2.2.3 Impacts of urban sprawl

Urban sprawl comes with many implications concerning the environment, thus there is need for measures aimed at curbing sprawl in line with sustainability goals. Previous studies have highlighted some of the common implications of urban sprawl to the environment. Though the term environment is broad in scope, in the light of this research the main focus is on social, economic and natural aspects. Some of the implications include an increase in agricultural land loss, biodiversity reduction, resource depletion, ecological stress and disturbance, runoff and flood potential increase, urban heat island expansion, the release of greenhouse gases, climate change, pollution and other indirect impacts (Pereira, *et al*., 2014). Concern on environmental damage has since risen globally over the past decades.

The primary influence and most relevant of urban sprawl is the consumption of land, soil, non-renewable resources and change of agricultural use to urban use (Pereira, *et al*., 2014). Urban sprawl is linked to many environmental evils. Kirkland *et al*. (1994) report that the impact of urban expansion on environmental quality is much larger than its spatial extent would imply. Widely dispersed development requires more pavements that cause more urban runoff, which pollutes waterways (Wasserman, 2000; Lassila, 1999). Urban sprawl is known for reducing forest cover, farmland, woodlots, and open spaces. It also breaks up ecosystems and fragments habitats (Lassila, 1999). Commutes become long when an urban area is sprawling and this increases both air pollution and traffic congestion, car-dependent lifestyle leads to increases in fossil fuel consumption and increases in greenhouse gas emissions (Stoel Jr., 1999)

2.2.3.1 Impacts associated with social factors

Urban sprawl has a number of social impacts. The reason behind the cities expansion is that citizens need more areas to stay as the populations grow and so they shift from the urban core characterised by limited lot sizes to urban edges and outer reaches of cities. Noise, heavy traffic, air population and lack of green space are also among major factors related to urban sprawl. The influence of built-up development is significant in the study of current urban studies, includes urban sprawl as an indefinite type of growth, or expansion (Linda, *et al*., 2014). The standard of living people adhere to always impacts on their social lives.

Over-dependency on the automobile has resulted in the increase of obesity. The urban population suffers a lot from hypertension and other disorders due to lack of exercise. Poor municipal planning, designing and auto-dependent development further makes it difficult for citizens to maintain a healthy weight. There is a strong connection between urban sprawl and the epidemic levels of obesity and the increase of chronic diseases associated with physical inactivity.

Demography, education standards, cultural aspects, socio-economic status and neighbourhood class are all social factors that impact directly or indirectly to the living standards (Menon,2004a). Social divides of race and class are also a common thing in sprawling cities. As people leave farther and farther away from each other relationships are weakened (Burchell, *et al*., 1998). Compact cities tend to promote social interactions when compared to sprawling cities (Nguyen, 2010). New urbanists have approved the notion and have since sought to construct high density and walkable communities as a perfect approach to develop suburban areas (Freeman, 2001). Urban sprawl contradicts social cohesion and promotes a negative trend called social fragmentation which is associated with the lowest level of social participation and contribution (Chakravarty & Fonseca, 2014). Inability and lack of capacity to deal with pluralism occurs with the incidence of sprawl in a community. Citizens fail to accept other lifestyles that depict the diversity of a city's society. The downside is the continued search for compatible people and the rejection of those who do not fit the lifestyle. Incidences of social ills and crimes in previously occupied places like the urban core become high further popularising abandonment of the urban cores to urban fringes by urbanites.

2.2.3.2 Impacts associated with economic factors

Urbanization and urban growth is a well-crafted productivity development linked to industrialisation, modernization and universal assimilation. It is a substantial sign of progressive movement that convey a sense of rapid development (Sanyal, 2008). The majority of land developments for built-up areas are in disagreement with the principles of sustainability in most places in the world. Agricultural loss due to city sprawl is a common thing in both developed and developing nations (David, 2004; Fengming, *et al*., 2012).

Economically cities and towns view urban sprawl as beneficial. However, economic problems often arise due to urban sprawl. Particularly problems such as the relocation of citizens from the urban core to the urban fringe result in the city collecting less revenue. Municipal expenditure increases due to the development of new areas, which costs more when compared to renovation of existing infrastructure. The cost of providing basic services also increases with further distance from the urban core.

The decline of the inner city is another economic impact associated with urban sprawl. The central urban core becomes less popular as humans relocate to the outer regions of the city.

2.2.3.3 Impacts associated with the ecosystem

Urban land use changes the ecosystem and modifies it by altering the surface of the earth through the replacement of vegetation with impervious surfaces such as tarmacs, concrete and buildings, which are known to change the functioning of the ecosystem.

Sprawling areas that were once covered by forests or used for farming have since been changed to impervious surfaces such as concrete, tar and asphalt deterring infiltration and seepage of water into the ground (Frumkin, 2002; EEA, 2006). Flora and fauna are not spared from the impacts of sprawl; species richness and abundance are greatly affected by sprawl. Urban sprawl has caused the evanescence of many kinds of birds and an increase in feral birds (Sushinsky *et al*. 2013). In Sushinsky *et al*. (2013) study, the authors developed two different scenarios of compact urban development and sprawled development and concluded that in a sprawled scenario many urban-sensitive birds will disappear whereas a compact scenario makes the city more bio diverse (Sushinsky *et al*. 2013). Reductions of the capacity of the soil to act as a carbon sink are also seen as an impact brought about by urban sprawl (EEA, 2006). Land converted to urban use and fragmentation has negatively affected the environment. McClennen *et al*. (2001) observed that animal activities could change along with the change in land use. Increase in the number of people due to urbanisation will also affect biodiversity, as humans tend to destroy nature both directly and indirectly. Construction of roads and buildings close to the habitats of wild animals and birds has resulted in an increase in the mortality of animals. Motorists and humans tend to kill birds since most members of this population are found in forests and natural places humans destruct for housing.

The table below summarises some of the impacts of urban sprawl towards the environment noted by various authors:

Table 2.2 Summary of the Impacts of Urban Sprawl on the Environment, economy and social aspects of the city.

Themes	**Impacts of Urban Sprawl**	**References**
Land cover	Landscape fragmentation and soil sealing. Land consumption (uptake for buildings and related infrastructure facilities) Loss of agricultural lands due to conversion into higher	Siedentop & Fina (2010) Siedentop & Fina (2010)

	built-up areas Removal of vegetative cover over enormous areas Soil compaction, soil sealing, loss of soil ecological functions, reduction and loss of water permeability, decrease of groundwater renewal, desertification and decline in evapotranspiration.	Yeh & Li (2001) Eigenbrod *et al*. (2011) Wilson and Chakraborty, (2013) Barbero-Sierra *et al*. (2013) Scalenghe & Marsan (2009)
Geomorphology	Local changes to geomorphology (e.g. cuts, slope stability) over vast areas	Rivas *et al*. (2006)
Local Climate	Changes in local climates (microclimates) resulting in urban heat island effect, with an effect of a reduced cover on vegetation, reduced albedo, increases in surface temperatures and increased variability.	Zhou *et al*., (2004) Stone *et al*., (2010)
	A modification of humidity conditions e.g. reduced evapotranspiration, due to vegetation removal and soil sealing; reduced moisture content due to soil compaction; and increased variability.	Taha, (1997)
	Climatic thresholds and the modification of wind conditions due to the removal of vegetative cover and the construction of buildings.	Song, (2005) Stone *et al*., (2010)
Flora & Fauna	Loss of valuable ecosystems for different kinds of animals Impacts on forest-breeding birds (e.g. birds' abundance, species richness and evenness) Death of animals caused by road mortality	Forys and Allen (2005) Gagne and Fahrig (2010)

	Change in animal movement behaviour due to changes in the land use (e.g. change of coyote movement pattern in suburban areas)	EEA (2011) Forys and Allen (2005)
	Higher numbers of invasive species and the spread of invasive species as a result of changes in climatic conditions	Nobis *et al*., (2009); Scalenghe and Marsan, (2009); Shochat *et al*., (2010)
	The increased fragmentation of the landscape: barrier effect, habitat fragmentation, disruption of migration pathways, impediment of dispersal, increased road mortality of wildlife, isolation of populations, degradation of ecological networks and loss of existing green infrastructure	Alberti, (2005); EEA, (2006b); EEA and FOEN, (2011a)
	The impoverishment or alteration of species' communities	McKinney, 2006, 2008; Raupp *et al*., (2010)
	The loss of soil biodiversity	Turbé *et al*., (2010)
Water	Negative impact on hydrological systems (for example accelerated drainage of water through road drains and city sewer systems, which alters the rates of infiltration, evaporation, and transpiration). Reduction of soil permeability. Increased water pollution (e.g. pollution by oil and fuel)	Muller *et al*. (2010) Frumkin (2002) EEA (2011) Jat et al., (2008);

	Reduction in both quantity and quality of groundwater, raising and lowering of groundwater table	Wilson & Chakraborty, (2013)
	Modification of surface watercourses	Feyen & Dankers, (2009); Haase, (2009)
	Water pollution, such as the pollution of rainwater by tire abrasion, dust and heavy metals, which washes into rivers	Tu *et al*., (2007)
	A higher risk of leakages per capita (there will be more leakages as the network of pipes increases)	Pauliuk *et al*., (2014)
	Lessened hydrological dynamics of wetlands around sprawled cities	EEA, (2006b)
	Increase in water consumption	March and Saurí, (2010)
	Urbanites will compete with farmers for water use especially in summer when the sources have reduced	EEA, (2006b)
Landscape Scenery	Visual stimuli and noise	Slabbekoorn & Peet, (2003); Moudon, (2009); Bennie *et al*., (2014)
	Landscapes can be read and interpreted less because of	Ewald and Klaus,

	visual breaks caused by the contrasts between nature and technology	(2009)
	character and identity of the landscape changes	Marull *et al*., (2010); Müller *et al*.,(2010)
	The increased exploitation of river beds and the expansion of quarries for construction materials	EEA, (2006b)
Economic impacts	costs for transport associated with commuting for households' increase Transport demand increases, amplified car use and an advanced cost for public transport infrastructure Higher costs associated with traffic congestion and the extension of urban infrastructure in newly developed regions Higher costs as a result of higher energy consumption per person increased public service costs and higher expenditure for construction and maintenance of infrastructure per capita (roads, electricity, water provision pipes, wastewater collection pipes, municipal garbage collection, snow removal, etc.) Higher material use for construction per housing unit A reduction in food production and self-sufficiency, and a higher Dependence on imported food An increased demand for raw materials, such as concrete,	Camagn *et al*., (2002); Bento *et al*., (2005); Travisi *et al*., (2010) Kenworthy *et al*., (1999) Hortas-Rico and Solé-Ollé, 2010; Klug and Hayashi, (2012); Cinyabuguma & McConnell, (2013) Kenworthy *et al*., (1999) Roy *et al*., (2015) Ewing, 1997;

	the expansion of quarries and the over-extraction of gravel from river beds increase the costs of service provision	Kenworthy et al.,1999; Pauliuk *et al*., (2014) Haber, (2007);
	dilapidation or loss of various ecosystem services, and advanced costs for their changeover or restoration by technology	Wilson & Chakraborty, (2013) Eigenbrod *et al*., (2011)
	Deviations in the distribution of populations relative to the locations of ecosystem service supplies, which can reduce the per capita supply and raise the costs of the provision of services	Cumming *et al*., (2014) EEA, (2006b)
	Environmentally degraded urban areas are less attractive to new investors and their highly qualified employees	EEA, (2006b)
	Economic losses in touristic areas in which the landscape scenery has been ruined	
Social impacts	Increase in the proportion of single households, resulting in a more resource-intensive lifestyle. Segregation of citizens based on their income and standard of living	Dura-Guimera, (2003); Howley, (2009) Power, (2001); Brade *et al*., (2009); Cassiers & Kesteloot,

	Social interaction reduction and longer commuting periods	(2012) Putnam, (2000)
	Increased incidence of diseases e.g. respiratory infections from pollution, obesity from lack of physical activity and exercise	Frumkin *et al*., (2004) Ewing *et al*., (2003); Garden and Jalaludin, (2009)
	Reduced human benefits from groundwater	EEA, (2006b)

The environmental penalties are immediately suggested with change in the surficial landscape capacity that affects the incidence of flood events and run-offs with point- and nonpoint-source pollution, water quality, and micro-site climate (as in so-called heat islands in urban areas with limited green open space), among other environmental consequences (Tan et al. 2010).

2.3 METHODS OF MEASURING URBAN SPRAWL

The spatial form that results from unprecedented urban growth has brought a number of challenges to the city. Due to the complexity of defining urban sprawl, its measurement is also difficult to quantify and measure with precision. Researchers executed a number of methods, aimed at obtaining a better understanding of the phenomenon. Qualitative and quantitative techniques were used to measure and assess urban sprawl, prior to the digital age. Empirical studies on urban sprawl have shown an understanding of the basis of sprawl as it provides quantitative information to the discussion and proposes solutions without which practical and ideological discussions would remain conceptual. Earlier generations of methods used coarse and zonal level data to measure urban sprawl (Banai & De Priest, 2014).

Urban sprawl is a system of spatial urban growth, characterised by low densities, scattered and discontinuous “leapfrog” expansion and segregation of land uses, encouraging the massive use of private vehicles and strip malls. The nature of this growth and development is normally found on the urban fringe and open rural land (Ewing, 1997a; Burchell *et al*., 1998; Peiser, 1989; Hadly, 2000; Razin & Rosentraub, 2000). Various research organizations have suggested a number of measurement indices, population movement from inner cities to suburbs; comparison between land use and population growth; time cost on traffic and a general decrease of open space are amongst the most discussed (Sierra Club, 1998; Smart Growth America, 2002; Fulton *et al*., 2001). For a comprehensive assessment of urban sprawl, it is important to adopt measures (indices) that capture the relative intensity of sprawl at different times and places (Wilson *et al*., 2003). Frenkel and Ashkenazi (2008) note that spatial metrics can assist in quantifying indices to describe structures and patterns of a landscape.

Indices work best when comparing cities, a single city between different regions or different times (Yue *et al*., 2013). Spatial metrics and statistics proposed as methods of measuring urban sprawl include the growth rate of urban land, population density, employment density, spatial geometry, accessibility, and aesthetic measures. (Frenkel & Ashkenazi, 2008; Ji *et al*., 2006; Jiang *et al*., 2007; Song & Knaap, 2004; Zhao, 2010).

Most of these urban sprawl measures suggested in the literature can be divided into five specific groups discussed on the heading below. Spatial indices generally used include growth rates such as population growth rates compared against built-up growth rates (Frenkel & Ashkenazi, 2008), to calculate a complete scale i.e. it creates a binary distinction between a compact city and a sprawled city (Bhatta *et al*., 2010), using a pre-determined threshold. Due to the complexity in the definition of sprawl, finding a suitable method for its measurement and analysis is still an important issue.

It is important to note that most of the urban sprawl measurement techniques are relative measures or precisely measures of urban growth used as indicators of urban sprawl (Bhatta *et al*., 2010). The specific methods used to measure urban sprawl include:

2.3.1 Growth rate

Growth rate is interrelated to urban sprawl since population increases often lead to a corresponding increase in infrastructure. Fulton *et al*., (2001) conducted comparison of the growth rate of a population and urban land consumption in relation to population change for every U.S metropolitan area. Thus, both scholars agreed if there was a corresponding increase, inland consumption, with that of the population the sprawl was definitely increasing (Fulton *et al*., 2001; Pendall, 1999). In this case, studies focused on growth rate as a measure of urban sprawl.

2.3.2 Density

This is the most common method of measuring urban sprawl (Galster *et al*., 2001) and some argue that its one that best describes the urban sprawl phenomenon (Maret, 2002). Contextually there are many facets to densities and sprawl; hence, there are a lot of methods and scales towards its measurement (Burton, 1996; Churchman, 1999). Over the last few decades, observations on urban density gradients have shown a general decrease in both developing and developed countries, which proves the universality of urban sprawl (Ingram, 1998). The density approach of measuring urban sprawl is the simplest and most frequently used variable (Peiser, 1989). Pendall (1999) explains the incidence of urban sprawl for large metropolitan areas based on land values, metropolitan political organization, local government spending, traffic congestion, and various local land use policies. Low-density zoning and building caps are associated with sprawl. Pendall's (1999) measure of sprawl is strictly related to density. To measure increases over time, estimates of 1982 and 1992 were divided by the estimates of urban land change within the same given period.

Zhang (2001) examined local and regional factors related to urban sprawl such as federal policy on mortgage interest taxation and public spending, community location, transportation accessibility, and community features of a neighbourhood. A great deal of Zhang's (2001) data came from local zoning ordinances and interviews with local government planners, which provided information on land use regulations. Zhang (2001) also examined transportation conditions and educational quality indicators further, to gauge the attraction of a community to new development.

2.3.3 Accessibility

Increase of human dependence on the automobile, which reduces access to the urban core, creates a condition of poor accessibility. Computing various parameters of accessibility can enable the measurement of urban sprawl. Calculating road length, road areas and the travelling time of households are all parameters used to measure how accessible a city is (Hadly, 2000). Approaches of accessibility measurement include fractal dimensions to road networks and ecological measures such as mean proximity index (MPI) (Torrens & Alberti, 2000).

2.3.4 Aesthetic measures

It is difficult to measure and quantify the aesthetics of urban sprawl. However, aesthetics depict changes that have occurred to an area. Recent studies on urban sprawl have endeavoured to define archetypes of urban growth or sprawl, such as residential sprawl or strip malls to compare various landscapes to those archetypes. Comparisons of such archetypes to recent forms of development clarify changes that have occurred, negative or positive. More research and clarity is still required on this method (Torrens & Alberti, 2000).

2.3.5 Spatial geometry

This comprises the largest group of measures of urban sprawl. There are several geometric techniques, most of which have been adopted from ecological research (Turner, 1989; McGarigal & Marks, 1995). Fractal geometry has also significantly contributed to the spatial geometric methods used in the measurement of urban sprawl (Torrens & Alberti, 2000; Batty & Kim, 1992; Herold & Menz, 2001). There are two main physiognomies of urban environments that are ecological and geometric, structure and composition. The geometry of the built-up category of the urban area is the structure, and composition referring to its level of conglomeration. As long as the geometric structure of an urban area is scattered, fragmented and irregular it is considered as sprawling.

Common measures include leapfrog or continuity (Galster *et al*., 2001), fractal dimension and mean patch size (MPS) (Batty & Longley, 1994; Torrens & Alberti, 2000). The percentage occupied by different land uses computes the level of heterogeneity (McGarigal & Marks, 1995; Frenkel, 2004b). However, all the approaches mentioned above should take the issue of landuse change analysis and urban sprawl pattern identification into account. The approaches mentioned above have been modified since times are changing due to technological advances. Density is the easiest measure of urban sprawl, thus in most studies, it stands out as the sole indicator of urban sprawl in most studies (Ewing *et al*., 2003). Scholars choose to use a combination of these techniques rather than sticking to a single approach.

Galster *et al*. (2001) adopted eight different metrics of landuse patterns to examine urban sprawl in thirteen different American cities (nucleation, centrality, clustering, density, continuity, mixed uses, concentration and proximity. Just like most studies on urban sprawl, there wasn't a single metric to measure sprawl independently.

Ewing *et al*., (2003a) developed a four-aspect sprawl index (accessibility of street network, the strength of activity centres and downtowns, residential density and neighbourhood mix of services, jobs, and homes) in eighty-three metropolitan regions in the US. The method evaluates the principal indicators of sprawl such as density, a mix of land uses, the strength of activity centres, and connectedness of the street network and also looks at the relationship between sprawl and its impacts. However, a large number of indicators used to calculate the defined four-factor sprawl index is the main limitation of this method.

Five metrics for characterizing urban sprawl and five indices for defining key manifestations of urban sprawl were applied to two cities Bangkok and Minneapolis (Angel *et al*., 2007). The metrics of ribbon development, urban fringe, secondary urban core, scatter development and the main urban core was applied and used to quantify urban sprawl mutually as a progression and form (Angel *et al*., 2007). The pattern of urban sprawl was measured over time and the authors used five elements for describing urban sprawl, developing five indices to measure each element. Hence their research lacked an independent index to summarise and show the level of urban sprawl as a substance of amount. As is always with most research on urban sprawl this research lacked a particular threshold of distinguishing a sprawling city from a non-sprawling city.

The methods discussed above have been used in a number of studies. However, each comes with its own weaknesses and strengths all the mentioned methods have strongly contributed towards the understanding of the urban sprawl phenomenon. Many metrics and statistics have been adopted as a measure of sprawl and these have been named spatial metrics. This is the category of measures that fall under spatial geometry and are arithmetical quantities that measure spatial patterns of land cover classes, land cover patches or the entire landscape mosaics of a geographical location (Bhatta, *et al*., 2010). The use of multiple indices, descriptive statistics, and their comparison has led to the perfection and adoption of the most robust and result yielding metrics (Batisani & Yarnal, 2009; Feraner, *et al*., 2010; Hasse, 2004). The indices encompass most of the methods discussed above and more for example population, employment, architecture aesthetics, resource consumption, and living quality among other things. Typically used indices include: growth rate such as growth rate of population or built-up area; density such as population density, residential density, employment density; spatial configuration such as fragmentation, accessibility, proximity; and others such as per-capita consumption of land, land-use efficiency, etc (Jiang, *et al*., 2007; Pendall, 1999; Fulton, *et al*., 2001).

Torrens' (2008) approach to the measurement of sprawl has some ground rules as to the nature of development of a methodology. The author proposes the use of forty-two measures in order to comprehensively capture urban sprawl. However, the approach and methodology is complex and can hence result in confusion because of the use of many measures and metrics. Jiang *et al*. (2007) suggested a thirteen-attribute approach to the measurement of urban sprawl under the term 'geospatial indices' in China. The approach was able to minimize the clarification effort but had wide-ranging data input requirements such as landuse maps, landuse master planning, population data, maps of highways and data on the GDP. The majority of the developing countries fail to provide current data of that nature due to financial constraints and therefore most metrics or indices are difficult to descend. Jiang's *et al*. (2007) type of temporal analysis is effective when comparing among urban areas or different sections of urban areas or distinction of an urban area at different periods. This type of analysis can depict with the change of time whether sprawling is increasing or not.

