

**An Assessment of Land Cover Changes Using GIS and  
Remote Sensing:  
A Case Study of the uMhlathuze Municipality,  
KwaZulu-Natal, South Africa**

by

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## ABSTRACT

Rapid growth of cities is a global phenomenon exerting much pressure on land resources and causing associated environmental and social problems. Sustainability of land resources has become a central issue since the Earth Summit in Rio de Janeiro in 1992. A better understanding of the processes and patterns of land cover change will aid urban planners and decision makers in guiding more environmentally conscious development. The objective of this study was firstly, to determine the location and extent of land use and land cover changes in the uMhlathuze municipality, KwaZulu-Natal, South Africa between 1992 and 2002, and secondly, to predict the likely expansion of urban areas for the year 2012. The uMhlathuze municipality has experienced rapid urban growth since 1976 when the South African Ports and Railways Administration built a deep water harbour at Richards Bay, a town within the municipality. Three Landsat satellite images were obtained for the years, 1992, 1997 and 2002. These images were classified into six classes representing the dominant land covers in the area. A post classification change detection technique was used to determine the extent and location of the changes taking place during the study period. Following this, a GIS-based land cover change suitability model, GEOMOD2, was used to determine the likely distribution of urban land cover in the year 2012. The model was validated using the 2002 image. Sugarcane was found to expand by 129% between 1992 and 1997. Urban land covers increased by an average of 24%, while forestry and woodlands decreased by 29% between 1992 and 1997. Variation in rainfall on the study years and diversity in sugarcane growth states had an impact on the classification accuracy. Overall accuracy in the study was 74% and the techniques gave a good indication of the location and extent of changes taking place in the study site, and show much promise in becoming a useful tool for regional planners and policy makers.

## PREFACE

The experimental work described in this dissertation was carried out in the Centre for Environment, Agriculture and Development, School of Environmental Science, University of KwaZulu-Natal, Pietermaritzburg Campus, from August 2004 to June 2005 under the supervision of Dr Trevor Hill and Dr Fethi Ahmed.

These studies represent the original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others it is duly acknowledged in the text.

This dissertation is divided into Component A and Component B. Component A contains an introduction, a summary of the study site, a literature review and a description of the methods used. Component B is written in the format of a journal paper prepared for the journal; Remote sensing of Environment. As specified by the Journal, the majority of the figures are presented in black and white.



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## LIST OF ABBREVIATIONS

UNPD	– United Nations Population Division
GIS	– Geographical Information Systems
SLEUTH	– Slope, Land cover, Exclusion, Urbanisation, Transport and Hillshade
LUCC Models	– Land Use and Land Cover Change Models
USGS	– United states Geological Survey
IDP	– Integrated Development Planning
MOSS	– Metropolitan Open Space System
SDI	– Spatial Development
GEAR	– Growth Employment and Redistribution
SMEs	– Small and Medium Enterprises
CTC	– Central Timber Corporation
UNPD	– United Nations Population Division
NASA	– National Aeronautics and Space Administration
ETM+	– Enhanced Thematic Mapper Plus
CRP	– Conservation Reserve Program
SGDT	– Small Grower Development Trust
CVA	– Change Vector Analysis
PCA	– Principal Component Analysis
GS	– Gramm-Schmidt
EM	– Expectation-Maximisation
ITLUP	– Integrated Transportation and Land-Use Package
CA	– Cellular Automata
CLUE	– Changing Land Use and Estuaries Model
ANN	– Artificial Neural Networks
LEAM	– Landuse Evolution and Impact Assessment Model
SME	– Spatial Modelling Environment
$K_{no}$	– Kappa for no information
$K_{location}$	– Kappa for location
$K_{quality}$	– Kappa for quality
$K_{standard}$	– standard Kappa
VPIL	– Value of Perfect Information of Location
VPIQ	– Value of Perfect Information of Quantity
MAS/LUCC	– Multi-Agent System Model of Land-Use/Cover Change
UGM	– Urban Growth Model
CURBA	– California Urban and Biodiversity Analysis
SDSS	– Spatial Decision Support System
TM	– Thematic Mapper
SPOT	– Systeme Probatoire d’Observation de la Terre
NOAA	– National Oceanic and Atmospheric Administration
AVHRR	– Advanced Very High Resolution Radiometer
MODIS	– Moderate Resolution Imaging Spectroradiometer
GPS	– Global Positioning System
MCE	– Multi-Criteria Evaluation

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# CHAPTER 1. INTRODUCTION

## 1.1. Introduction

*“To understand how urban ecosystems work and to achieve ecological sustainability in urban areas, we must be able to quantify and project land use and land cover change and its ecological consequences” (Wu et al., 2003).*

Rapid growth of cities is a global phenomenon, particularly pertinent to the Third World (United Nations Population Division, 2002). This growth exerts much pressure on the land and resources surrounding a city and has associated environmental and social problems. Development needs to take place in a manner sensitive to such impacts. Thus to plan and manage development appropriately and suitably, one needs to understand the process of urban growth and the impacts of land use and land cover changes.

Changes in land uses and land covers take place in response to human needs and wants and are a consequence of a range of factors stemming from many different disciplines, interlinking to provide the existing patterns. Such factors need to be understood in order to determine the impacts of such changes (Verburg *et al.*, 1999). The impacts are usually significant in economic, social and environmental terms and consequently have significant implications for a range of policy issues including the management of urban areas, protection of wildlife habitats and mitigation of global climate change (Lubowski *et al.*, 2003). Policy is frequently formulated in response to changes as a way of reducing or regulating the negative impacts of changes and as such policy makers need to be kept well informed of the changes taking place.

Governments have an obligation to create, update and implement laws and policies regarding current and future uses of land. Such decisions need to be based on a sound knowledge of the current and past land use patterns as these will demonstrate the trajectory of change over time and allow one to estimate the most likely future trends with improved confidence. Readily

available data of land use and land cover changes would allow planners to implement appropriate strategies.

Various models and techniques have been created to provide information on such changes. Verburg *et al.* (in press) describe Land Use and Land Cover Change (LUCC) models as tools designed to support the analysis of the causes and consequences of land use dynamics in order to improve our understanding of the processes of the land use system and to aid land use planning and policy. Models have proved to be a successful way of understanding complex interactions between the socio-economic and biophysical forces that impact the rate and spatial arrangement of land use and land cover change and for calculating the impacts of land use and land cover change (Muller & Middleton 1994; Brown *et al.*, 2000; Wu & Webster 2000; Weng 2002; Barredo *et al.*, 2004; Leao *et al.*, 2004; Verburg *et al.*, 1999, in press).

The capability and accuracy of models is constantly increasing as they are developed and modified. With growing application, LUCC models are becoming a valuable tool providing planners and policy makers with important information to make better informed decisions.

## **1.2. The Importance of Land**

Land is the basic natural resource from which humans draw most of their sustenance, fuel and shelter (Mather, 1989). In addition, it provides a biophysical resource base for the production of biological products such as food and fodder, and raw materials for people, livestock and industry (Bonte-Friedmeim & Kassam, 1994). It is also a source of biodiversity, minerals, fossils, renewable energy and other natural resources that contribute to the wealth of human life.

Human population growth has, and is continuing to place enormous pressure on this resource. As populations grow, so too does the living space required and more importantly, the agricultural land required to produce enough food, and other space required to produce consumable products required by the population. It is thus imperative to acknowledge the importance of policy to promote more sustainable land use strategies (Deal, 2001).

Land is a vital resource in terms of regulating the climate and natural environment. Changes in land use and land cover affect the climate, the hydrological cycle, nutrient cycling and many other important services provided by the land (Bonte-Friedmein & Kassam, 1994). Without regulation on access and use of land such system will inevitably break down having serious consequences for all living beings.

### **1.3.Land Uses and Land Covers**

Knowledge of land uses is fundamental for socio-economic planning such as the placement of new schools and services, and for the allocation of appropriate income tax rates (Verburg *et al.*, 2004). Land cover knowledge is important for such studies as rainfall runoff characteristics, soil loss, habitat distribution and agricultural planning (Campbell, 1983). Similarly, changes in land use and land cover have large impacts on large scale ecological and environmental systems and must be incorporated into policy to address problems such as urbanisation, global climate change, desertification and resource management (Wu *et al.*, 2003). Furthermore, Lillesand & Kiefer (1994) consider a good understanding of land use and land cover to be vital for modelling the earth as a system.

Land cover describes the types of features present on the surface of the earth (Lillesand & Kiefer, 1994) or as Kivel (1991) describes it, the nature of the elements of the landscape. The land cover, in effect, represents either the vegetative cover of the land whether it is natural or human generated, or the visible evidence of the land use (Campbell, 1983). It has no emphasis on the economic function of the area. Land use has been defined as “the use of land by humans, usually with emphasis on the functional role of land in economic activities” (Campbell, 1983: 8). Due to the wide range of objectives of land use studies, no single definition is best in all contexts. The land use of an area is not necessarily represented by the visible cover of the land but is usually associated with some sort of visible cover or artefacts present that are representative of a particular land use. Land use has often been subdivided into urban and rural classes for the sake of clarity.

The definition of the term 'urban' is another subject that has undergone much discussion and is important to this research. Some of the more common methods of defining the term include; the imposition of a population size threshold, consideration of continuous built-up areas covered by buildings and urban structures and the spatial distribution of city functions (Campbell, 1983). Others have used a residual urban definition from agricultural surveys or have attempted to define the rural urban boundary through statistical techniques (Kivel, 1991).

A further aspect of land that requires mention is that it varies greatly in quality and suitability for different purposes. Thus, the characteristics of land can provide valuable information regarding land uses and changes in land uses (Coppock, 1991). Aspects such as relief, 1 in 50 year flood lines, soil conditions and proximity to favourable/unfavourable areas can all limit the range of land uses available to a particular site. There are several land use and land cover classification systems used today such as that developed by the United States Geological Survey (USGS) (Anderson 1976), the National Land Use Classification (NLUC) used in Britain and the Standard Land-Cover Classification Scheme used in South Africa (Thompson, 1996).

Many of the authors use the terms 'land cover' and 'land use' interchangeably or use the term 'land use and land cover', similarly, and many papers dealing with models of land use and/or land cover change refer to the models as 'Land Use and Land Cover Change (LUCC) models'. For the purpose of this study both 'land cover' and 'land use' will be included. However, since the principal data used in this study was satellite imagery, which depicts only the 'land cover', the term 'land cover' will be used in the methods section.

#### **1.4. Aims and Objectives**

The aim of the research was to assess the land cover changes in the uMhlathuze Municipality from the year 1992 to the year 2002 and to predict the extent of built-up areas in 2012. This area has undergone rapid change since the late 1970s mainly driven by industrial development.

The objectives were as follows:

- To determine the dominant land cover changes that took place in the uMhlathuze Municipality.
- To evaluate the extent and location of the different land cover changes that took place in the uMhlathuze Municipality.
- To evaluate the rate of the different land cover changes that took place in the uMhlathuze Municipality.
- To determine the significant environmental impacts of the land cover changes.
- To predict future urban expansion in the uMhlathuze Municipality in the year 2012 with the use of a GIS-based land cover change model; GEOMOD2.

### **1.5. Summary**

Chapter one has introduced the relevance of the study and the importance of such work to planning and policy. In it, I have expressed the importance of land as a valuable resource, presented the various definitions and relevance aspects of the terms land use and land cover, and provided the aims and objectives of this study.

Chapter two introduces the study site, providing the relevant information through a summary of the natural / biophysical environment, a brief account of the planning history underpinning the current trajectory of development, and an account of the current and historical development strategies and government policies that have or have had a bearing on the development and growth of the Municipality.

