Use of orthophotos and GIS in spatio-temporal assessment of land use land cover change: a case of Pietermaritzburg city, KwaZulu-Natal

by

Johane Hlatywayo

206523448

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Centre of Environment, Agriculture and Development
School of Environmental Sciences
University of KwaZulu-Natal
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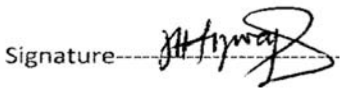
Declaration

This document describes work undertaken as part of a programme of study at the Centre of Environment, Agriculture and Development (CEAD), University of KwaZulu-Natal, Pietermaritzburg, KwaZulu-Natal. It represents the original work of the author and any work taken from other authors is duly acknowledged within the text and references list.



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Johane Hlatywayo (206523448)
University of KwaZulu-Natal, Pietermaritzburg 2012

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Supervisor: Dr J. Odindi
University of KwaZulu-Natal, Pietermaritzburg 2012

ABSTRACT

In order to manage the often highly dynamic urban landscapes, it is important to map different themes from time to time. This study made use of Geographical Information System and aerial photographs to determine LULC transformation in the eastern suburbs of Pietermaritzburg in KwaZulu-Natal, South Africa. Land use land cover maps for the eastern suburbs (Copesville, Eastwood, Raisethorpe and Willowton) for the years 1989 to 2009 were generated and transformations based on twelve LULCs determined. Results in this study showed that the most significant increase were in residential (formal and informal) and industrial LULCs while the most significant decrease were recorded in the cultivated and open LULC. Generally, results in this study further show that urban LULC attributed to human influx has been at the expense of internal open green spaces and peripheral cultivated and uncultivated lands. The study concludes that aerial photographs in concert with GIS are valuable tools in mapping rapidly changing urban landscapes.

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Chapter 1

Introduction

1.1 Background

Prediction of urban growth is often based on the dynamic land use/cover (LULC) pattern vis-avis selected socio-economic and environmental factors. Typically, land use change in urban landscapes is a reflection of population growth and socio-economic development. Consequently, the analysis of spatial-temporal patterns for LULC changes provide an objective basis for understanding the relationships between urban growths and related economic, population and environmental factors (Irwin and Geoghegan, 2001)

The term "Land cover" was originally restricted to surface vegetation types like forests and grass cover (Meyer 1995). However, usage of this term has been subsequently broadened to include among others physical structures, soil types, biodiversity, surface and ground water (Meyer, 1995: 25). Meyer and Turner (1996) further note that land cover includes the quality and type of surface vegetation, water and earth materials (Meyer and Turner, 1996:5). According to Moser (1996:247) "the term originally referred to the type of vegetation that covered the land surface, but has been broadened subsequently to include human structures, such as buildings or pavement, and other physical and environmental aspects like soils, biodiversity and ground water". The term "Land use" on the other hand is described by Turner et al (1995:20) as the manner in which the biophysical attributes of the land is manipulated and the intent underlying that manipulation. Meyer (1995:25) states that land use refers to "the use of the land by humans, usually with emphasis on the functional role of land in economic activities". Whereas economics is a major factor in defining land use Campbell (2007) and Mather (1986) note that physical, social, legal and political factors may determine the definition of a given land use type.

According to (Opeyemi, 2008), land use affects land cover and changes in land cover affects land use. Generally, a change in either does not necessarily mean degradation (Opeyemi, 2008).

However, Riebsame et al (1994) note that generation of reliable LULC maps is critical in managing urban landscape as shifting land use patterns are commonly driven by a variety of social causes that result in land cover changes that affects biodiversity, water and many environmental variables.

In the old political dispensation, the city of Pietermaritzburg, like any other city in South Africa was structured on apartheid racial segregation and restricted movement into urban areas. However after the end of the previous political dispensation in 1994 and the new regime that allowed free movement into urban areas, the city witnessed unprecedented growth of settlement (Wood, 2000). An audit done in February 1997 by the city's planning unit for instance showed that informal settlements within the city grew by a 7% monthly average in the early years of South Africa's democratisation (Wood, 2000). Consequently, the city of Pietermaritzburg offers an ideal setting to test the feasibility of multi-temporal aerial photographs in LULC change mapping.

Traditionally, combinations of cartographic techniques, GIS, remote sensing and aerial photographs have been extensively used to assess LULC changes in urban landscapes (Ghaffar; 2005; Hara et al, 2005; Wentz et al, 2006). Aerial photographs have also been used as ancillary data to validate the accuracy of land cover maps generated from remotely sensed satellite imagery (Deguchi and Sugio, 1994, Mas, 2003; Rembold et al, 2000; Wentz et al, 2006). Deguchi and Sugio (1994) and Wentz et al (2006) note that aerial photographs alone can be used to generate reliable LULC maps in urban environments.

Urban LULC change is commonly attributed to an increase in population (Wood, 2000). Such increase often lead to pressure on non-urban lands surrounding the city and may leads to among others, decrease in peripheral agricultural productivity, reduction in urban environmental quality and pressure on existing social and physical services (Wood, 2000). According to Ramesh (1989), these concerns have increased the relevance of LULC maps and data formats that can be used to generate such LULCs.

As has been previously mentioned, previous studies seem to be biased towards the use of Remote Sensing and GIS. However, due to their relative low cost, widespread availability and high spatial resolution, multi-temporal aerial photographs have great potential in mapping urban landscapes often characterised by a complex mosaic of LULC types (Ramesh 1989). Aerial photographs are particularly useful in determining historical LULC changes as they pre-date other LULC data sources like satellite imagery (Ramesh 1989; Rembold, 2000). In third world countries, aerial photographs can be an ideal data source for generating LULC maps as the availability and cost of satellite data are often prohibitive (Ramesh, 1989).

1.2 Research Problem

Pursuit of this research is based on two main problems; firstly, existing literature and land cover maps are often based on a combination of aerial photographs, GIS and remote sensing. Very few studies on existing LULC maps for urban landscapes are solely based on aerial photographs. Secondly, the new political dispensation in South Africa has seen significant changes in urban landscapes that have led to socio-economic challenges. Dealing with these challenges requires cheap and up to date LULC maps for planning and optimisation of urban spaces. Based on post 1994 eastern Pietermaritzburg settlement trends, up-to-date LULC changes will form a valuable basis for the management of the city’s LULC and associated challenges

1.3 Aims and objectives

1.3.1 The overall aim of the study

The main aim of this research was to demonstrate the potential of aerial photographs and GIS in mapping LULC trends of the eastern suburbs of the city of Pietermaritzburg between 1989 and 2009.

1.3.2 Specific research objectives

1. To use aerial photographs to map and analyse 'spatia-temporal' extents within the study area from 1989 to 2009.

2. To determine the reasons for LULC changes in the eastern suburbs of Pietermaritzburg city between 1989 and 2009.

3. Ascertain whether or not 'land use' land cover changes has taken place in the study area.

1.3.3 Significance of the research

It is hoped that this study will augment to the existing literature on mapping LULC changes and prediction using GIS and aerial photographs. Such study is also critical for the city's landscape planning and mitigation of un-desired urban trends.

1.4 Research delimitation

Firstly, whereas it is acknowledged that there was LULC changes prior to 1989; this research was restricted to the formal zoning of Pietermaritzburg after 1989. Secondly, whereas post 2009 aerial could have been valuable in the analysis of LULC changes, challenges in accessing post 2009 limited the study to the mentioned time span.

1.5 Summary

In this chapter, the background of the study, the research problem and the objectives have been highlighted. Furthermore research significance has also been mentioned. The next chapter provides a detailed review of literature on the issues under investigation.

Chapter 2

Literature Review

2.1 Introduction

Before an analysis of ‘spatial temporal’ dynamics, it is important to review a historical background, concepts and related literature on land use land cover changes (LULC) using Geographical Information Technologies. Consequently, this chapter reviews literature on existing relevant literature on LULC changes using Geographic Information Systems (GIS) and aerial photographs. The chapter also highlights the implication of LULC changes within urban landscapes.

2.2 Urbanisation; the concept

There are multiple definitions of the term “urbanisation”. Pacione (2001: 67) defines urbanisation as an “increase in the proportion of the total population that lives in urban areas”. According to Pacione (2001), urbanisation is a contemporary and on-going process. To further understand the ‘urban’ concept, Pacione (2005:28) distinct between “what an urban place is” and “what is urban”. The definition is based on an urban area as a physical entity and an urban area as a place with a unique physical and social quality of life. Based on entity, four methods are used to define urban places. These are population size, economic base, administrative criteria and functional definitions. Since urban places are generally larger than rural places, it is often common to define a transition between rural to urban along the population size continuums. Urban areas can also be identified by their economic base. In some countries population size is combined with other subjective criteria to define an urban place. In India for instance, the definition of an urban area is based on over a 75% of the adult male that is employed in non-agricultural work. On the other hand, Pacione (2005) notes that an urban area can be defined based on lifestyle lead by people in a community. According to Pacione (2005), whereas urban areas exist as physical objects, they are often not perceived by inhabitants as structured by objects, consequently, Pacione (2005) notes that it is reasonable to think of a city as having both an objective physical structure and a subjective or cognitive structure. Whereas the origin of urban centres may be for defence, trade, political or religious reasons (Harvey, 1996); economic forces often reinforce the original impetus. Commonly, urban growth is associated with industrialisation which induces intensive use of buildings and changes in their use which in turn influence outward expansion and outward LULC changes.

2.3 Geographic Information Systems

Currently, there is a wide array of definitions for Geographic Information Systems (GIS). However, depending on its 'application', the existing definitions revolve around technology, application or organizational aspects (Chou, 1996). Whereas dynamic technology makes defining GIS challenging, most current definitions describe GIS as an organised collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store update, manipulate, analyse and display all forms of geographically referenced information Chou, 1996; Goodchild, 1992, Green et al, 1994. In virtually all definitions, two common features emerge; GIS is a system which deals with geographical information linked to the earth's surface and people are a critical component in a GIS system (Walford, 1999).

2.4 Aerial photography and interpretation

Aerial photographs are described by Lo (1976) as descriptive models of reality that can be used to deduct geographic themes. Historically, aerial photography interpretation (API) has been the basis for mapping LULC (Wentz et al, 2006). Interpretation of aerial photos focuses on extraction of spatial qualitative and to a limited extent quantitative data (Estes, 2001). The major advantage of using aerial photography in urban LULC mapping is the high interpretation accuracy that can be achieved in complex landscapes (Cowen and Jensen, 1998). Typically, effective uses of aerial photographs for LULC changes are restricted to those taken at nadir (Bretts et al, 2006). There are a number of shortcoming in using aerial photographs, the further an object is from nadir, the more distorted the feature is on the ground. Interpreting aerial photography is often costly, time consuming and subject to interpretation errors (Mumby et al

1999 cited in Wentz et al, 2006). Furthermore, aerial photographs are often not generated frequently; consequently, generating up-to-date LULC maps might be difficult.

According to Lo (1976) and Estes (2001), there are three distinct stages of photo-interpretation. Generation and examination aims at gaining a general impression of what is shown on the aerial photograph. This stage involves selectively picking out objects or elements from the image to get a holistic view of the landscape. Identification stage aims at picking out landscape geographic features using characteristics like pattern, shape, tone, texture, shadow, associated features, and size (Heyde, 1998, Lo, 1976;). Classification involves assigning geographic features and objects that have been recognised and identified into their appropriate classes as defined by the author (Cann, 1997). Like other types of remotely sensed data sets, aerial photographs taken from two or more dates are useful in determining the presence or absence of LULC change (Wentz et al, 2006).

2.5 Use of aerial photographs; global examples

A number of studies have made use of aerial photographs in landscape delineation (Fraizer et al, 2000). Due to shortage of relevant satellite imagery of the study area, often common in developing countries, Reimbold et al (2000) used aerial photographs and field survey to determine LULC in Ziwat-shala lake basin in Eithiopia. Wentz et al (2006) on the other hand compared methods used to map LULC in an arid urban environment of Phoenix metropolitan area in USA using aerial photography interpretation (API), satellite imagery and on the ground observations (OTG) (Wentz et al, 2006). They concluded that the quality of classes based on API match those obtained from the other two methods. They further noted that differences in levels of accuracy using the three methods arise from positional errors, incorrect ground observations, or discrepancies between the sizes of sampling unit in the ground versus classes generated.