Some of the researches discussed above have contributed a lot towards understanding the concept of sprawl. Though accuracy and issues to do with the threshold between a compact city and a sprawling city often cause problems as to whether one can strongly say a city is indeed sprawling. The earlier generations methods of measuring sprawl are the basis of recent technologies and approaches adopted. The fusion of these principal elements into recent technologies like GIS and Remote Sensing has yielded positive results. Though the recent technologies yield many accurate and relevant results they come with their own weaknesses. For instance, most of these recent techniques do not consider the causal social processes that lead to urban sprawl. Issues to do with population control and contraception to avoid an ever-booming population growth are rarely tackled instead governments continue to grant citizens incentives to give birth. Issues to do with planning and policy also play a significant role and should also be incorporated into the measurement aspect of urban sprawl.

The issue of failure to define a threshold also accentuates the problems in sprawl measurement, relative evaluations can give vision on the phenomenon, though methods are often not satisfactory and need to provide more clarity to the depiction of sprawl (Bhatta, *et al*., 2010). The issue of the number of metrics adopted is another challenge, the discussion reveals that quite a number of scales and parameters are in use when it comes to sprawl measurement. Which leads us to the question, what are the most rigorous tools for the measurement of urban sprawl and how effective are these tools when measuring sprawl? The answer is yet to be revealed. Literature suggests that there is no standard set metrics best suited for the measurement of urban sprawl since the purpose of choice of a particular metric vary with the objectives of each study and the attributes of the area under examination (Bhatta, *et al*., 2010).

It is worth noting that most of the metrics correlate and thus contain redundant information. Riitters, *et al*., (1995) assessed the relations among fifty-five different spatial metrics by factor analysis and only came up with five independent factors. This means that many of the metrics do not measure different qualities of spatial pattern but rather they measure the same parameter, which is the spatial pattern (Bhatta, *et al*., 2010). It is therefore paramount to select metrics that are independent of each other, being careful to select each metric or group of metrics that are capable of identifying sensible patterns of urban landscape change that results in consistent measures of urban sprawl. Therefore, there is need to have more than one metric to increase the reliability of the assessment, not just a single metric, but not too many again because the deter the reaching of a concise conclusion. Again the use of highly correlated metrics or methods do not yield anything new, but instead, increase the difficulty in making interpretations.

Spatial resolution of imagery is also a challenge when deciding which methods to adopt. Many metrics are dependent on resolution for example Patch and Shannon entropy analyses (Bhatta, et al., 2010). Imagery with a low spatial resolution make objects appear compact or merged which in essence is not the actual case. Essentially an area with low-density development will be viewed as developed four times on a thirty-metre resolution image when compared to a fifteen-metre resolution image. Hence fine-scale data is the most preferred when representing discrete units for example pieces of land or buildings. With this in mind, high-resolution data, on the other hand, provides better understandability by the observer, but the downside of high-resolution data is high object diversity which causes problems on classification algorithms applied to the dataset. Due to this, increased heterogeneity in high-resolution imagery, analysis of spatial heterogeneity or spatial association will be subjective at a higher notch (Torrens, 2008). Likewise, the measurement of urban sprawl or temporal analysis as a procedure may use images from sensors that have different resolutions. In such instances, metrics dependant on resolution will not be applicable.

Observing all these complications, researchers have proposed metrics that are modest and capable of a clear representation of sprawl from remote sensing data. Most of urban sprawl measurements reveal the relationship between population growth and change and land conversion to urban practices. Hypothetically, researchers' determination approach is when built-up growth rate exceeds population growth rate, and then sprawl is positive in that area (Sudhira, *et al*., 2004; Bhatta, 2009). It is problematic to distinguish population change in a given locality as either the cause of the effect of urban growth, thus the population aspect in its singleness cannot indicate a sprawling town or city (Ji, *et al*., 2006).

2.3.6 GIS technology in spatial geometry

The study of urban sprawl requires sophisticated methods. Recent advances in spatial analysis and spatial statistical methods in collaboration with Remote Sensing and GIS present a unique platform for the in-depth study of the complex urban sprawl phenomena. Initially, urban sprawl was identified by measuring urban growth in various ways.

2.3.6.1 The role of GIS and Remote Sensing in mapping Urban Sprawl

The measurement of sprawl has been a major challenge for quite some time now. Due to the complex nature of most urban systems, it is difficult to use a model based on a single approach (Allen & Lu, 2003). GIS provides the adequate platform to handle a variety of spatial data all at once enabling it to be the most suitable method of measuring and assessing sprawl. GIS combined with remote sensing allows researchers to play around with their data to produce meaningful visual results that everyone can understand.

The conventional way of trying to measure urban sprawl is both expensive and rather time consuming, most of the municipalities do not have a database of the collective information were researchers can easily retrieve data, especially in developing countries. This best explains the increased research interest channelled towards the mapping, monitoring, and modelling of urban sprawl or growth using GIS and Remote Sensing.

Remotely sensed data with an acceptable spatial and spectral resolution, together with GIS software have become increasingly available. These provide a unique tool to retrieve a number of key variables, relevant to the quantification of urban sprawl and land consumption from a local scale to a global scale (Boyd & Foody, 2011). Due to its cost-effectiveness and versatility, researchers are adopting this technology as it is less time consuming (Sudhira, *et al*., 2004). Research using remote sensing in urban morphology and change has been ongoing for the last three decades and as technology continues to advance improvements are fused.

Landscape ecological research through the incorporation of GIS and remote sensing techniques has supported the understanding of the impacts of urban sprawl and fragmentation on such biophysical factors like wildlife habitat, extent and land use patterns and biodiversity. However, GIS and earth observation techniques are improving and easing the compilation of inventories on land use and land cover. Municipalities and councils continue to sprawl. This is probably due to poor policy planning or poor methods of controlling population growth.

The convergence of GIS, Remote Sensing and Database management systems has helped in quantifying, monitoring and subsequently predicting this phenomenon (Sudhira, Ramachandra, & Jagadish, 2004). Technological advancement on the access to information via the internet coupled with scientific analytical methods in computations brought the field to a data-driven era. It is important to capture the extent of damage upon the environment to reduce the negative impacts of urban sprawl for both the urban population and the ecosystem in line with the sustainable development measures. Classified remote sensing imagery can show the spatial configuration, structure, and fragmentation of urban areas.

The use of two registered Aerial or Satellite multi-spectral bands from the same geographical location obtained at two different times is usually used for the analysis of land-use change or urban growth (a remote sensing technique) (Radke, *et al*., 2005). The adoption Remote sensing data over in-situ data collection methods such as field surveys has increased due to its many advantages (Barr & Ford, 2010; Vintrou, *et al*., 2012). Earth observation using remote sensing data provides the same view from the air or space making it practical for researchers and scientists to create boundaries for their chosen areas of study (Miller & Small, 2003). Another ability of Remote Sensing data is its ability for routine, periodic and unobtrusive updating (Taubenbock, Esch, Wurm, Roth, & Dech, 2010). Earth observation through remote sensing has the capacity to describe, classify and measure critical physical aspects about the environment that would be prohibitively expensive (Cowen & Jensen, 1998) time consuming, (Sherbinin, *et al*., 2002) or rather impossible to attain in-situ or from combining various sources (Barr & Ford, 2010). The high rate of urbanisation and informal urban development for most developing countries makes it difficult for municipal records to stay ahead.

2.3.6.2 Image classification

Image classification is a common technique adopted in remote sensing for the extraction of land cover and land use information from remotely sensed imagery. Classification results are the basis for many environmental and socio-economic applications (Lu & Weng, 2007). Scientists and practitioners have made great efforts in developing advanced classification approaches and techniques for improving classification accuracy (Gong & Howarth, 1992; Aplin, Atkinson, & Curran, 1999a; Stuckens, Coppin, & Bauer, 2000; Franklin, Peddle, Dechka, & Stenhouse, 2002). These techniques aim to classify homogenous features into target landcover classes. These classes can be a priori defined by the user (supervised classification), or automatically defined by the computer, based on a clustering algorithm (unsupervised classification). Imagery consists of rows and columns of pixels; hence, pixels are the basis of landcover mapping. Classification techniques take into account the spectral reflectance value of a single pixel of the image assigning them into target classes both calculated and defined.

It is rare however that one achieves an accuracy greater than 80% when using pixel-based classification algorithms (Mather, 1999), specifically in urban areas. Rather object-based classification offers greater accuracy when compared to pixel-based classification algorithms.

Classifying remotely sensed images has its own challenges, a number of factors should be considered, factors like the complexity of the landscape in a study area, selected remote sensing data, image processing, classification approaches all need to be considered prior to performing classification.

The scale of the study area, the economic conditions, and analytical skills are factors that influence one's choice of remotely sensed data, the design of the classification procedure and the quality of results produced. Generally, a classification is designed, based on the users need, the spatial resolution of selected datasets, compatibility with previous studies, image- processing and classification algorithms available and time constraints, such systems should be informative, exhaustive and separable (Jensen, 1996). Training samples are actual ground points that help in improving accuracy within a land cover class. A sufficient number of training samples and their representatives are required for image classifications (Chen & Stow, 2002). Different collection strategies for training samples can be used, such as single pixel, seed, and polygon can be used though they have an influence on the results especially classifications with fine spatial resolution imagery (Chen & Stow, 2002).

Several types of research have since adopted the use of new classification techniques for high-resolution images (Thomas, Hendrix, & Congalton, 2003). Due to the high spatial information contents of high-resolution imagery, pixel-based classification is insufficient to account for the spatial heterogeneity (Thomas, *et al.*, 2003). Object-based classification, however, considers spectral, topological and spatial relationships inclusively resulting in higher classification accuracies (Herolde, Liu, & Clarke, 2003).

A number of classification approaches have been developed with the aim of producing landcover and landuse maps (Aplin & Atkinson, 2004). Table 2.3 Summary of remote sensing classification techniques adopted from (Jensen,2005)

Methods	Examples	Characteristics
Parametric	Maximum likelihood classification and unsupervised classification etc.	Assumptions: Data are normally distributed. Prior knowledge of class density functions
Non –Parametric	Nearest-neighbour classification, fuzzy classification, neural networks and	No prior assumption

	support vector machines etc.	
Non-metric	Rule-based decision tree classification	Can operate on both real-valued data and nominal scaled data statistical analysis
Supervised	Maximum likelihood, Minimum distance, and parallelepiped classification etc.	Analyst identifies training sites to represent in classes and each class and each pixel is classified based on statistical analysis
Unsupervised	ISO-data and K-means	Prior ground information not known. Pixels with similar spectral characteristics are grouped according to specific criteria.
Hard (parametric)	Supervised and unsupervised classification	Classification using discrete categories.
Soft (Non – parametric)	Fuzzy Set Classification logic	Considers the heterogeneous nature of the real world. Each pixel is assigned a proportion of the in landcover type found within the pixel.
Per-pixel		Image classification pixel by pixel
Object-oriented		Image regenerated into homogenous objects. Classification performed on each object and pixel.
Hybrid		Includes expert systems and

approaches		artificial intelligence.

2.3.6.1 Unsupervised classification

Software delineates a large number of unknown pixels in an image based on their reflectance into classes or clusters without any assistance from the analyst (Tou & Gonzalez, 1974). In the primary stages of image analysis, unsupervised classification is valuable to gain insight into the structure of data (Moik, 1980). Unsupervised classification also uses algorithms like:

2.3.6.2 Cluster Algorithm

This technique makes use of the histogram peak method to classify image data. The crux of its classification is on the natural assemblage of pixels in the image data when plotted on a spectral space (Jensen, 2005, Eastman, 2006).

2.3.6.3 ISODATA Algorithm

Stands for Iterative Self-Organizing Data Analysis Technique, which is a method that uses the least spectral distance formula to iteratively classify the pixels and redefine the criteria of each landuse class. The data is classified until either a maximum number of iterations have been performed or a maximum percentage of unchanged pixels have been reached between two iterations (Jensen, 2005)

Unsupervised classification reduces the possibility of human error and enhances the recognition unique classes as discrete units (Campbell, 2006). The limitations of unsupervised classification are that classes, which are spectrally similar, do not necessarily correspond to the informational cluster of interest to the analyst and spectral properties of features may change over time (Campbell, 2006).

2.3.6.4 Supervised classification

Classifying an image using this procedure means that the analyst supervises the pixel categorization process. This is done by assigning parameters to each of the desired output classes on the basis of knowledge of representative sections of the sampling universe or, availability of a sufficient number of known pixels (Lillesand, Keifer, & Chipman, 2014). The image analyst supervises the classification by defining small areas, called training sites on the satellite image. Training sites are representative of the desired landuse classes. Classically, spectrally oriented techniques for landcover mapping have formed the backbone of multispectral imagery classification (Lillesand, Kiefer, & Chipman, 2008). Each class of interest is assigned attributes with corresponding locations of pixels within the class for easier description. Each pixel is then classified into the feature class it resembles the most. The accuracy of classification is dependent on the distribution of training sites throughout the image and the quality of training areas chosen by the analyst (Lillesand, Keifer, & Chipman, 2014).

After characterizing the training sites, the application determines the spectral signatures of each training site using extracted statistics and then classifies the image according to the chosen classification algorithm (Jensen, 2005). These various supervised classification algorithms include:

Maximum likelihood classification: this classification algorithm is based on the probability density function associated with a particular training site signature. Pixels are assigned to the most likely class and this will be based on a statistical analysis (Jensen, 2005). The algorithm is thrust on the assumption that the training data statistics for each class in each band follow a normal distribution (Gaussian) (Jensen, 2005). The following equations as suggested by Schowengerdt, (2012) define the maximum likelihood classifier :

$$g(x) = \log \rho(w_i) . \rho(x \mid w_i)$$

Equation 2.1Maximum likelihood algorithm equation adopted from (Chen, 2007)

Where $g(x)$ = probability density

$\rho(wi)$ = a priori probability

$\rho(x|w)$ = probability of x for falling in class i

$i = 1, 2, 3, \ldots n$

For equal a priori probability with Gaussian distribution:

$$g_i(x) = -\log|\Sigma_i| - \frac{1}{2}\log\left[(x-\mu_i)^t \, \Sigma^{-1} (x-\mu_i)\right]$$

Equation 2.2Priori probability with Gaussian distribution equation (Chen, 2007)

Where $|\sum i|$ = determinant of the variance-covariance matrix of class i

$\sum$-1 = inverse of variance-covariance matrix

x = measurement vector, i.e. DN values of any pixel for all the channels

μi = mean vector for i^{th} class

t = transpose

A pixel is classified into the i^{th} class only if:

$$g_i(x) \geq g_j(x) \text{ for all } i \neq j$$

Equation 2.3 Maximum likelihood classifier adopted from (Chen, 2007)

The weakness of this classifier is that it involves a number of computations, to classify each pixel, thus it has a longer processing time when compared to other algorithms (Lillesand *et al*., 2008). Regardless, of the complex and time-consuming computations of the maximum likelihood classifier algorithm it is still more beneficial to apply it for all but very large imagery (Aronoff, 2005).

Minimum distance classification: this procedure calculates spectral distance and pixel assignment to classes occurs based on the means closest to the value of that pixel (Jensen, 2005; Eastman, 2006).

Parallel Piped Classification: this classification is based on a set of lower and upper threshold reflectance determined for each signature on each band. To belong to a particular class the pixel must exhibit reflectance within the lower and upper thresholds (Jensen, 2005; Eastman 2006). The major risk associated with supervised classification is that the analyst may not be able to select sample sites to represent all the different classes within an image.

2.3.6.5 Object-based classification

In early 2000, the development of software to delineate and analyse image objects (rather than individual pixels) from remotely sensed images occurred. OBIA (object-based image analysis) was the reference towards the concept in research back during that time (Blaschke *et al*., 2000). Object-based classification first combines image pixels into spectrally similar image objects using an image segmentation algorithm thereby classifying the discrete objects (Liu & Xia, 2010).

The major difference between the two classification methods (object and pixel-based) is that pixel-based approaches deal with individual units and object-based deal with features. The advantages of object-based image analysis are that the change of pixel units to image objects or features reduces the within-class spectral dissimilarities and the removal of the general salt and pepper effects that are common in pixel-based approach. Furthermore, with object-based approaches, an unlimited set of features illustrating objects, contextual, spatial and textural properties can be delineated as conforming information to the direct spectral interpretations thus potentially improving classification accuracy (Guo *et al*., 2007).

However, despite these strengths, object-based classification has its own limitations and disadvantages. Errors like under-segmentation and over-segmentation (Kampouraki *et al*., 2008) often exist and such errors often affect the overall classification procedure in two ways:

Under segmentation leads to image features (objects) that cover more than one class introducing mistakes since all pixels in the mixed image object have to be assigned to the same class. Objects extracted from mis-segmented image features with both under or over–segmentation do not represent the truth on the ground (e.g. area or shape) and this may reduce the accuracy of the classification (Liu & Xia, 2010; Song *et al*., 2005). The issue of image resolution is also key when applying the object-based classification techniques. High-resolution imagery proves to be the most suitable for object-based classification the rest work better with a pixel-based approach.

Less attention has been paid to the potential limitations of object-based classifications since most studies have shown the advantages of object-based classification over pixel-based classification, (Kampouraki *et al*. 2008).

2.3.6.1 Change detection

Change detection is defined as, “the use of multi-temporal data sets to discriminate areas of land cover change between dates of imaging,” (Lillesand, Kiefer, & Chipman, 2008). Change Detection techniques made use of aerial photographs in the past. Technological advancements in recent times have improved and continue to improve change detection techniques thanks to high-resolution data. Availability of high-resolution data has tremendously enhanced the results in terms of precision to studies that involve change detection analysis (Rogan & Chen, 2004).

The application of change detection and the connected analysis has numerous benefits to global and local efforts to monitor LULC. Techniques can identify the location, manner, and type in which LULC transformations occur (Jansen & Gregario, 2002; Nackaerts, Vaesen, & *et al*., 2005). Change detection is essential in identifying changes in urban sprawl. The system relies on differences in radiance values between two or more dates (Pathak, 2014). Change detection has proven to be ideal for monitoring land conversion in certain studies however according to Rashed *et al*. (2005) countless times change detection fails to identify changes that have occurred within specific classes but is rather suited to assessing whether a change has occurred or not. Other studies have noted that the LULC changes that occur in developing countries particularly, take place at a slow rate and hence the difficulties in the identification of transformation (Olang & Kundu, 2011). Although there are a number of change detection procedures, image differencing is one of the most prevalent and extensively used change detection algorithm and it demands the subtraction of two co-registered images attained at different periods (Coppin et al., 2004; Jensen, 2005; Sader et al., 2003).

There are a number of techniques that have been developed and these can be grouped into algebraic/ statistical, change vector transformation, classification or combinations of them. There is no comprehensively prime technique, the choice is dependent on the application. A change map using post-classification of two images can be as accurate as the accuracies of the two individual classifications.

A number of authors Jianya, Haiganga, Guoruia, & Qimingb, (2008); Lu, Mausel, Brondizio, & Moran, (2004); Macleod & Conglaton, (1998); Mas, (1999) did use of multi-temporal remote sensing data for analysis of change detection. The type of CD technique one decides to make use of, on a particular study unswervingly determines the map output (Nackaerts *et al*., 2005). In as much as there are a lot of methods to adopt in a CD procedure, it is imperative to take note of two prominent factors.

It is important to recognize the objective of the study or research with respect to CD and remote sensing. This enables the researcher to determine whether it’s a complete transformation of land-cover or it's just a modification. As such, Jansen and Di Gregorio (2002) explain that absolute land conversion results in a clear change whereas land cover modification results in small change hence making it difficult to detect on the CD process. Lambin and Geist (2006) also adhere to the fact that the process of CD and remote sensing can detect LULC changes that are conversions related to visibility, while modifications are subtle and hard to detect. The second prominent factor is the choice of remote sensor itself, resolution, thematic, spatial, temporal, and spectral constraints might arise due to the choice of sensor. Remote Sensing data has become a major source of CD studies because of its high temporal frequency, digital format suitable for computation, synoptic view and wider selection of spatial and spectral resolutions (Chen, Hay, Carvalho, & Wulder, 2012a; Coops, Wulder, & White , 2006; Lunetta, Johnson , Lyon, & Crotwell, 2004). Prior to applying CD methods, it is essential to be sure these conditions are met, precise image registration of multi-temporal images, precise radiometric and atmospheric calibration or normalization and the selection of the same spatial and spectral resolution images.

2.3.6.2 Pixel-based Change detection

The basis of pixel-based change detection is the use of spectral information of individual pixels for the creation of relevant landcover classes. An image pixel is the atomic analytical unit in these techniques whose spectral characteristics are exploited to detect and measure changes (Masroor, 2013a). Within this category of pixel-based methods, there are several methods that can be adopted in a CD procedure. Various CD reviews built on pixel-based analysis of remote sensing data have been brought forth. Publications have summarized and categorized CD techniques based on varying viewpoints (Coppin, Jonckheere, Nackaerts, Muys, & Lambin, 2004; Deer, 1995; Jianyaa, Haiganga, & Qimingb, 2008).

Some of the techniques include Principal Component Analysis (PCA), Temporal Image Differencing (TID), Temporal Image Rationing (TIR) and Post Classification Comparison (PCC). Pixel-based CD techniques use processes and algorithms for change extraction and combine it with processes in order to achieve change separation.

2.3.6.3 Landscape metrics in the measurement of urban sprawl

Change in the landscape can be measured and monitored using spatially oriented metrics. In general, spatial metrics can be defined as quantitative and aggregate measurements derived from digital analysis of thematic-categorical maps showing spatial heterogeneity at a specific scale and resolution (McGarigal, Cushman, Neel, & Ene, 2002; Herolde, Goldstein, & Clarke, 2003). Often landscape metrics, deal with the multi-temporal landscape parameters. Due to the lack of appropriate indicators and information, that provide a holistic standpoint on urban areas that captures all aspects, it is often difficult to quantify urban sprawl. Measuring landscape properties involves the calculation of patchiness, patch density, interspersion and juxtaposition, relative richness, diversity, fragmentation, and dominance in terms of structure, function and change (Civco, Hurd, Wilson, Song, & Zhang, 2002). GIS technology and landscape pattern calculation software (FRAGSTATS, APACK) make it practically possible to generate many landscape pattern measurements without doing the actual mathematical computations involved.