Chapter three provides a review of the wide range of literature pertinent to the study and includes the environmental and ecological factors taken into consideration in land use and land cover changes, the roles that Geographical Information Systems (GIS) and Remote Sensing can play, a summary of the underlying factors influencing the changes in land cover and land use, the processes and methods used in land use and land cover change detection, and the development of processes of LUCC and urban growth modelling.

Chapter four gives an account of the methods and data used in the study. It includes the preprocessing of the data, the classification process, the change detection process and the land cover change modelling process.



## CHAPTER 2. STUDY SITE

### 2.1. The uMhlathuze Municipality

The uMhlathuze municipality is situated on the north coast of KwaZulu-Natal, South Africa between latitudes 28°37'S and 28°57'S, and longitudes 31°42'E and 32°09'E (Figure 2-1). It comprises the towns and settlements; Richards Bay, Empangeni, Esikhawini, Ngwelezane, Nseleni, and Felixton as well as 5 Tribal Authorities, 21 rural settlements and 61 farms (Anon, no date).

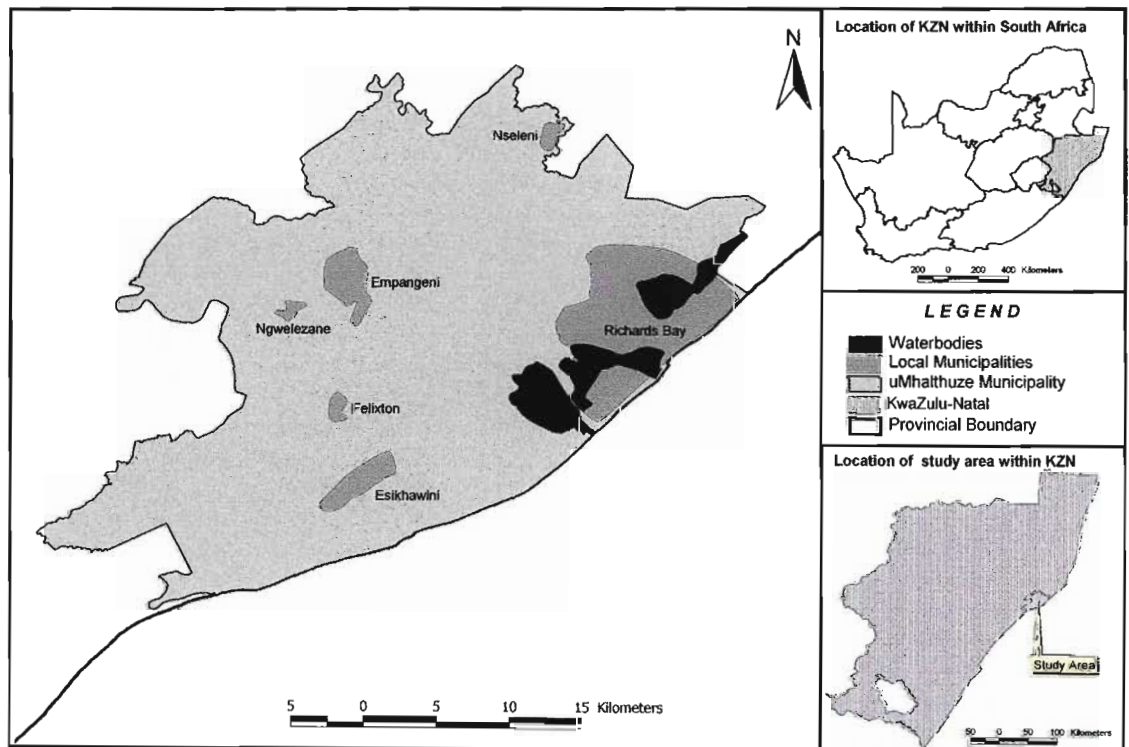


Figure 2-1 Location of urban areas, settlements and lakes within the uMhlathuze municipality.

The uMhlathuze municipality covers an area of 796 km<sup>2</sup>, with a population of 296 339 and an average of 372 people per km<sup>2</sup>. An estimated 169 008 of these people are resident in urban

areas and 41% are between the ages of 15 and 34 years. The total unemployment rate in the area is 41%, although this figure only relates to the formal sector. (Anon, no date).

## **2.2. The Natural Environment**

The uMhlathuze municipality experiences a sub-tropical climate, with humid summers and hot winters. The mean summer temperature is 30°C and during winter the temperatures rarely fall below 11°C (uMhlathuze Municipality, 2002). Winds blow from either a north-easterly or a south-westerly direction for approximately 28% and 20% of the time respectively. The average annual rainfall in the area is 1 200 mm with falls predominantly between January and May, and decreases from the coast inland. The climate is very favourable for sugarcane production, which comprises the majority of the cultivated lands.

The uMhlathuze Municipality falls within the Savanna biome (Rutherford & Westfall, 1994) and comprises three vegetation types; Sand Forest, Valley Thicket and Coastal Bushveld-Grassland (Low & Rebelo, 1998). The most extensive of these is the Coastal Bushveld-Grassland, which makes up 92% of the municipality with 72 967ha. This vegetation type covers 11 881 km<sup>2</sup> within South Africa and has a total of 14% conserved. The biophysical conditions of this vegetation type are considered good for sugarcane and exotic timber plantations (Low & Rebelo, 1998). Valley thicket comprises approximately 5% of the municipality with 3 668ha. This vegetation type covers 22 616 km<sup>2</sup> within South Africa and is only 2% conserved (Low & Rebelo, 1998). Sand forest makes up just 1% of the municipality with 726ha. This vegetation type has been relatively well conserved (45% of a total 354 km<sup>2</sup>) (Low & Rebelo, 1998).

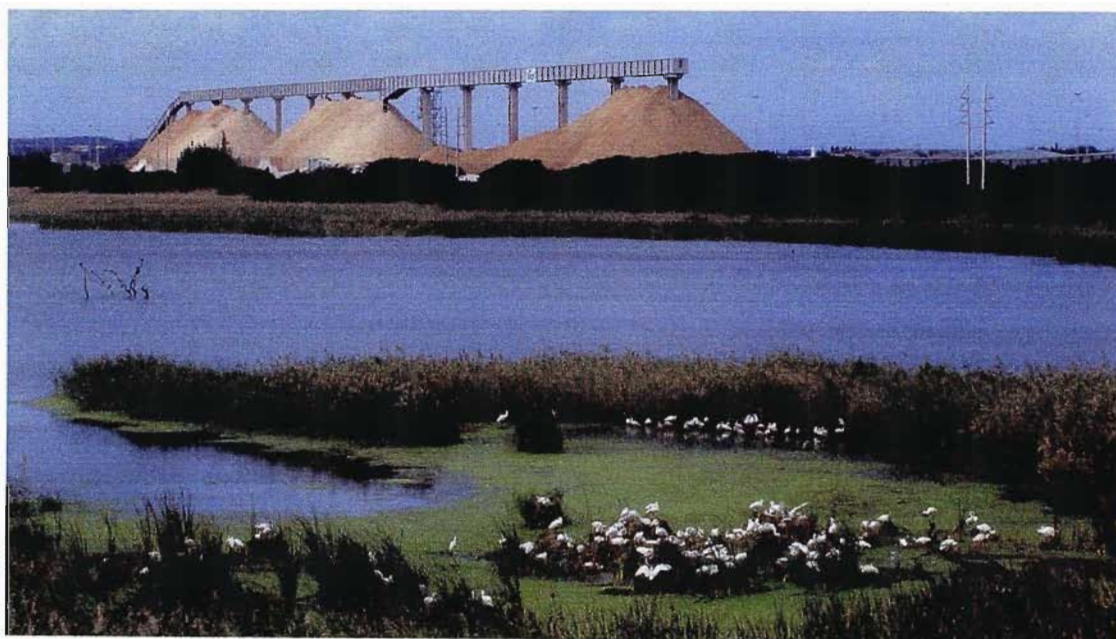
The uMhlathuze municipality is recognised as having high conservation significance in terms of biodiversity (uMhlathuze Municipality, 2002). It is situated at the southern end of the East African Coastal Plain (a major biogeographical region) (Bruton & Cooper, 1980) and is within the Maputaland Centre of Endemism (van Wyk & Smith, 2001). It contains a rich diversity of species of local and proximate biogeographical origin. The dune ridge running down the coast is considered a particularly important corridor for genetic exchange between certain species

from different biogeographical units. This is the only real remaining passageway as the majority of inland vegetation has been converted to sugar cane (uMhlathuze Municipality, 2002).

The uMhlathuze municipality contains the following numbers of faunal species (uMhlathuze Municipality, 2002):

- 36 species of fish, including certain red data species;
- 36 species and subspecies of amphibians, including two red data species;
- 59 species of reptiles including four red data species;
- 350 species of birds, including 23 red data species; and
- 69 species of mammals, including 12 red data species

Before human intervention, the area contained the second largest wetland system in KwaZulu-Natal after the Greater St Lucia Wetland Complex. This system has been significantly reduced over time but remains an extensive and important wetland stretching between the large industries as shown in Figure 2-2. It is made up of many interlinking lakes and wetlands which grade from a freshwater to a marine environment. The most important of these are the harbour, the sanctuary and Lake Mzingazi (uMhlathuze Municipality, 2002).



**Figure 2-2 Wetland area with large Industries in the background.**

These wetlands perform many fundamental ecological functions including; water purification, water release during dry periods and animal breeding grounds (uMhlathuze Municipality, 2002). They also form the habitat of many species of aquatic avifauna, zooplankton, ichthyofauna, macrocrustacea, benthic and other aquatic invertebrates (Cyrus, 2001).

Richards Bay is the largest town in the uMhlathuze Municipality and contains a substantial industrial sector. This industrial sector has a widely dispersed arrangement with many of the large extractive industries sparsely distributed within extensive areas of natural vegetation. Although much of the area is zoned as industrial, large tracts are still covered by modified natural vegetation as illustrated in Figure 2-3. These areas allow for many of the natural ecosystem processes to continue to function.



**Figure 2-3 Grassland area situated between large industrial areas in Richards Bay**

The town of Richards Bay has a formal Metropolitan Open Space System (MOSS) that incorporates public open spaces, formal play lots, sports and recreation facilities, community centres, wide landscaped public streets with pedestrian walkways, and unspoilt natural areas (uMhlathuze IDP, 2002). There are ten broad planning principles on which the MOSS is based. They are; the systems hierarchical diversity, linkages, visibility and accessibility, natural features and ecologically sensitive areas, landscaping, elimination of vacant/waste land and the integration of streets and open spaces. These principles aid in the successful implementation of the system (uMhlathuze Municipality, 2002).

### **2.3. History of the uMhlathuze Municipality**

The first substantial human settlement in the area was in 1906 when Zululand Fisheries was established at Richards Bay. Shortly after this in 1907, the first wagon track to the area was built from Empangeni, allowing Empangeni to develop into a small village.

Empangeni grew slowly becoming an agricultural centre serving the farmers in the area, while Richards Bay remained a small fishing village until the late 1960s when the South African Railways and Harbours Administration decided it was time to build a new harbour on the eastern coast that could accommodate large vessels. This development was part of an overall National Development Plan and the harbour was to be linked to the main inland development areas with a railway (Department of Planning, 1972). It was acknowledged at the time that this development would lead to the growth of a large urban area containing industrial, commercial and residential components.

A Richards Bay town board was established in 1971 to cover an area of 310 km<sup>2</sup>. The Board had freedom to plan the new city around certain fixed features such as the harbour, aluminium smelter, electricity substation, petro-chemical complex, railway marshalling yard and railway lines whose locations were previously determined. The natural beauty of the area, recreational potential of the bay and freshwater lakes were considered important assets and thus incorporated as valuable resources in the planning (Department of Planning, 1972). The town quickly grew into the largest and most important urban area in the uMhlathuze Municipality.