Hara et al (2005) used aerial photographs to determine transformation on the urban fringe of Bangkok, Thailand, while Deguchi and Sugio (1994) cited by Wentz et al (2006) compared aerial photography and a variety of satellite datasets for impervious areas and the density of urbanized area of Wake County in the state of North Carolina, USA. The two studies concluded that both aerial photography and satellite data returned results of similar accuracy. Ventura and Harris (1994) compared the performance of standard classification techniques using manual interpretation for both aerial photography and satellite data for Beaverdam, Wisconsim, USA and concluded that aerial photographs provide the higher classification accuracy in a number of LULC categories.

Robbins (1997) used aerial photographs to investigate temporal change in sea grass in Tampa Bay on Gulf coast of Florida, USA. The verification of polygon categories used in this study was conducted by sampling and ground truthing LULC types. The maps were geo-referenced and overlaid on a base map of the Tampa Bay shoreline. Comparison of total sea grass cover was made between dates by constructing a difference map using ARC/INFO GIS software.

Whereas some of the examples given above may not have been specifically carried out in urban areas, approaches and techniques used in these studies are commonly adopted and applied in urban LULC change analysis.

2.6 Land use and land cover change analysis techniques

A number of studies have attempted to define change detection (Fraizer, et al. 2000). According to Singh (1998) change detection is a process of identifying differences in the state of an object or phenomenon by observing it at different time periods. Huang and Hsiao (2000) define change detection as the comparison and contrast of multi temporal images of the same geographical area. This is achieved by using image-handling techniques to analyse the changed areas of the landscape over different time periods. Change detection is essential for the monitoring of the earth's natural resources through the analysis of the spatial distribution of the associated population. Aspects of change detection important for monitoring natural or man-mad resources are: detecting changes that have happened, identifying the nature of the change, measuring the magnitude of the change, and assessing the spatial pattern of the change (Macleod and Congalton, 1998). Change detection is useful for a wide range of applications. It is used in areas such as land use analysis, monitoring cultivation patterns, urban growth, natural disaster and environmental monitoring (Bottomely, 1998; Inglis-Smith, 2006).

Until recently, the collection and compilation of spatial data was restricted to hard copy maps. As aforementioned, techniques based on hard copy maps is costly and time-consuming. The use of aerial photos in concert with GIS has made it easier to undertake LULC mapping. Large sets of data can be processed into digital forms to provide rapid and consistent measurement of change and trends. Integration of aerial photographs into GIS to monitor and analyse LULC change has proved a popular and efficient method in urban landscapes (Iwao, 1998; Read et al, 2002; Saipothog et al, 2000). This has mainly been possible because GIS provides an array of spatial tools and techniques that can be used to continuously monitor and analyse LULC trends quickly, accurately and cost effectively.

A range of change detection techniques have been developed over the years (Lu et al. 2004). Most of the existing detection techniques are restricted to satellite multispectral satellite imagery characterised by representative object pixels. These techniques include among others Normalized Difference Vegetation Index (NDVI), Principal Component Analysis (PCA), Image Rationing, Maximum Posterior A Probability (MAP), and Post Classification Comparison (PCC), Direct Multi-date Classification (DMC) (Emani and Gabriels, 2006 and Mohamed, 2003). Whereas these classification techniques are mainly applicable to satellite imagery characterised by bands and pixels, techniques based on PCC for instance are applicable in analysing aerial photographs and have been widely adopted in aerial photograph LULC mapping (Asubonteng, 2007). Typically, PCC technique classifies two dates separately and compares two post classes (Ernani and Gabriels, 2006). The technique provides detailed "from-to" change class information that is essential for landscape monitoring (Ernani and Gabriels, 2006). Whereas use of the technique makes use of multi-date imagery characterised by image bands and pixels, analysis of aerial photographs using this technique requires that LULC types are classified by digitizing and changes determined by comparing different dates. To generate reliable urban LULC types, this technique requires knowledge, expertise and time (Lu et al, 2004).

2.7 Spatial referencing and validation in LULC analysis

Geographic location is the element that distinguishes geographic information from all other types of studies; consequently, methods for specifying location on the earth's surface are important in creating useful geographic information (Longley et al, 2005). Without location, data of an area is regarded to be non-spatial and would have no value within GIS (Longley et al, 2005).

Geographic referencing also referred to as geo-rectification is a prerequisite to LULC analysis. Geo-referencing or geo-rectification is the process where images are rectified to fit into world map coordinates and related to known spatial points (ER Mapper, 1998). This process distinguishes geographic information from all other types of information (Longley et al, 2005). Rochinia and Di Rita (2005) describe geo-rectification as a process which gives a precise geographical location to ground objects. Geo-rectification methods vary from complex ortho-rectification methods to polynominal methods. Generally, ortho-rectification methods are compatible with GIS and are therefore ideal for referencing data to use for map production and geographical analysis in GIS (Cots-Folch et al, 2007, Okeke and Karniel, 2006). However, despite its ability to yield high accuracy, ortho-rectification method is not widely used because it is costly and highly technical (Hughes et al, 2006).

Polynomial techniques on the other hand are widely used. The method makes use of matching control points on the target image to identify locations on reference data. Polynominal transformation algorithms that are commonly used range from the simpler first, second and third-order polynomials to the more curvilinear mathematical transformation algorithms such as the spline transformation commonly known as 'rubber sheeting' (ESRI 2007, Hughes et al, 2006). In the geo-rectification process, it is critical to take cognisance of the various factors that influence the overall geo-rectification accuracy. These include among others the number of Ground Control Points (GCPs) used, topography of the environment in focus, the map scale (i.e. global and local scales) used and the complexity of mathematical transformation algorithms (Hughes et al, 2006; Yanalak et al, 2005). Validation of the LULC types is often considered a final critical process in any mapping process. A common method employed to assess errors is by carrying out field work and verifying points on the ground using a Global Positioning System (GPS) and other ancillary data (Misakova, 2006, Wentz et al, 2006).

2.8 Land use and land cover change: a social and environmental perspective

Whereas LULC maps form a critical basis for decision making, their full value can be realised if related to physical, social and environmental perspectives (Erle and Pontius, 2007). Humans have modified land to obtain food and other essentials for thousands of years. Currently, the extent and intensities of LULC change is greater than ever in human history (Yesserie, 2006). This has caused unprecedented change in ecosystems and environmental processes at local, regional and global scales (Yesserie, 2006). Currently, LULC change encompasses the greatest environmental concerns of the human population, including climate change, biodiversity depletion and pollution of water, soil and air. Consequently, monitoring and mitigating unsustainable land use practices has become a major priority of researchers and policy makers. (Erle and Pontuis, 2007; Verburg et al, 1999).

2.9 Urbanization and LULC: a South African context

Before determining existing LULC, it is important to contextualise LULC. Typically, population data as timelines of historical events (and related information) can be used to explain the mapped changes (USGS, 2004). For instance population increase suggest economic growth and the availability of jobs in an area while population declines suggest a decline in local economy (USGS, 2004), these can be determined by event time lines.

In South Africa, ‘apartheid city’ was established by the Group Areas Act of 1950 (Tony et al, 2002). Urban structures and life during this period was controlled by legislation segregating racial groups. During this era land zoning in urban areas was divided according to race. The introduction of the Group Areas Act of 1950 and 1966 and the 1953 Reservation of Separate Amenities Act extended the principle of racial segregation to produce the urban structure of the apartheid city designed to minimise interracial contact (Pacione, 2005). The apartheid city was characterised by racially divided areas and a lack of services, infrastructure and development in the poor “black” townships. Local governance was minimal and imposed without democratic representation. Access to adequate housing, land, water, electricity, transportation and other urban services was limited for the majority of the population. In 1991 two legislative pillars of apartheid, the Group Areas Act (1950) and the Natives Land Act (1913) were repealed as part of a reform strategy in the face of intensifying “struggle”. This, among others, was a key aspect of negotiations between the apartheid government and the African National Congress (ANC). During the negotiation process the Local Government Transition Act was passed in 1993 and approved by multiparty negotiating forum. This set out the phases of a transition process for local government and became a significant milestone in South African urban development (Wood, 1999).

Despite the collapse of the apartheid regime in 1994, the legacy of almost half a century of apartheid urban policy remains a strong influence on urban form and zoning in South Africa. Prior to 1994 the role of local authorities was limited to controlling technical processes and land use by regulations and restrictions. Municipal planning benefited privileged groups and areas and environmental sustainability and meaningful public participation were neglected. As such, the form of the future post-apartheid city in South Africa is constrained by the social and physical structure created under apartheid. Although some signs of change is evident in the emergence of inner-city ‘grey areas’, white areas of the apartheid city in which some non-whites have taken up residence still reflect the old system (Pacione, 2005).

2.10 The Legislation governing land use planning in South Africa

A number of legislations govern land use planning in South Africa and directly influence LULC. This legislation can be found at local, regional and national level. They include among others:

-Townships and Town Planning Ordinance Act (TTPOA)
-The Planning and Development Programme Act (PDA)
-The Development Facilitation Act (DFA)
-The Reconstruction and Development Programme (RDP), and

-Land Agenda 21 (LA21).

2.10.1 The Townships and Town Planning Ordinance (Act 15 of 1986)

This Act is the key piece of provincial legislation providing for land use control. It provides for the drawing up, extending and amendment of town planning schemes and the approval of applications for the establishment of new schemes. The town planning schemes are the instruments that control the practical implementation of the Ordinance. It regulates the use of land in urban areas. In an application for approval of a new township, the applicant will apply for the zoning of the properties within the new township (Drake, 2004). The local authorities use the zoning of a property to determine its development potential and thus the value at which a property will be rated (McConnachie, 1999). It also gives the local authorities power to control development within their areas of jurisdiction.

2.10.2 Development Facilitation Act (Act 67 of 1995) (DFA)

Physical planning was introduced in South Africa for among other reasons to mitigate increasing pressure on non-renewable resources. The legislation was required to ensure that both the provincial and local authorities took cognisance of economic, social, health and other administrative issues. These concerns heralded the introduction of the Physical Planning Act of 1991 (Act no. 125 of 1991). The act provided for a system of policy plans at national, regional and local levels. Due to the political transition in South Africa, the preparation of the new plans according to the provisions of the Act was not implemented. Key focus areas were to**:**

I. introduce extraordinary measures to facilitate and speed up the implementation of reconstruction and development programmes and projects in relation to land,
II. provide for the establishment in the provinces of development tribunals which to facilitate the formulation and implementation of land development objectives and provide for nationally uniform procedures for the subdivision and development of land in urban and rural areas.

This Act was the first coherent attempt to bring about uniformity in township establishment, land registration and planning systems (McConnachie, 1999). Its aims were:

-To speed up reconstruction and development programmes and projects and set out principles for land development

-To provide for a Development and Planning Commission to advise government and to provide for development tribunals in the provinces

-To implement land development objectives and measure local government performance

-To provide nationally uniform procedures for the subdivision and development of land in urban and rural areas and

-To promote security of tenure and the early provision of subsidies and loans in the land development process.

2.10.3 Reconstruction and Development Programme (RDP)

The Reconstruction and Development Programme (RDP) was introduced in 1994. It aimed at improving the quality of life and standard of living of all South Africans. The RDP was an integrated growth and development policy that aimed to address poverty and inequality and generate sustainable economic growth. The introduction of RDP heralded the construction of new houses in most urban areas. It emerged as the key strategy to address the social and economic inequalities of apartheid and the facilitation of the transition to non-racial democracy. The RDP through the Urban Development Strategy (UDS) aimed to integrate the segregated city by concentrating on rebuilding the townships, creating employment opportunities, providing housing and urban amenities, reducing community distances, “facilitating better use of underutilised or vacant land” and introducing urban management (Cilliers, 2010: 38). Specifically, the intention was to ensure that the resources of the built environment were used efficiently by integrating the needs of the urban poor and urban areas economic productivity (Maharaj, 1997).

According to Maharaj (1997), Urban Development Strategy (UDS) identifies five priorities namely:

-Integrating the cities and managing urban growth

-Investing in urban development

-Building habitable and safe environments

-Promoting urban economic development

-Creating Institutions for delivery.

The introduction of RDP and its strategic plans such as UDS caused spatial urban changes in most metropolitans, cities and towns of South Africa. A lot of houses and other amenities were built in most urban areas in South Africa. Many open/vacant lands were transformed into formal and informal residential areas as more people flock to urban areas. Consequently, urban expansion has been tremendous for the past eighteen years and this has resulted in shortage of accommodation in many cities.