It is therefore important to understand the factors that influence the interpretation of a landscape metric or indicator. Most of the metrics are sensitive to changes in spatial resolution (grain size) of the data or the area (extent) of the landscape (Wickham & Riitters, 1995), and numerous correlations occur among landscape indices (Riitters, *et al*., 1995). There are a number of metrics and most of them are correlated to each other making it difficult to interpret them. Galster *et al*. (2001) used eight different metrics of land use patterns (density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity) to measure sprawl in 13 American cities. Similarly, like many other studies, in this study, there is no proposed metric to measure the level of urban sprawl independently and hence the research adopted a number of metrics to help examine the urban sprawl occurring in Buffalo City metropolitan municipality.

Literature has proven that most studies on urban sprawl use causes and consequences of urban sprawl as indicators of the phenomenon. Methods used in literature in their variety have indicated, compared and summed up the level of urban sprawl in different study sites. Tsai (2005) used density, diversity and spatial structure patterns to measure sprawl. The Sierra Club (1998) made use of four attributes that is population moving from the inner city into suburban areas, population growth, time spent on traffic and the amount of decrease in open space to rank capital cities. The weakness with most methods is that a large amount of data is required to compare different indicators to determine the extent of urban sprawl. There are only a few methods in which there is reasonable data amount usage, to measure the extent of urban sprawl that is, weighted urban proliferation and Shannon entropy method.

2.3.6.4 Shannon entropy approach to measuring urban sprawl

Many studies have used Shannon entropy in conjunction with GIS and remote sensing to quantify urban sprawl over a particular period (Dadras *et al*., 2015; Bhatta *et al*., 2010; Sun *et al*., 2007). Shannon entropy is one of the popular methods used to quantify urban sprawl, because of its lack of sensitivity to problems concerning the modification of the areal unit, where alterations to the magnitude, size, shape, and quantity of regions can occur (Bhatta *et al*., 2010). Masoumi and Roque, (2015) observed that Shannon entropy has been used to quantify urban sprawl in a number of developed and developing countries like India, China, Iran, and others.

Shannon entropy metric analyses and assesses any geographical variable. The method reveals the configuration and orientation of spatial patterns and can analyse spatial variables within a GIS (Sudhira, Ramachandra, & Jagadish, 2004; Xie, Shi, Zhu, Peng, & Chen, 2016; Kumar, Pathan, &

Bhanaeri, 2007; Yeh & Xia, 2001). The degree and extent of urban sprawl is recognized by an entropy value. The relative entropy scale starts from zero to one. A value of 0 denotes the compact distribution of the urban area, whereas values closer to one represent a dispersed distribution of urban areas. Hence, higher values represent a high occurrence of urban sprawl in the specific area under study.

2.3.6.5 Patch density index, Aggregation index and land Patch index

Other metrics to support Shannon entropy are Patch density index (PDI), land patch index (LPI), aggregation index (AI) among other metrics. Patch density index describes the number of patches on a particular piece of land, land patch index (LPI) describes the proportion or percentage of landscape comprised of the largest patch. Aggregation Index describes the number of like adjacencies linking the corresponding class, divided by the maximum possible number of like adjacencies involving the corresponding class, which is achieved when the class is maximally clumped into a single, compact patch; multiplied by 100 (to convert to a percentage) (McGarigal & Marks , 1995). It can be expressed using the following equation:

$$AI = \left[\frac{g_{ii}}{\max \rightarrow g_{ii}} \right] (100)$$

Equation 2.4 Aggregation Index Equation (McGarigal & Marks, 1995)

If a_i is the area of class i (in terms of number of cells) and n is the side of a largest integer square smaller than a_i, and $m = a_i - n^2$, then the largest number of shared edges for class i, max-g_{ii} will take one of the three forms:

max-g_{ii} = 2n(n-1), when m = 0, or

max-g_{ii} = 2n(n-1) + 2m -1, when $m \leq n$, or

max-g_{ii} = 2n(n-1) + 2m -2, when $m > n$.

Note, because of the design of the metric, similar adjacencies are tallied using the single-count method, and all landscape boundary edge segments are ignored, even if a border is provided.

Patch density on the other hand PDI equals the number of patches of the corresponding patch type divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares). Note, total landscape area (A) includes any internal background present.

$$PD = \frac{n_i}{A}(10{,}000)(100)$$

Equation 2.5 Patch Density Index (Hadly, 2000)

LPI refers to the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, LPI equals the proportion of the landscape comprised by the largest patch. Note, total landscape area (A) includes any internal background present.

$$LPI = \frac{\max\limits_{j=1}^{n}(a_{ij})}{A}(100)$$

Equation 2.6 Largest patch index (LPI) equation (McGarigal & Marks, 1995)

LPI approaches 0 when the largest patch of the corresponding patch type is increasingly small. LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type; that is when the largest patch comprises 100% of the landscape.

2.4 JUSTIFICATION OF CHOICE OF MEASURES OF URBAN SPRAWL ADOPTED

Due to the nature of the research, adoption of the GIS and remote sensing approach for the measurement of urban sprawl in BCMM was inescapable since literature has proven that it is important to assess urban sprawl over a period and compare whether changes and growth have indeed occurred over the given period.

However, the use of GIS and remote sensing on its own cannot give a conclusive assessment, hence; there is a need for the use of landscape metrics that enable us to draw a comprehensive judgement. Due to the abundance and variance of such metrics, only those relevant, robust and accurate is used. Urban sprawl can be accounted for using numerous criteria, those finally adopted for the study were in accordance with the set objectives, information available and researcher's experience. The choice of metrics chosen was the best for bringing out the problems at hand.

2.5 CHALLENGES FACING URBAN SPRAWL RESEARCH

Understanding exactly how the urban landscape has and continues to transform is a difficult procedure, which is fraught with a range of data, methodological and analytical challenges (Bhatta, *et al*., 2010). Some of the challenges faced in urban sprawl research include the lack of a threshold of a sprawling and non-sprawling city. As such it is difficult for one to distinguish natural urban growth and the consequence of that growth thereof (urban sprawl). Methods suggested and used for the measurement of urban sprawl are usually methods that are used to determine whether the city has been expanding or not, hence, there is a lack of specific methods meant to measure sprawl singularly.

So long there is lack of a standard definition of sprawl, urban sprawl remains undetermined, an eclectic repertoire of methods the efficiency of which will be debated. Akin to this, it is imperative that an agreement be reached as to what urban sprawl really is so that parameters can be set instead of using a number of approaches to investigate the concept of sprawl.

2.6 CONCLUSION

Studies on urban sprawl have shown that there is a need for further investigation and quantification of urban sprawl. Eastern Cape is gradually growing socially and economically, however, there is limited information with regard to the impacts of such growth on the environment. This study takes a considerable interest in understanding the dynamics of urban growth and expansion of BCMM. GIS and remote sensing are used to assess the changes that have occurred to the metropolitan municipality over the given period.

CHAPTER 3: METHODOLOGY AND METHODS

In this chapter, the research explores the methods used to investigate and quantify urban sprawl in the Buffalo City Metropolitan Municipality. The chapter also determines research methods, data collection and the analysis of spatial data. The chapter defines the scope of the research design and situates the research amongst the existing research traditions in urban sprawl. Data acquired from SANSA in the form of SPOT imagery is used in this research. Images from 1994, 2000, 2006,and 2012were chosen based on a six-year interval that would be appropriate to show any changes to the urban areas.

3.1 METHODOLOGY

Quantitative techniques that aim on understanding urban growth and expansion are the basis of the methodology adopted. Urban sprawl is best understood from an expansion and growth perspective. Analysis is based on the principal dimensions of urban sprawl measurement selected for the study. Land use and land cover change analysis plays a key role in any measurements related to urban change or growth. Assessment of landscape pattern and form is another crucial step. Everything has been summarised in the flowchart below:

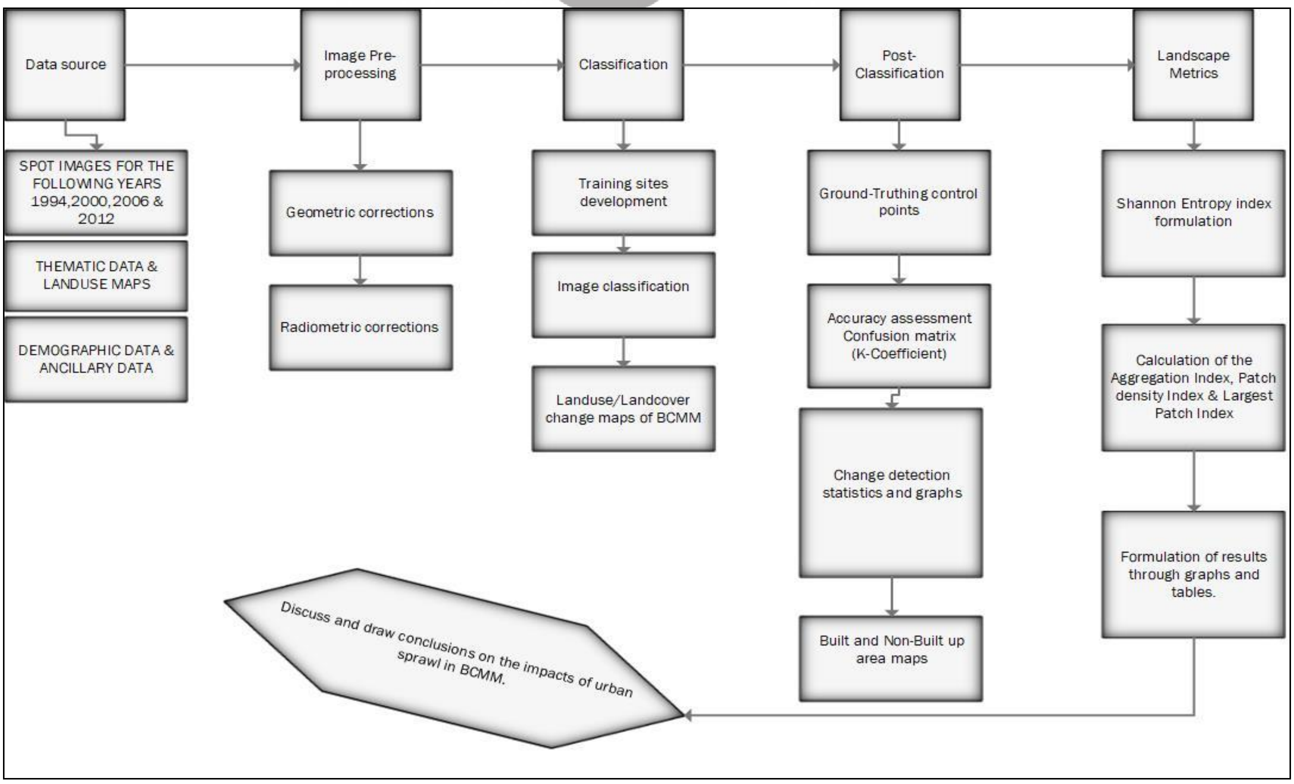

Figure 3-1 Methodology flow chart

3.2 DATA DESCRIPTION AND COLLECTION

The section describes the materials and methods used throughout the research by the researcher. The data collected was processed and analysed using the methods mentioned in the sections below

3.2.1 Description of the study area

Buffalo City Metropolitan Municipality covers approximately 2536 km^2 and is centrally located in Eastern Cape Province between 32.4100.13°S to 33.1659.05° north latitudes and 27.1953.11°E to 27.2831.29° East longitudes (fig 3.2). It comprises of an urban concentration along the South-eastern side of the Buffalo City Metropolitan Municipality. The metropolitan municipality houses a network of urban areas, stretching from the upper west in Dimbaza through to Mdanstane and ending at the port in East London. The major urban centres of the metropolitan municipality include Bhisho, East London, King Williams's town, Mdanstane, and Zwelitshe townships. Buffalo City is surrounded by sparse rural areas and is isolated from South Africa's major urban centres. BCMM is a composite settlement and land use pattern, which integrates peri-urban, urban and rural components. According to the Buffalo City Metropolitan Municipality (2016), the existing urban areas and settlements in Buffalo City are spatially fragmented, which is a feature of the entire municipality. The spatial fragmentation creates a negative urban dimension that in turn affects the natural environment of the local municipality. A general assessment of the metropolitan municipality shows that East London is the principal industrial and service centre that attracts people from all corners of the Eastern Cape Province to better access urban services and facilities. The choice of measuring urban sprawl in Buffalo City Metropolitan municipality was based on the fact that Eastern Cape has two large cities one (Port Elizabeth and East London) of them had to be assessed since time and resources limited the researcher from studying the both of them. The area has a well-developed manufacturing base, with the auto industry playing a major role in its economy. Eastern Cape also has two metropolitan municipalities with both of them having a large city each. Choice of one of the two metropolitan municipalities was based on proximity and nearness to the researcher to lower costs of travel to and from the site. BCMM's population has been increasing over the past decade and an assessment of what this increase has impacted on was necessary to achieve the issue of sustainability was a national concern. The study site was chosen to characterize the changes that have occurred to the landuse and landcover patterns of BCMM because of urban growth and expansion. Problems of pollution and fragmentation of natural land are experienced in the region and as such, the study seeks to clarify the roots of most of the environmental problems being experienced

The population of the metropolitan municipality is estimated at 834 997 (Statistics South Africa, 2016). Many people migrate towards the urban areas within the district. The annual population growth rate of BCMM is 0.8%. Most South African urban areas are expanding primarily through the development of new housing areas beyond the existing urban boundary in a haphazard way. The boundaries of urban centres in BCMM comprise of both legal and illegal housing settlements that are separated from each other by patches of open spaces or roads. Due to the nature of development, taking place within the Province the study area was selected based on the undocumented environmental impacts that BCMM is facing owing to urbanisation. In addition, the Metropolitan municipality has been expanding rapidly in terms of both infrastructure and population growth. This rapid development has made the urban planning process clumsy and in-turn negatively affected the environment. Below is a map showing the location of Buffalo city metropolitan municipality with respect to South Africa and the Eastern Cape Province (fig 3.2):

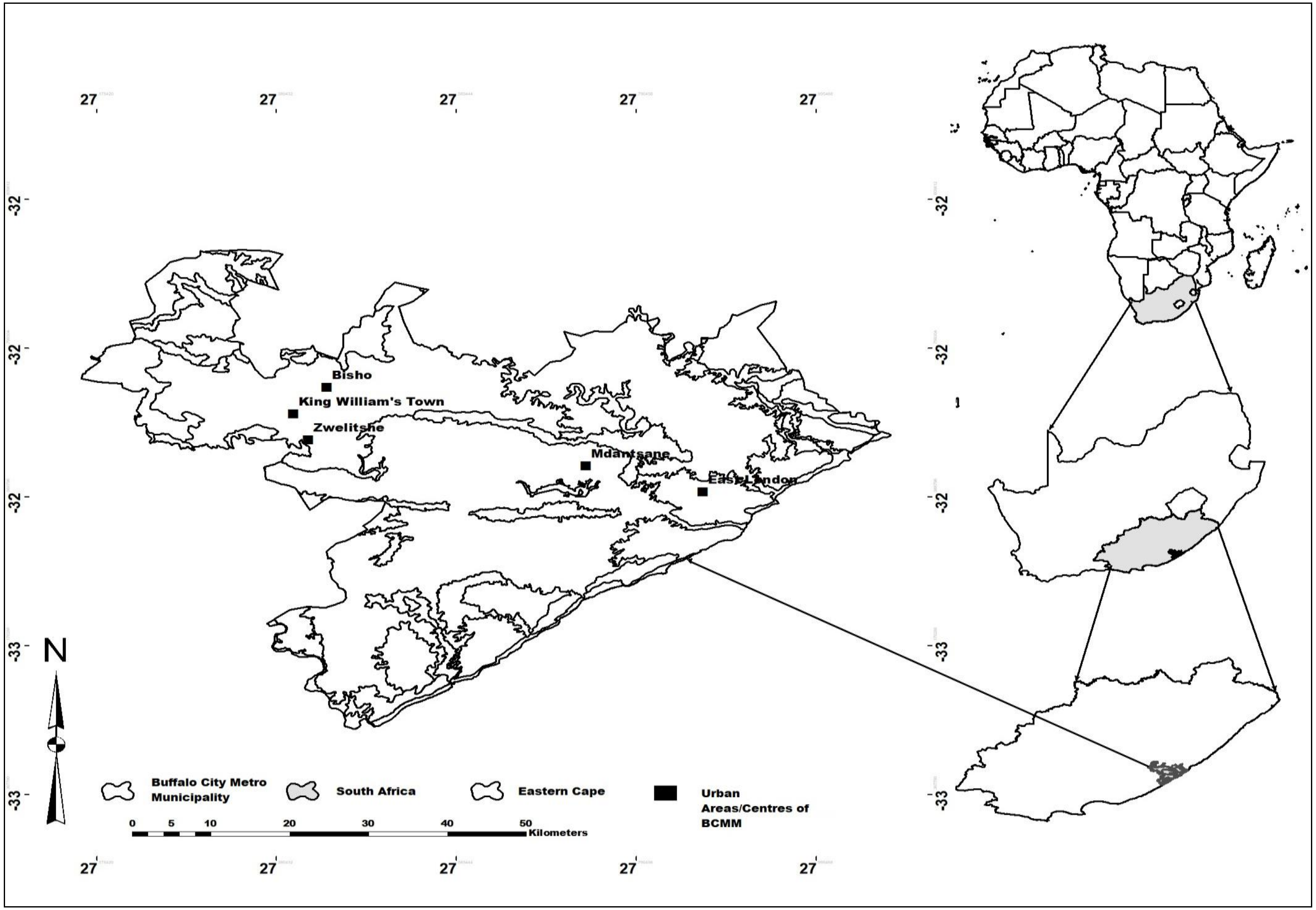

Figure 3-2 Study Area Map Buffalo City Metropolitan Municipality, Eastern Cap

3.2.2 Field data collection

Extensive reference data was collected to support the remote sensing data available and to perform an accuracy assessment. The data collection was conducted with the aim of recording the locations of various land cover classes within Buffalo City Metropolitan Municipality to be used as ground-truthing data. Major land cover classes considered in the scope of this research were urban, non-urban and water. A hand-held GPS recorded the coordinate locations of the different classes. The idea behind the collection of data using field surveys is to verify information extracted from the satellite image and to support overall analysis and interpretation of the acquired data (Lillesand, Keifer, & Chipman, 2014). Collection of reference data, is crucial for any image classification procedure of remotely sensed data and the post- classification accuracy assessment.

Though one can still go into the field to collect data advances in technology have allowed for the easy accessibility of topographic maps, aerial photographs and ortho-imagery, which can all provide one with reference data (Lu & Weng, 2007). However, fieldwork provides a far greater level of accuracy compared to other methods and can be conducted efficiently and timeously.

Fieldwork for this study was done on the (17th of October 2017) and (23 of March 2018) in Buffalo City Metropolitan Municipality. An overall of 360 GCPs for the six classes namely built-up, open-grassland, dense-natural vegetation, agriculture-farms, sand and water was collected for the purpose of this research from different locations throughout the entire study area to ensure documentation of the differing landcover classes and land uses. The GPS handheld device used for the fieldwork was a Garmin GPSMAP 64ST Handheld GPS and had a root mean square error 0.0346 of less than one metre. The GPS measured locations were recorded in tabular format and converted into a point map.

3.2.3 Data source

SPOT data was acquired from the South African National Space Agency (SANSA) for four-time intervals (1994, 2000, 2006, and 2012), for the purpose of this research. Because South Africa obtained its independence in 1994, the researcher thought it rational to be the start year for the study to compare the different regimes. Hence, the researcher sought to find out changes that have occurred since the change in governance. However, it is not easy to have multi-date data of the same time of the year, particularly, in tropical regions where cloud cover is common (Mas, 1999).

SPOT is a group of remote sensing satellites stationed at space and responsible for capturing satellite imagery periodically. It was first launched in 1986 February 22 with the primary aim of obtaining earth data on land-use, water resources, cartography, agriculture, regional planning, and GIS operations. To date, seven satellites have been launched since 1986; however, of the total seven, only three are still functional, as some have outlived their timeline. Operation of the satellites is done by the French space agency (Centre National d'Etudes Spatiales CNES).

3.2.4 Acquisition of additional data

For the purpose of the research endeavour, interviews of key informants were done in the light of obtaining information from the metropolitan municipality. The qualitative aspects of this study consisted of interviews with local land developers, planners, and analysis of jurisdictional comprehensive plans. With a qualitative approach, I hoped to gain a better understanding of multivariate phenomenon such as urban sprawl and further be able to account for development based on land value and zoning ordinances. It is not practical to assume that a strictly quantitative or qualitative approach alone would be adequate enough to make any conclusions about sprawl trends in a given area. While my maps will provide visualization of the spatial distribution of built-up land, they cannot explain why one parcel is more attractive to a developer or investor than another parcel of land. Conversely, my interviews with developers and audits of comprehensive plans alone will not allow for quantification and classification of growth areas into meaningful classes of urban sprawl. Therefore, it was vital to incorporate aspects of both qualitative and quantitative analysis techniques in order to be able to reasonably describe and understand whether and to what extent urban sprawl trends exist in BCMM. The table 3.1 summarises the details of the individual SPOT images selected for the study in BCMM.