A large number of parties participated in the overall planning of development in the area including authorities responsible for the future of the harbour, the railways, national roads and electric power supply, as well as engineering services such as the road network, water supply, storm water canals and drains, and sewerage and industrial pipelines (Department of Planning, 1972). This wide range of actors often meant conflicting desires and frequent adjustments to plans.

Under the Apartheid regime the town of Richards Bay and the surrounding land was situated in an area designated as a White population area and the land to the north and south was designated as Homelands. The close proximity to Homelands influenced the citing of the harbour, as there was at the time an industrial decentralisation policy that emphasised development of industrial areas on the borders of Homelands. Also, particular attention in the planning of the town was paid to large numbers of daily commuters coming into the industrial areas from the surrounding Homelands (Department of Planning, 1972).

Since the inception of the harbour at Richards Bay, a national planning policy has stimulated rapid industrial development in the area in support of the harbour and associated infrastructure (uMhlathuze Municipality, 2002), and subsequently many large extractive industries have been established owing to this infrastructure.

#### **2.4. Development Strategies and Government Policies**

Richards Bay is based on an industrial foundation with large extractive industries supporting an affluent society in the formal sector. On the other hand, it also contains a very large element of what Hall (2004) describes as a *city coping with informal hypergrowth*. A category into which many cities in sub-Saharan Africa fall and are characterised by rapid population growth from migration and natural increase and supporting economies heavily dependant on the informal sector. Such cities contain extensive informal housing areas, widespread poverty and environmental and health problems. Richards Bay contains both the formal and informal sectors mixing together to give the prevalent trajectories of growth.

During the Apartheid era, Richards Bay experienced rapid industrial development as a consequence of planning policies designed to stimulate industrial development in support of the harbour and the towns close proximity to Homelands (uMhlathuze Municipality, 2002). One such policy was the Decentralisation Policy, which was aimed at shifting investment in the manufacturing industries away from the metropolitan areas and into designated growth areas situated near or within the former Homelands to provide a rural-urban economic balance (Kihato, 1999; Crush & Rogerson, 2001).

In 1996 the Spatial Development Initiative (SDI) programme was introduced as a support pillar of South Africa's Growth, Employment and Redistribution (GEAR) macro economic policy (Crush & Rogerson, 2001). The uMhlathuze municipality was designated an important node of this programme, which was aimed at fostering sustainable industrial development in areas where poverty and unemployment were at their highest and where economic potential existed.

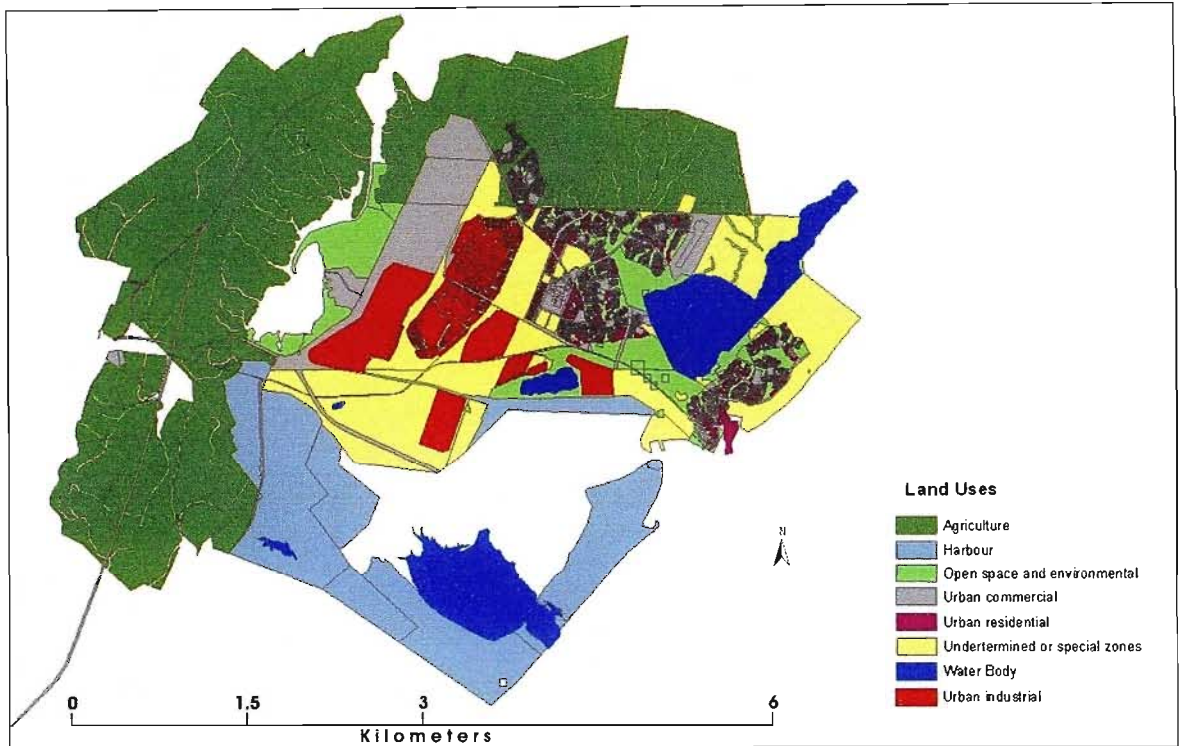
The SDI was set out to encourage economic growth and spatial redistribution (Hall, 2000). Some of the main objectives include increasing foreign exchange and earning, substantial job creation, restructuring the Apartheid economy, public-private partnerships, better utilization of existing infrastructure and resources and broadening the ownership base of the economy. The Richards Bay SDI includes 15 industrial projects that have been established since 1996 and brought in new investment totalling just under 700 million Rand and 1039 new jobs. A further 19 potential projects are under consideration and six Small and Medium Enterprises (SMEs) have been initiated (KZN DEDT, 2002).

The implementation of the SDI structure in Richards Bay has been criticised for reflecting, rather than challenging the existing regional institutional structure, and has simply resulted in a policy that may strengthen the existing and problematic development course (Hall, 2000). Hall (2000) further notes that regional policies are frequently simply reflections of national government strategies interpreted through the regional planners objectives, meaning that development may simply continue in the same mode, without fulfilling all the objectives of the SDI.

Richards Bay has clearly demarcated urban zones (Figure 2-4) and steers development through a systematic Structure Plan framework that is related to long-term port expansion plans and a predicted population of over one million people by 2030 (Hall, 2000). The framework has allocated 1200 hectares of industrial estate for general industries and has stipulated five basic nodes of industrial development in Richards Bay, they are:

- Alton and Alton North industrial areas;

- Alusaf Bayside Smelter;
- Mondi Kraft paper mill;
- Alusaf Hillside, Indian Ocean Fertiliser, CTC, Bell and Silvacel; and
- The coal terminal and harbour



**Figure 2-4 Map of the broad land use zones in Richards Bay**

It must also be noted that, since Richards Bay developed around a few large industries, the local economy is subject to boom-bust cycles associated with the construction of mega-projects (Hall, 2000).

## **2.5. Summary**

This chapter has described the study site, including the location, the natural environment, the history and relevant development strategies and government policies that have impacted on the land cover changes in the area.



The uMhlathuze Municipality section gives basic information and provides a location map showing the spatial distribution of the urban areas. The natural environment section describes the vegetation and natural land covers, as well as the wetland system and faunal species resident in the area. The MOSS system is also explained. The section on the history of the uMhlathuze Municipality provides an account of the development of the area since the establishment of the first two villages. The section on development strategies and government policies gives a brief report on the various strategies and policies that have guided development in the uMhlathuze Municipality such as the Decentralisation Policy and SDI.

## CHAPTER 3. LITERATURE REVIEW

### 3.1. Ecological Urban Dynamics and Environmental Considerations

#### 3.1.1. Urban Expansion and Population Growth

The United Nations Population Division (UNPD) (2002) estimate that the vast majority of the population growth expected over the next 30 years will take place in urban areas; that half the world population will live in urban areas by 2007 and that the vast majority of the population increase between the years 2000 and 2030 will be absorbed by the urban areas of less developed countries. Since most of the world's population resides in urban areas, it is in these areas that economic, social and environmental processes will primarily affect human societies. Urban areas have to maintain an equilibrium balance between economic activities, population growth, and pollution and waste so that the urban system and its dynamic processes can evolve in harmony with minimal impacts on the environment (Barredo *et al.*, 2004).

In developing countries, urban growth often takes place for two main reasons, firstly, in response to economic growth in the cities and secondly as a consequence of migration taking place due to a lack of opportunity in rural areas (Wahba, 1996). The influx of large numbers of people unable to generate revenue places immense strain on the planning and management of urban areas. The high degree of land modification completely transforms the natural landscape and forms new habitats and ecosystems, vastly different from the original habitats.

Informal settlements develop in areas without services or formal planning. These settlements are frequently on unsuitable land, such as along rivers' and often grow quickly. Planners in Developing countries usually do not have the financial means to adequately provide for such settlements, leaving them to develop with minimal government guidance Campbell (1983). Campbell (1983) notes that this type of uncoordinated development can lead to bad land use patterns and conditions that are environmentally, socially and economically unfavourable.

The impacts of disturbance on the land, formation of urban heat islands and modifications in nutrient dynamics such as an increase in chronic nitrogen inputs changes the local climate preventing re-habitation of the original species. (Zipperer *et al.*, 2000). Policy makers are being forced to put environmental concerns high on the agenda as the destructive nature of urbanisation is being realised. Consequently, Braissoulis (2001) notes that land use change is increasingly becoming the subject of policy disciplines due to its strong relation with environmental problems and climate change.

The densely concentrated human habitation in urban areas is maintained by the import of materials and energy from external areas. This external dependence means that the human system is not restricted by the constraints of the local ecosystems but extends the ecological footprint of human influence beyond the boundaries of the city. However, with such an inflow of materials and energy into the city, the city becomes a producer of other materials such as finished goods and wastes (Luck *et al.*, 2001).

Sustainability of a city has come to the forefront of planners' agendas in recent years. The main emphasis of sustainability is that every citizen present or future has a decent quality of life (Laurini, 2001). Laurini (2001) points out the five main components of a sustainable city model:

- The human economy: human activities in urban space;
- The city metabolism: material flows within and through urban space;
- Integrity of ecological life support system;
- Quality of human life: level of human needs satisfaction; and
- Vitality of ecological systems: status of species

These five aspects all need consideration and essentially need to be achieved simultaneously to improve the sustainability of cities.

### 3.1.2. Urban Ecosystems

The spatial patterns of urban areas have received much attention from geographers and social scientists (Harris, 1998) but there has been little work done on the ecology of these areas (Wu *et al.*, 2003). Urban ecological systems play a number of important roles such as; the reduction of pollution, seed dispersal, air filtration, microclimate regulation, noise reduction, rainwater drainage and sewerage treatment (Elmqvist *et al.*, 2004). These systems are characterised by complex interaction between humans and the natural environment at a variety of spatial and temporal scales (Luck *et al.*, 2001).

Elmqvist *et al.* (2004) note that one of the key challenges is sustaining the capacity of ecosystems to generate the services they deliver in growing urban areas. Planners and policy makers need to understand how proposed land use changes will affect the ecological components so as to produce strategies to preserve ecosystem capacity. Zipperer *et al.* (2000) suggest that to understand and preserve the dynamics of urban ecosystems one needs to incorporate the classic ecosystem approach and a patch dynamic approach. The ecosystem approach concentrates on the magnitude and control of the fluxes of energy, matter and species, while the patch dynamic approach concentrates on the spatial heterogeneity within landscapes and how such heterogeneity affects energy flows, matter and species. Zipperer *et al.* (2000) further note that an ecological approach to land use planning is essential to maintain the long-term sustainability of ecosystem benefits, services and resources. In a similar fashion, to account for human impacts on the urban landscape, the ecosystem concept needs to incorporate humans as a component.