2.10.4 Impacts of urbanisation on people and the environment

The city of Pietermaritzburg is growing at unprecedented rate. This has resulted to a reduction in the city's space (Sutton, 2008). Many of the farmlands, wetlands and forests that were part of the city have in the past 20 years been transformed into human settlements. This expansion threatens green space (Mahmoodzabeh, 2006).

2.12 The study areas

The city of Pietermaritzburg is located in the KwaZulu-Natal midlands, Umgungundlovu District's Msunduzi Municipality (Figure 2.1). The history of the city of Pietermaritzburg dates back to the defeat of the Zulu people in the Blood River battle of 1838. The city was named after a former leader Pieter Mauritz Retief. In 1843, the town was annexed by the British; however, the name Pietermaritzburg was retained. Due to its relative central location in the province (Figure 2.1) and favourable climate, Pietermaritzburg has been an important urban node in the province (Msunduzi IDP, 2008-2012).

Temperatures in the city are moderately warm. The average daily maximum temperature is 26 degrees Celsius. While temperatures of over 35 degrees are often recorded between the months of December to May, the coldest temperatures of around 11 degrees are experienced between

May and August. The city receives an average of 844mm of rain distributed across the year. Over 138 days receive at least 1mm of rain. The wettest months are January to March and September to December. Generally, the city's capital status, mildly warm climate and relatively high rainfall have made it attractive for settlement. The eastern suburbs in particular are expanding at a very high rate, especially after 1994. Consequently, areas like Copesville and Eastwood (Figure 2.1) are characterised by high density urban sprawl moving outwards into the surrounding agricultural land.

Pietermaritzburg was declared the administration capital city of the province in the year 2000. Consequently, there was significant socio-economic growth and spatial transformation. The political transformation around this time (1989 to 2009) also acted as inertia to the city's spatial transformation (Msunduzi IDP 2003-2010).

The study area is made up of four suburbs, namely Copesville, Raisethorpe, Willowton and Eastwood. Copesville and Eastwood, which border farming areas, were included to investigate how much farming land was lost to the expanding city. Raisethope is partly surrounded by other suburbs and is relatively old. It was included in the study to find out whether there is any land use or cover changes in old suburb areas. Willowton is an industrial area. It was included in the study to investigate the growth of industries in the area studied.

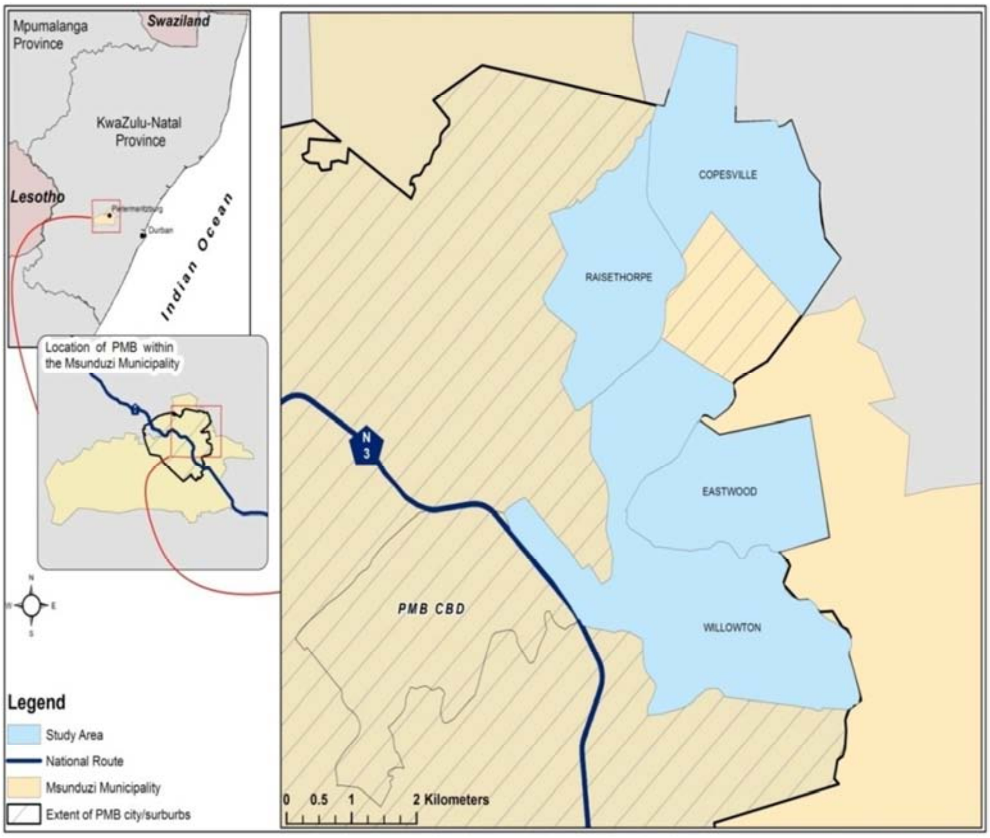

Figure 2.1: The study area.

2.13 Summary

The chapter has broadly outlined the nature and use of GIS and how it can be used to analyse and asses LULC changes using aerial photographs. The chapter has also described the study area and how the policies and legislations which were introduced after 1994 have a bearing on its development and consequent LULC.

Chapter 3

Material and Methods

3.1 Introduction

This chapter describes the methods and the materials used and the approaches adopted in achieving the aims set in chapter one. The research focuses on how GIS and aerial photographs can be used to analyse LULC change patterns in the study area. To achieve this, digital aerial photographs taken between 1989 and 2009, topographic maps produced in 1982, 1989 and 2000 and the Zoning map obtained from the Department of Town Planning in the GIS department, in Pietermaritzburg city were used. A methodology illustrated in Figure 2.2 provides a summary of how the aforementioned objectives of the study were achieved.

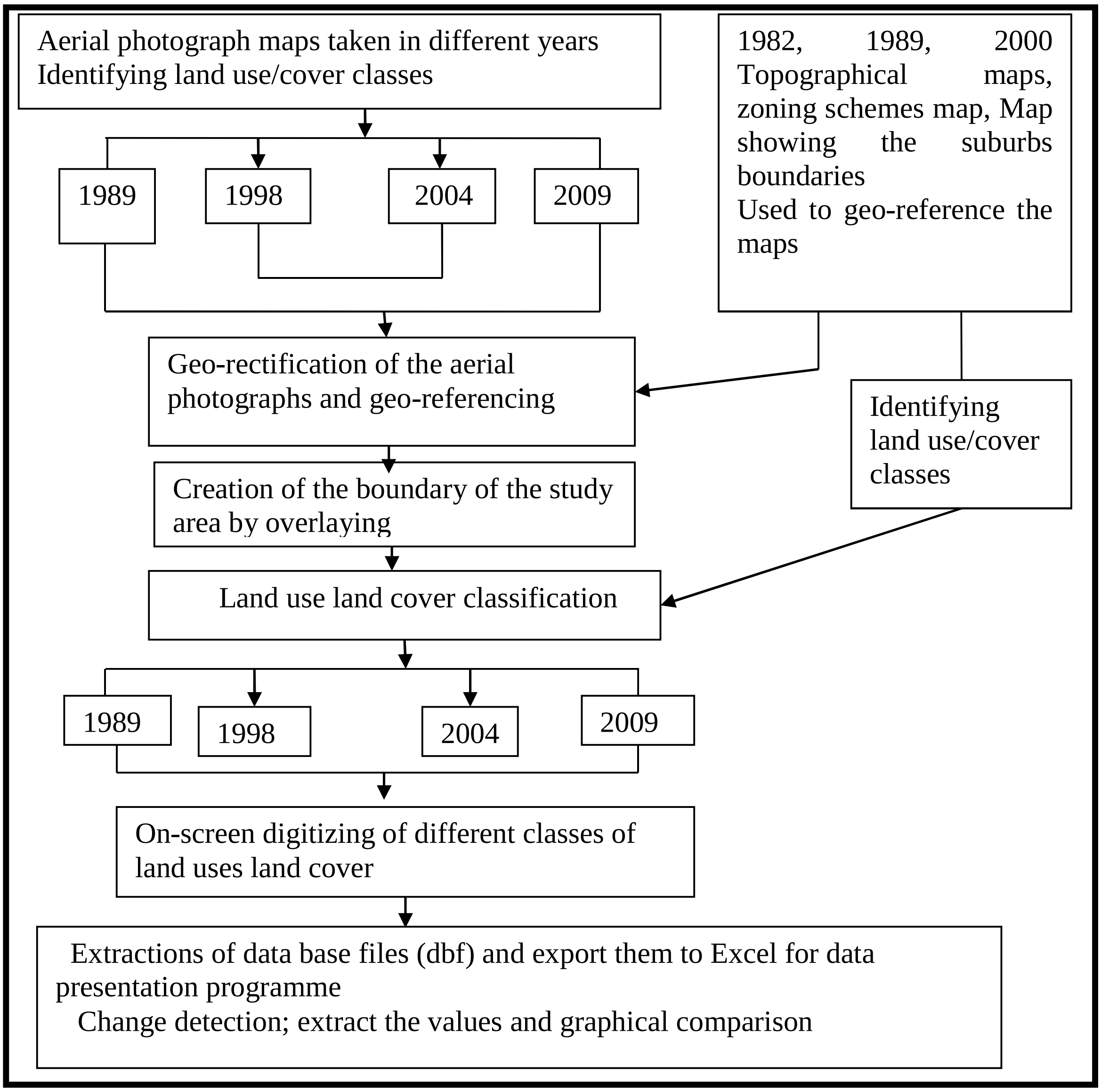

Figure 2.2: Procedure for mapping LULC changes in the study area (1989 to 2009).

3.2 Data sets collection, processing and analysis

3.2.1 Data sets

The aerial photos (Table 3.1), topographic maps, zoning schemes and city suburb maps used in this study were obtained from the Pietermaritzburg Surveyor General's Office, Department of

Town Planning in Pietermaritzburg, the Chief Directorate, Survey and Mapping, the GIS Department in Msunduzi Municipality and Geography Department at the University of KwaZulu-Natal.

Table 3.1: Aerial photographs of Pietermaritzburg used in the study.

	Date	Scale	Type
1	1989	1:50 000	Black &white
3	1998	1:20 000	Colour
4	2004	1:20 000	Colour
5	2009	1:25 000	Colour

Topographic maps, zoning schemes and city suburb maps

Top maps	1982, 1989 and 2000	1: 50 000	Topographic
Zoning Schemes map	2006	1:10 000	Zoning map
City suburb map		1:10 000	City boundaries

3.2.2 Data sets processing

The processing of data used in this research consisted of two important procedures: Geo-rectification of the aerial photographs and On-screen digitization of the LULC classes. Geo-rectification was done to eliminate positional errors that could affect change detection accuracy, while digitization was used to create various land use maps required for analysis. The Spline geo-rectification technique was used to geo-rectify the aerial photographs taken in 1989 and 1998. Since the 2004 and 2009 photographs were acquired when already geo-rectified, the 2009 photograph was used for the geo-rectification process to accommodate any new features in existence. The geo-rectification procedures determine the accuracy of the final LULC change analysis whose accuracy is dependent on the positional accuracy of individual pixels on the aerial photographs used. According to Boone et al (2007), a good positional accuracy of individual pixels that make up the entire aerial photograph implies that on any two multi-temporal photographs, pixels of a feature in the image from an earlier date correspond specifically to the location of pixels of the same feature in the image taken in a subsequent date.

3.2.3 Geo-rectification process used

Aerial photography is an efficient surveying tool for inventory and mapping. It can be used to collect spatial, temporal and spectral data (Congalton and Green, 1999). Before land use information could be extracted from the aerial photographs, the data was cleaned, rectified and converted to an accurate representation of the area. The Gauss Conformal map projection was used throughout the LULC classification process. Roblin (1969) recommends conformal projections as suitable option as accurate distance; shape and azimuth (direction) can be produced. Transverse Mercator was used to project the maps used in the study. To accurately determine where and what LULC changes that exist in the photographs, the images had to be geo-referenced. Geo-referencing helps to tag or locate records with geographic locations. The primary requirement in the geo-rectification process is that a location must be unique and only a single location should be associated with a point. The geo-referencing process should also be persistent through time as it would be expensive and confusing if geo-referencing changed frequently (Longley et al, 2005).