Table 3.1 Summary of SPOT Images used for the study

Satellites	**Acquisition date (day/month/year)**	**Sensor**	**Spatial resolution**	**Projection**	**True colour composites (TCC)**
SPOT 2	08/06/1994	HRV	20 Metres	WGS84/UTM35S	TCC
SPOT 2	08/06/1994	HRV	20Metres	WGS84/UTM35S	TCC

SPOT 2	08/06/1994	HRV	20Metres	WGS84/UTM35S	TCC
SPOT 4	20/05/2000	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 4	15/05/2000	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 4	18/05/2000	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 5	26/08/2006	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 5	26/08/2006	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 5	18/07/2006	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 5	03/07/2006	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 6	02/04/2012	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 6	18/04/2012	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 6	15/04/2012	HRVIR	20Metres	WGS84/UTM35S	TCC
SPOT 6	02/04/2012	HRVIR	20Metres	WGS84/UTM35S	TCC

3.2.5 Criteria for choosing spot imagery

Many satellites offer remote sensing data. Nevertheless, not all of this data and information is open for all. Most of the imagery comes with a cost. However, of the huge list of remote sensing data providers, shown in table 3.2 below, SPOT imagery proved to be the best choice for the study. Though LANDSAT imagery is known for its huge archive of remote sensing data that dates back to 1972 (Chander, Markham, & Barsi, 2007). SPOT imagery was chosen for this research based on its high resolution of 20 metres, which is key, in the analysis of the environment. Imagery from the same season was selected with the aim of ensuring a clear distinguishable spectral reflectance pattern of the different land uses. The SPOT datasets with the least cloud cover were selected, though in extenuating cases the researcher was forced to take images with a certain degree of cloud cover. The images in that category were corrected to improve accuracy. The diagram below is a list of satellite sensors and their pros and cons of each sensor. Issues like resolution, cost, orbit cycle and type of sensor are considered when one attempts to research on a topic. Various sensors capture varying degrees of information as illustrated by the table below:

Table 3.2 List of Remote Sensing service providers and their specifications

Satellite	Sensor	Resolution (spatial)	Orbit cycle	Image cost
TERRA	MODIS	250m	2 days	Low
		500m		
		1000m		
LANDSAT 7	ETM+	15m (185 km)	16 days	Medium
		30m (185km)		
DMC II		32m (80X80km)	1 day	Medium
SPOT 1-3	XS	20m (60X60km)	26 days	Medium
	PAN	10m (60X60km)		
SPOT 4	XS	20m (60x60km)	26 days	Medium
	PAN	10m (60x60km)		
	VGT	1m (2000km)		
SPOT 5	HRS	10m (60x60km)	26 days	Medium
	HRG	5m (60x60km)		
TERRA	ASTER	15m		Medium
		30m		
IRS-C	PAN	5.8m (70km)		
	LISS-III	23m (142km)		
IKONOS	PAN	1m (min10x10km)	3 days	High

	MS	4m (min10x10km)		
QUICKBIRD		2.5m (22x22km)	3 days	High
		61cm (22x22km)		
ALOS	PRISM	2.5m (70km)	46 days	High
	AVNIR2	10m (70km)		
	PALSAR	10m (70km)		

3.3 DATA MANAGEMENT

This section presents all procedures done to the datasets prior to its use for the research. It is important to pre-process data to get rid of errors and improve accuracy.

3.3.1 Image pre-processing

Satellite imagery requires pre-processing prior to its use in GIS and Remote Sensing. It is hence important to correct all errors that come with satellite imagery, in order to improve the accuracy of results the researcher intends to acquire. Images are georeferenced and projected to enable them to overlay, clip or mosaic correctly. Due to the nature of the earth's shape (geoid), locations on the earth's surface are described in a geographical or angular coordinate system, with longitude and latitudes. Due to the complexity involved in representing the three-dimensional surface of the earth on a two-dimensional surface of a map, it is hence important to introduce shape, size, and direction to avoid distortion. This transformation is what is termed projection. Many projection types have been brought forth but all are based on geometric models or spatial properties that they preserve.

The reclassification was performed on all the datasets used for the research so that all null values were changed to "no data" using the reclassify tool in ArcGIS Spatial Analyst. This was done to ensure that no calculation would occur on sections were no digital data is present. Data was further pre-processed using the correction methods discussed below to ensure that data was accurate and relevant.

3.3.1.1 Geometric corrections

Geometric correction is essential when pre-processing remotely sensed data in order to remove internal and external distortion so that individual image pixels are in their appropriate plan metric *(x, y)* map locations. The correction process refers to the transformation of multispectral data (images) acquired from satellite sensors to match a certain cartographic projection, free of distortions and each image pixel is given a specific coordinate. The effects of the atmosphere coupled with features reflection are part of the correction process (from radiance to ground reflectance). Imagery rectification is aimed at facilitating the overlay of supplementary data.

Residual unknown systematic distortions and random distortions need the analysis of well-distributed ground control points (GCPs) for correction. GCPs are features of known location that can be accurately located on the imagery. In the correction procedure, a number of GCPs are identified in terms of their two image coordinates (column, row numbers) on the distorted image and in terms of the actual ground coordinates. Least squares regression analysis then determines coefficients for two coordinate transformation equations that are then used to inter-relate the geometrically correct (map) coordinates and the distorted image coordinates. Once the coefficients are determined, the distorted image coordinates for any map position can be precisely estimated as expressed by the equation

x = f1(X, Y)

y = f2(X, Y)

Equation 3.1 Geometric correction equation adopted from (Lillesand, et al., 2014)

Where (x, y) = distorted image coordinates

(X, Y) = correct (map) coordinates

f1, f2 = transformation functions

Fig 3 shows the corrected output matrix of cells (solid lines) overlaid over the original, distorted matrix of image pixels (dashed lines). An average of 90 GCPs was collected for the entire study area of BCMM a first-order polynomial algorithm was used. An average root means square error of 0.334 of the 15 SPOT images was obtained.

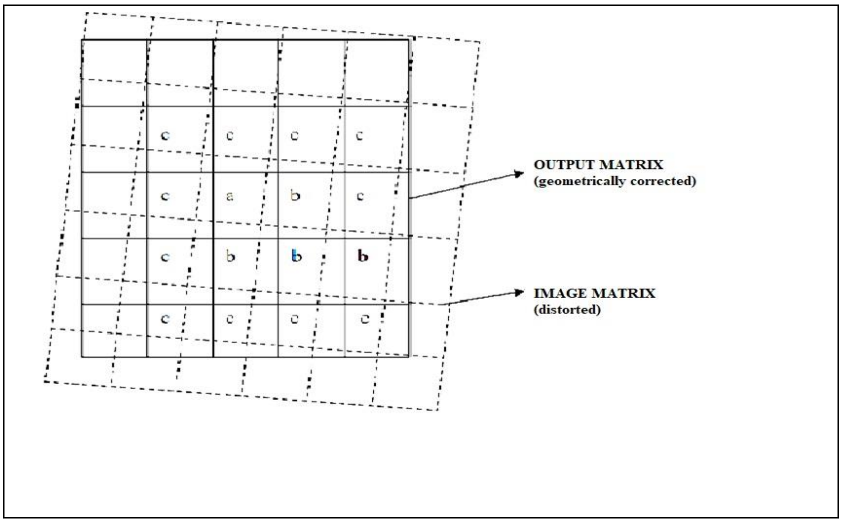

Figure 3-3 Geometric image correction adapted from (Lillesand, Keifer, & Chipman, 2014)

SPOT images acquired from the SANSA database are Level 1A, which means that images are radiometrically correct and all images have a coordinate system. All the images had geometric errors, centred on their positioning. For these images to perfectly overlay and hence mosaic it is important to correct them geometrically. The procedure shown in figure 3.3 below summarises the process.

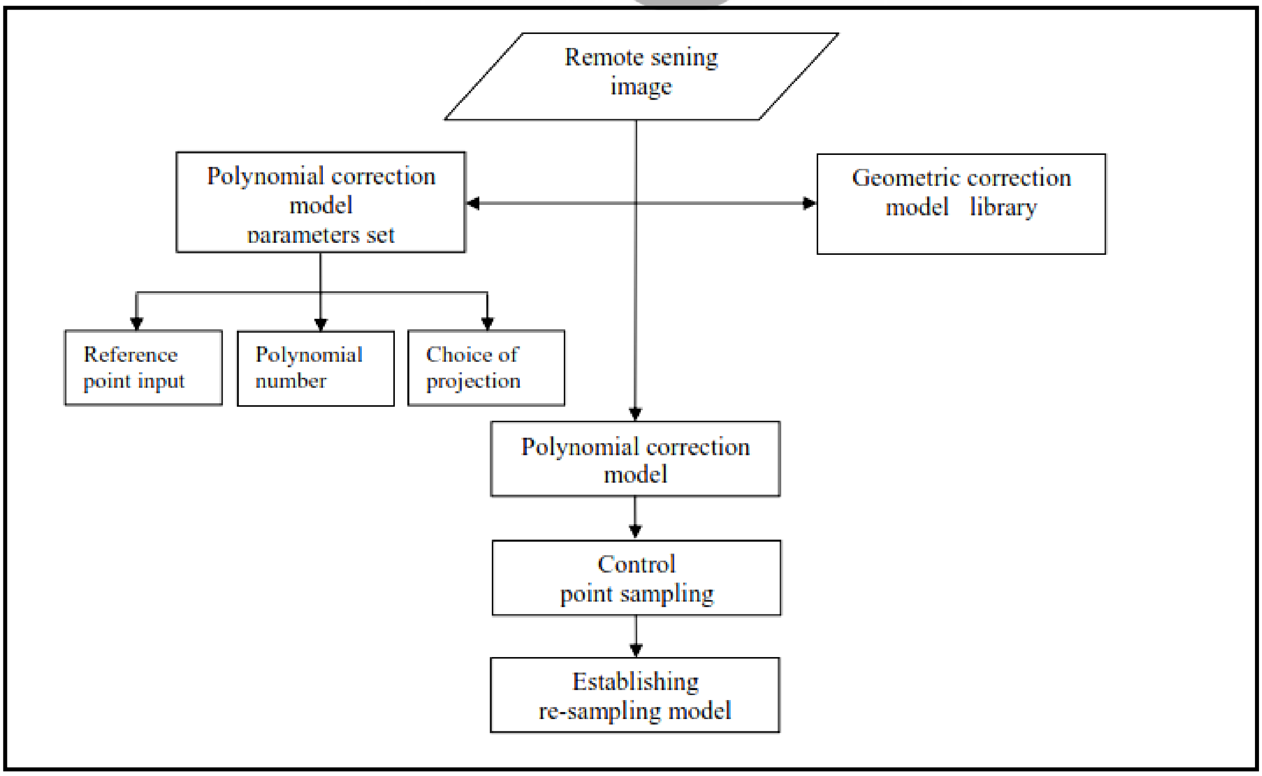

Figure 3-4 Summary of geometric correction procedure

3.3.1.2 Radiometric Correction

For change detection analysis it is important to reduce the influence of sensor characteristics, solar angle, sensor view angle and atmospheric condition. Corrections are categorised into two types that are relative and absolute corrections. Absolute corrections were digital number values (DN) are converted to surface reflectance and relative corrections which normalize numerous satellite images to one reference image. Methods like dark object subtraction are part of the radiometric corrections and the commonly used. DOS assumes that the impact of the atmosphere is uniform across the study area. Hence any radiance received from the sensor for a dark object pixel (i.e. a pixel with near zero percent reflectance) is solely a result of atmospheric scattering (path radiance) and can hereafter be subtracted from the signals produced by other objects in the image.

It is important to note that all of the images used in this study displayed none radiometric anomalies and were received from SANSA were they were corrected prior to their dissemination to the researcher. However, the researcher acknowledges the procedures involved in radiometric correction.

3.3.1.3 Image sub-setting

Due to the nature of the research, the focus is mainly directed towards known urban centres and areas of human residence. As such, it is important to cut out the unwanted parts of the stacked images to increase processing speed and allow the computation of necessary areas within the municipality. Thus, mosaicked images have been subset according to the jurisdictional boundary of the metropolitan municipality as shown below in figure 3.

The subset image displays the green red and near infrared of the SPOT data with blue, red and green colour guns. Sub-setting an image is essentially the selection and reduction of spatial extent, cropping of the specific area of study to cover the actual area of interest also involving the selection of the specific bands relevant to the study and skipping the unnecessary bands. The diagram below is a subset image of BCMM taken from one of the SPOT images obtained from SANSA:

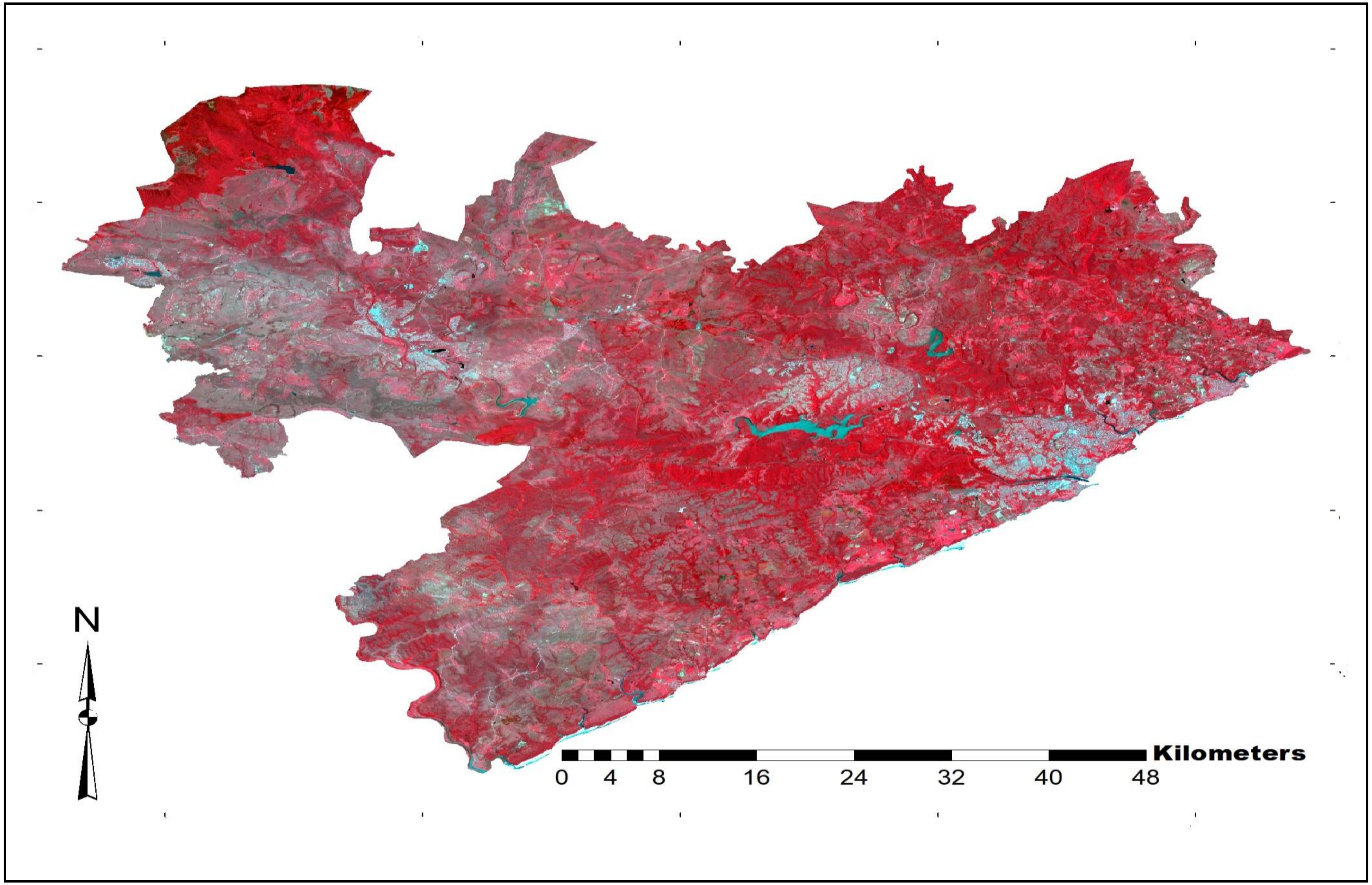

Figure 3-5 BCMM subset image in true colour (RBG)

3.3.1.4 Training sites development

The first step of the classification process is the extraction of class signatures or training sample spectral library development (see table 3.3 for land-cover class descriptions). Training samples are initially collected on a per-pixel basis to reduce redundancy and spatial auto-correlation (Gong & Howarth, 1990). A training site is a sample of homogenous areas selected by the image analyst prior to the classification procedure. These areas were determined from ancillary data and the knowledge of the place under study. The training sites chosen were big enough for good statistical representation. Intensive field visits were done over the study area. The six classes named in table 3.3 below, were initially used in the development of training sites. Sixty points for each class were collected during field visits to the study area. Apart from the identification of the land use and land cover class, the training sample points were further used to validate similar spectral response confusions by different spatial features.

With the intention of developing a spectral library (n=360) half of the n was converted to ROIs (regions of interest). The spectral signatures for all the (n=6) classes were then extracted from a panchromatic SPOT image of the study area and coordinates of the area collected on field visits and saved as a spectral library using ERDAS IMAGINE 14 software.

3.4 METHODS

This section presents the methods implored in the assessment of urban sprawl in BCMM. The methods are in line with the objectives of the study.

3.4.1 Image classification of the investigation and quantification of urban sprawl

Mosaicking of satellite imagery was done prior to a classification procedure, which is the process of combining different scenes into one image to enable the classification of the entire study that lies on a number of scenes. Image classification is the assigning of landcover classes to pixels from a multi-band raster image. Mapping of specific study areas requires the division of land into specific landcover classes to enable analysis. Supervised and unsupervised are the two types of classification available. Supervised classification requires the input of an analyst before any computations. This input involves the creation of training data where the analyst identifies known features into landcover classes. Accuracy is highly dependent on the choice of sample locations chosen by the analyst. It is therefore important for the analyst to be familiar with the area covered by the image to increase accuracy. Individual pixels in the image dataset undergo a numerical comparison to each landcover type in the interpretation key and labelled according to the landcover type it “looks most like”.

The study used standard image analysis procedures and supervised classification based on the nature of the data available and its robustness and accuracy was chosen. When prior knowledge of the land cover of the study area is known, supervised classification is most suitable. Training data was obtained from the field. The classification procedure entails that the analyst supervises the pixel categorization by allocating bounds to each of the desired output classes based on the knowledge of the sampling universe. Training areas, usually small and discrete as compared to the whole image, are used to “train” the classification algorithm to identify landcover classes based on spectral signatures. Areas chosen as training sites should fully represent the variability found within a single class, of an image. A number of factors particularly the signatures of landcover classes can affect training sets. Factors about the environment such as soil health of vegetation, soil type, and varying soil moisture all affect the spectral signatures automatically affecting the accuracy of the product. Algorithms are chosen based on the result and as such, the maximum likelihood classifier was chosen since it proved to be more accurate when compared to other classifiers. Results showed that the maximum likelihood classifier required only sixty training sample pixels per class to reach the highest accuracy irrespective of the number of bands involved. Hence, they echoed this to show a level of robustness and capability to generalisation. For each of the four classifications performed in the study, sixty pixels per class were therefore considered the standard requirement. Training samples actually ranged in size between 100 and 1800 pixels per class dependant on class abundance and spectral variability. The landuse and landcover schema used to detect urban sprawl were relatively simple, with pixels classed as either urban, non-urban and water bodies. However, the nature of the spectral variability within non-urban and urban classes, the classification was initially performed with six classes which were later regrouped into the three major classes as shown in table 5 below. The final built-up class was derived from the identification of training samples representative of the six classes adopted from the land-cover classification scheme of South Africa (Thompson, 1996).

Table 3.3 Supervised classification landcover schema

Final landcover class	Supervised classification class	Description
1. Urban	**1. Built-up**	Land with residential rooftops, Driveways and local roads dominate, with a small amount of vegetation. The land where rooftops of large Buildings, car parks, multilane roads, railway yards dominate.
2. Non-urban	**2. Open-Grassland**	Grazing pastures, golf courses, parks
	3. Dense-Natural vegetation	Indigenous vegetation and vegetation found within urban areas.
	4.Agriculture- Farms	Land under cultivation were crops grown mainly are cereal crops.
	5. Sand	Sand deposited by water near water bodies.
6. Water	**6. Water**	Includes oceans, rivers, and lakes

Because of the major objective of the study, the six classes were further merged and regrouped as urban, non-urban and water as shown in the final landcover class in table six above. This assisted in discussing and analyzing the extent and pattern of urban sprawl in BCMM. This facilitated the categorization of the heterogeneous nature of different classes under certain major categories. Nonetheless, it was not an easy task differentiating similar spectral values of the features in urban centres this risked the distortion of the accuracy of the classification. All computations related to classification were executed using ERDAS IMAGINE 2014 software.

3.4.1.1 Post-classification procedure

After the completion of the classification procedure, the next crucial step is carrying out the accuracy assessment, change detection and measurement of the urban sprawl using landscape metrics.

3.4.1.2 Classification Accuracy Assessment

An accuracy assessment of individual classification maps is essential to correct and effective analysis of LULC change. The degree of accuracy is important for decision-making and hence if the information is not accurate there is a need for revision. Classification accuracy is assessed based on all the spectral features. Common errors of image classification imprecision include spectral mixing, errors of spatial registration and incorrect assignment of pixels to respective class groups. An interpreter can confuse a classification error, assuming that change has occurred. Accuracy assessment is considered as an integral part for any image classification. This is because classification algorithms can classify pixels or a cluster of pixels into the wrong class. Common errors include errors of omission and commission. For further use of classified images in change detection analysis, there is a need to quantify and evaluate classification errors in terms of a classification accuracy assessment. The technique provides both statistical and analytical approaches in the analysis of classification accuracy. The popular measure used to address the differences between change agreement and actual agreement the Kappa Co-efficient was also calculated. The reference data used for the whole accuracy procedure was obtained from ground truth points from the field and Panchromatic Spot images of the study area.

3.4.1.3 Change detection analysis

To conclude the dynamic phenomenon of urban sprawl in BCMM there is a need for land use change analyses. The patterns of landcover changes for Buffalo City Metropolitan Municipality, Eastern Cape, South Africa were determined based on multi-spectral SPOT remote sensing data. Image classification used pixel-based maximum likelihood (ML) classifier algorithm in ERDAS IMAGINE 2014 software. This permits the quantification and observation of spatial and temporal variations in the distribution of land cover classes. Change detection analysis using multi-temporal imagery enables the use of various approaches to studying changes in the same area and different times. Each technique has a specific contribution to each field of study. Post-classification change detection is the most common procedure used to analyse and detect changes in vegetation. Change detection analyses classified images from different dates independently. Change detection in the case of this study used the image differencing technique. The algorithm includes a cell-by-cell subtraction of one image from another, both of which have been co-registered initially (Sader *et al*., 2003). It subtracts the first date image, from the second date image, pixel by pixel to produce a third image. The subsequent image comprises of the numerical differences between the pairs of pixels. Sections on the image, which have not changed, will display values that are very small, that are values towards zero; on the other hand, those areas that have changed will possess larger positive or negative values. Its low cost and latent for huge data processing are the two main benefits characterised with image differencing. Despite its failure to provide a rather more detailed change matrix when compared with other algorithms used in change detection, image differencing is a modest and straightforward method and yields results that can be interpreted easily. For this research image, differencing algorithm was applied to the classified images using ENVI 5.1 software.