Zipperer *et al.* (2000) assembled a list of the key ecological principals needing attention in urban land use change decision-making:

- *Content* refers to the structural and functional attributes of a patch where structure is the physical arrangement of the ecological, physical and social components, and function refers to the way the components interact;

- *Context* refers to the patch's location relative to the rest of the landscape as well as the adjacent and nearby land units that are in direct contact or linked to a patch by active interactions;
- *Connectivity* refers to how spatially or functionally continuous a patch, corridor, network or matrix of concern is;
- *Dynamics* refers to how a patch or patch mosaic changes structurally and functionally through time;
- *Heterogeneity* refers to the spatial and temporal distribution of patches across a landscape. Heterogeneity creates the barriers or pathways to the flow of energy, matter, species and information; and
- *Hierarchy* refers to a system of discrete functional units that are linked but operate at two or more scales. Proper coupling of spatial and temporal hierarchies provides a key to simplifying and understanding the complexity of urban landscapes.

Urban landscapes have great spatial heterogeneity at multiple scales made up of a mosaic of biological and physical patches (Zipperer *et al.*, 2000). Modification of landforms, drainage networks, extensive infrastructure and the introduction of exotic species all contribute to this heterogeneity. Ecological processes operate at these various scales and thus any strategy to conserve such processes and elements needs to encompass such a diversity of scales (Noss, 1991).

The arrangement of landscape elements such as parks, urban blocks, vegetation patches, golf courses and agricultural fields influence many ecosystem processes such as water discharge characteristics, primary production and nutrient cycling (Wu *et al.*, 2003). These impacts need to be understood to determine how development can proceed in a manner that has the least possible impact on such processes. Wu & Qi (2000) suggest that spatial pattern analysis is an important way of quantifying the changes to the landscape structure and relating landscape pattern to ecological processes.

### 3.1.3. Urban Open Space

Urban open spaces are areas of either natural or modified vegetation such as parks, sports and recreation facilities, community centres, wide landscaped public streets with pedestrian walkways, and unspoilt natural areas. The central goal of urban open spaces is to manage and maintain ecological processes at a regional scale (Flores *et al.*, 1998). They also provide a variety of other benefits to cities such as the delivery of ecosystem services, areas for recreation, places for tranquillity, educational value and the intrinsic values of nature.

Urban growth places barriers to species dispersion, isolating populations and rendering them more vulnerable to extinction, due to reduced access to resources, genetic deterioration and increased susceptibility to catastrophes (Noss, 1991; Leao *et al.*, 2004). Habitat fragmentation is considered by many biologists to be the single greatest threat to biological diversity (Noss, 1991). Habitat sizes are important for the preservation of viable populations of certain species. If areas of natural vegetation are situated strategically throughout the urban areas they can provide landscape linkages and habitat corridors between large habitat patches. These linkages reduce the impacts of fragmentation so prevalent in urban areas by allowing for species migration.

Habitat connectivity has been found to be vital in the ability of urban green areas to support biodiversity over long periods of time (Elmqvist *et al.*, 2004). A loss of diversity in an ecosystem can lead to a loss of guilds, ecological services and long-term productivity, and increases the vulnerability of the system to pest and invasive alien species (Wilson, 1994; Begon *et al.*, 1996). Greenways are corridors of open space connecting parks and natural areas. Such areas may comprise a riverfront, a pathway, a stream valley or suchlike and play important ecological roles as connectors of habitat islands (Hay, 1991).

Elmqvist *et al.* (2004) note that recreation is among the most important services provided by urban open spaces. Open areas for playing sports, walking or just places where people can go to find peace and quiet are all important aspects that people living in urban areas value. Also, urban open spaces provide communication points between urban residents and nature and for

various social groups; the elderly, teenagers and children and thus they contribute to cultural diversity and social cohesion in urban areas (Elmqvist *et al.*, 2004).

Chapter 2 of the South African Constitution states that everyone has the right “to have the environment protected through reasonable legislative and other measures that promote conservation and secure ecologically sustainable development and the use of natural resources, while promoting justifiable economic and social development”. Likewise, chapter 10 of Agenda 21 states that an integrated approach to the planning and management of land resources requires the various levels of governments to review and develop policies to support the best possible use of land and the sustainable management of land resources (United Nations, 2004). These documents provide an official need to preserve natural areas in cities and are partly achieved by Metropolitan Open Space Systems (MOSS), a strategy currently in place at Richards Bay.

### **3.2. The Role of GIS and Remote Sensing in Land Use and Land Cover Change**

Land use and land cover studies have undergone large changes in both the planning and technical contexts over the last six decades. In the 1940s and 1950s planning was based on detailed land use maps produced at great expense. Since then the discipline has undergone a series of technical developments. However, it was not until aerial photography and remote sensing that substantial improvements came about (Kivel, 1991). At the same time manual analysis and drafting gave way to digital mapping, computerised land management systems and geographical information systems (GIS).

Prior to the 1980s, collection and compilation of data and publication of printed maps was costly and time consuming (Borrough, 1986) and prevented many remote areas from being mapped. Developments in both computers and GIS have increased the user-friendly nature of model planning systems and allowed researchers to tackle problems previously considered analytically impossible (Wilson, 1998 cited in Berling-Wolff & Wu, 2004). The scope of opportunity is constantly increasing as the technical tools are developed.

### 3.2.1. The Benefits and Limitations of GIS

Biby and Shepard (1999) noted that the representation and analysis of land cover has been a primary application of GIS since the technology was introduced in the early 1970s. GIS has the ability to capture, convert, edit, update and manage data as well as several spatial analysis functions and the ability to create high quality cartographic outputs (Chou, 1996). GIS tools provide a method to quantify and measure the extent and spatial changes in land covers and moreover can link these patterns to other spatially referenced dataset to provide information on determinants of change and related factors.

A central function of GIS is the transformation of spatial data to information in a form that one can use to aid in decision-making. Through functions such as spatial and database manipulations one can transform and manipulate geographic data to add value to it and reveal patterns (Longley *et al.*, 2001). Although such analysis was possible before the advent of GIS, the high functionality and speed of current software packages has brought these capabilities to a far wider range of users.

The capabilities of GIS rely on both the availability and accuracy of the input data. A GIS is designed for the purpose of processing spatial data so any errors or inconsistencies in the input data will produce the same inconsistencies in the output, often compounded depending on the processes carried out. The availability of good quality input data is accordingly critical to the production of meaningful outputs. The development of remote sensing technology has substantially aided in the provision of good quality data and has thus advanced the field of GIS. It must be noted that the development of GIS and remote sensing capabilities has increased the requirement for statistical measures to determine the accuracy of output data (Congalton & Green, 1993).



### 3.2.2. The Benefits and Limitations of Remote Sensing

The term remote sensing can be defined as “the acquisition and recording of information about an object without being in direct contact with that object” (Gibson, 2000: 76), and includes both aerial photography and airborne satellite imagery. Aerial photography provides data in a simple image format while satellite scanners record data in a number of light spectrum bands. Such scanners allow the acquisition of data from wavelengths beyond the spectrum of visible light, including the thermal infrared and microwave ranges (Gibson, 2000).

Different features on the ground surface have different reflectance values indicated by tonal and textural differences in the remotely sensed imagery (Gibson, 2000). Lower reflectance values are indicated by darker tones. Land cover classes can be determined by grouping areas with similar tones and textures. Each pixel in the image is assigned a digital number relating to its reflectance value and only this spectral information given by the image is utilised. The lower the reflectance value the lower the digital number. This digital nature of the data medium lends itself well to digital analysis.

Weng (2002) notes that several previous studies of land use and land cover change (Muller & Middleton, 1994; Brown *et al.*, 2000; Hsu & Cheng, 2000) have utilised existing maps, aerial photography or samples from field surveys in which data uncertainty is relatively high. Satellite imagery creates an opportunity to improve this analysis. Weng (2002) further notes that an operational procedure needs to be developed to effectively integrate the techniques of satellite remote sensing and GIS with various modelling procedures to improve analysis of land use and land cover change.

Some of the difficulties associated with the use of satellite remote sensing for change detection include an absence of prior information about the shapes of changed areas, a lack of reference background data, differences in light and atmospheric conditions, sensor calibration difficulties, ground moisture and registration noise (Bruzzone & Cossu, 2002). One of the dominant problems with classifying urban areas is the range of spectral responses stemming from the heterogeneity of urban areas (Foody & Curran, 1994). Roofs, roads, concrete, trees, and many other urban features present a range of spectral reflectance values both higher and

lower than other land cover classes, making it difficult to classify as a single class. Classification approaches such as object-oriented classification take the form, textures and spectral information into account and thus can improve the accuracy of the results (Oruc *et al.*, 2004).

### 3.2.3. Landsat Satellite Imagery

The National Aeronautics and Space Administration (NASA) with co-operation from the United States Department of Interior launched the Landsat program of satellite in 1972. The program had an ‘open skies’ principle meaning that there was non-discriminatory access to data collected from the satellites anywhere in the world (Lillesand & Kiefer, 1994). There was a total of seven satellites in the series, namely Landsat-1 through Landsat-7. Landsat-1, -2 and -3 were very alike in operation as were Landsat-4 and -5. Landsat-6 experienced a launch failure and Landsat-7 was unique in operation as it contains an improved scanning radiometer.

Imagery from the Landsat-5 and Landsat-7 series was used in this study so only these two satellites will be described in more detail.

Landsat-5 was launched on 1 March 1984 (Lillesand & Kiefer, 1994). It uses a Thematic Mapper (TM) sensor which contains seven spectral bands with eight-bit radiometric resolution and a 28.5 m spatial resolution for all bands except the thermal (band 6), which has a spatial resolution of 120 m. The wavelengths of the spectral bands are produced in Table 3-1. This satellite has a 16-day return period.

**Table 3-1 Landsat-5 band wavelengths**

Band	Wavelength (microns)
1, Blue	0.45 to 0.52 $\mu$ m
2, Green	0.52 to 0.60 $\mu$ m
3, Red	0.63 to 0.69 $\mu$ m
4, NIR	0.76 to 0.90 $\mu$ m
5, NIR	1.55 to 1.75 $\mu$ m
6, NIR	10.40 to 12.50 $\mu$ m
7, NIR	2.08 to 2.35 $\mu$ m

*(Developed from Lillesand & Kiefer, 1994)*

Landsat-7 was launched in 1999. It uses an Enhanced Thematic Mapper Plus (ETM+) sensor with a 15 m spatial resolution in the panchromatic band, a 30 m spatial resolution in the multi-spectral bands, two radiometric sensitivity ranges and a 60 m spatial resolution thermal-infrared band. It has a 5% radiometric calibration with full aperture. Landsat-7 also has a 16-day return period. Table 3-2 provides the characteristics of the spectral bands. In May 2003 Landsat-7 experienced a fault with the Scan Line Corrector resulting in gaps in the processed product.