3.2.4 LULC classification approach and description of classes

Since there are different kinds of land cover types and possible land uses, it is necessary to identify and classify land according to characteristics and use potential (Rhind, 1993). Land use and land cover maps typically enumerate the types of land usages and vegetation covering the earth. For the purpose of this study, detailed observations of LULC had to be classified into defined groups or categories in order to characterise the land use features with some level of consistency and accuracy over time and space. Classification as defined by FAO (2005:209) "is an abstract representation of the situation in the field using well-defined diagnostic criteria". It is a means of organising spatial information in an orderly and logical way and it is fundamental to any mapping project as it creates order in the total number of classes (Congalton and Green 1999). In order to determine the number of LULC mapping classes on a multi-temporal data set, standardised classification schemes need to be followed (FAO 1977). To achieve this scheme the following had to be reviewed:

-The anticipated use of the land

-The relationship between features and the study area, and

-The level of detail required by the user

To differentiate the boundaries between the LULC types, the major LULC types were manually digitized from the geo-rectified aerial photographs using shape, pattern, tone, texture and association (Campbell, 2007; Harvey and Hill, 2001, Lillesand et al, 2004).

The classification scheme in this study was adopted from the guidelines by Thompson et al (2001). In this study a 2000 (4^{th} edition) topographical map was used as a base map to identify and classify LULC types on 2009 aerial photograph. As aforementioned the interpretation was done using urban aerial photo feature characteristics such as shape, size, tone, pattern and association. First, the 2000 topographic map was interpreted for LULC details and the same details were transferred to 2009 aerial photograph. Second, aerial photographs from 1998 were interpreted for the same LULC classification as those from 2009 and details transferred into the base map by the method of matching the details. Topographic map for 1982 (2^{nd} edition) was used to classify LULC for 1989 and LULC on 1998 aerial photographs were classified using 2000 (4^{th} edition) topographic map. Whereas topographic maps acquired in tandem with aerial photographs could have been ideal, they were not available and the closest possible set had to be used instead.

Typically a classification scheme has two critical components; a set of labels and a set of rules or classifications. Without a clear set of rules, the assignment of labels of LULC types can be arbitrary and with no consistency (Congalton and Green, 1999). If a rigorous set of rules and labels are not developed prior to mapping, the accuracy of mapping is compromised and individual allocation of classes becomes difficult. Table 3.2 provides a description of different classes and rules selected for the study.

Table 3.2: Description of LULC classes *(*adopted from Thompson et. al. 2001).

Land use/cover classes	**Description**
Urban Build–up (residential)	Formal build-up area; permanent or near permanent residences, identifiable by the high density residence and associated infrastructure. Includes high density, medium and low density areas.
Urban Build-up residential l (informal settlements)	Non-permanent informal type dwellings (that is, in tin, cardboard, wood extra.) typically established on an informal adhoc basis on non-served sites. Typically high building densities. Refers to all unplanned residential areas without proper planning. Houses mainly built of corrugated iron sheets.
Urban Build-up (residential informal township undeveloped planned residential area	Permanent (that is, bricks) structure (predominately single level) located on serviced sites in a pre-planned manner. Includes both low and high building densities. Also includes stands which are at foundation level with developed roads and demarcation for residential areas.
Urban Build-up, industrial/ transport, heavy and light business.	Non-residential areas with major industries (that is, manufacture and/or processing of goods, manufacturing or transport related infrastructure. Examples, light manufacture units, warehouses and business development centres. Also includes land which has been designated for light and heavy industries.
Business	Incorporated all legal commercial land use such as retail shops and garages.
Education	All the schools and tertiary institutions in the area.
Cultivation	Land that are under subsistence agriculture within the study area.
Municipal	Includes land which is controlled and owned by the municipal such as sewage works and power stations.
Trees and bushes	Incorporate all land that is covered by a maximum of 60% natural vegetation of indigenous trees and bushes or 60% commercial forest.
Degraded shrubland and low fynbos	Permanent or near permanent, man-induced areas of very low vegetation cover (that is, removal of trees, bushes, or herbaceous cover) in comparison to surrounding natural vegetation cover. Typically associated with subsistence level agriculture and rural population centres, where overgrazing of livestock and/or wood resources has been locally excessive often associated with severe soil erosion problems

3.2.7 Methods of aerial photograph interpretation

According to Estes (2001) and Lo (1976) there are three distinct stages of photo-interpretation and adopted in this study; General examination: This aims at gaining a general impression of what is shown on the aerial photograph. This involves selectively picking out objects or elements from the image so as to get a holistic view of the image that is being interpreted. Identification: In identifying geographic features represented in aerial photos, several image characteristics may be used; these include patterns, shapes, tone, texture, shadow, associated features and size (Heyde, 1998, Lo, 1976). Classification: As pointed out earlier, classification involves assigning geographical features and objects that have been recognised and identified into their appropriate class as defined by the author.

3.2.8 Creating land use maps

To create choropleth maps and graphically illustrate temporal aerial divisions of different LULC classes between 1989 and 2009, common boundaries of the suburbs were achieved by overlaying suburbs grids obtained from the Town Planning Department in Pietermaritzburg. The grid covering the study area was extracted from the grid that covers the whole city by selection and clipping. The grid map which was created was overlaid on the aerial photographs taken from the aforementioned multi-temporal periods. The different classified LULC types were saved as vector files containing shapes of each LULC type.

3.2.9 Digitising

Digitising is the process of converting hard copy geographic information into digital vector images. Traditionally, digitising is done on a digitising tablet - a large board with an attached mouse or ‘puck’. The digitising table has a fine grid of wires embedded in it that acts as a Cartesian coordinate system. This underlying circuitry converts points where you dictate the puck into x and y coordinates (Haddock, 2001, Weng, 1990). Due to improvement in computer technology, high-resolution digital imagery and aerial photographs can be linked into a GIS software package that allows for capturing, editing and delineation of features directly on the computer screen. This method of digitising is often referred to as 'on-screen' or 'head-up' digitising (Gillings et al, 1998).

In this study an 'on-screen' digitising was employed. After the classification of the different LULCs, different LULCs in the study area were digitised. The corrected digital orthophotos of the study area were imported and displayed in ArcCatalog making it was possible to zoom in to identify locations of the boundaries between LULC types. These boundaries were digitised directly on the screen in ArcMap at an area threshold determined by the resolution of the aerial imagery.

3.2.10 Editing, creating polygons and attribute data

This process involved manually moving nodes at the beginning or end of arcs. These nodes either overshot or fell short of other lines. Accidentally digitized slivers were also removed. As the polygon did not contain attribute data, corresponding attributes such as formal residential, informal residential area, cultivated land, recreation, education trees and bushes and area were manually populated with data associated with each individual polygon.

3.2.11 Error and accuracy assessment

Aerial photograph interpretation is subjective and dependent on the interpreter. Lo (1996:252) states that, "aerial photograph interpretation involves deductive and inductive evaluation of various elements detected on the photographs based on common sense, field experiences as well as interpreters' skills". In urban areas the complexity of landscapes makes interpretation difficult. Consequently, ancillary data and supporting documents are often useful. In this research a zoning map which shows different LULC in the study area were overlaid on the aerial photographs. Different LULC areas were then digitized based on these overlays. To reduce human error when interpreting an aerial photo; Estes (2001) suggest that the interpretation should:

-Be conducted logically one step at a time

-Begin with the general and proceed to specific, and

-Should proceed from the known to the unknown.

These principles were adopted and followed whilst conducting the photo-interpretations process. This process was followed to eliminate any interpretation error and to provide consistency in LULC delineation.

Maps that are created using GIS are powerful spatial analysis tools. However, GIS products may possess significant amounts of error (Walsh et al, 1987). Generally, there is usually more information on aerial photographs than can be accurately presented on the map. Thus the interpreter of a LULC map is often seeing a “filtered” version of what is actually on the ground (Campbell, 1983). The process of transcribing information from aerial photographs to a LULC map is “essentially a process of segmenting the image into mosaic of parcels, with each parcel assigned to a land use class” (Weng, 1990). This process inevitably leads to error. According to Dunn et al, (1991) there are broad ways in which this operational error can occur. Errors can occur in interpretation of photographs and omission of parcels on the ground. Errors of commission may occur when the location of boundaries between lands parcels are not clear. Errors may also occur during the digitizing process. Digitizing is essentially a sampling process where a limited number of straight lines represent the true line, which is often a smooth curve (Moore, 1997). Thus a discrepancy often exists between the positions of the original line on the map and the digitized line (Dunn et al, 1991). All the above mentioned errors were considered in the final evaluation of the generated LULC maps.

3.2.12 Accuracy assessment of Land use maps

On the ground observation (OTG) (Wentz et al, 2006) was employed in this study to verify certain sites and LULCs. Ten sets of co-ordinates of features common to all aerial photographs interpreted were chosen for accuracy assessment. The LULC types and objects which corresponded to these co-ordinates on 2009 LULC map were identified. The same positions were then located in the field using a hand held GPS (Global Positioning System). The OTG exercise produced eight sites out of ten which were correct and two sites which were slightly incorrect (Table 3. 3).

Table 3.3: Actual versus interpreted sites for the study area.

	Location			
Site	**Longitudes**	**Latitudes**	**Actual LULC**	**Interpreted LULC**
1	30.42709	-29.55356	Education (in Copesville suburb)	Education (in Copesville suburb)
2	30.42194	-29.54449	Water reservior (in Copesville suburb)	Water reservior (in Copesville)
3	30.42998	-29.60068	Municipal works/sewages (in Willowton suburb)	Municipal works/sewage (in willowton suburb)
4	30.42397	-29.59618	Education (in Willowton suburb)	Education (Willowton suburb)
5	30.41754	-29.55515	Education (in Raisethorpe suburb)	Education (in Raisethorpe)
6	30.41424	-29.57227	Formal residential (Raisethorpe suburb)	Formal residential (in Raisethoe suburb)
7	30.42244	-29.57438	Formal residential (in Eastwood suburb)	Planned undeveloped residential Area (in Eastwood)
8	30.42244	-29.58978	Formal residential (in Eastwood suburb)	Planned undeveloped residential Area (in Eastwood)
9	30.42213	-29.54351	Informal settlement residential (in Copesville	Informal settlement (in Copesville)
10	30.40955	-29.56923	Business (Raisethorpe suburb)	Business (Raisethorpe suburb)

3.3 Summary

In this chapter, procedures followed to create LULC classification system using aerial photographs have been described. The techniques used in aerial photographs interpretations are outlined and the methodologies used to reduce errors have been described. The methods, steps and tools used to create the LULC datasets have been discussed and measures taken to assess the accuracy of the final datasets explained. In the ensuing chapter, the results obtained using the methods already described are presented and discussed.

Chapter 4

Results and discussion

4.1 Introduction

The aim of this chapter is to describe LULC changes that took place from 1989 to 2009 within the study area. The chapter further identifies and describes the changes that occurred between each of the temporal datasets, the relationship between different changes over time and possible future LULC in the study area.

4.2 Results

The LULC datasets produced from the aerial photographs show the location and distribution of LULC processes at specific time periods from 1989 to 2009. In total, eleven classes were evaluated. Topographic maps and orthophoto taken from the previous years were used as basis to classify the LULC in the study area. For instance, the 1982 topographical map was used to identify and classify the LULC on the aerial photographs for 1989 and 1998 while the topographic map of 2000 was used as a base map to identify and classify the LULC for 2004 and 2009.As earlier mentioned, whereas topographic maps for the actual years of analysis could have been ideal, earlier topographic maps were used as maps coinciding with years of analysis were not available. Visual interpretation and manual classification using aforementioned techniques were used to distinguish between classes. The interpretation and the digitizing process were then used to generate choropleth LULC map datasets from which respective LULC areas were calculated. The results are shown on Figures 4.1 to Figure 4.7 and on Tables 4.1 to table 4.4

4.2.1 General LULC changes between 1989 and 2009

The land uses for 1989 to 2009 are given in Figure 4.1. The LULC datasets produced from the aerial photographs show spatial location, distribution and surface area of the LULC classes in the four suburbs studied (Copesville, Raisethorpe, Eastwood and Wilowton).