3.4.2 Identification and measurement of urban sprawl using landscape metrics

Landscape metrics or indices exist as quantitative indices that describe structures and patterns of landscapes. The transformation of built-up areas using only remote sensing data is not enough to show real patterns of urban sprawl, hence landscape metrics are used to create quantitative measures of spatial patterns on remote sensing images.

A single landscape metric cannot capture all aspects of landscape characteristics. Therefore, a combination of metrics can be beneficial in interpreting landscape change. With the wide array of these metrics present to choose from, most of the metrics correlate. It is important that the choice of metrics meet several criteria. The current study divides the metropolitan municipality into four zones to assess the urban sprawl area of BCMM to compute Shannon's entropy. The quantity of variables under study in each zone is used to measure the overall dispersion of those variables across all zones. The city centres themselves are not included in the computations, because of consideration for the centrality aspect of urban sprawl. Centrality considers the spread of developed areas away from a central business district or city centre, rather than within the city centre itself.

For this particular study Shannon entropy, PDI (patch density index), LPI (largest Patch Index) and aggregation index (AI) were used. PDI is the number of patches of the corresponding land cover type divided by the total area of interest. LPI measures the percentage total of land area occupied by the largest patch at the class level, exposing the dominance of a particular land cover type. The AI is calculated from the patch adjacency matrix, which measures the degree of fragmentation of a land cover type or landscape. The metrics were generated for BCMM. Fragstats software was used to compute the various metrics. The results of the operation are shown in the next chapter.

3.5 CONCLUSION

The chapter summarizes the data and methods used during the course of this research. Akin to the data used, SPOT imagery was readily available and suitable with the object of the research. Six land cover classes i.e. built-up, open grassland, dense natural vegetation, agriculture farms, sand, and water, were identified using a combination of remotely sensed imagery and field visits. Considering the methodology, a brief summary of the classification algorithms adopted was given followed by the steps involved in the actual classification. Change detection methods used and accuracy assessments were also discussed in this chapter. Finally, the landscape metrics used for the study were assessed and discussed concluding the chapter.

CHAPTER 4: RESULTS AND DISCUSSION

This chapter provides a detailed account of the results generated from all the procedures described in chapter four. Results presentation is in the form of maps, tables and graphs, relevant landuse change and land cover maps of the stipulated time series are explained comprehensively. Change detection is analysed and discussed, linking it to urban sprawl.

4.1 INVESTIGATION AND QUANTIFICATION OF IMAGE CLASSIFICATION IN BCMM (DYNAMIC CHANGE ANALYSIS) 1994-2012

The results of the classified maps of BCMM from the period 1994-2012 are shown in figures 4-1 through to 4-4 , it can be noted that prior to the independence of South Africa in 1994 (figure 4-1), the municipality was dominantly covered by dense vegetation and open grasslands. Open grassland and vegetation are the dominant classes shown by the classification image product. Transformation of these two classes into other land uses occurred within the municipality, post-independence.

Of the total 254 710 hectares of land covered by BCMM in 1994, 80 489ha (32 %) were covered by dense-vegetation class, 90 956 ha (36%) was open-grassland which was the largest class, the built-up class was very small covering only 19 685 ha (8 %). Over the approaching years, a significant transformation was witnessed in Buffalo City metropolitan municipality. There was not much in terms of built-up areas save for the towns that were already in existence from the time of the regime. As shown in figure 4.1 farms were scattered around areas of human habitation and were not so much in terms of distribution. Most agriculture was witnessed in the north-west direction of the of the metropolitan municipality areas around King Williams town and Zwelitshe. Not much damage had occurred to the environment in 1994 though signs were present to show that growth was inevitable. However, due to the time, the image was taken a number of pixels were misclassified especially in the built-up class. The misclassified pixels explain the patches of red within the image and some of these pixels represent rocks and bare surfaces with spectral signatures that look almost like the built-up areas.

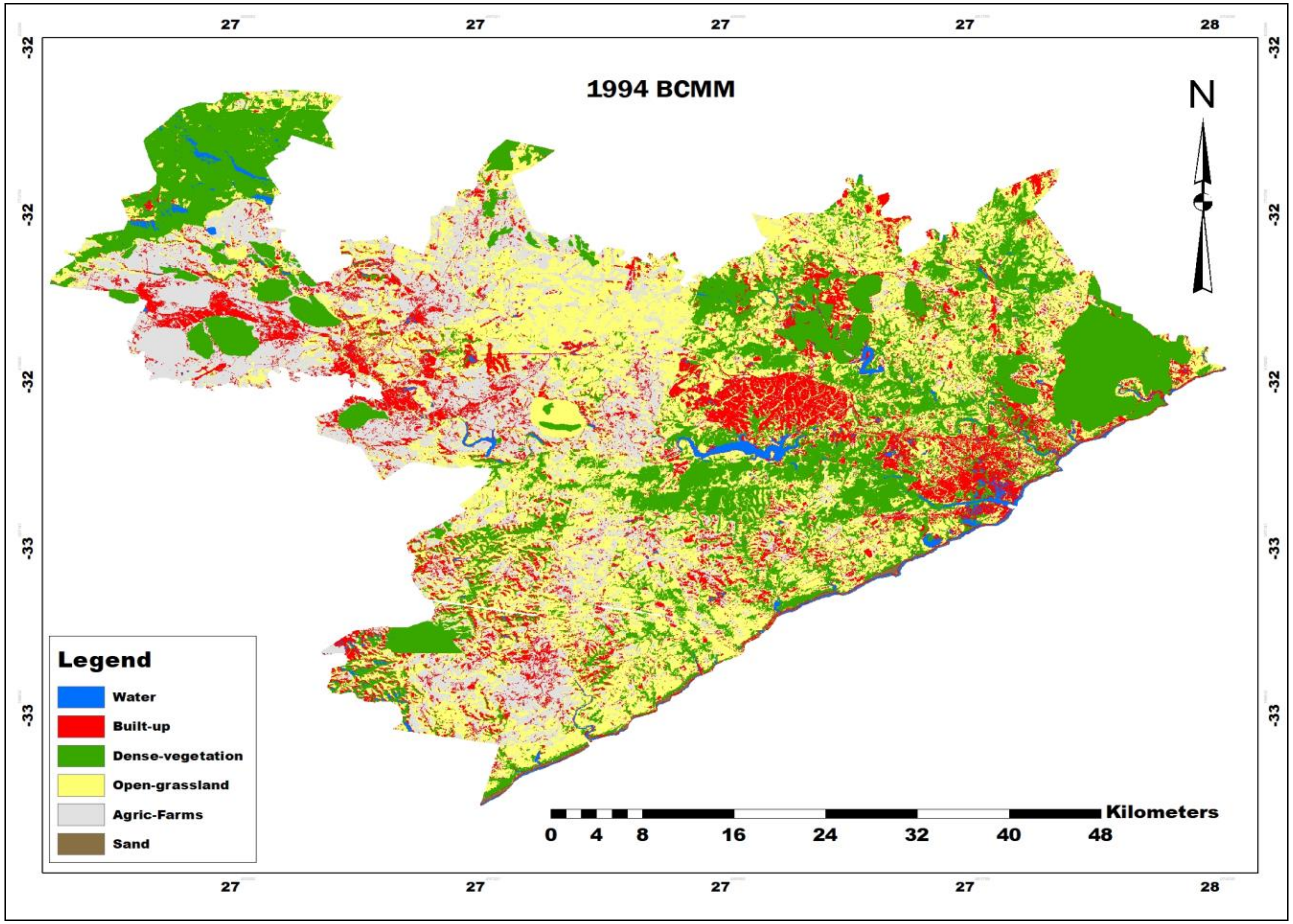

Figure 4-1 Classified image of BCMM 1994

4.1.1 Classified image 2000

Transformation is shown in 2000 classified image if one compares the 1994 classified image and the 2000 classified image. Major changes are revealed to the dense vegetation class, the built-up class, and the open-grassland class. An increase in the area covered by the built-up class affirmed a transformation, of open-grassland and dense vegetation into the built-up class. The 2000 classified image of BCMM also shows an increase in the area covered by the agriculture farms when compared to its size in 1994. In figure 4.2 a clear and concise representation of classes is shown, most of the pixels fell into the correct category.

The growth of the built-up class is shown in the East-London area and Mdantsane, which were initially smaller in terms of aerial coverage when compared to the 1994 classified image. The increase in the number of people in the Eastern Cape metropolitan municipality initiated the need to increase the number of houses. In relation to sprawl, the 2000 classified image of BCMM signifies the period of rapid growth. The water class does not have any major changes to it. Scattered growth is also seen along major highways and freeways connecting the CBDs of BCMM. This scattered growth lacks cohesive planning and as such, many problems have arisen as a result thereof.

Urban sprawl was at its peak during this time following up to 2006. Planners lacked the vision of what would result from this unprecedented development. Owing to the economic development of East London, some areas that were initially open-grassland were transformed into built-up class. It is therefore important for planners to consider sustainability when there are making decisions. A more compact approach to development is important, the focus should be on the erection of vertical infrastructure as a means of preserving the natural ecosystems that remain untouched and in their natural form.

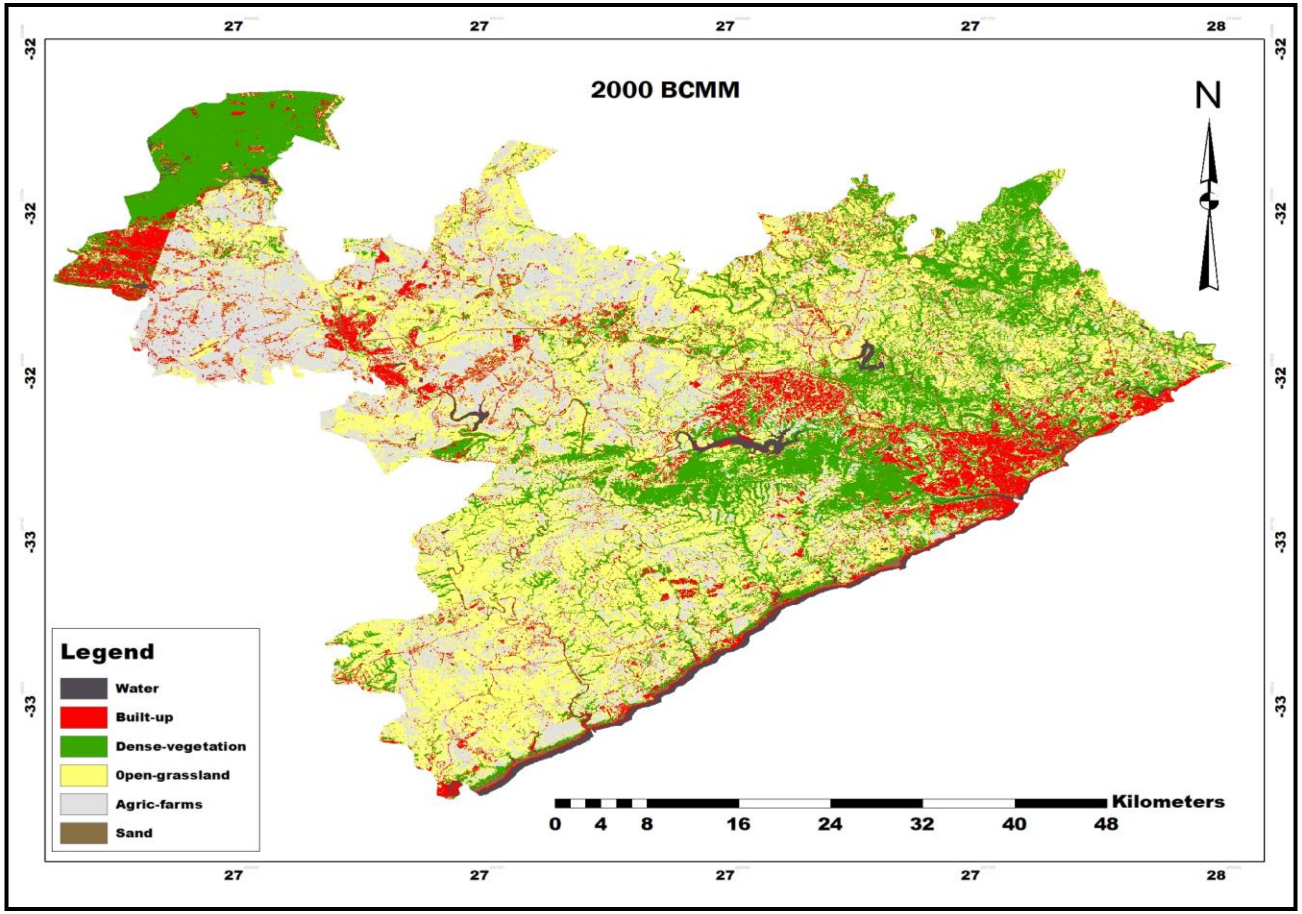

Figure 4-2 Classified image of BCMM 2000

4.1.2 2006 Classified image

In 2006, a significant growth of King Williams Town is shown from the classified image of 2006. Urban expansion was at its peak and reached its highest threshold in the period covered. Transformation of the agriculture class in other classes is also evident. The aerial size covered by the agriculture farms class is not as big when compared with the 2000 classified image. There is scattered development in the northeast of BCMM. People residing in this area definitely depend on the automobile and have decided to isolate themselves from the CBD.

However, this scattered development has impacts on the environment and the immediate ecosystem that would have been transformed. Problems like biodiversity loss and habitat fragmentation emanate from this nature of development. Fragmentation would mean patches of habitat to specific species and this might slowly drive that species to extinction.

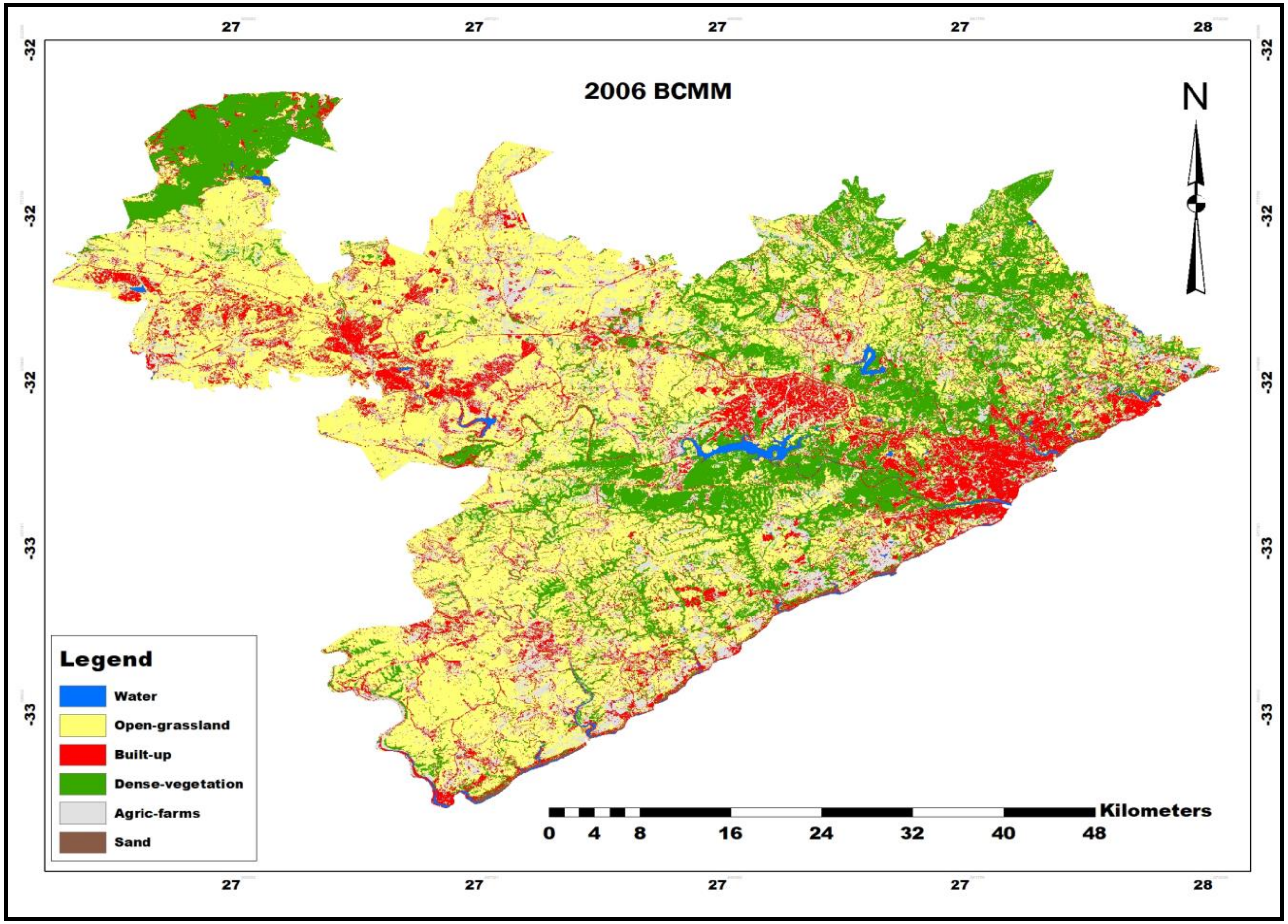

Figure 4-3 Classified image of BCMM 2006

4.1.3 2012 Classified image

The 2012 classified image displays transformations within the different classes. The built-up class has increased in areal coverage, signifying growth and expansion. With reference to chapter two of the literature review, a number of types of sprawl were discussed. Upon observing, the results shown on the map it is evident that the leapfrog scattered growth is present within the metropolitan municipality's built-up class, affirming urban sprawl. According to Batty, Besussi & Chin (2003) is expansion that barricades and leapfrogs over existing barriers. In the case of BCMM the boundaries within the municipality have been barricaded as evidenced by the numerous small clusters of red on the map.The growth of the metropolitan municipality has meant a reduction and fragmentation of the dense-vegetation and open-grassland class. The other classes like the sand have not changed that much and remain the same along the coastline of BCMM. Agriculture has increased in the south-eastern corner of the metropolitan municipality around the East London area. The increase of buildings in and around the urban fringe has also affected the major traffic lines that feed into the five urban centres. There is also evidence of new roads that connect the expanded residential areas like Mdanstane to the CBD of East London. The urban change was highest in the residential and industrial areas of the metropolitan municipality. The figure 4-15 showing a bar graph on the population of BCMM from 1996-2016 can affirm that the municipality is under pressure due to its growing population.

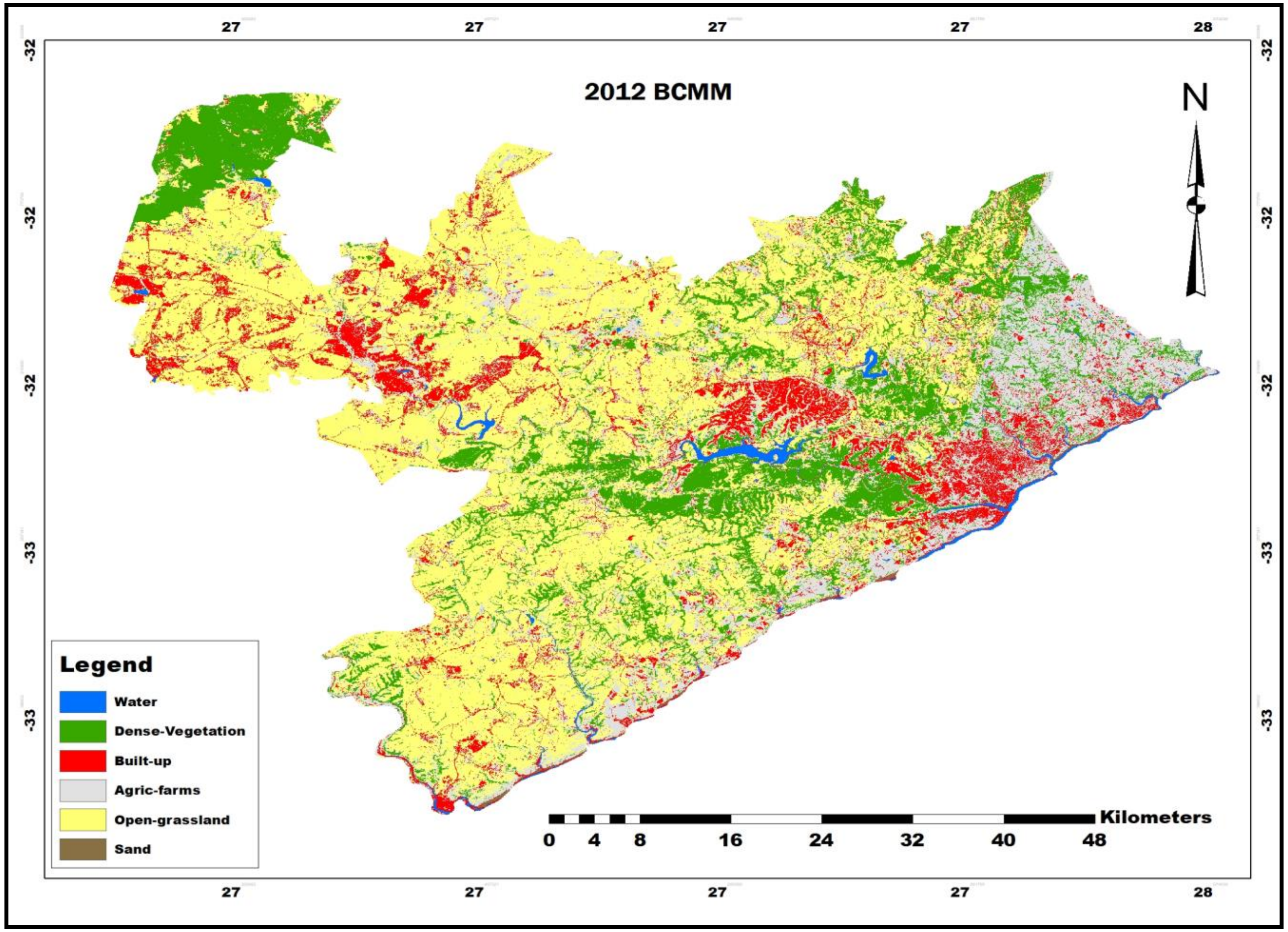

Figure 4-4 Classified Image of BCMM 2012

4.1.4 Classification accuracy

The consistency of the spatial and temporal trends of the landuse and landcover presented in this chapter is dependent on the classification accuracy of the imagery. Overall accuracy and Kappa Co-efficient, present this. The confusion matrix using ground truth ROIs module in ENVI 5.1 provides a reliable assessment of classification accuracy, by means of Kappa Co-efficient. Classification accuracy assessment is considered substantial if the Kappa Co-efficient is greater than 0.70. A classified image can be considered accurate if it provides an unbiased representation of the land cover of the region it portrays.