**Table 3-2 Landsat-7 Characteristics**

Band Number	Wavelength (microns)	Resolution (m)
1	0.45 to 0.52 $\mu\text{m}$	30
2	0.52 to 0.60 $\mu\text{m}$	30
3	0.63 to 0.69 $\mu\text{m}$	30
4	0.76 to 0.90 $\mu\text{m}$	30
5	1.55 to 1.75 $\mu\text{m}$	30
6	10.4 to 12.5 $\mu\text{m}$	60
7	2.08 to 2.35 $\mu\text{m}$	30
Panchromatic (8)	0.50 to 0.90 $\mu\text{m}$	15

*(Taken from ERDAS, Inc, 1997)*

The seven recorded bands, representing the different wavelengths, allow a composite image to be produced representing either true colour (blue, green, red) or a variety of false colour composites allowing the user superior visual interpretation. It must be noted that certain bands are often better suited to specific applications. Bands 4 and 5 are best for distinguishing urban areas, roads, gravel pits and quarries, bands 6 and 7 are best for delineating water bodies, bands 6 and 7 are best for geological studies and agricultural areas are best distinguished with bands 5, 6 and 7 (Lillesand and Kiefer, 1994). Zha *et al.* (2003) found that a combination of bands 2 (blue), 3 (green) and 4 (red) were most suitable for distinguishing between a range of land covers including built up, woodland, farmland, barren lands and water. Weng (2002) also found this combination most suitable for a similar application.

### **3.3.Determinants of Land Use and Land Cover Change**

Land use and land cover changes take place primarily as a result of human actions in response to needs and wants. A variety of other factors then influence the extent, pattern and rate of

such changes. In predicting future patterns of land use change, it is imperative that one assesses the problem at the cause rather than simply addressing the symptoms. An understanding of the factors causing changes will provide insight into the trajectories of change.

Verburg *et al.* (2004) note that studies of land use change should conceptualise the interactions among the driving forces of land use change, their mitigating procedures and human behaviour and organisation. Human actions take place in response to the socio-cultural and physical environment and are aimed at increasing their economic and socio-cultural well being (Verburg *et al.*, in press). Land use patterns are a consequence of these human actions and should not be viewed independently of the driving forces underlying the motivation for production and consumption.

Urban growth plays a large part in changing land uses and land covers as land is quickly transformed by developments. Urban growth stems from expansion of residential, industrial, commercial and recreational areas (Verburg *et al.*, 2004) and radically transforms the landscape. The patterns and location of such changes are normally a result of spatial policies, accessibility measures and neighbourhood interactions (Verburg *et al.*, 2004). Land use decisions are often the product of both macro- and micro-level processes (Bergeron & Pender, 1999). The macro-level factors include land policies, markets, trade, aggregate population growth and technology development, while the micro-level factors include the lands biophysical characteristics, the human and economic endowment of the households and community characteristics.

The three over-arching categories that need consideration in understanding determinants of land use changes are environmental or biophysical, social and economic considerations. These processes interact with each other leading to complex patterns of land use and land cover change. One needs to understand the many factors within each group as well as the relationships between the three groups to comprehend the prevalent land use changes (Braissoulis, 2001). Verburg *et al.* (2004) discussed five dominant determinants of land use change. These are spatial policies, economic factors, biophysical constraints and potentials,

social factors and spatial interactions. These five factors will be discussed in more detail below.

### **3.3.1. Economic Factors**

Economics is a vital determinant of land uses. The pattern of land use evolves primarily from activities competing for sites through the process of supply and demand (Kivel, 1991). Economists view the relation between land uses and location factors based on the assumption that in equilibrium land is used for the activity that generates the highest potential profitability (Verburg *et al.*, 2004). However, there are many other relevant factors such as social change, credit availability and inflation, which cause the urban land market to function imperfectly. Furthermore, the land market is rarely a free market and often heavily constrained by local and national governments. This results in the actual land use of a certain plot being somewhat different to its potential land use in a planning context (Kivel, 1991).

It is also noted that the level of economic development of an area can have a bearing on land use changes as it is often representative of the level of wealth of the population or society. The level of wealth can influence access to resources available to a population and hence the degree to which the landscape can be modified (Turner & Meyer, 1991). Similarly, levels of wealth can shape the modes of land resource utilization.

### **3.3.2. Social Factors**

Important social determinants of land uses include individuals' cultural values, norms, preferences, and peoples' financial, temporal and transport means (Verburg *et al.*, 2004). Site characteristics can influence peoples' choices of residential areas. These include housing prices, levels of services supplied, quality of landscapes and social composition of neighbourhoods (Verburg *et al.*, 2004).

Population growth has been found to be a principal factor driving land use changes (Turner and Meyer, 1991; Verburg *et al.*, 1999). Growth of a population increases the need for

residential, commercial, industrial and agricultural land. In highly populated areas competition for land becomes a very contentious issue leading to several environmental and social problems.

### **3.3.3. Spatial Interactions and Neighbourhood Characteristics**

The land use of a particular area will normally be influenced by the land uses in adjacent areas. Each development affects the conditions of neighbouring locations. Harbours will generally be associated with bulk storage and industrial areas, and urban expansion will be situated near existing urban areas. Certain land uses are attracted to each other while others repel each other (Verburg *et al.*, 2004).

Spatial relations often result from certain network interactions. Physical networks such as roads, services and power supplies, and interaction networks such as related industries and businesses, influence the choice of land use in an area (Verburg *et al.*, 2004). In Third World countries, housing can make a large claim on the land as inexpensive accommodation tends to spread outwards rather than upwards (Robinson *et al.*, 2004).

### **3.3.4. Biophysical Factors**

The biophysical environment, whilst not a strong driver of land use change, is more important in terms of land use allocation decisions (Verburg *et al.*, in press). The natural environment can provide constraints on the possible land uses. Soil formations and strength, geology and drainage conditions can influence the suitability of a location for various land uses (Verburg *et al.*, 2004). Furthermore, physical factors, which although may not determine the amount of land use change, are fundamental in determining the pattern (Hall *et al.*, 1995a).

### **3.3.5. Policy Factors**

Both local and national policies can have a variety of influences, directly and indirectly on land uses. It is important to understand how and why decision makers make their decisions, so

that the potential benefits can be exploited and the negative consequences minimised (Bergeron & Pender, 1999).

Many policies relating to conservation, land tenure changes or areas designated for subsidised developments, are manifested spatially (Verburg *et al.*, 2004). They can have a large influence on the spatial pattern of land use changes. Lubowski *et al.* (2003) found that changes in government policies in the United States of America had a large impact on land use changes. They found that policies such as the Conservation Reserve Program (CRP) and government payments to crop producers were significant factors impacting land use.

In South Africa several new policies have come into being since a majority government came into power in 1994. The relevant land related policies and legislation include (Fourie, 2000):

- Restitution of land to those who were removed;
- Large scale formal housing development for low income groups;
- Restructuring the cities and towns;
- Upgrading and giving title to informal settlements; and
- Redistribution of land

Other relevant legislation includes; the Land Reform (Labour Tenants) Act No. 3 of 1996, the Interim Protection of Informal Rights Act No. 31 of 1996, the Communal Property Association Act No. 28 of 1996 and the Extension of Security of Tenure Act No. 62 of 1997.

South Africa has also established the Spatial Development Initiative (SDI) program, which is a policy, aimed at fostering sustainable industrial development in areas where poverty and unemployment are high and where economic potential exists. More detail of the SDI in Richards Bay is provided in section 2.4.

### **3.3.6. Sugarcane Expansion**

Sugarcane expansion is included in this section as the study site is an important sugarcane growing area in South Africa and contains the largest sugar mill in the country. Sugarcane

growing is the leading agricultural practice in the uMhlathuze municipality and is vitally important in terms of land use (uMhlathuze Municipality, 2002). It is the largest land use in the municipality and has many impacts on both the economy and environment. Economic trends within the South African Sugar Industry could trigger significant changes in land cover in the uMhlathuze municipality.

The South African Sugar Industry contributes approximately five billion Rand annually to the South African economy (Anon, 2003) It is a major contributor to rural economies and an important provider of jobs in cane growing areas of South Africa (Maloa, 2001). The industry provides jobs directly involved with sugar and also many upstream and downstream linkages such as businesses supplying the industry (Maloa, 2001). In recent years much emphasis has been placed on the development of small-scale Black growers, and the production of sugar on communally held land has increased significantly since the late 1970s reaching 15% of South Africa's total cane production in 2001 (Maloa, 2001). In 1992 the Small Grower Development Trust (SGDT) was formed to improve the ability of small-scale Black growers to participate in the market (Maloa, 2001).

The biophysical conditions present in the uMhlathuze municipality are excellent for sugarcane (Low and Rebelo, 1998), and farmers obtain high sugarcane yields averaging 87.5 t/ha/annum (Schulze *et al.*, 1999). In 1994, Tongaat-Hulett Sugar developed the largest private irrigation scheme in South Africa in the uMhlathuze region. This scheme has had a large influence on increasing sugarcane production in the area (Fortman, 2005 *pers comm.*).

### **3.4.Land Use and Land Cover Change Detection**

#### **3.4.1. The Importance of Change Analysis**

Both human and physical forces are constantly modifying the landscape. Changes in vegetation and landscape cover have ripple effects on many factors such as wildlife habitat, fire conditions, regional planning and aesthetic and historical values. Changes in the landscape



are also determinants of the policy and management strategies of an area. Thus it is vital to gain an understanding of the changes taking place.

Analysis of multi-temporal remote sensing images has been used for several applications including monitoring land cover dynamics, damage mapping, risk assessment and urban expansion assessment (Bruzzone & Cossu, 2002; Civco *et al.*, 2002; Weng 2002; Chen *et al.*, 2003). The wide range of different applications (forest dynamics, ecological process, urban grow, agricultural expansion, etc) leads to a variety of techniques designed for different purposes (Bruzzone & Cossu, 2002). Such studies usually include the three main steps; preprocessing, image comparison and analysis of the results.

#### **3.4.2. Data Preprocessing**

Preprocessing of remotely sensed imagery refers to the correction for geometric distortions, radiometric deficiencies and atmospheric deficiencies, and the removal of data errors and flaws (Mather, 1989). These operations are carried out prior to the analysis of the imagery. The remote nature of the sensors allows an array of atmospheric conditions to cause distortions and deficiencies in the signals received by the sensors. Similarly, the signals can be hindered by the effects of interactions between both incoming and outgoing electromagnetic radiation and the elements of the atmosphere (Lillesand & Kiefer, 1994).

The basic corrections are carried out in the ground receiving stations of the satellites. However, further specified corrections are carried out by the user. However, not all corrections need to be carried out for all imagery and all purposes. The relevant techniques depend on the application and quality of the imagery (Mather, 1989).

Studies of temporal change involve the analysis of multi-temporal images that must be compared to one another. They thus require a degree of consistency between the reflectance values and registration of the different images to ensure they are comparable in both the spectral and spatial domains (Lu *et al.*, 2004). This presents the need for further refined preprocessing such as co-registration and radiometric calibration. Co-registering the images

ensures that the coordinates of the pixels in all the images represent the same area on the ground (Bruzzone & Cossu, 2002), whilst, radiometric calibration ensures that the grey levels of the images represent the same reflectance values in all the images.

Further limitations in multi temporal analysis can stem from differences in sun angles, soil moisture, plant phenological state and sensor calibration (Jensen, 2000; Singh, 1989). These factors can compromise the accuracy of simultaneous image analysis. Furthermore, spectral and spatial resolutions of the different images are also important considerations when attempting to compare different images (Lu *et al.*, 2004).

### **3.4.3. Image Classification**

Image classification is the process of categorizing the pixels of an image into a specific number of individual classes based on set criteria (ERDAS, Inc, 1997). Categorisation is primarily based on the spectral patterns and radiance measurements obtained in the various bands of the individual pixels in an image (Lillesand & Kiefer, 1994).

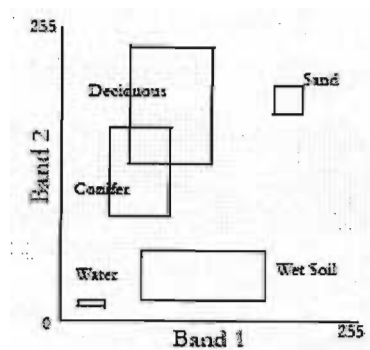
Classification procedures employ a spectral pattern recognition procedure but can incorporate the spatial relationships of certain pixels with those surrounding them. The process can select the number of bands to be utilized in the process. Increasing the number of bands will increase the likelihood of each land cover having a unique value (Gibson, 2000).