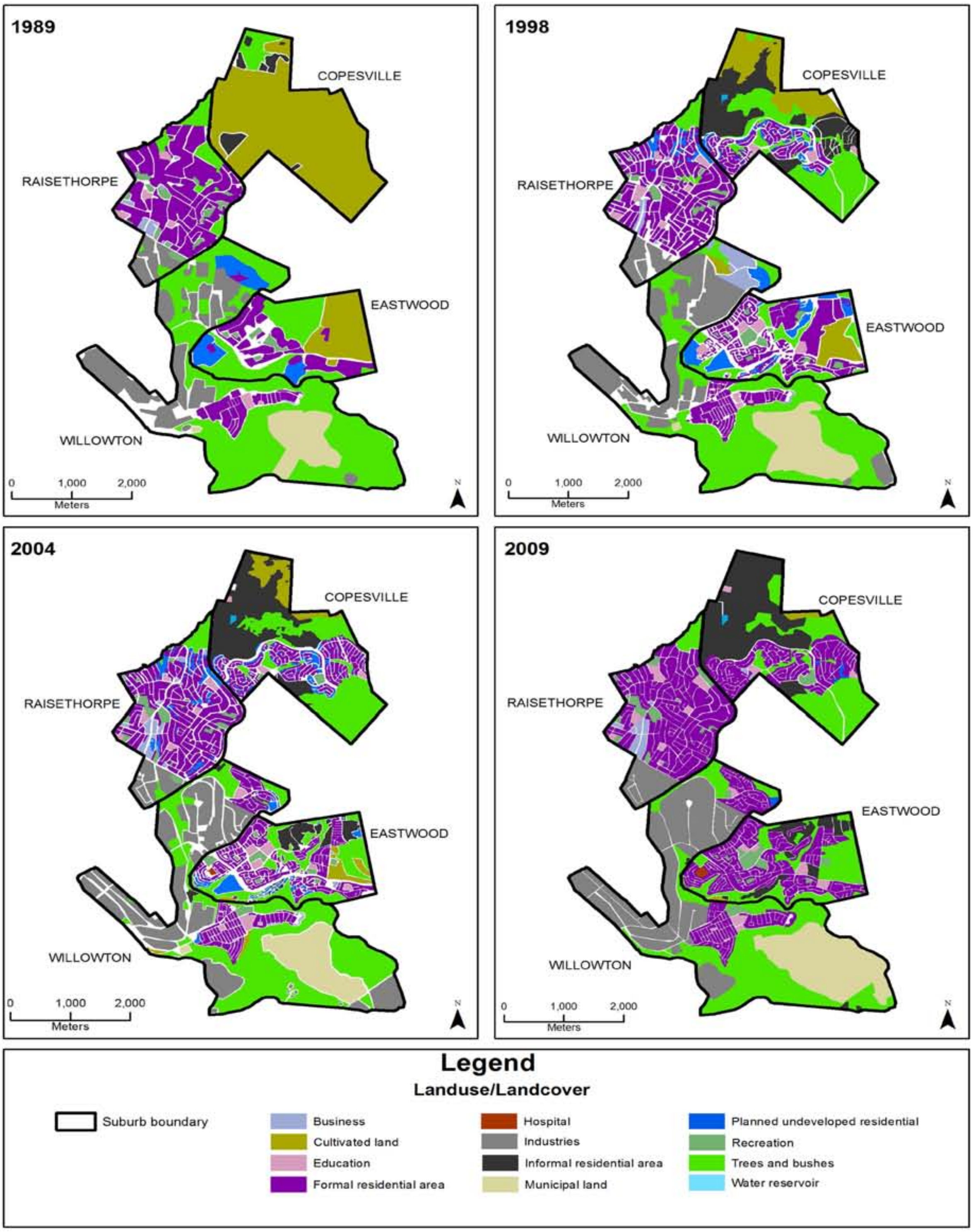

Figure 4.1: Digitized LULC maps of the study area (1989 to 2009).

Table 4.1 and Figure 4.2 show changes in hectares in the study area. Cultivated LULC class has been changed drastically from 1989 to 2009.For example cultivated land covered 571.5 hectares in 1989 and 11.01 hectares in 2009. Residential area covered 380 hectares in 1989 and 656.47 hectares in 2009 (Table 4.1) Out of 756.1 hectares which was trees and bushes in 1989,583.65 remained trees and bushes in 2009. At the same time planned undeveloped residential area increased from 25.1 hectares to 85.4 hectares in 1998 and gradually decreased to 5.68 hectares in 2009. This was attributed to the development of these stands into formal residential areas. Table 4.1 and Figure 4.2 present a summary of the major LULC changes that took place between 1989 and 2009.

Table 4.1: Areas (hectares) for 1989 to 2009 LULC.

	1989	1998	2004	2009
Land use/land cover type	Area (ha)	Area (ha)	Area (ha)	Area (ha)
Business	10	18.5	20	21
Cultivated land	571.5	180	66.8	11.01
Education	16.9	26.8	33.52	38.1
Hospital	0	0	2.95	2.95
Industries	219.5	312	317.6	374.26
Formal residential area	380	448	623.2	656.47
Informal residential area	26	174	210	264.97
Municipal	100.5	140	140.1	140.1
Recreation	32	180	44.1	57.08
Trees and bushes	756.1	572	627.2	583.65
Planned undeveloped residential area	25.1	85.4	69.4	5.68
Water reservoir	0	1.1	1.1	1.1

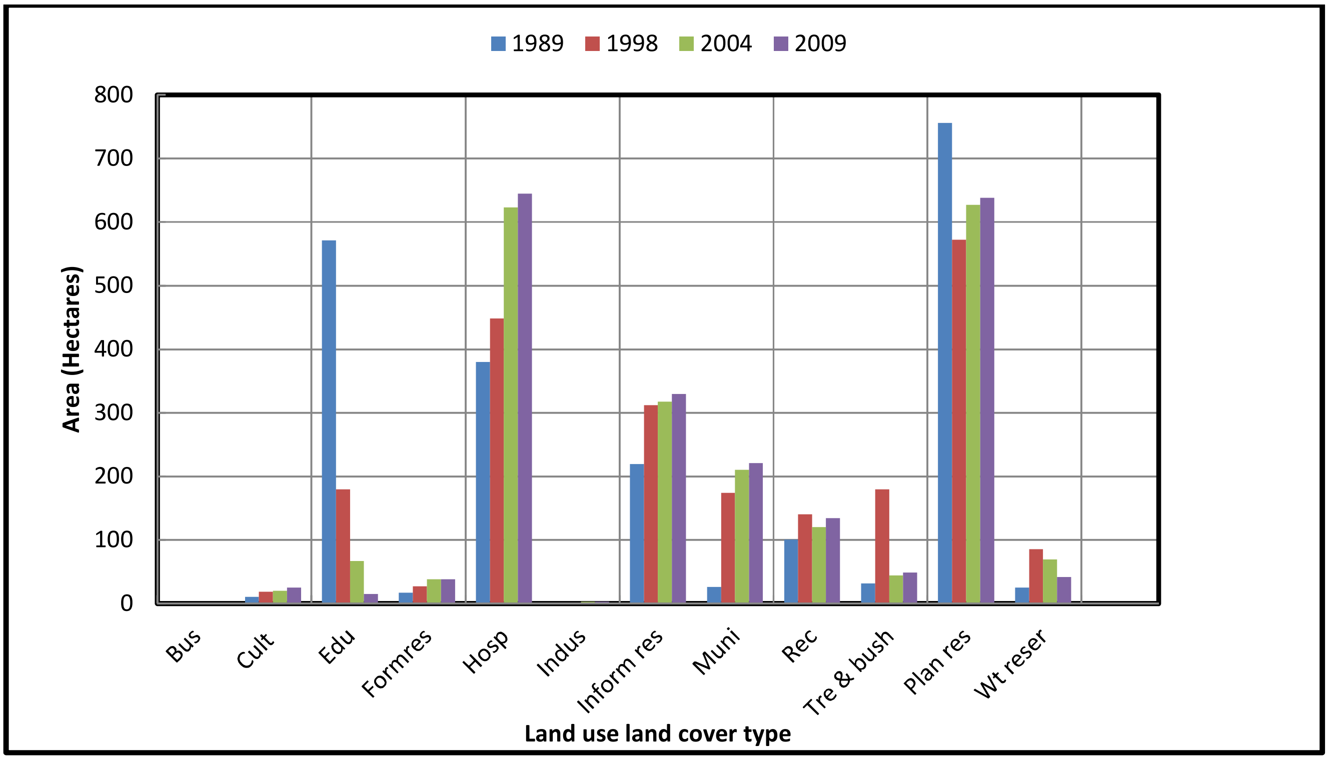

Figure 4.2: Land use/cover in hectares

(Bus-Business, Cult-Cultivated land, Formres-Formal residential area, Hosp-Hospital, Indus-Industries, Inform res-Informal residential area, Muni-Municipal land, Rec-Recreation, trees & bush-Trees & bushes, Plan res-Planned undeveloped residential area, Wtreser-Water reservoir)

4.2.2 Percentage changes between 1989 to 1998 (9 years period)

The 1998 maps (Figure 4.3) show that formal residential area increased from17.8% in 1989 to 20.96% in 1998 (3.16% increase). Cultivated land decreased from 26.7% in 1989 to 8.4% in 1998, a decrease of 18.3%. Industries increased by 4.3% over this period. Informal residential and planned undeveloped residential LULC increased by 7.2% and 2.79% respectively (Figure 4.3).

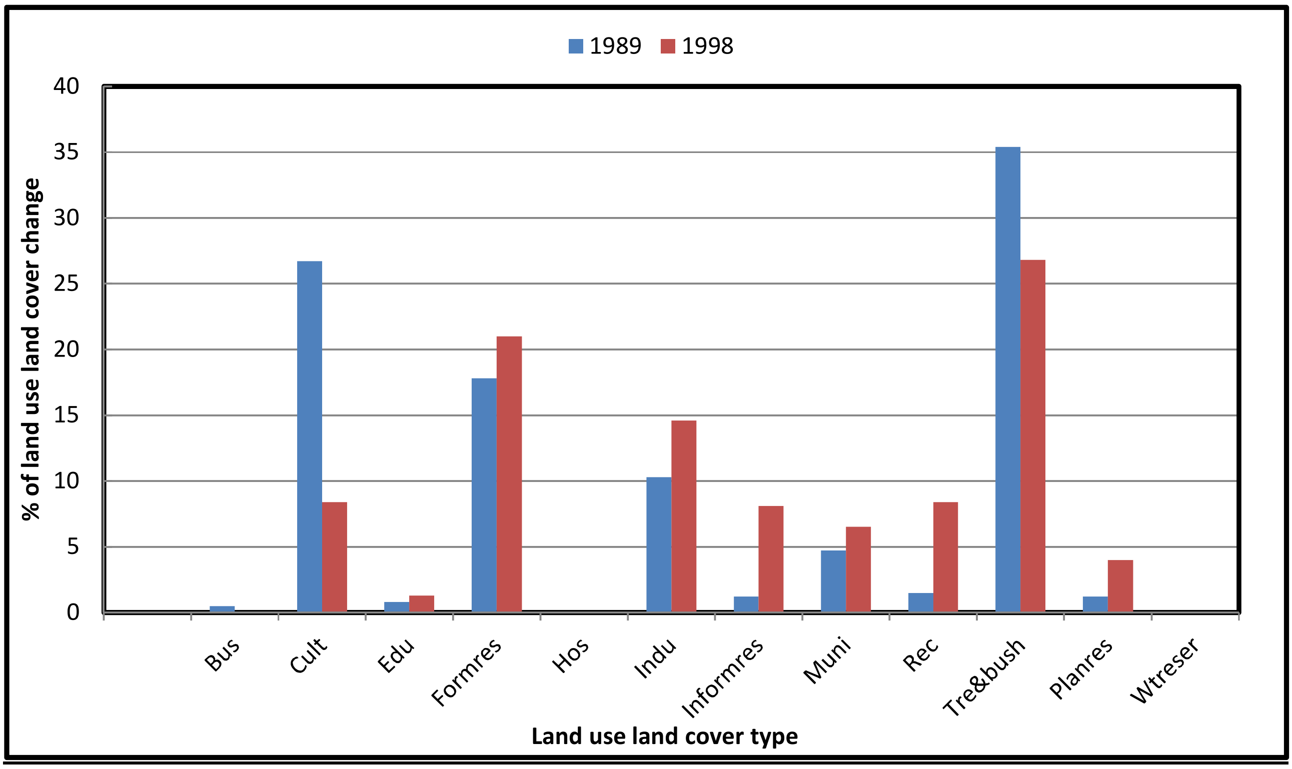

Figure 4.3: Percentage change between 1989-1998 (*Bus-Business, Cult-Cultivated land, Formres-Formal residential area, Hosp-Hospital, Indus-Industries, Inform res-Informal residential area, Muni-Municipal land, Rec-Recreation, trees & bush-Trees & bushes, Plan res-Planned undeveloped residential area, Wtreser-Water reservoir).*