Table 4.1 Confusion Matrices for validation of 1994, 2000, 2006 and 2012 LULC maps

Accuracy statistics				**Classification data (classes)**					
Year	**Overall accuracy (%)**	**Kappa Co-eff**	**Accuracy Type**	**Water**	**Built -up**	**Dense Vegetation**	**Agric-Farms**	**Open-Grassland**	**Sand**
1994	82	0.78	**Producer's**	88	73	77	92	92	98
			User's	100	70	82	84	90	93
2000	82.2	0.85	**Producer's**	96	75	82	75	77	100
			User's	100	82	88	81	70	100
2006	84	0.77	**Producer's**	100	85	79	76	88	95
			User's	100	88	84	84	82	97
2012	85	0.79	**Producer's**	100	85	78	86	94	94

			User's	100	87	82	80	79	97

4.1.4.1 Producer's accuracy

It entails the probability of a reference pixel being classified correctly. The error of omission as it is sometimes called only gives the proportion of correctly classified pixels. Obtained by the division of the correctly classified pixels in a class by the total number of pixels in that class. The product of this revealed that lower producer's accuracies existed in landuse classes "built-up areas" and "dense vegetation". This was probably due to the spectral similarity of signatures of some of the features in these landuse and land cover classes with each other (e.g. built-up areas with bare land, vegetated lands with built-up areas, open grasslands with farms and bare land in the dry season).

4.1.4.2 User's accuracy

The likelihood that pixels in a classified map or image represent the same class on the ground is what is termed user's accuracy (Congalton, 1991). The division of the total number of correctly classified pixels in the category by the total number of pixels on the classified data calculates it. With reference to the study, the user's accuracy calculation revealed that "built-up areas" and "open-grasslands" had low accuracies on the study years on average. This suggests that to some extent the "built-up" and "open-grassland" classes were misclassified. This is probably due to the spectral similarity of signatures within the study area.

4.1.4.3 Kappa Co-efficient

For the study, the Kappa Co-efficient for the classified images for the time period was an average of 0.7975.

4.1.5 Discussion of the landuse and landcover change detection

The goal of a CD procedure is to elaborate the extent of change that has occurred to a particular study area between two time periods, be it short or long (Lillesand, Kiefer, & Chipman, 2008; Gibson, Hassan, & Tansey, 2013; Harris, 2003). The study used the image differencing method that calculates the changes of pixels per class category for the time period. The applied CD process generated the statistics show on table 4.2 below which shows the percentage area for each class area for the period of study.

Table 4.2 Class area as a percentage

Class Category	**1994**	**2000**	**2006**	**2012**
Water	1.790905	1.798897	1.068161	1.789051
Built-up	7.728312	9.953365	14.92051	16.75572
Dense-Vegetation	31.60019	27.19937	24.33831	25.74502
Agriculture- Farms	22.78515	27.21429	30.25744	29.02546
Open-Grassland	35.70946	33.32337	29.17628	26.3997
Sand	0.38599	0.51078	0.239298	0.28505
Total	**100**	**100**	**100**	**100**

The built-up class gradually increased in terms of size and area covered over the period of the study. From 1994- 2000 the built-up class increased with 2.25 % across the metropolitan municipality. This shows a significant growth, it further increased to 4.96% from 2000-2006. In the period from 2006-2012, the municipality increased by 1.83 % all this growth within the municipality was not necessarily compacted growth, rather most of the CBDs experienced a dispersed expansion in all directions. Natural vegetation and open grassland have been transformed into other classes.

Accelerated urbanisation creates a scenario were rural-urban migration shoots up on a daily basis as more and more people move to the urban cores. These people exert pressure on burdened infrastructure. This condition leads to the creation of both formal and informal settlements to new areas that were initially left out in terms of development, to serve as breathing spaces and green spaces that regulate the toxicity of the urban environment. The graph below (figure 4.5) is a pictorial depiction the class area covered by the different classes as a percentage.

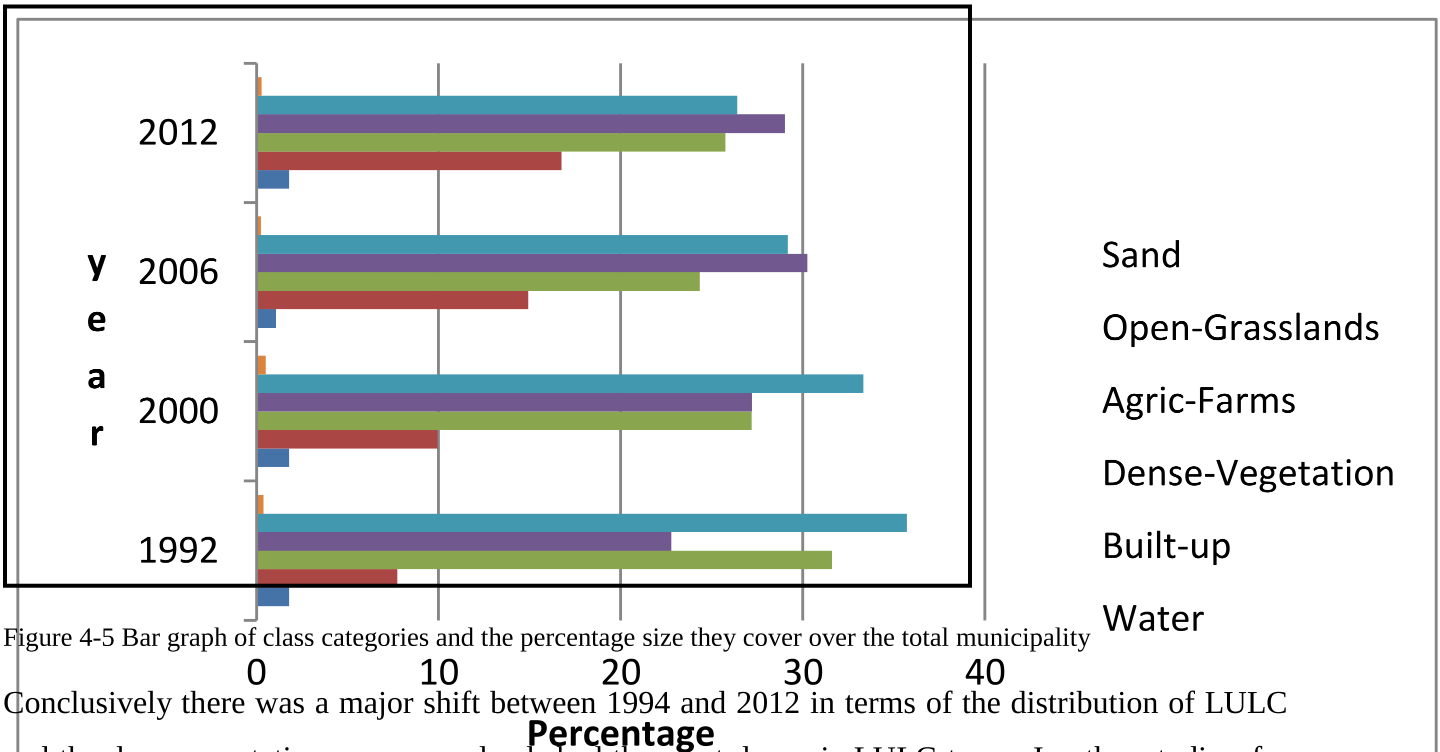

Figure 4-5 Bar graph of class categories and the percentage size they cover over the total municipality

Conclusively there was a major shift between 1994 and 2012 in terms of the distribution of LULC and the dense vegetation, open grasslands had the most dynamic LULC types. In other studies, for example (Tewolde & Cabral, 2011; Haregeweyn, *et al.*, 2012) revealed that developing nations' rapid expansion largely affected the neighboring agricultural lands, which had a strong negative impact on the livelihood of farmers in the urban fringe. In the case of BCMM not only farmers have been affected by urban sprawl, the ecosystem has seriously come under threat as well. Investigation and measurement of urban sprawl types is essential in urban planning. From the classification output, the following urban sprawl types were observed leapfrog, strip (linear), scattered (extension) and poly-nucleated development are all present in BCMM. Results show that scattered extension development was in most parts of the municipality especially on the 2012 classified image, thus it made it the predominant type of expansion. All the other types of urban sprawl were not in abundance and were found in various sections of the administrative boundary. Wilson *et al.* (2003) suggests that compact or infill growth could be a positive remedy to control urban sprawl and the damage it causes to the environment. However, in the context of BCMM compact type of urban sprawl is very low in BCMM because of the vast abundance of pristine land that is being abused. BCMM possesses the potential of adopting that type of growth and limit its unsustainable land resource consumption. A well-crafted and studied urban development plan is required to promote compact urban expansion and more intensive use and rehabilitation of existing buildings and other public services preserving the natural land in the urban fringe.

The table below (table 4.3) presents the percentage changes of the different classes and furthermore, the graph 4.6 that follows gives a simpler pictorial presentation of the same changes that occurred in the LULC classes in BCMM.

Table 4.3 Percentage change of different LULC in BCMM

Class Category	**Percentage increase/decrease (- presents decrease)**		
Year interval	1994-2000	2000-2006	2006-2012
Water	0.007992	-0.7307809	0.72089
Built-up	2.225053	4.967141	1.83521
Dense-Vegetation	-4.40082	-2.86106	1.40671
Agriculture-Farms	4.42914	3.04315	-1.23198
Open-Grassland	-2.38609	-4.14709	-2.77658
Sand	0.12476	-0.271452	0.045752

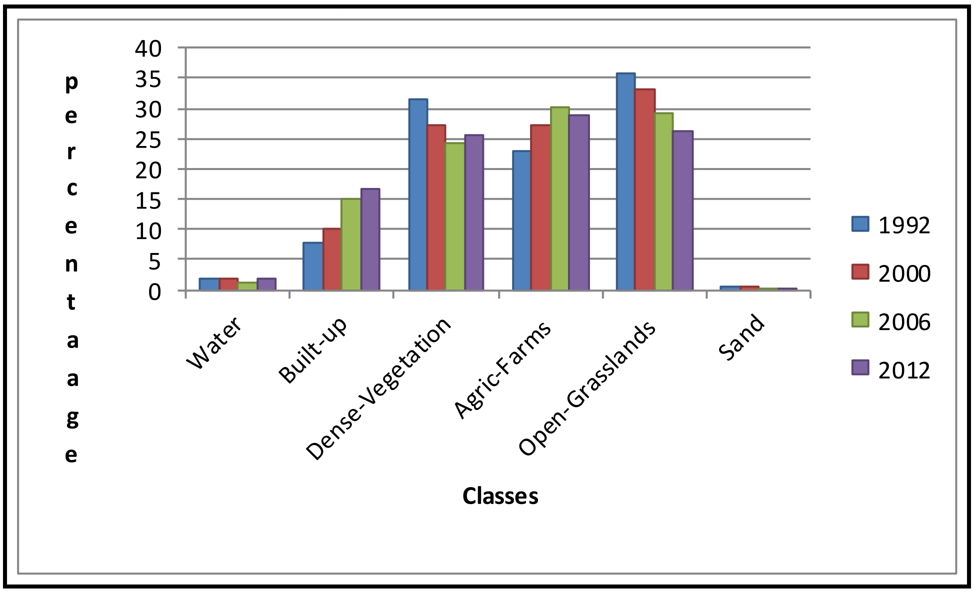

Figure 4-6 Bar graph showing percentage changes in each class

4.1.6 Percentage changes in land cover classes in periods

I. 1994-2000 period

Development during this period in BCMM was not very rapid. In 1994, the majority of the metropolitan municipality was traditional grassland and vegetation. Gradual growth was experienced post-1994 after the independence of South Africa, which saw an increase in the construction of economic and technical development zones supported by transport infrastructure resulting in a change in the pattern of landuse. Since the land was an abundant resource back in 1994, planning policies of that time were not so much into sustainability and hence were not as reasonable when compared to modern-day policies. The rate of sprawl was moderately evidenced by a 2.2% increase in the size of the built-up class shown on the graph figure 11 below.

II. 2000-2006 period

This period is responsible for most of the changes that took place within BCMM. Rapid growth and rapid urbanization in BCMM were experienced as evidenced by a 4.96% increase in the built-up class. Expansion and growth of residential suburbs and townships like Zwelitshe and Mdanstane can be noticed when comparing figure 13 and 14. Scattered development in all directions of the metropolitan municipality is present. However, the North-west direction has a higher concentration of buildings when compared to other parts. This is the King Williams town section, which entails that the town expanded the most during the period 2000-2006.

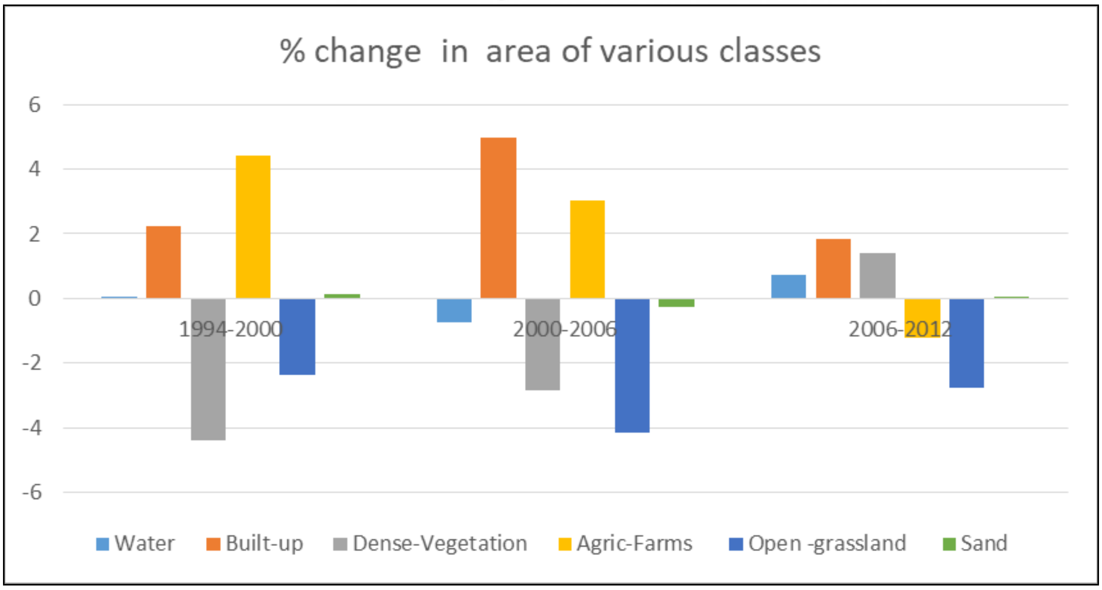

Figure 4-7 Change in area of various classes

III. 2006-2012 period

This period was not as vibrant as the previous period and the rate of increase of built-up areas reduced to 1.83 % growth is more steady and grounded. Though the rate reduced growth is still positive.

4.2 THE MEASUREMENT OF URBAN EXPANSION USING LANDSCAPE METRICS

The study used four metrics to calculate the urban expansion of the Buffalo City Metropolitan Municipality. The four metrics are Shannon entropy, patch density index, aggregation index, and largest patch index. The variations in urban growth are discussed below spatial metrics for 1994, 2000, 2006 and 2012 are presented. The built-up class is the major class under scrutiny in this section.

4.2.1 Built-up area extraction

The figure 4-8 below reveals the built-up class of BCMM, which are the areas of intense use of land for purposes of erecting structures. It comprises of towns, villages, leapfrog development on the urban fringe, along highways, institutions, malls and the urban core. The impervious (concretized) areas in BCMM have a unique spectral signature and reflectance pattern when compared to other natural components however, similarity often happens with natural rocks and stones. Urban extent is often synonymous with the built-up areas extracted from the satellite imagery (Zha, et al., 2003). The sum of all urban area patches within the administrative boundary of BCMM. The figure 4.8 indicate the built-up area of BCMM from 1994-2012.

The Trend of urban growth shown on the diagram below indicates a gradual expansion of the built-up class from 1994-2012. It is revealed from the figure that areas located on the north-west and southeast of the municipality show significant expansion. It is interesting to note that activities in these particular areas have occurred in a rapid manner and have led to the development of such patterns on the map. The dispersed urban growth pattern throughout the study area also indicates the occurrence of urban sprawl

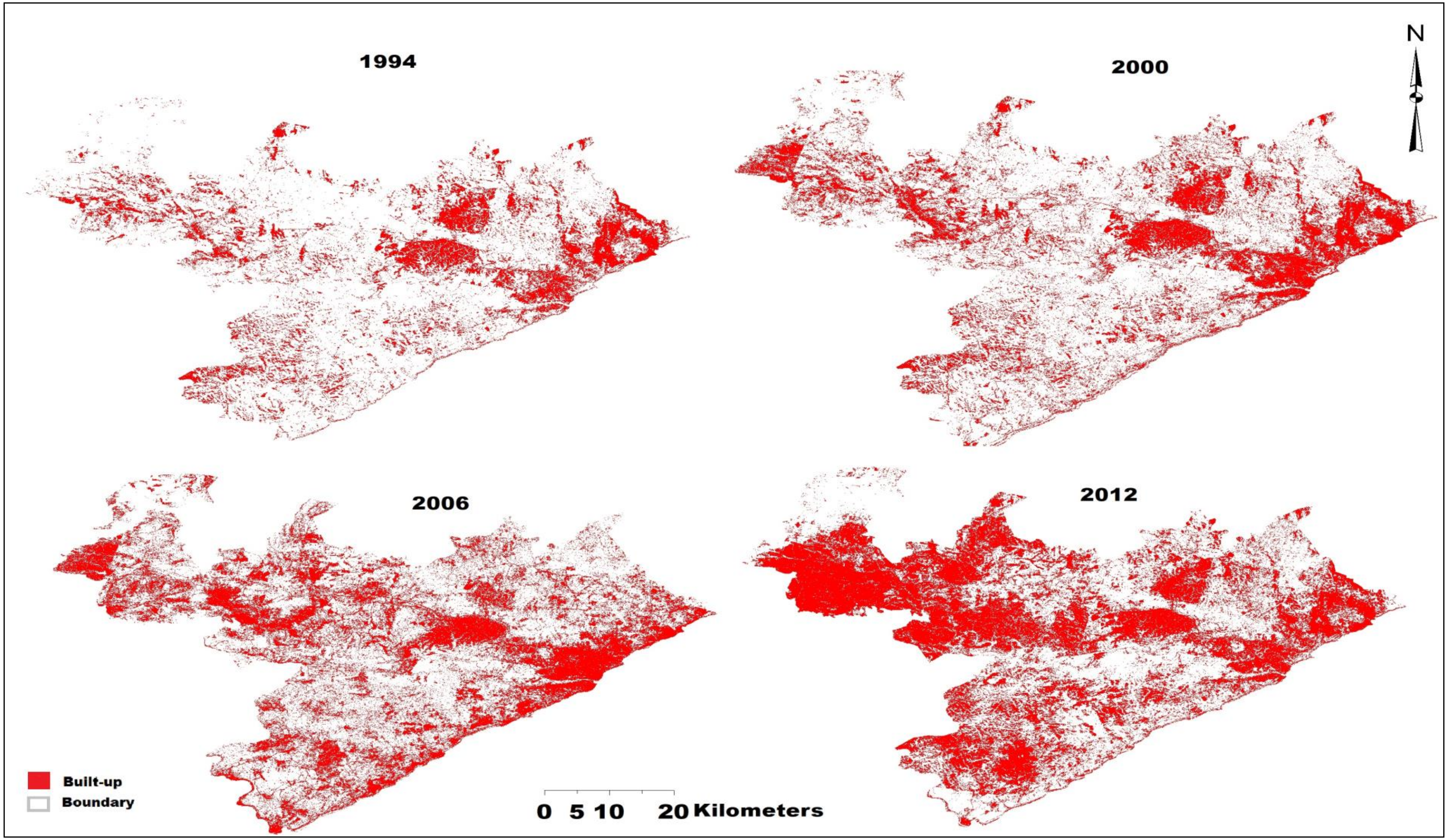

Figure 4-8 Built-up area of BCMM 1994-2012

The Figure 4.8 is a visual interpretation of the built- up class over the period. It aims to express the changes that have occurred mainly in the built-up class. Scattered growth represented by the red patches is evident on the map. Distribution of patches is throughout the map and this shows that sprawl has occurred in all directions. The high natural increase of the population is amongst the major drivers of the trends shown. The population of BCMM is a young population that has many dependants.

The summary of the transformations of LULC for BCMM in figure 4.8 and the visual comparison of built-up and non-built-up areas as depicted in figure 4.8 (pg. 85) indicate the incidence of the encroachment of the built-up class into the non-built class. The discontinuous patches of the red class showing the degree of urban sprawl within the metropolitan municipality affirm rapid transformation. Observed as a time-series, the rates of landuse and land cover change have been varied over the study period. The built-up areas in BCMM have significantly increased from 1994-2012 and this increase is largely linked to both the social and economic changes the metropolitan municipality has faced over the study period. Figures 4.9-4.12 give a vivid expression of the occurrence of urban sprawl and display the gradual changes over time.