There are two broad categories of classification; *supervised* and *unsupervised*. *Unsupervised classification* involves the use of algorithms to examine all the pixels in an image and aggregates them into a set number of classes based on the natural groupings that are present in the data (Jensen, 2000). The method is based on the premise that the values present within each cover types should be similar and different from other classes. The classes resulting from this method will only be distinct in a purely spectrally nature. The analyst needs to compare the classes with reference data to determine what land cover each one represents (Lillesand & Kiefer, 1994). Usually the user will specify the computer to use a large number of classes, which are later, combined to more broad classes of interest.

*Supervised classification* involves three steps; (1) the *training stage*, (2) the *classification stage* and (3) the *output stage*. During the *training (or pilot) stage* representative training areas are identified and a numerical description of the spectral attributes of each particular land cover type is developed. Thereafter the *classification stage* classifies each pixel in the image into the land cover class to which it most closely resembles. The *output stage* involves the production of an output image, tables of statistics and digital data files (Eastman, 2001).

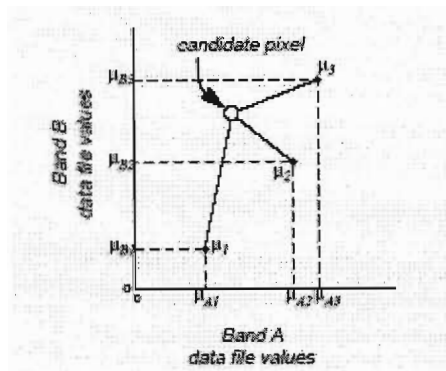
One needs to take cognizance of the fact that supervised classification requires some prior knowledge of the study site and the types of land covers that are present. Furthermore, the analyst must stipulate, through training sites, the spectral profiles of the required classes (Gibson, 2000). The process uses a decision rule to determine which class a pixel will be allocated to. The three most common of these are the ‘parallelepiped’, the ‘minimum distance to means’ and the ‘maximum likelihood’ decision rule.

The ‘parallelepiped’ decision rule is based on Boolean logic. Each signature has high and low limits in every band as illustrated by the blocks in Figure 3-1. If a pixel’s data values fall between these limits for every band in a signature then the pixel is assigned to that signature class. It is a quick method but generally provides poor results as the classes often overlap giving areas of ambiguity (Eastman, 2001). The signature classes can have, what is referred to as ‘corners’ allowing pixels to fall within a class when they are actually spectrally dissimilar from the class mean (ERDAS, Inc, 1997).



**Figure 3-1** Diagrammatic illustration of the class allocation method of the ‘parallelepiped’ decision rule (taken from Eastman, 2001).

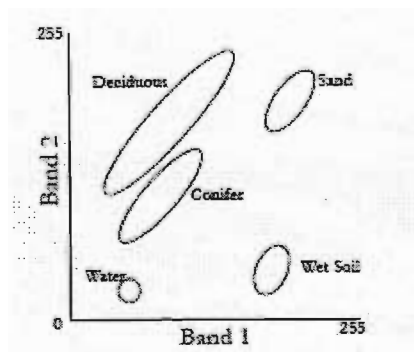
The 'minimum distance to means' decision rule calculates the distance to each mean signature class vector from each pixel. The candidate pixel is assigned to the class with the closest mean as illustrated in Figure 3-2. This decision rule is one of the fastest and has been shown to perform moderately well, however, problems do arise as it does not account for signature variability (Eastman, 2001). In other words, outlying pixels of variable land covers such as urban may be misclassified (ERDAS, Inc, 1997).



**Figure 3-2** Diagrammatic illustration of the class allocation method of the 'minimum distance to means' decision rule (taken from ERDAS, Inc, 1997).

The 'maximum likelihood' decision rule is the most complex of the three and allows for the determination of the probability of each pixel belonging to a class where the probability is greatest at the mean of the class and decreases away from the mean in an elliptical pattern (Eastman, 2001) as depicted in Figure 3-3.

The algorithm initially calculates a considerable amount of information about the class membership, including the mean and variance/covariance data of the signature (Eastman, 2001) From this information it assigns each pixel to the class that is considered statistically most likely to have given rise to that pixel (Jensen, 2000).



**Figure 3-3** Diagrammatic illustration of the class allocation method of the 'maximum likelihood' decision rule (taken from Eastman, 2001).

The 'maximum likelihood' decision rule considered the most accurate used in the ERDAS IMAGINE system (ERDAS, Inc, 1997), as by using covariance matrices it accounts for a large degree of variability in the signature classes. Nonetheless, this decision rule takes a longer time to compute and it tends to over-classify signatures with large values in the covariance matrix (ERDAS, Inc, 1997).

#### 3.4.4. Classification Accuracy Assessment

Lillesand and Kiefer (1994) note that a classification is only complete when the accuracy has been assessed. This is because a classified map is not a perfect representation of reality and there will always be some errors. The only way to validate ones' results and determine the extent of errors is to implement an accuracy assessment (Lu *et al.*, 2004). Andersen *et al.* (1976) set out a number of criteria that a remote sensing land cover classification should meet. The first of these is that the minimum level of interpretation accuracy, in the identification of land use and land cover categories from remote sensor data, should be at least 85%. For the complete list of criteria see Andersen *et al.*, (1976).

There are two basic types of error in classified land cover maps; position error and thematic error (Horning, 2004). Positional error occurs when the shape and size of a particular class is correct but the placement on the map is incorrect. Thematic error occurs when a land cover is misclassified and the quantity of cells in the classified image does not equal that of the reference image (Pontius, 2000). These errors are commonly determined through the creation

of an error matrix, which compare the relationship between a set of known reference data and the corresponding points within a classified image on a category-by-category basis (Lillesand & Kiefer, 1994). Additional statistics such as Kappa coefficients can be used to further determine the character of the errors (Pontius, 2000; Lu *et al.*, 2004).

Error matrices allow the user to analyse the errors of omission (exclusion) and the errors of commission (inclusion). An overall accuracy can be obtained, as well as *producer's accuracies* which indicate how well the training set pixels of each cover type are classified, and *user's accuracies*, which indicate the probability that a pixel classified to a certain category actually corresponds to that category on the ground (Lillesand & Kiefer, 1994). The *producer's accuracy* is determined by dividing the correctly classified pixels by the total number sampled for each class. The *user's accuracy* is determined by dividing the correctly classified pixels by the total number of sample pixels classified as that class.

Lu *et al.* (2004) noted that the following factors must be considered to properly generate an error matrix on order to gain a fair assessment of the error:

- Ground truth data collection;
- Classification scheme;
- Sampling scheme;
- Spatial auto-correlation; and
- Sample size and sample unit

One needs to note that the results of the error matrix only indicate the accuracy of the classification at the areas where the ground truth points were taken, and not the overall accuracy of the entire classified image (Lillesand & Kiefer, 1994).

### **3.4.5. Change Detection Techniques**

Change detection refers to the process of identifying differences in the state of an object or feature by observing it at different time periods (Singh, 1989). Essentially, it is the identification of temporal changes from a multi-temporal data set. Different land covers and

land uses result in different reflectance values, so areas where changes in a landscape have occurred will result in changes in the radiance values of the pixels in that area. Thus by overlaying one image on to another one can determine the pixels where the reflectance values have changed from one date to the next.

There is a large number of change detection techniques (sometimes referred to as algorithms) discussed in the literature (Singh, 1989; Mouat *et al.*, 1993; Mas, 1999; Liu *et al.*, 2004), and research in this subject is an active topic (Lu *et al.*, 2004). There is no single approach that is optimal to every occasion and the choice of techniques relates to the specific application and study site.

Change detection techniques can be divided into bi-temporal analysis and multi-temporal analysis. Bi-temporal involves the analysis of images taken from two different dates and multi-temporal involves the analysis of images from a number of dates in a temporal trajectory. The majority of techniques have been developed for bitemporal studies, however, many of them can be applied to multi-temporal analysis. Techniques can also be divided into those classified independently and compared later and those simultaneously classified and analysed (Singh, 1989).

Lu *et al.* (2004) grouped the techniques into seven categories as follows:

- *Algebra* (image differencing, image regression, image ratioing, vegetation index differencing, change vector analysis (CVA) and background subtraction);
- *Transformation* (Principal Component Analysis (PCA), Gram-Schmidt (GS) and Chi-square transformations);
- *Classification* (Post-classification comparison, spectral-temporal combined analysis, expectation-maximisation algorithms (EM) change detection and unsupervised change detection);
- *Advanced models* (Li-Strahler reflectance model, spectral mixture models and biophysical parameter estimation models);
- *Geographical information system (GIS) approaches* (includes integrated GIS and remote sensing methods and pure GIS methods);

- *Visual analysis* (includes visual interpretation of multi-temporal image composite and on screen digitising of changed areas); and
- *Other approaches*

Detail is only provided for the ‘post classification comparison’ technique as this was the technique found most appropriate for the study.

#### **3.4.6. Post Classification Comparison**

This method, also known as ‘delta classification’, involves the comparison of independently produced classified images (Singh, 1989). The different classes are coded and entered into a matrix of change, from which the areas of change can be determined. The imagery from the different dates is classified separately reducing the need to register the images to each other accurately. It also minimises the problems from atmospheric and sensor differences between the images. This technique can produce a complete matrix of change directions (Lu *et al.*, 2004).

The accuracy of this method is largely dependant on that of the initial classifications as the ‘difference image’ accuracy is a result of the multiplication of the accuracies of the individual classified images. For example if the two classified images have an accuracy of 80% each, when they are integrated they will result in a ‘difference image’ accuracy of 64 per cent ( $0.80 \times 0.80 = 0.64$ ). Errors of mis-classification and mis-registration present in the classified images are compounded in the integration process (Coppin *et al.*, 2004). This technique requires a large amount of time and expertise to create classification products (Lu *et al.*, 2004).



## **3.5. Modelling Land Cover Change and Urban Landscape**

### **3.5.1. Introduction**

The use of Geographic Information Systems (GIS) and remote sensing for land use and land cover change analysis has been greatly increased by the development of models built on the capabilities of GIS and remote sensing but with added functionality. Such models utilize the capabilities of GIS and remote sensing in combination with statistical and mathematical procedures to provide meaningful results for planners and decision makers.

A mathematical model is a purposeful abstraction designed to represent complex reality and represents the various relationships between the different elements in a system as a series of equations, in order to simulate the likely progression of the system (Masser, 1972). Only the relevant features of a particular subject under consideration are incorporated in the model, while unnecessary detail is not utilised. Models that describe changes in a system over time are known as dynamic models. Simulation models (or predictive models) are a subcategory of dynamic models designed to extrapolate predictions into the future. Models can also be categorized as either deterministic or stochastic. Deterministic models produce a single value result, while stochastic models incorporate some natural variation into the model to provide a range of possible outcomes, i.e. the input values are not fixed and thus can predict different outcome scenarios (Beltrami, 1987).

The general process of models involves fitting the model to a historical pattern of change and then extending the same pattern to get likely future scenarios (Brown *et al.*, 2000). The output of such models can provide urban and regional planners with information needed to understand land use and land cover systems and achieve their desired goals (Yang & Lo, 2003). Furthermore, these models are valuable tools for improving understanding and analysis of the interactions between socio-economic processes, agricultural activities and natural resource management (Brown *et al.*, 2000).