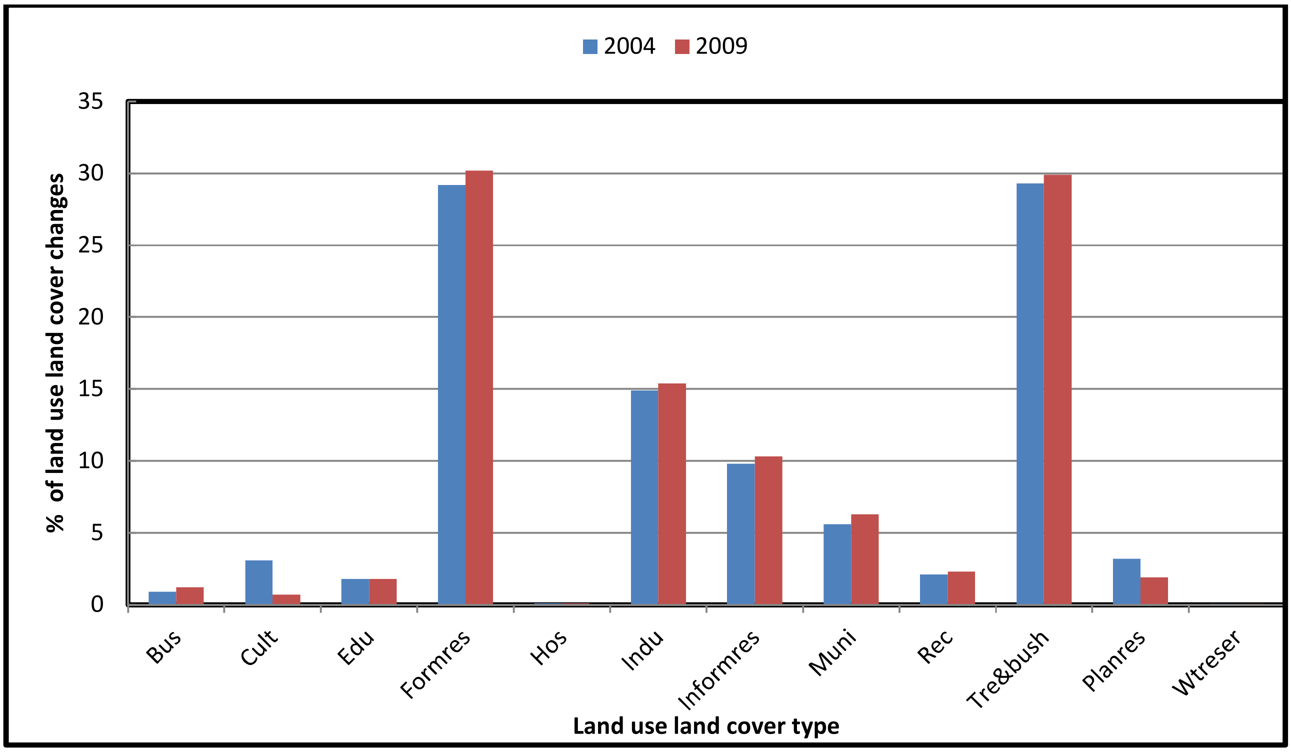

Figure 4.4: Percentage change between 2004 -2009 (*Bus-Business, Cult-Cultivated land, Formres-Formal residential area, Hosp-Hospital, Indus-Industries, Inform res-Informal residential area, Muni-Municipal land, Rec-Recreation, trees & bush-Trees & bushes, Plan res-Planned undeveloped residential area, Wtreser-Water reservoir).*

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4.3 Land use land cover changes in Copesville, Eastwood, Raisethorpe and Willowton.

4.3.1 Land use/land cover in 1989

Cultivation was the most dominant LULC in Copesville with 89.8% of the total area under cultivation in 1989. In this area, only 5% of the land was used for informal residential while 27.6% of the land was covered by trees and bushes (Appendix 1). In Eastwood, the main LULC was trees and bushes (149.3 hectare of the total area of 361.8) which translated to 41.3%. This was followed by cultivated LULC (27.5%) and formal residential (27.7%). In Raisethorpe, the major LULC was formal residential which constituted 65.5% of the total area, followed by trees and bushes which constituted about 13.6% of the total area. In Willowton the main LULC was trees and bushes which constitute about 59.2% of the total area of the suburb followed by industrial (20.6%) and municipal land (11.2%).

4.3.2 Land use changes in 1998

The results obtained from 1998 from the entire study area shows that the formal residential area increased from 0% in 1989 to 10.9%. Land under cultivation decreased by 64.5%. In Eastwood the main LULC was formal residential area (43.8%), trees and bushes (19.2), undeveloped planned residential area (13.6) and cultivated land (13.4). In Willowton trees and bushes increased by about 1.6% from 1995. (13.4). In Eastwood, planned undeveloped residential stands increased from 5.4% to 13.6%. Cultivated land also decreased from 31.6% to 13.4%. This means that most of the land used for farming was lost to residential or built up areas.

4.3.3 Land use changes in 2004

The Copesville results obtained in 2004 show that the informal residential class increased by 3.3% and the undeveloped residential class decreased by 1.1% from the previous data set (1998). In Eastwood, the formal residential class increased by 17.8% and undeveloped planned residential plots dropped by 4.8%. This means that a lot of undeveloped planned plots were developed into formal residential areas. Furthermore, formal residential class increased in Raisethorpe while undeveloped planned residential areas decreased from the previous temporal dataset by 2.5% and 2.5% respectively. Results also show that the industrial LULC class in Willowton increased by 5.8% and formal residential class increased by 2.6% between 1998 and 2004. The increase in the built-up area has many reasons. Willowton is famous industrial area; large numbers of people from rural areas are flocking to the city to look for jobs and this has led to the increase of built-up area.

4.3.4 Land use changes in 2009

There was a significant change in cultivated LULC in 2009. In Copesville, this LULC class decreased from 8% in 2004 to 1.6% in 2009. Formal and informal residential areas increased by

3.5% and 5.2% respectively (see Appendix 1). Industrial LULC in Raisethorpe and Willowton increased by 2.3% and 3.9% respectively from 2004 to 2009 (Appendix 1).

4.4 General LULC changes in the city's eastern suburbs between the temporal datasets

To further understand LULC changes in the study area, variables which showed much change were identified and compared into two time series (from 1989 to 1998 and from 1998 to 2009). The land uses for 1989 and 1998 are shown in the aforementioned Figures 4.1 and 4.2. The total areas and percentage of the total suburb area for each LULC, as well as changes in area, are given in Table 4.2 and Figure 4.5 below.

4.4.1 Changes between 1989 and 1998 (9 years period)

The area under formal residential area in 1989 was 380 hectares, this increased to 448.2 hectares in 1998. Residential area increased by17.9% from 1989 to 1998. On the other hand the informal residential and industrial land use classes also increased by 148 and 92.9 hectares respectively (Figure 4.2)

Table 4.2: Areas (hectares) and change for 1989 to 1998 LULC.

Land use/land cover type	Area 1989 (ha)	Area 1998 (ha)	Change (ha)	% change
Business	10	18.5	8.5	85
Cultivated land	571.5	179.6	-391.9	-24.4
Education	16.9	26.6	9.9	58.5
Hospital	0	0	0	0
Industry	219.5	312.3	92.8	42.3
Form Residential area	380	448.2	68.2	17.9
Informal residential area	26	174	148	569.2
Municipal	100.5	140	39.5	39.3
Recreation	32	179.6	147.6	461.2
Trees & bushes	756.1	572.2	-183.9	-24
Planned undeveloped residential area	25.1	85.4	60.3	240.2
Water reservoir	0	1.1	1.1	100

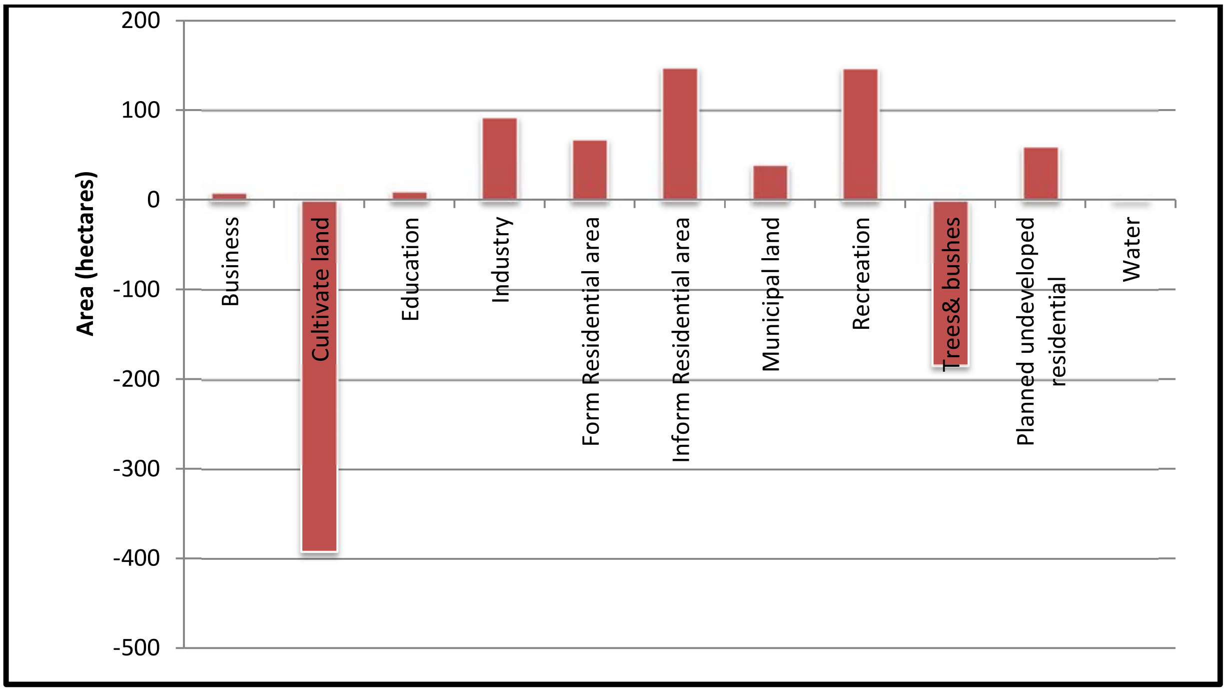

Figure 4.5: Land use land cover change between 1989 and 1998.

Whereas the figures above show LULC changes in the entire study area, the highest LULC transformation was in Copesville and Eastwood (Appendix 1) while the lowest LULC change was in Raisethorpe. In 1989 land under cultivation was 571. 6 hectares (26.7% of the total area), while in 1998 the cultivated LULC decreased to 179.6 hectares. There was a net decrease of 391.9 hectares (24.4%) of agricultural land which was converted to residential area. Significant change of LULC change was also noticed in land covered by trees and bushes. In 1989 trees and bushes covered about 756.1 hectares (35.4%) and in 1998 it decreased to 572.2 hectares (26.8%). There was net loss of 183.9 hectares (24%) in the study area. Industrial LULC class increased from 219.5 hectares (10.3%) in 1989 to 312.3 hectares (42.3%) in 1998.

Table 4.3: Areas (hectares) and change for 1998 to 2004 LULC.

Land use/land cover type	Area 1998(ha)	Area 2004 (ha)	Change (ha)	% change
Business	18.5	20	1.5	8.1
Cultivated land	180	66.8	-113.2	62.9
Education	26.8	33.52	6.72	25.1
Hospital	0	2.95	2.95	100
Industry	312.3	317.6	5.3	1.7
Formal residential area	448.2	623.2	175	39
Informal residential area	174	210	36	20.7
Municipal land	140.1	140.1	0	0
Recreation	180	44.1	-135.9	75.5
Trees & Bushes	572.2	627.2	55	9.6
Planned undeveloped residential	85.4	69.4	-16	18.7
Water reservoir	1.1	1.1	0	0

4.4.2 Percentage changes between 1998 to 2009 (11years period)

As shown in Table 4.3 and Figure 4.6, an area of 442.8 hectares was under formal residential LULC category in 1998 and 656.47 hectares in 2009. There was an increase of 43.8% over a period of eleven years. Informal residential area also increased by 52.2%. Cultivated LULC experienced a significant decrease of 168.99 hectares (Figure 4.6). Cultivated LULC decreased from 8.4% in 1998 to 0.5% in 2009, residential LULC increased by 9.7%, informal residential LULC increased by 4.3% while industrial LULC increased by 2.9% over this period (Figure 4.4).