4.2.2 Percentage change of the built-up area of BCMM

Table 4.4The rate of Built-up expansion in BCMM

Year	**Built-up area (ha)**	**Rate of urban expansion (% year $^{-1}$)**		
		Year:1994-2000	**Year:2000-2006**	**Year:2006-2012**
1994	19 685	2.225053		
2000	25 352		4.967141	
2006	38004			1.83521
2012	42678			
Changes (ha year $^{-1}$)		5667	12652	4674

To better, understand urban growth and expansion of BCMM 3km buffer zones were created as shown in the diagram below (figure 4.14) this was part of the procedures done prior to the use of metrics.

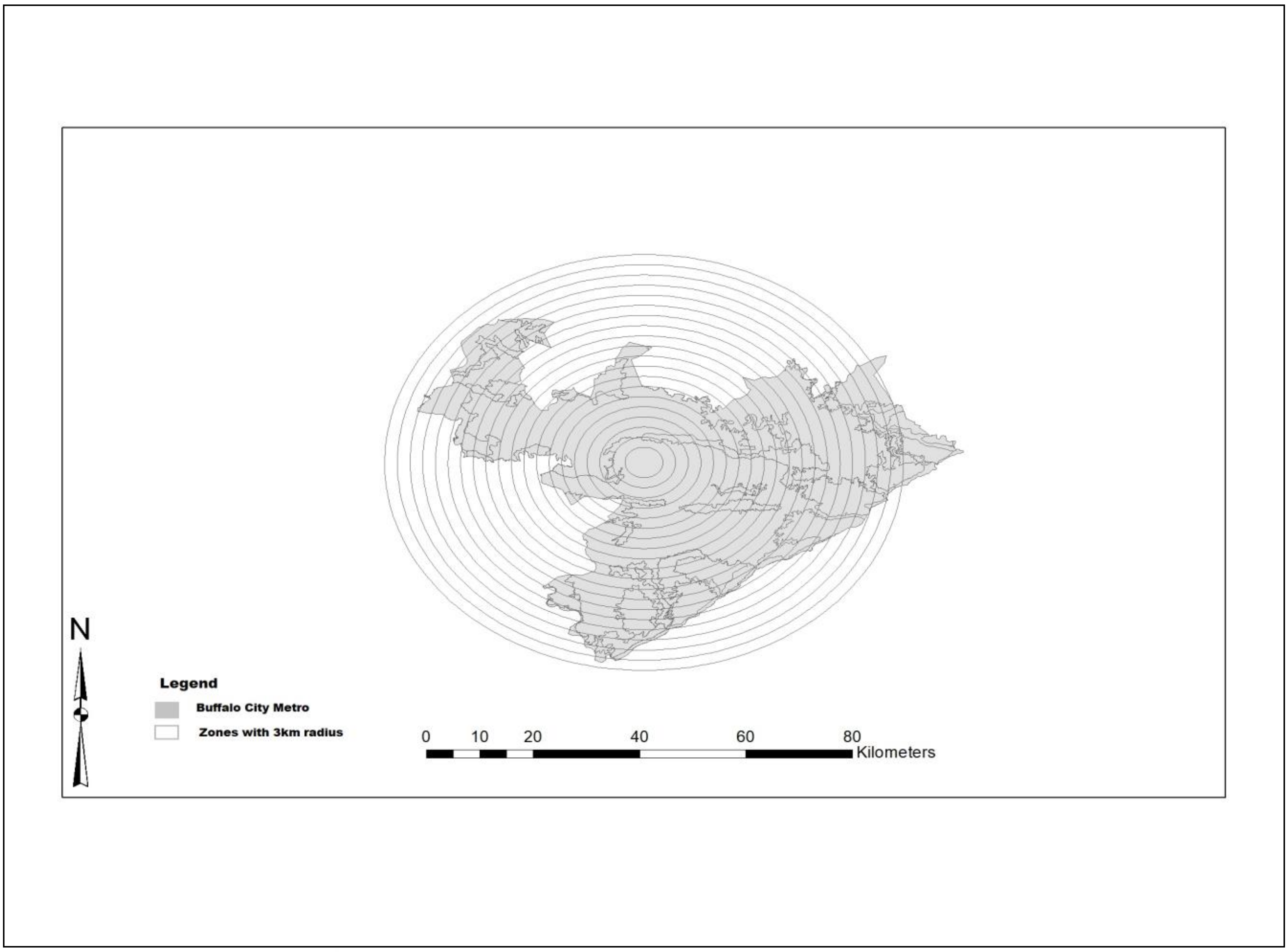

Figure 4-9 division of the study area (BCMM) into concentric zones of 3km intervals

4.2.3 Shannon Entropy of urban expansion

This metric is commonly used in urban sprawl studies due to its precision in the measurement of spatial concentration and dispersion. In this study, the relative Shannon entropy was calculated and the following results were obtained:

Table 4.5 Overall Shannon's Entropy of BCMM from 1994-2012

Year	**1994**	**2000**	**2006**	**2012**
Entropy H_n	0.575	0.722	0.863	0.885

The table above demonstrates the overall values of relative entropy obtained from BCMM in different years. It is evident that no value is less than 0.5 from the table, thus we can conclude that BCMM is indeed sprawling. Moreover, the sprawling trend is increasing over the period of study. It is a clear indication that the urban growth process requires a strong urban planning policy.

The diagram below gives a picture of the buffer zones of BCMM over the period of study from 1994-2012.

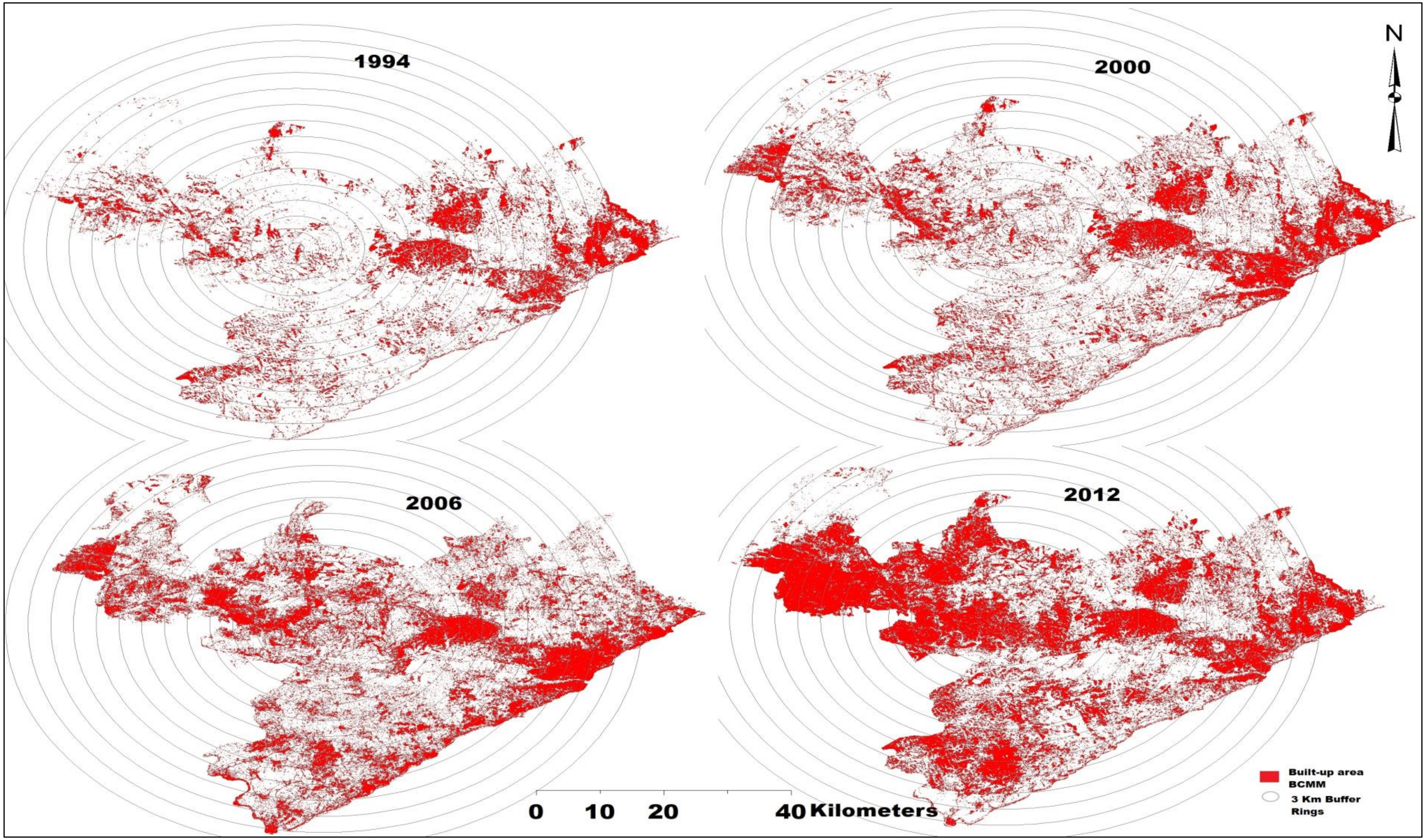

Figure 4-10Concentric zones of BCMM from 1994-2012 showing built-up areas

The general trend of urban sprawl is similar to the study area. Movement away from the core CBDs of the metropolitan municipality in any direction shows that the degree of compactness reduces paving way for dispersion that increases significantly in the urban fringe. Urban sprawl in BCMM is influenced by both direction and distance from the CBD. The dispersed pattern of built-up areas is responsible for the entropy values obtained. The entropy values give a glimpse of the pattern of development within the metropolitan municipality. Rather than taking a more compact pattern of development BCMM is taking a dispersed pattern of development. High entropy values confirm that land development is spreading into the surrounding rural areas via the urban fringe.

4.2.4 Other landscape metrics

The landscape metrics helped identify the effects of urban expansion in the study area (BCMM). Generally, dense-vegetation and open-grassland became more fragmented because of the increase of built-up areas over the study period. This is shown by the graph below figure 4.15and 4.16.

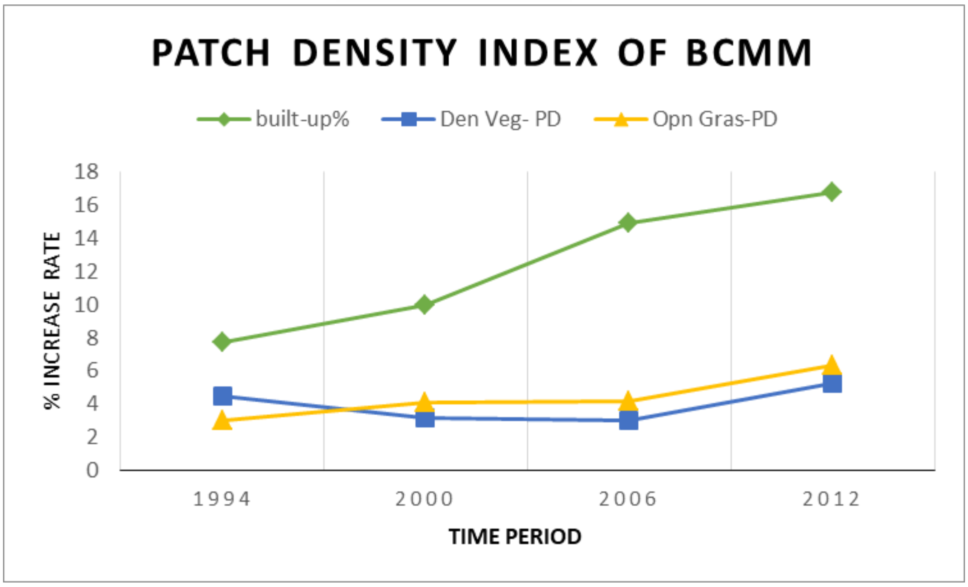

Figure 4-11 Patch Density Index of BCMM

The correlation between built-up area (%) and the patch density index of dense-vegetation open-grassland values indicate that the dense-vegetation and open-grassland became more fragmented as a result of the expansion of the built-up area. A higher PDI value denotes the presence and the inverse denoted less fragmentation, as such from the results of BCMM there is a general increase save for the dense-vegetation class that was a bit stable between 2000-2006 and began to rise between 2006-2012.

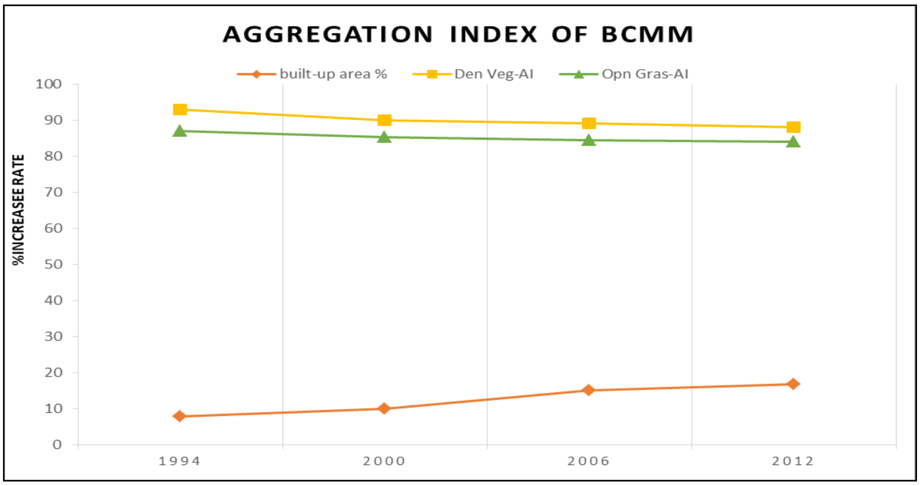

Figure 4-12 Aggregation Index of BCMM

The correlation shown on the graph indicates that the aggregation index (AI) for the dense-vegetation and open-grassland class was generally decreasing. Decreased AI values signify a fragmented land and an increasing value signifies less fragmentation. From the values obtained its evident that the two classes dense-vegetation and open-grassland have been affected by the expansion of the built-up areas in BCMM.

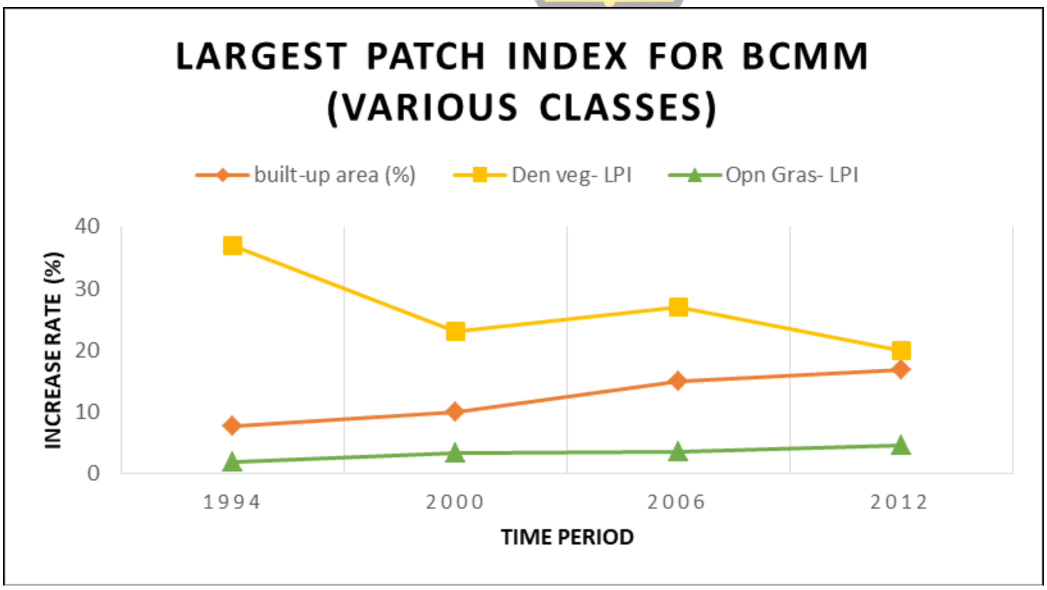

Figure 4-13 Largest Patch Index for various classes in BCMM

The Largest Patch Index of BCMM shown on the graph above indicates that the dense vegetation class has variations in its values signifying that it was the most affected in terms of the largest patch index. The open-grassland class was less affected because it shows an average and consistent value throughout the study period. When the LPI value is closer to 100 it entails that there is a single large patch and when the LPI is closer to zero it means that there are many small patches. The dense vegetation class shows that it was once a single large patch in 1994 however, this has changed significantly as shown by the fluctuations and continued decrease of the values.

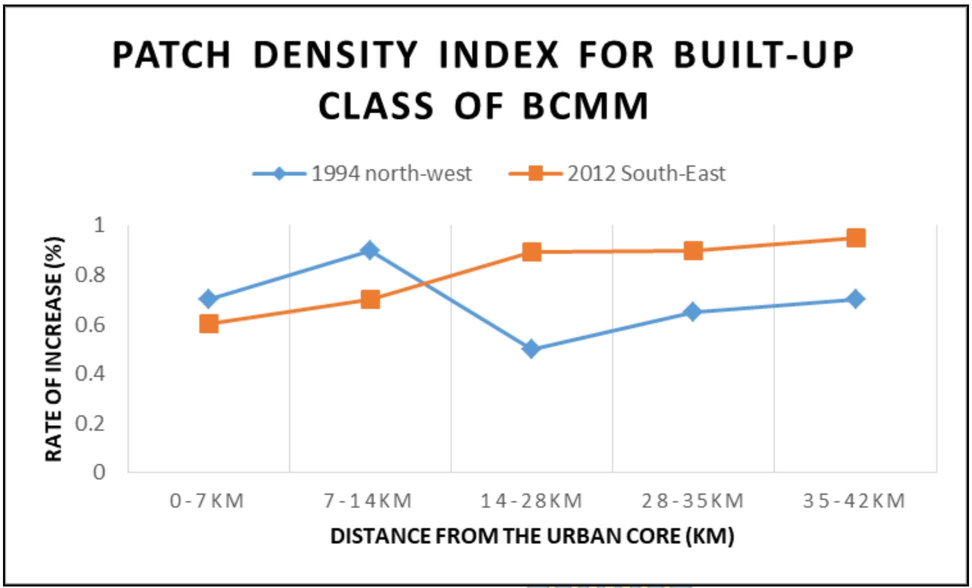

Figure 4-14 Built-up Patch density index of BCMM at different distances from the urban core

The patch density index for the built-up class of BCMM at different distances from the urban core in two particular directions suggests that the stage of the metropolitan development is different within the municipality. As shown on the graph in 1994in the north-east direction of the metropolitan municipality values suggests that initial values were at 0.7 and as you moved away from the urban core the values decreased to about 0.5 at the 14-28km zone. Values began to rise from this point onwards and this means that there were occasional patches of housing in the peri-urban segment of the metropolitan municipality. The 2012 southeast direction tells a different story altogether values shown on the graph suggest a generally ascending trend suggesting a rapidly proceeding urban development with built-up clusters. Higher values and variations suggest urbanization whilst lower patch density values suggest “fill-in” or stagnant growth.

Evidence of urban pockets within the metropolitan municipality is represented generally by the metrics used. Hence, these urban clusters suggest that urban sprawl has affected the metropolitan municipality and it is no longer compact. There is a serious need for smart growth policies that emphasize the idea of sustainability and growth vertically rather than horizontally. Landscape metrics are a good measure of quantifying the degree of sprawling of a particular urban environment.

4.2.5 Population growth

The need for accommodation and subsistence explains the growth and urban sprawl that has been taking place in Buffalo City metropolitan municipality. Growth of the population of BCMM has been rapid since 1996 as shown on the graph (fig 4.14). 1n 1994 the metropolitan municipality had approximately 600 000 people residing on 19 685 hectares of built-up land. From 1996-2001 the city population increased by approximately 25000 people. The metropolitan municipality grew by (0.9 %), and the rate of urban expansion was in terms of the urban built-up area. This indicates that the urban sprawl has indeed occurred within the metropolitan municipality with glaring signs of outward dispersed expansion instead of the recommended compaction observed in prior years. There is a correlation between population size and the built-up class of BCMM. The scattered buildings across the land show the presence of humans.

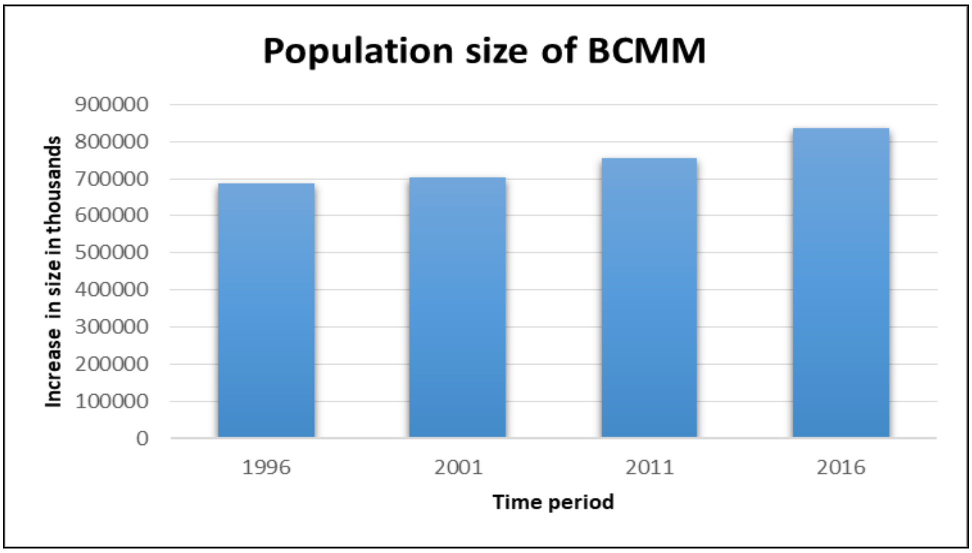

Figure 4-15 Bar graph showing the population of BCMM (source Stats SA, 2011)

4.3 THE IMPACTS OF URBAN SPRAWL ON VEGETATION AND LAND IN BCMM

Urban sprawl has more disadvantages than benefits and as such, it affects many dimensions within the society. Strategies aimed at combating the phenomena can be implemented if the forces behind the problem are known. It is important to analyse the causes of sprawl in order to fully understand its impacts. Causes of urban sprawl continue to be analysed by scholars. However, there are known common causes which are rapid population growth, the rise in the standard of living for households, poor policies on urban planning and promotion of infrastructure development through subsidization.