### **3.5.2. The Development of Land Use and Land Cover Change (LUCC) and Urban Landscape Models**

Urban modelling began in the late 1950s when car ownership increased, causing traffic problems and brought a realisation among planners of a need for scientific study (Berling-Wolff & Wu, 2004). The introduction of computers increased processing capabilities and thus the ability of planners to model cities. The first models in transportation studies were derived from relating spatial interactions to Newton's law of gravitational force (Masser, 1972), and sought to incorporate different activity systems according to their spatial distribution obtained from interaction functions developed from Newton's gravitational theory.

Later, during the early 1960s the Lowry model was developed. This model was a combination that linked together the production constrained gravity model and the attraction constrained gravity model (Masser, 1972). Its primary purpose was to generate estimates of population distribution that would work in and serve a particular sector and the transportation networks pertaining there to. However, the early models based on gravity theory lacked the underlying economic and behavioural theory required to accurately portray the urban dynamics (Berling-Wolff & Wu, 2004).

Following this, efforts to simulate urban markets led to the development of models derived from linear programming techniques. These models incorporated economic theory of land use, the best known of these was possibly the Herbert-Stevens deterministic equilibrium model (Berling-Wolff & Wu, 2004).

During the late 1960s, land use and transportation models became more integrated to form more holistic models incorporating a wider range of determinants. For example the Integrated Transportation and Land-Use Package (ITLUP) model. However, by the early 1970s there was widespread realisation that urban models were failing due to a number of fundamental flaws. They lacked underlying theoretical bases, required vast amounts of data, were complicated and too expensive (Berling-Wolff & Wu, 2004).

Fortunately, by the early 1980s computer developments were such as to allow for vastly increased processing power with associated user-friendly customer driven software. Similarly, new mathematical and economic theories were being developed allowing for large improvements in urban modelling. Models were able to contain dynamic features and modellers began to incorporate the temporal dimensions of social phenomena (Berling-Wolff & Wu, 2004). Thus providing an example of a dualistic use of technology and theory for improved modelling and decision making.

### **3.5.3. Cellular Automata Models**

Cellular automata based modelling has been applied to a large variety of urban phenomena and has proved to be an effective approach to exploring and investigating land use and land cover changes (Parker *et al.*, 2003; Weng, 2002; White & Engelen, 1993; Herold *et al.*, 2003; Leao *et al.*, 2004).

Cellular Automata are “discrete dynamic systems whose behaviour is completely specified in terms of a local relation” (Toffoli & Margolus, 1987:5). In remote sensing applications, they are made up of four elements; cells, states, neighbourhood rules and transition rules (Leao *et al.*, 2004). The cells are the units in a regular grid representing space; they contain certain data and have adjacency to one another. These cells can take on only one state (or land cover) at any one time but can change with time. The set of possible states is identical for each cell and the same transition rules are applied to all cells.

Change through time occurs in discrete steps and the cells may be updated in either a synchronous or asynchronous fashion (Parker *et al.*, 2003). The neighbourhood of a cell consists of the cells immediately adjacent to it and determines the state of the cell. The changes of state are driven by the transition rules derived from a local spatio-temporal neighbourhood and applied uniformly to the grid. Time progresses in discrete steps and in each step each cell computes its new state from that of its close neighbours (Toffoli & Margolus, 1987).

The transition rules determine the system dynamics by mapping the present state of a cell's neighbourhood at time  $t$ , to an outcome state for that cell at time  $(t+1)$ . The state of a cell is generally representative of the land cover or land use of that cell but can also be representative of land values, population densities and other such spatial classes (O'Sullivan & Torrens, 2001).

Since land use and land cover changes do not mutate in a predictable fashion such as cell cultures on a microscope slide, but rather are a consequence of human agents such as developers, firms, financiers, regulatory authorities, landlords and homebuyers (O'Sullivan & Torrens, 2001), other transitions rules need to represent these factors, and are accordingly a vital element in achieving a realistic model representing realistic system behaviour (Wu & Webster, 2000). Transition rules provide a means of incorporating such external factors into the progression of the model.

A cellular automaton is formally described as follows (Leao *et al.*, 2004):

$$Q = \langle S, N, T \rangle$$

Where  $Q$  = state of the system

$S$  = set of all possible states of the system

$N$  = Neighbourhood of all cells that provide input values for the transition function  $T$

$T$  = Transition function that defines the change in state of the cellular automaton.

Figure 3-4 illustrates how the cellular automata process progresses to model spatial changes in a realistic growth manner.

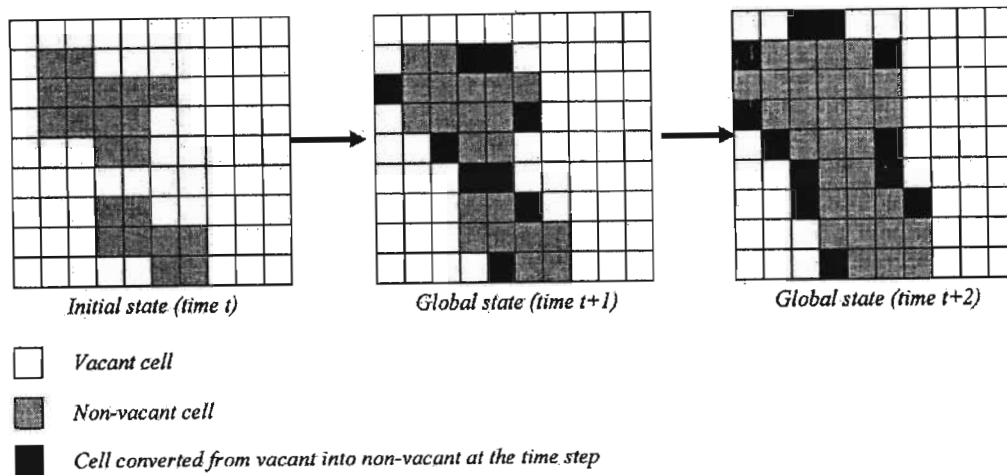


Figure 3-4 Transition process of a generic cellular automaton (taken from Leao *et al.*, 2004)

### 3.5.4. Markov Chain Models

Markov models are a form of cellular model and like cellular automata models, operate on a lattice of congruent cells (Parker *et al.*, 2003). However, with Markov models the states of the cells are probabilistically dependant on temporally delayed cell state values (Parker *et al.*, 2003).

A basic Markov chain transition model can be expressed as follows (Brown *et al.*, 2000):

$$n_{t+1} = Pn_t$$

Where  $n_t$  is a vector of land area fractions in each land cover type at time  $t$ .  $n_{t+1}$  is the vector of land area fraction of the same types at time  $t+1$ .  $P$  is the matrix of the different land covers, which illustrates the possibilities that the sites in state  $I$  at time  $t$  will change to state  $j$  at time  $t+1$ . This basic transition can be repeated several times using the updated matrix at each step in the chain process.

When Cellular Automata and Markov chain models are combined, one can derive the benefits of both modelling approaches to gain a more accurate modelling approach. When the cellular automata component is added to a Markov model it allows the transition probabilities of a

certain pixel to be a function of the neighbouring pixels (Pontius & Malanson, 2005). Thus, transitions can go through several states to give probabilistic land cover changes at many temporal stages.

To apply a Markov chain model several assumptions are made. These include that the Markov models are assumed to be a first order process, which means that the state at time  $t+1$  is dependant only on the state at time  $t$  and the transition probabilities (Cheng, 2000). In other words, the antecedent conditioning before the study time period has no effect. Secondly, the models are assumed to be stochastic as they are based on the transitions, which are simply probabilities (Weng, 2002). Thirdly, the transition probabilities must remain stationary over the time period (Baker, 1989), and lastly that land use change is not random over the time period in the study (Muller & Middleton, 1994).

Cellular models are still simplistic and have difficulty representing urban dynamics and incorporating human decision-making (Parker *et al.*, 2003). Furthermore, since they operate on discrete time steps while land use and land cover changes affect processes operating over multiple timescales, they have trouble representing these processes (O'Sullivan & Torrens, 2001). Not withstanding these points cellular models have proved a valuable and accurate means of simulating land cover change.

Brown *et al.* (2000) note that one of the primary limitations of Markov transition probability-based models for land use and land cover change is the difficulty of assigning causes within the model. The transition probabilities are derived purely from the transition stages of the known land covers with no description of the processes taking place (Baker, 1989). This limitation is of particular concern for study areas where changes are largely driven by social and economic processes (Brown *et al.*, 2000). However, this problem can, to some extent, be overcome by incorporating higher order effects, allowing for the influence of endogenous and exogenous variables such as socio-economic factors or climate change and spatial effects (Baker, 1989).

### 3.5.5. Common Land Use and Cover Change (LUCC) Models

There has been a diverse array of models designed to simulate land use and land cover change, and urban growth. Models range in complexity and purpose depending on the objectives of the developers. Some of the more common models have been briefly described in Table 3-3. GEOMOD2 has not been included in this table as a detailed description is given in section 3.5.6.

**Table 3-3 Brief description of some of the more common LUCC models**

Model	Description
Clarke Urban Growth Model (SLEUTH)	A raster-based model developed to simulate urban growth to improve understanding of how expanding urban areas transform the surrounding land and local environment (Clarke & Gaydos, 1998).
Clue (Changing Land Use and Estuaries Model)	A model developed to work as a tool to improve understanding of the linkages between human activities on land and the functioning of coastal ecosystems with specific emphasis on nitrogen loading. (Veldkamp & Fresco, 1996).
Environment Explorer	A model developed to aid planners, spatial scientists and decision makers with the spatial elements of a wide range of social, economic and environmental issues. The model incorporated several sub models representing the natural social and economic sub systems and uses cellular automata based models to determine the physical and environmental factors and types of activities in the various regions. The model was designed specifically for the Netherlands (Engelen <i>et al.</i> , 2002).
Land Transformation Model	A regression based model that uses Artificial Neural Networks (ANN) to model the relationship between potential drivers and the occurrence of transitions. It uses a GIS to make spatial calculations between the driving of land use change and the extent of the change to produce land transformation probabilities (Pijanowski <i>et al.</i> , 2002)
Land Use Scanner	A logic model designed to simulate future land uses in a GIS setting. The model uses maps of current and historical land use, physical suitability, distance decay and spatial policies, as well as certain outputs of economic sectoral models. It is an economically based equilibrium model that produces a future land use map (Borsboom-van Beurden, <i>et al.</i> , 2002).
Land Use Evolution and Impact Assessment Model (LEAM)	A model developed to simulate the growth of urban systems through a spatial dynamic approach. The model is built on a cellular automata (CA) base and uses Spatial Modelling Environment (SME) software capabilities for simulating land use transformation scenarios. It incorporates driving forces such as economic, population, social, land price, geographical, transport and random factors (Deal, 2001)

### 3.5.6. GEOMOD2

GEOMOD2 is a GIS based model that measures factors associated with land use change and simulates changes in the land cover both forwards and backwards in time (Pontius *et al.*, 2001). The model is primarily based on Markov Chain Analysis and Cellular Automata, which allow it to predict the transition from one land cover state to another. The model simulates the spatial patterns of land use change based on the patterns of biogeophysical attributes and existing land uses derived from digital raster maps. (Hall *et al.*, 1995a). These biogeophysical attributes allow the model to determine how land is developed over space and time, and to simulate how such patterns are likely to continue (Hall *et al.*, 1995a).