Table 4.4: Areas (hectares) and change for 1998 to 2009 LULC.

Land use/land cover type	Area 1998 (ha)	Area 2009 (ha)	Change(ha)	% change
Business	18.5	21	2.5	13.5
Cultivated land	180	11.01	-168.99	-93.8
Education	26.8	33.52	6.72	25
Hospital	0	2.95	2.95	100
Industry	312.3	374.26	61.96	19.8
Form Residential area	448.2	644.7	196.5	43.8
Informal residential area	174	264.97	90.97	52.2
Municipal	140.1	140.1	0	0
Recreation	180	57.08	-122.92	-68.2
Trees & bushes	572.2	583.65	11.45	1.9
Planned undeveloped residential area	85.4	5.68	-79.72	-93.3
Water	1.1	1.1	0	0

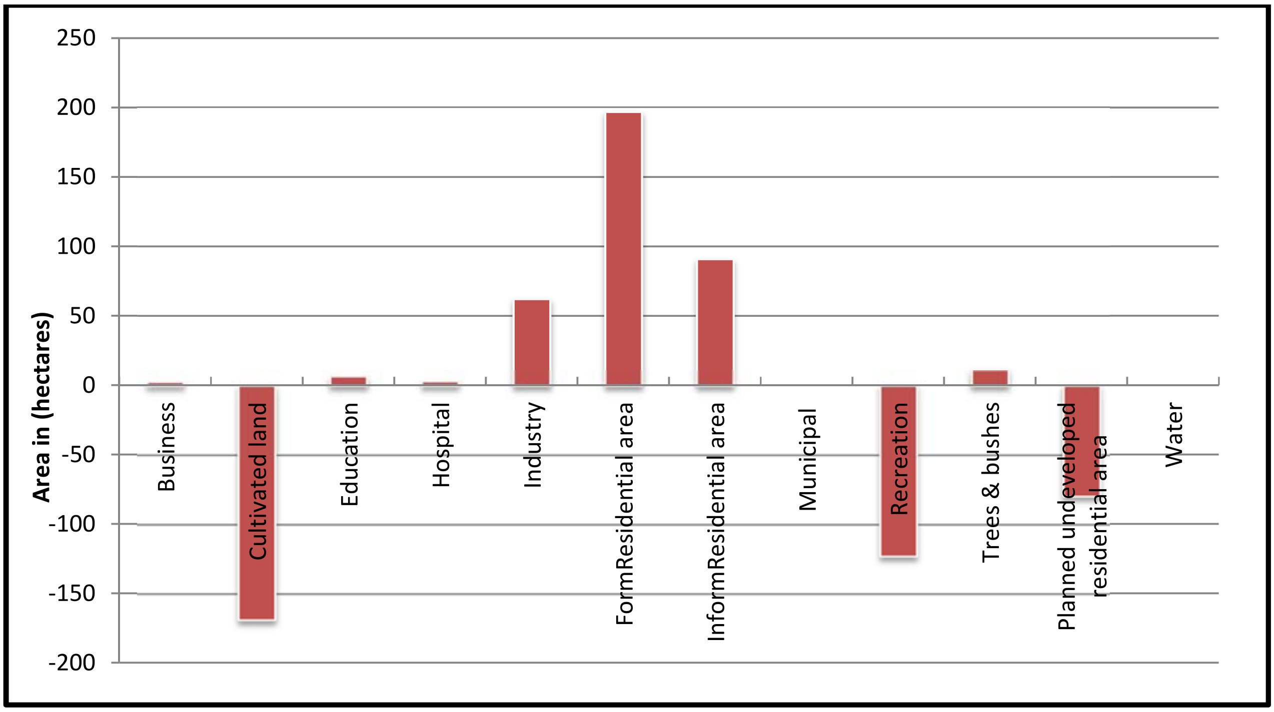

Figure 4.6: Land use land cover change between 1998 and 2009.

To analyse LULC extents in the study area, variables which showed much change were identified and compared. Formal residential, Informal settlement, Planned undeveloped residential, Industrial and cultivated areas were identified as areas with the highest transformation.

4.4.3 Percentage changes between 1989 to 2009 (20 years period)

Cultivated land, trees and bushes and planned undeveloped residential classes saw a negative growth over the study period. Over 560 hectares of land of cultivation and 162.35 hectares of land under trees and bushes were lost over the study period of 20 years (Figure 4.7 and Table 4.4) Land which was lost from the aforementioned classes was gained by other classes which experienced some increase over the study period. Formal and informal residential area classes show a net gain of over 419 hectares. Formal residential area increased by 69.7% and informal residential area increased by 919% over 20 years.

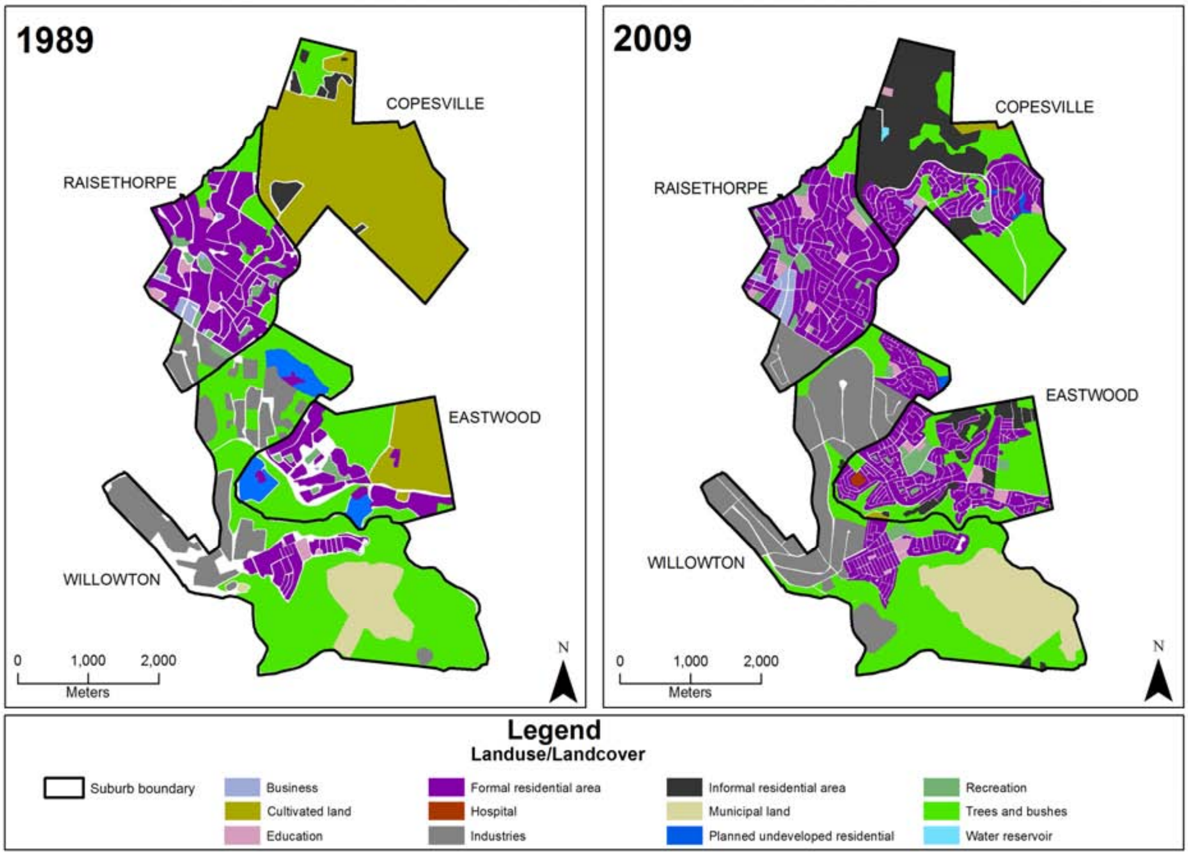

Figure 4.7 Land use land cover change map 1989 to 2009 (20 year period)

Table 4.5: Areas (hectares) and change for 1989 to 2009 LULC.

Land use/land cover type	Area 1989 (ha)	Area 2009 (ha)	Change(ha)	% change
Business	10	21	11	110
Cultivated land	571.5	11.01	-560.49	-98
Education	16.9	33.52	16.62	98.3
Hospital	0	2.95	2.95	100
Industry	219.5	374.26	154.76	70.5
Form Residential area	380	644.7	264.70	69.7
Informal residential area	26	264.97	238.97	919.1
Municipal	100.5	140.1	39.6	39.4
Recreation	32	57.08	25.08	78.4
Trees & bushes	756.1	583.65	-162.35	-21.4
Planned undeveloped residential area	25.1	5.68	-19.32	77
Water	0	1.1	1.1	100

4.5 Spatial extents of residential area per suburb over the study period

4.5.1 Land use land cover changes in Copesville 1989 to 2009

Figure 4.7 shows the spatial extents of major LULC types that had the most significant changes followed by a breakdown of suburb by suburb.

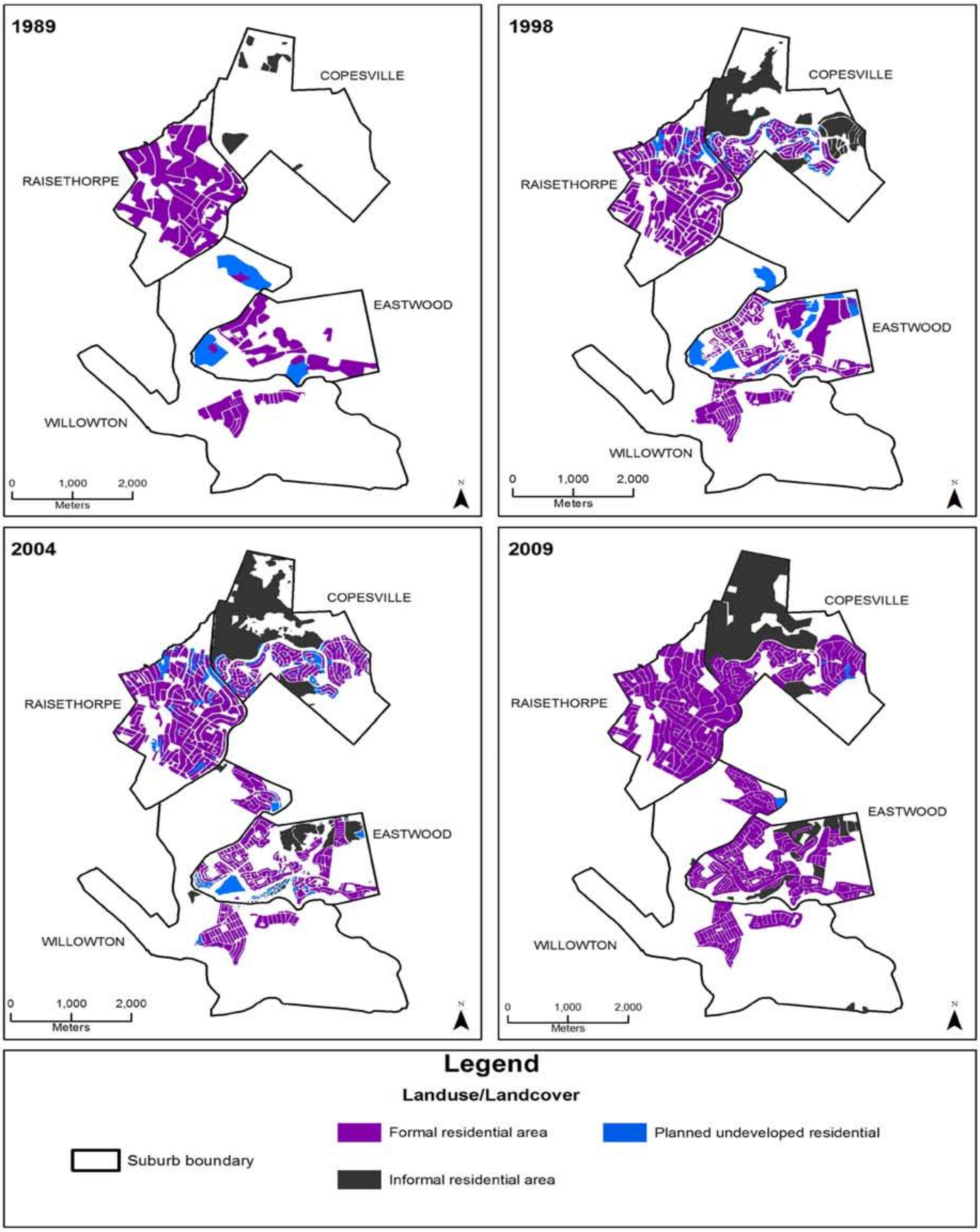

Figure 4.8: The extent of the formal, informal and planned undeveloped residential area (residential areas) between 1989 and 2009.