Urban sprawl in the western context can be regarded as a product of development post economic prosperity that is the age of automobiles giving rise to Malls that are outside the CBD. Conversely, it is not the case with South African urban sprawl. Urban sprawl in South Africa is unique as a result of economic transformation owing to the stage the country is in terms of development. The growing population and economy are both leading to the consumption of previously pristine land as a way of trying to balance the size of the population in relation to where people reside. South Africa also has a high incidence of informal settlements and this has added to the sprawl already occurring within the country. It is, therefore, the duty of land use policy to bring order and sanity to development projects within a particular place. Despite the urban sprawl, occurring urban areas are entitled to grow naturally with time, as such, BCMM has also been growing naturally. The pattern of growth is questionable. Irrational land use and land consumption to a certain degree are caused by ineffective and unbalanced landuse planning. In the 90s, urbanization was not as profound as it is now economy was more of agro-based and this has been evidenced by figure 4.1. Industrialization was in its early stages. It is after the 90s that the economic structure of BCMM began to diversify, many new industries were developed during this phase.

The significance of industrialization post the 90s era support the fact that urbanization is largely responsible for the presence of urban sprawl in BCMM. Due to the attractiveness of the urban-fringe most businesses target such areas for developing their companies.

4.3.1 Environmental impacts of urban sprawl

Urban sprawl poses a big threat to both the humans and animals of the environment. Some of the impacts can be easily noted while other impacts cannot be directly seen now but will be seen in the future. The impacts of urban sprawl to the environment can be sub-divided into two categories those that pose an immediate threat to the aesthetic appearance of the environment and those that affect the functionality of the ecosystem, which is a major problem (Johnson, 2001). BCMM has been affected by the following impacts on its environment because of urban sprawl, increased air pollution, decreased aesthetic appeal of the land, reduced species diversity, ecosystem fragmentation, and loss of environmentally fragile lands and degradation of water quality among other impacts.

In BCMM, the major consequence of the unwarranted growth of built-up areas as shown by the classified images is the transformation of agricultural lands and the open grasslands and other natural ecosystems into built-up areas. Water bodies are also disappearing within the metropolitan municipality. These transformations of the natural land use tend to affect not only the environment it also indirectly affects the functioning of the ecosystem. Wetlands are usually found in these pristine areas and once humans begin to interfere with this natural environment a number of natural cycles that protect the humans are altered. Important cycles like the carbon, water and nitrogen cycles can easily be altered by human interference and as such, urban sprawl should be mitigated to reduce these externalities. These externalities if not managed can be a strain on the economy of a municipality in the future and hence it is always cheaper to prevent than to mitigate. Unwarranted expansion inflicts costs on development economically, environmentally and socially.

Due to the nature of the relationship that exists between landuse and ecological functions of the ecosystem. It is usually obvious that humans as they alter the landcover many externalities will arise. The environment has its own natural way of regulating itself, if human alterations then exceed this natural ability of the environment to regulate itself, then degradation is inevitable. The rate at which humans are transforming the natural environment risks their own well-being. Urban sprawl has been observed as a contributor to some of the health issues humans face today. Past-planning practices and a need for shelter have been driving the current trend of urban sprawl being witnessed in BCMM. Though the metropolitan municipality intends to conform to the principles of a compact and sustainable infrastructure, the damage has already occurred with the current infrastructure. A significant contribution to biodiversity loss has been noted and certain species are now endangered with these transformations.

Buffalo City Metro is characterised by spatially divided urban settlements with a complex social structure. The spatial division in the metro was a result of the apartheid regime’s plan to divide blacks. This, however, gave rise to a landuse pattern that is not sustainable and was sprawling.

Johnson (2001) identified four classes of environmental impacts linked to urban sprawl. Broadly, these four categories are air, water, land, and energy. Loss of land to the built-up class is amongst the most common problems associated with urban sprawl and this is a huge environmental impact that humans do not value since their major concern is having shelter. Land transformation indirectly means loss of habitat and biodiversity to the species being cleared and destroyed to pave way for the construction of new buildings. Species diversity and the benefits that come with it are all lost when a land developing company decides to build an industrial park on a piece of land that was previously natural and dormant. Destruction of green spaces that have many benefits to both humans and animals become the order of the day as urban sprawl takes charge (Raza et al., 2016).

The increase of the population of BCMM as shown in figure 4.4 (pg74) affirms that indeed the number of people in the metropolitan municipality is growing. This population increase results in an increase of buildings, gaseous emissions, water pollution and loss of agricultural land. Since the developed residential suburbs will be located, distances from the CBD automobiles tend to emit more noxious gases into the atmosphere leading to global warming. More people also mean more litter produced and consumed and usually these end up in places that are not expected like the water sources.

A reduction of the soil's capacity to act as carbon sinks is another environmental problem that comes with urban sprawl. This has a direct impact on the atmosphere and this gradually leads to global warming. Temperatures have been modified because of urban sprawl. The incidence of urban heat islands definitely increases with the construction of more buildings.

4.3.1.1 Air pollution and urban sprawl

Gaseous emissions from various sources within the urban environment are a cause of concern. Industries and vehicles are the major sources of these emissions that bring toxicants into the environment. Diesel emissions are the prominent source of highly toxin dioxin, which accumulates in the food chain. The creation of acid rain and ozone depletion also emanates from such emissions; urban sprawl often leads to the construction of new road linkages that join the expanded place to the CBD. Urban sprawl depends more on vehicles and it would mean more vehicles and this increase in the number of vehicles leads to increased pollution.

Places like Bhisho and East London have industries that have been growing and some residents leave near such places, and have been affected by these emissions. Indirectly carbon dioxide, carbon monoxide, sulphur dioxide, nitrous oxide and chlorofluorocarbons produced from these emissions have been leading to global warming. Smog is recurring in all the five urban centres in Buffalo City metropolitan municipality. The number of automobile owners has been increasing with the population increase. The same increase has given rise to a number of informal settlements that have been starting domestic fires in these informal settlements, some of these, end up as veld fires. All these combined effects have polluted the air quality of BCMM so much. The effect of a polluted air quality is that the municipality will have many health issues (respiratory diseases and skin diseases) being reported. The surrounding ecosystem of BCMM is also at risk as pollution also affects the flora and fauna. Buffalo city metropolitan municipality lacks compliance with NEM: AQA and thus, there is an urgent need of addressing this issue (Future Works Sustainability Consulting, 2014).

4.3.1.2 Water pollution and urban sprawl

Gaseous emissions into the atmosphere give rise to acid rain, oil leaks and industrial effluents all have the capacity to pollute the water sources. BCMM has encountered such pollution in its rivers and freshwater sources. Sewage leakage into freshwater streams has also been noted. High incidences of water pollution have been recorded to rivers that are near informal settlements in BCMM. The Buffalo and Nahoon catchments have been severely affected by pollution (River Health Programme, 2004). Another key source of contamination has been identified as sewage overflow from poorly functioning and overloaded wastewater treatment works (River Health Programme, 2004).

Implications of such pollution are that it's now also affecting the oceans as most river catchments feed directly into the ocean. Pollution is a major threat as it could render coastal water unfit for recreational uses, which will, in turn, affect tourism (River Health Programme, 2004). All this pollution is linked to an increase in population size, which in turn leads to urban sprawl. Urban sprawl is a major driver of this water pollution and should be curbed to stop any further damage to our aquatic ecosystems and water quality. The informal settlements have been and continue to be a major source of the pollution. Industrial effluent, on the other hand, is also contaminating the water sources and a continued growth due to urbanisation would mean more effluent.

4.3.2 Demography, urban sprawl, and the environment

A huge or ever-growing population size is likely to bear more stress on the environment as compared to an optimum population size that maintains its size. Nonetheless, in Southern Africa the concept of a managed population is far from being reached. Eastern Cape has not been spared in terms of rapid population growth. The impact of such population dynamics on the environment has since been noted. According to the UNEP (2012), "it is not only the scale or quantity of the population that affects the nature of a pressure on the environment…how human populations are organized in cities and villages makes a difference in the capacity of the environment to support them.” A growing population is likely to make more demands on the environment as compared to an optimum population. According to Statistics South Africa (2011), BCMM had a total population of 685 727 in 1996, 704 855 in 2001 and 755 200 in 2011. The annual growth rate was +1.62% (Statistics South Africa, 2011).

A growing population will demand shelter and this demand will be thrust on the environment. This then means the transformation of a particular land use into the built-up class category. Construction of these households needs raw materials that are obtained from the environment. An increase in population size would also mean an increase in the demand for energy and resources by that particular population. A large population size that is growing would mean more air, water and land pollution due to the increase in the numbers of people. The environmental problems associated with a large population that causes urban sprawl are interlinked and thus if one section of the link changes it, therefore, means the whole system changes. The urban sprawl episode investigated by this study has created amorphous suburbs, which are both illegal and legal. Population growth is the most significant factor that has been driving urban sprawl. As a population, sizes increase or continue to grow so does the demand for land for residential and commercial purpose increase.

The nature of employment of the population has a significant role in urban sprawl. A largely agro-based population that depends on agriculture is less likely to damage the environment when compared to a population that is largely dependent on industry. Real estate agents are after developing the land into residential suburbs thus they transform land previously used as farming lands. Loss of fertile lands being transformed into built-up areas is a consequence of the environment. A significant reduction in the agriculture farmland can be noted in BCMM. Plain areas are chosen most for industrial development zones in BCMM. The ecosystem benefits and land resources reserved are all lost when the transformation occurs.

Built-up areas come with their own disadvantages and problems to the environment. Tarmac and paved surfaces are known to deter the infiltration of water into the ground. Drainage patterns of BCMM have since been altered due to the increase of built-up areas within the metropolitan municipality. This alteration poses a risk of flooding in the metropolitan municipality. Paved surfaces are known to increase the likelihood of flooding. Building place destruction, fuel leaks, oil drips, lawn chemicals, and plastic all add to water pollution (Raza et al., 2016).

4.3.3 Economic development, urban sprawl, and the environment

Economic development and urban growth are difficult to separate as these two are closely linked. Economic development often implies the conversion of rural, natural and agricultural land into urban land uses (commercial, residential and industrial). This transformation is associated mostly with developing nations experiencing structural economic adjustments as they grow. In developed nations, economic growth is now limited to the peri-urban zone of the CBD.

Modernization has had deep effects on urban sprawl. Changes in technology have substituted for the need of geographical proximity. This increased rate of globalization has incited rapid economic growth in many developing countries. In Eastern Cape, capital inflows and foreign direct investment (FDI) have transformed both the urban and rural parts of this province. East London's industry has been significantly transformed during the 1994-2012 period. According to Brueckner (2000) for cities to grow spatially, developers should be able to bid away additional land from agricultural users. Preference is given to urban land uses when compared to agricultural uses, since it is believed that urban land uses to generate more benefits. However, urban land uses pose a greater threat to the environment when compared to agricultural uses, which also pose threats though to a lesser extent. The productive agricultural land is more resistant to urban expansion than unproductive land (Brueckner, 2000).

In BCMM, development has also been affected by the limited authority the government has on private property and a general lack of democratic control on construction activities. The need for a strong monitoring initiative is vital to help curtail this nature of urban growth.

The spatial metrics successfully described the structure and nature of transformations of the urban sprawl occurring in BCMM.

4.3.4 Results of interviews

Key findings of the interviews conducted with the three key management personnel of BCMM revealed that the metropolitan municipality was expanding at an uncontrolled rate mainly due to the increases in human populations residing in urban areas. It was noted that the emergence of informal settlements were indeed increasing in the municipality and most if not all areas with informal settlements housed some of the poorest citizens. Insufficient developable land was cited as one of the reasons leading to this increase; constraints' affecting the municipality to create land for homeless was another factor. Constraints such as floodplains, geo-technically unsuitable land, environmental concerns, overstep slopes etc. All interviewed personnel agreed that the growth and expansion of BCMM was affecting the environment. These observations and acknowledgements only supported what the spatial metrics and GIS had found.

4.4 SUMMARY

The measurement and analysis of urban sprawl by means of built-up area extraction using remote sensing and GIS techniques have indicated a significant growth and expansion of the built-up areas from 1994-2012. The time-series approach is an effective way of depicting changes that occur in various land cover classes. SPOT data is more than conducive in the analysis of timing change of urban sprawl. Results indicate that urban sprawl in BCMM is significant, the nature of sprawl is complex from scattered, disorderly and haphazard development is present. Fragmentation of vegetation and open- grassland also reveal the incidence of urban sprawl in BCMM.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations drawn for BCMM in relation to the urban sprawl being witnessed within the metropolitan municipality.

5.1 CONCLUSIONS

The study was conducted to examine the environmental impacts of urban sprawl and the extent of urban sprawl in totality. The phenomena present a huge challenge to urban and landuse planning in forthcoming centuries. Grounded on the findings of the research we can conclude that. The study indicates that the integration of time series remotely sensed SPOT imagery and landscape metrics in analysing urban sprawl is beneficial in understanding the spatial and temporal patterns of urban sprawl. From 1994-2012 urban expansion significantly altered the scenery of BCMM area. The built-up land covers class increased at the expense of the open-grassland and dense vegetation class.

Despite the numerous debates and conventions, both at the local level and international level on smart growth policies and sustainable development as the best forms of approach to curbing the problem of urban sprawl. There is still no solid approach to monitor and control urban sprawl. Thus, there is still a need for further research to find a single solution of preventing the negative consequences of urban sprawl at all levels. The methods presented in this study are just variables that measure indicators of urban sprawl, these, however, do not measure sprawl itself. Therefore, measures of variables that are the causes and effects of urban sprawl cannot comprehensively account for urban sprawl since variation or transformation in these variables can misguide the outcome. Another challenge is the lack of threshold values that clearly demarcate a sprawling city from a non-sprawling city.

There is a need for more rigorous measures of preventing urban sprawl and comprehensive long-term plans. Urban planning that has effective resource utilization, natural resource distribution and infrastructure inventiveness are crucial matters. The study sorts the environmental impacts of urban sprawl in Buffalo City Metropolitan municipality in Eastern Cape, quantified by the measurement of urban sprawl using landscape metrics (patchiness, built-up density, and Shannon entropy). GIS and remote sensing techniques have been used to demonstrate their capability in the monitoring and assessment of urban sprawl. Patchiness, built-up density, and Shannon entropy were computed to draw an understanding of the form and spatial patterns of urban sprawl occurring in BCMM. A high threshold value of entropy reveals the incidence of sprawl and its spatial distribution. Urban sprawl is occurring in the urban fringe, bringing more land under the built-up class as revealed by the metrics (dispersed growth).

5.2 LIMITATIONS

Data is readily available however, it's processing for use by the end user is still slow, and hence there is a need for more institutions that process data like SANSA to avoid a scenario of waiting for data to be processed for the use of the end user.

5.3 RECOMMENDATIONS

Urban sprawl is prominently a big problem in many cities in the developing world and thus needs to be fixed before it reaches severity were fixing the problem would be impossible. Stopping urban sprawl would mean stopping new development in all natural areas around BCMM completely, though this is not practical with the current increasing population trends. The problem posed by urban sprawl cannot be regarded as a pure lack of policy planning remedies given the past approaches that have failed to control it. However, ambiguities existed in past planning policy hence the need for a rather dynamic and holistic strategy that is specific particularly to BCMM. The approach should be able to cut across all disciplines and take into account the importance of sustainability. Little importance has been placed on the effects of urban sprawl on the environment over the past years and hence there is a need to seriously consider those given the damage was already done by humankind. Urban environmental problems in BCMM are multi-faceted and are closely linked to urban sprawl and all developmental challenges that come with it.

With respect to the growing population, there is a need for policies and incentives to curb this unprecedented growth of the population. A growing population means a growing economy and this growth should be supported by infrastructure. If the government chooses to expand, it should be vertical expansion adhering to smart-growth policies that believe in a compact city. Smart growth preserves open spaces, farmland, biological hotspots and the aesthetic value of the environment. Informal settlements like Phola Park in Scenery Park, East London should formalise and furnished with basic amenities. It is important to engage the community on policies that affect them. BCMM should adopt a community involvement approach that ensures that citizens are aware of the threats they pose to their livelihood. It is also important that the government address the housing issue to avoid informal settlements. The ecological balance between resources and humans should be kept at threshold lest environmental consequences and disasters arise from these imbalances. It is therefore rather wise to deal with the problem of population growth now before any disasters have arisen because it will be capital intensive since the size of the population will not allow innovative methods of tackling the problems at hand. The issue of the quality of housing for urban residents is a cause of great concern, in most of the informal settlements there is a lack of service delivery from the local municipality, the type of material used for the construction of the buildings is substandard.

Statistics from Eastern Cape Soci-Economic Consultative Council (2012) reveal that about 373 000 people of the urbanites in BCMM are living in poverty. The poor are the most vulnerable crowd to the prevalent environmental problems associated with urban sprawl. Environmental decay is inevitable if issues of the environment are left unabated, posing a serious threat to the achievement of sustainability beyond the MDGs of 2015. BCMM has to embrace strategies that adhere to the concept of sustainability. Sustainability approaches take into consideration the links that exist between humans and where they settle be it rural or urban areas. As obstinate as the approaches may seem, there are highly potent, vigorous and desirable paths of smart growth.

For a much specific impact in BCMM on problems, arising from urban expansion (urban sprawl) strategies should be holistic and approach each problem from all perspectives political, social, economic and environment. Based on these approaches this research offers the following suggestions:

- Rapid population growth remains one of the major causes of urban sprawl in BCMM. This population growth is emanating from migration as well as natural increase. This migration is probably due to the gap that exists between the rural and urban areas in terms of basic infrastructural development and job opportunities. This gap can best be solved through rural infrastructure provision and community-based job creation organizations that emphasize and promote agro-based initiatives and incentives. Empower the youths with education to reduce population growth and engage them in activities and skills that enable them to make a living in the areas they are residing. Such approaches will gradually reduce the growth of the population and aim towards an optimum population.
- Built environment specialists and town planners have a huge role to play in BCMM. There is a need for the creation of a built environment that does not endanger urbanites' 'health and well-being'. Planners and municipal decision makers should guarantee to take responsibility to use their knowledge and skill to protect the environment for the present

and future generations to come. Use of appropriate designs, construction and management solutions that result in sustainable development (Okeke, 2016).

- Policy responses are noted to address the reduction of pressures on the environment not directly addressing the drivers leading to that transformation and pressure. A more direct approach is required. Policy mediations targeted directly at the drivers of population dynamics and economy may not be politically or morally sound and may often give rise to humanitarian concerns (UNEP, 2006. Nonetheless, such initiatives are capable of reducing a driver indirectly, for example, policies that favour incentivising environmentally sound behaviour or incentivising small families that have one child.

- There is still no credible consensus as to what urban sprawl really is. As such it is important to further study the concept so that we state the rules and procedures that govern what sprawl really is, and what one can consider being urban sprawl. Determination of low-density growth, threshold distance for development (what will be classified as an extension) in the vicinity of built-up environment, which growth patterns can be characterised as uneven and which expansion can be classified as normal urban growth. Though a lot has been done in terms of describing the patterns of urban sprawl, poly-nucleated, linear, scattered, or leapfrogging little has been done on the clarity and consensus of the rules that govern each description. Though its practically impossible to reach a consensus due to the varying conditions at the international scale it is important to have general guidelines that each country can follow. Once a consensus of what urban sprawl entails and guidelines and rules that operationalize urban sprawl are set, the quantification and assessment of urban sprawl becomes more compelling.

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PERSONAL COMMUNICATIONS

Matiza Collins (201512637@ufh.ac.za)2018. RE: An assessment of the environmental impacts of urban sprawl in the Buffalo city metropolitan municipality, Eastern Cape Province. (31 December 2018)

Du Plessis Anna-Jacob Elizabeth (Mdupessis@ufh.ac.za) 2013. RE: UFH Department template. Email to K R Marembo (kmarembo@ufh.ac.za) (24 July 2017).

APPENDICES

APPENDIX A: ETHICAL CLEARANCE

University of Fort Hare
Together in Excellence

ETHICAL CLEARANCE CERTIFICATE
REC-270710-028-RA Level 01

Certificate Reference Number:	MAR021SMAT01
Project title:	**The Environmental Impacts of Urban Sprawl in Buffalo City Metropolitan Municipality, Eastern Cape, South Africa.**
Nature of Project	Masters in Remote Sensing & GIS
Principal Researcher:	Collins Matiza
Supervisor:	Ms K.R Marembo
Co-supervisor:	Ms M du Plessis

On behalf of the University of Fort Hare's Research Ethics Committee (UREC) I hereby give ethical approval in respect of the undertakings contained in the above-mentioned project and research instrument(s). Should any other instruments be used, these require separate authorization. The Researcher may therefore commence with the research as from the date of this certificate, using the reference number indicated above.

Please note that the UREC must be informed immediately of

- Any material change in the conditions or undertakings mentioned in the document;
- Any material breaches of ethical undertakings or events that impact upon the ethical conduct of the research.

The Principal Researcher must report to the UREC in the prescribed format, where applicable, annually, and at the end of the project, in respect of ethical compliance.

Special conditions: *Research that includes children as per the official regulations of the act must take the following into account.*

Note: The UREC is aware of the provisions of s71 of the National Health Act 61 of 2003 and that matters pertaining to obtaining the Minister's consent are under discussion and remain unresolved. Nonetheless, as was decided at a meeting between the National Health Research Ethics Committee and stakeholders on 6 June 2013, university ethics committees may continue to grant ethical clearance for research involving children without the Minister's consent, provided that the prescripts of the previous rules have been met. This certificate is granted in terms of this agreement.

The UREC retains the right to

- Withdraw or amend this Ethical Clearance Certificate if
  - Any unethical principal or practices are revealed or suspected;
  - Relevant information has been withheld or misrepresented;
  - Regulatory changes of whatsoever nature so require;
  - The conditions contained in the Certificate have not been adhered to.
- Request access to any information or data at any time during the course or after completion of the project.
- In addition to the need to comply with the highest level of ethical conduct principle investigators must report back annually as an evaluation and monitoring mechanism on the progress being made by the research. Such a report must be sent to the Dean of Research's office.

The Ethics Committee wished you well in your research.

Yours sincerely

26/07/2018

Professor Pumla Dineo Gqola
Dean of Research

20 July 2018