4.6 Discussion

Results show that a major part of the area in 1989 in Copesville suburb was under cultivation. This LULC constituted 472.1 hectares (89.8%) (Appendix 1). There was no formal residential area, school or recreational area in the area in 1989. There were few scattered homesteads, about 5% of the total area of the suburb (Appendix 1).

In 1998 to 2004 cultivated LULC decreased while residential area (formal and informal combined) increased. Planned undeveloped residential plots increased from 3.3% in 1998 to 4.1% in 2004, however there was a decrease from 2004 to 2009. The increase followed by a slight decrease of planned undeveloped residential plots can be attributed to government intervention in 1994. According to (Cronje 2009) these changes can be attributed to a number of factors; firstly, the influx of rural-urban migration and secondly, the collapse of apartheid. The increase of planned undeveloped residential plots between 1989 and 1998, and then a gradual decrease of planned undeveloped residential stands between 1998 and 2009, was due to the RDP programme adopted by the democratic government in 1994. A lot of undeveloped plots were planned under this programme to provide decent accommodation for the previously disadvantaged residents in the area.

4.6.1 Land use land cover changes in Eastwood

In Eastwood, Trees and bushes, cultivated land and Formal residential areas were the dominant LULC in 1989. Trees and bushes constituted 41.3% of the total area while cultivated area and formal residential area constituted 27.7% and 27.7% respectively. Cultivation decreased from 13.7% in 1998 to 6.7% in 2004 and land covered by trees and bushes increased. This change can be attributed to the fact that as a farm is acquired for residential development for the first time it may be left fallow (unused) before development takes place. The planned undeveloped residential areas increased from 0% in 1989 to 13.6% in 1998 and then decreases to 7.1% in 2004. This was due to government interventions in 1994. The introduction of Reconstruction Development Programme (RDP) heralded a massive increase in planned accommodation, hence this increase. The planned undeveloped residential stands gradually decreased from 13.7% in

1998 to 7.1% in 2004 to 2.4% in 2009. On the other hand formal residential class increased. As planned undeveloped residential areas decreased, formal residential area class land increased. The LULC lost to the planned undeveloped residential stand and informal residential classes were gained by the formal residential area (Appendix 1).

4.6.2 Land use land cover changes in Raisethorpe

The LULCs changes in the Raisethorpe in 1989 to 1998 were not significant. Formal residential class did not change much. There was a gradual increase with 230 hectares in 1989, 235 hectares in 1998, 236 hectares in 2004 and 259 hectares in 2009 (Appendix 1). The slight fluctuation may have been due to inconsistency of orthophotos maps used to make the thematic maps.

In general, Raisethorpe did not experience significant changes over the study period; this suburb does not border farming areas. Furthermore, this observation can be attributed to the nature and status of the suburb. The suburb is more affluent than the other suburbs under study. It is a common fact that suburbs of a low income experience a larger influx of rural-urban migration than the high income areas. Poor rural-urban migrant people often first settle in low income residential areas before moving into high income areas (Harvey, 1996; Pacione 2005).

4.6.3 Land use land cover changes in Willowton suburb

The dominant LULC in Willowton was industrial. The multi-temporal analysis shows that the industrial LULC steadily increased over the study period (Appendix 1). The highest increase occurred between 1989 and 1998 (6%). The decrease noticed between 2004 and 2009 was attributed to inconsistency in digitisation by the researcher. It can therefore be concluded that many industries increased between 1989 and 1998 while the 1998 and 2009 period saw minimal growth. This can be attributed to the opening of new industrial areas within the city such as Mkondeni at around the same time.

4.7 Possible causes of urban growth in the study area

4.7.1 Economic theory

The expansion of the study area over the years was a result of a number of factors. Pietermaritzburg city, which falls under Msunduzi municipality, is surrounded by six municipalities. These municipalities play a critical role in "importing" goods, services and human capital to the city. As a result the city is bound to expand both in space and services. Based on spatial trends already discussed, it can be concluded that the city has expanded due to economic factors which further attracts people into the area of study. The transformation of LULC in the study area can be explained by the economic base theory. The theory hypothesises that the size of an urban area depends on the amount of goods and services that is supplied to "outsiders". The income derived from "out-supply" generate purchasing power which sustains internal demand. The increased internal demand driven by higher purchasing power will increase population inflow to the urban centre (Harvey, 1996).

This might be true as more and more people migrate to urban areas, in this case into Pietermaritzburg, more goods and services will be consumed and the income generated from these activities are used to expand the business in the study area and attracts more people.

4.7.2 Laws, politics and the past history

The pass law during the apartheid regime made it illegal for black people to live in white areas. Black people were not allowed to rent formal houses and were restricted to informal dwellings. When these restrictions and other racial restrictions were repealed in 1994, as in the case of many other urban settlements in South Africa, there was unprecedented rural urban migration (Cronje, 2009). The shifting of provincial capital status from Ulundi to Pietermaritzburg in 2004 triggered the city's urban expansion. This had a spiral demand on residential and associated services. It can be concluded that there was an influx of people who wanted to exploit opportunities offered by the city's new status.

4.8 Summary

In this chapter, results from the four suburbs have been identified and discussed. The chapter further provided a detailed explanation of the results obtained from tables and change maps for a change pattern analysis. Possible reasons for LULC changes have also been highlighted.

Chapter 5

Conclusion

The main objective of this research was to establish spatio-temporal change patterns that took place in the study area using GIS and aerial photograph maps. It went on to investigate the capability of GIS in effectively and accurately analysing LULC and, LULC trends using maps generated from aerial photograph. It was assumed from the outset that the spatial approach using aerial photographs and GIS would provide better insight and understanding of the LULC dynamics in the eastern suburbs of Pietermaritzburg.

Research questions that met the main objective are:

-How has land use land cover changed between 1989, 1998, 2004 and 2009 of the selected area?

-What are the present land use types of the study area?

-What was the previous land uses land covers?

These questions under the set objectives were achieved by a multi-temporal LULC change analysis using a series of aerial photographs of Pietermaritzburg of 1989, 1998, 2004 and 2009.

The processes to achieve the objectives followed a multi-temporal change detection process outlined. These processes were to;

1. Create maps that show how the study area has been growing over the years
2. Use aerial photographs to map and analyse the extent of spatio-temporal of the study area from 1989 to 2009.
3. Explain the changes in LULC patterns within the study area.
4. Produce maps of the study area which indicates different temporal periods (1989, 1998, 2004 and 2009).

The information generated in this project can assist in answering the following questions: why is LULC in its current state? Has it changed and why? How do these changes occur and what factors contributed to these changes? Furthermore the information generated has potential for use by the municipality for spatial planning and mitigation of urban sprawl. The following conclusions can be drawn from this study. During the study period (1989 to 2009), there was a significant LULC change, particularly in Copesville,Eastwood and Willowton suburbs. The land which was mainly used for agriculture in 1989 in Copesville suburb changed into residential in subsequent years. Cultivated land decreased while formal residential and informal residential LULC increased. Undeveloped planned areas increased from 1989 to 1998 but decreased from 2004 and 2009. Industrial areas increased by 4.4% in 1989 to 1998 and 1.7% from 1998 to 2009. Informal residential areas increased in 1989, 1998, 2004 and 2009.

The significant increase in residential area (formal and informal) can be attributed to the influx of rural-urban migration from the surrounding areas. Understanding the changes in the use and cover of land resources is critical for land management and planning. This study validates aerial photographs and GIS techniques as effective tools for mapping heterogeneous and dynamic urban landscapes. Such a process is valuable for assessing, monitoring and planning urban physical, social and natural resources.

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APPENDIX 1: Area and percentage of each land use class in the eastern suburb over the time series.

	1989							
LULC	**Copesville**		**Eastwood**		**Raisethorpe**		**Willowton**	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
Business	0	0	0.2	0.1	9.1	2.6	0.7	0.1
Cultivated land	472.1	89.92381	99.4	27.5	0	0.0	0	0.0
Education	0	0	3.4	0.9	8.5	2.4	5	0.6
Formal residential area	0	0	100.2	27.7	230.8	65.5	49	5.5
Industries	0	0	0	0.0	34.6	9.8	184.8	20.6
Informal residential area	26	4.952381	0	0.0	0	0.0	0	0.0
Municipal land	0	0	0	0.0	0	0.0	100.5	11.2
Recreation	0	0	9.3	2.6	21.8	6.2	1	0.1
Trees and bushes	27.6	5.257143	149.3	41.3	47.8	13.5	531.4	59.2
Undeveloped Planned residential stands	0	0	0	0.0	0	0.0	25.1	2.8
Water reservior	0	0	0	0.0	0	0.0	0	0.0
Total	**525.8**	100	**361.8**	100.0	**352.6**	**100**	**897.4**	100.0

	1998							
	Copesville		**Eastwood**		**Raisethorpe**		**Willowton**	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
Business	0	0	0	0.0	8.1	2.6	34.8	3.9
Cultivated land	125	25.5	39.4	13.4	0	0.0	7	0.8
Education	7.3	1.5	12.9	4.4	14.8	4.7	3.5	0.4
Formal residential area	53.6	10.9	128.9	43.8	235	74.5	56.3	6.4
Industries	0	0.0	0	0.0	37.1	11.8	238.5	27.0
Informal residential area	164	33.4	0	0.0	0	0.0	0	0.0
Municipal land	0	0.0	0	0.0	0	0.0	140	15.8
Recreation	0	0.0	16.9	5.7	16.3	5.2	0	0.0
Trees and bushes	158.3	32.3	56.4	19.2	21.2	6.7	393.2	44.5
Undeveloped Planned residential stands	16.1	3.3	40	13.6	14.6	4.6	10.8	1.2
Water reservoir	1.2	0.2	0	0	0	0.0	0	0.0
Total	**525.5**	107.1356	**294.5**	100	**315.4**	100.0	**884**	100.0

	2004							
	Copesville		**Eastwood**		**Raisethorpe**		**Willowton**	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
Business	0	0	0	0.0	17.2	5.1714	2.7	0.3
Cultivated land	42	8.0	20	6.7	0	0	4.8	0.6
Education	4.7	1.0	12.7	4.2	11	3.3073	9.7	1.1
Formal residential area	100.4	20.7	100.8	33.7	236	70.956	76.7	8.9
Industries	0	0.0	0	0.0	36.5	10.974	281	32.8
Informal residential area	180	34.5	37.7	12.6	0	0	3.6	0.4
Municipal land	0	0.0	0	0.0	0	0	140.1	16.3
Recreation	3.7	0.8	12.8	4.3	23.6	7.0956	3.9	0.5
Trees and bushes	170	32.6	93.7	31.3	22.4	6.7348	350.3	40.9
Undeveloped Planned residential stands	20.1	4.1	21.3	7.1	23.7	7.1257	4.3	0.5
Water reservoir	1.2	0.2	0	0	0	0	0	0
Total	**522.1**	**100**	**299**	**100.0**	**332.6**	**100**	**857**	**100**

	2009							
	Copesville		**Eastwood**		**Raisethorpe**		**Willowton**	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
Business	2.2	0.4	0.0	0.0	15.8	4.3072	0.0	0.0
Cultivated land	8.4	1.6	2.6	0.7	0.0	0	0.0	0.0
Education	6.2	1.2	9.4	2.6	17.0	4.6582	8.0	0.9
Formal residential area	125.2	24.0	171.2	47.5	259.0	70.815	101.0	11.4
Hospital	0.0	0.0	2.9	0.8	0.0	0	0.0	0.0
Industries	0.0	0.0	0.0	0.0	48.5	13.254	325.8	36.7
Informal residential area	218.4	41.8	42.9	11.9	0.0	0	3.7	0.4
Municipal land	0.0	0.0	0.0	0.0	0.0	0	140.0	15.8
Recreation	5.6	1.1	19.4	5.4		0	6.6	0.7
Trees and bushes	152.0	29.1	115.3	32.0	25.5	6.9653	298.9	33.7
Planned undeveloped residential	3.2	0.6	0.0	0.0	0.0	0	2.4	0.3
Water reservoir	1.5	0.3	0.0	0.0	0.0	0	1.5	0.2
Total	**522.784**	**100.00**	**363.659**	100.8	**365.74**		**887.9**	**100.0**