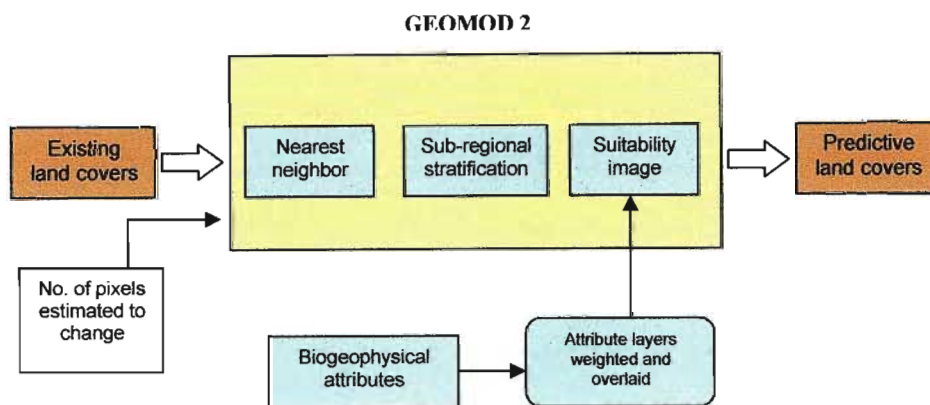
GEOMOD2 uses a statistical analysis of how people use land (Hall *et al.*, 1995b) to determine the spatial patterns of change most likely to occur. It is an empirical adaptation of GEOMOD1, which used data on elevation and slope through hypothesis deduction for the purpose of simulating land cover change in tropical Asia (Hall *et al.*, 1995a). GEOMOD2 only uses two land cover categories and predicts the change from one land cover to the other.

The predictive model uses three decision rules to select the locations of land to be converted (Pontius *et al.*, 2001), as illustrated in Figure 3-5. The first decision rule is derived from the nearest neighbour principal and ensures that in each time step the model limits the development of a land cover to areas adjacent to the land cover. The second decision rule is based on the biogeophysical attributes of the study area. This rule allows the model to predict changes at locations that have attributes similar to that of the land cover to which an area can change. This rule uses a suitability map created from several attribute maps such as elevation, soil type, soil moisture, land use zones, proximity to transportation networks and precipitation.

The suitability map contains high values in areas where the biogeophysical attributes are most suitable to expanding land cover, and low values in areas where the biogeophysical attributes are least suitable for the expanding land cover. The model then simulates future changes in areas that have the highest available suitability value (Pontius *et al.*, 2001). Each of the attribute layers is weighted depending on the impact of that particular factor on the land cover change.



The third decision rule involves sub-regional stratification. This decision rule is optional and specifies the amount of land use change per time step in each of a number of sub-regions within the study area (Pontius *et al.*, 2001). This rule permits the user more control over where the changes may take place.



**Figure 3-5** Diagrammatic representation of GEOMOD2 land use and land cover change model (adapted from Pontius *et al.*, 2001).

GEOMOD2 has dominantly been used to predict land development in tropical areas (Hall *et al.*, 1995a; Hall *et al.*, 1995b; Pontius *et al.*, 2001), but has also been used in Massachusetts, USA (Pontius *et al.*, 2004; Pontius & Malanson, 2005). Applications in tropical areas have concentrated on patterns of deforestation and natural vegetation loss, and the resulting impacts, while application in Massachusetts concentrated on changes from non-built to built land. The model has been specifically designed to be robust enough to perform in various study sites in many parts of the world (Pontius *et al.*, 2001).

Various studies have found GEOMOD2 to provide very accurate results, usually between 80% and 90% (Hall *et al.*, 1995a; Hall *et al.*, 1995b; Pontius *et al.*, 2001). The accuracy of the model is mainly affected by time scale used, the number of land cover classes used and the accuracy of the initial data (Hall *et al.*, 1995b). The shorter the predictive time span and the fewer the number of land use classes the more accurate the model (Hall *et al.*, 1995b).

GEOMOD2 simulates the pattern and locations of land cover change and not the quantity, which must be obtained from another source. Pontius *et al.* (2001) emphasize that it is a good idea to merge GEOMOD2 with another model that predicts the quantity of land use change over time.

### 3.5.7. Model Validation

Validation is an important part of Land Use and Land Cover Change (LUCC) modelling as it provides a means to analyse the likely success of a model to a particular situation. Validation allows the user to determine the truthfulness of the model in accordance with the problem domain and how closely the outcome represents the real system behaviour (Parker *et al.*, 2003). If models are not validated or have been poorly validated they can give the modeller a misleading understanding of the models accuracy (Pontius *et al.*, 2004). A model's usefulness can only be measured by an objective evaluation of the design and performance (Gardner & Urban, 2003) Assessment of the design involves a qualitative assessment of the model structure while analysis of the performance involves a quantitative comparison of predictions against independently gathered information (Gardner & Urban, 2003).

Model validation has been defined as “a demonstration that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of a model” (Rykiel, 1996:230). This is achieved by using the model to predict a period of time for which there is a known set of reference data and then compare the model results to known data.

In the remote sensing software package Idrisi Kilimanjaro (Clarke Labs, 2003) there is a function called ‘VALIDATE’, which provides statistics for measuring the similarity between two qualitative images, such as specified Kappa statistics, that enable one to distinguish between errors of quantity and errors of location (Eastman, 2001). The Kappa statistics include (Pontius, 2000; Eastman, 2001):

- Kappa for no information ( $K_{no}$ ) – The proportion of pixels classified correctly relative to the expected proportion classified correctly by a simulation with no ability to specify accurately quantity or location;
- Kappa for location ( $K_{location}$ ) – The simulation's ability to specify location correctly;
- Kappa for quantity ( $K_{quantity}$ ) – The systems ability to specify quantity correctly;
- Kappa standard ( $K_{standard}$ ) – A measure of a systems ability to attain perfect classification;
- Value of Perfect Information of Location (VPIL); and
- Value of Perfect Information of Quantity (VPIQ)

This breakdown allows the user to analyze the success with which one can specify the location of change and the quantity of change.

### 3.5.8. Recent Developments in Urban Modelling

Many modellers have modified the basic Cellular Automata (CA) model to improve accuracy or to incorporate specific factors such as ecological systems or human behaviour (Deal, 2001; Parker et al., 2003). Most LUCC models, especially those developed for urban applications are founded on relationships between location, density and urban evolution. Through the use of fractal geometry and the laws of particle physics, modellers are able to link the growth process to the geometry of the system. By combining the ideas of evolution, self-organisation and fractal geometry with cellular automata it is possible to achieve high levels of spatial detail and realism (White & Engelen, 1993). Modellers are continually developing new techniques to improve the accuracy and application of models.

Parker *et al.* (2003) proposed the use of a multi-agent system model of land use/land cover change (MAS/LUCC models) to complement existing modelling approaches and improve the accuracy. Their models combined cellular modelling and multi-agent modelling into an integrated system. The cellular component represents the landscape and transitions and the agent-based component describes the decision-making architecture of the key actors in the system and focuses on human actions (Parker *et al.*, 2003). The model addresses the

limitations of equation-based models when representing dynamic processes and feedbacks. They found that MAS/LUCC models offer important tools to assisting progress in understanding the processes of land use and land cover change.

Herold *et al.* (2003) used spatial metrics in combination with SLEUTH urban growth model to provide a time series of the development of Santa Barbara, California. The spatial metrics were used to quantify the spatial and temporal characteristics of development in the area, while the SLEUTH model was used to fill in the gaps in historical data and provide a forecast of growth patterns for the year 2030. Leao *et al.* (2004) noted that CA-based models have been chiefly developed for urban areas of the developed world. Since urban expansion occurs through largely different processes in the developed and developing worlds, the applicability of such models to the third world has been questioned. However, Barredo *et al.* (2004) used a prototype cellular automata model to simulate urban growth in Lagos, Nigeria and found the model to be highly effective and realistic. Similarly, Leao *et al.* (2004) applied a slightly modified version of the Urban Growth Model (UGM) to Porto Alegre City in Brazil and also found the model to be successful.

There are currently several developments in spatial modelling techniques for ecologically based systems designed to improve approaches to incorporating ecological processes into urban system modelling (Deal, 2001). These techniques utilize modern ecological theories such as hierarchal patch theory, in conjunction with dynamic urban systems modelling (Deal, 2001; Wu *et al.*, 2003).

In a similar study, Landis *et al.* (1998 cited in Berling-Wolff & Wu, 2004) developed the California Urban and Biodiversity Analysis (CURBA) model, which included many features for simulating the effects of different development and conservation policies on urban growth patterns. Other related cellular models such as the Land Use Evolution and Impact Assessment Model (LEAM) utilise a Spatial Decision Support System (SDSS) to evaluate the patterns of human development (Deal, 2001). The LEAM model describes land use changes resulting from the interactions of economic, ecological and social systems (Deal, 2001).

### **3.6. Summary**

Firstly, this chapter described the environmental impacts of land use and land cover changes and the importance of ecosystem processes and environmental sustainability in urban areas. Secondly, the drivers and determinants that influence the rate, extent and patterns of land use and land cover change were discussed. It is critical to have a clear understanding of the driving forces to fully understand the patterns of change taking place over time.

Section 3.2 provided a description of the capabilities of GIS and remote sensing and the roles these technologies play in land cover change analysis. Following this, the considerations and processes of land cover change detection were discussed. Lastly, a detailed account was given of LUCC models which build on the data and technology provided by both GIS and remote sensing. A brief explanation was given of the underlying mathematical processes and important considerations. Particular attention was given to one such model, GEOMOD2 as this was the model used in the study.

## **CHAPTER 4. METHODS**

### **4.1. Introduction**

This chapter describes the data used and the methods undertaken during the study. The data and the preprocessing of the data is described. The methods used for the image classification and change detection procedures are explained, and an account is given of the procedures followed during the predictive modelling section. Diagrams are used to provide a clear demonstration of the processes carried out.

### **4.2. Data**

#### **4.2.1. Satellite Imagery**

The primary data used in the study was a set of three satellite images representing the study area at a frequency of five years. Images were chosen at five-year intervals representing the years 1992, 1997 and 2002, and were obtained during the months of July, August and October respectively. Five year intervals were chosen to provide an accurate trajectory of the changes taking place. It was attempted to obtain imagery from dates in the same season to reduce problems resulting from seasonal changes such as different sun angles and changes in plant phenology (Singh, 1989).

Images from Landsat-5 TM and Landsat-7 ETM+ series were used due to their availability and finer spectral resolution than other commonly used satellites such as SPOT, NOAA-AVHRR and MODIS.

#### **4.2.2. Data Preprocessing**

Before any analysis took place the imagery was subjected to a preprocessing stage, which included radiometric calibration and co-registration of the three images. For temporal

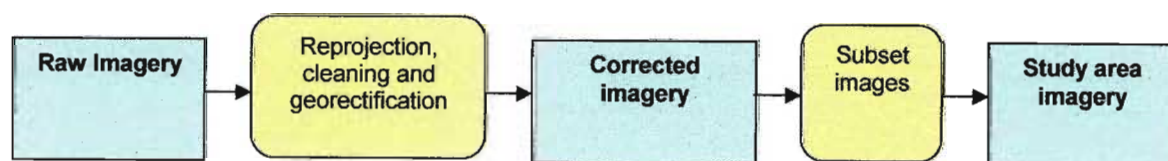
trajectory analysis it is important to render the images comparable in both the spectral and spatial domains (Bruzzone & Cossu, 2002; Coppin *et al.*, 2004).

The radiance measured by a system is influenced by factors such as scene illumination, atmospheric conditions, viewing geometry and the instrument response characteristics (Lillesand & Kiefer, 1994). It was therefore necessary to subject the images to radiometric calibration, which involved modifying the histograms of the images to enable the same grey level values in the different images to represent the same reflectance values, regardless of the reflectance values on the ground. This process was carried out prior to my receiving of the images.

Co-registration involved re-sampling the images through a projection transformation to ensure that the pixels in the different images represent the same coordinates. The three images were re-projected to a Transverse Mercator projection with a Cape datum and a Clarke 1880 spheroid to ensure comparability and prevent spatial errors occurring during the analysis process. They were then geometrically corrected to ensure that they represented precisely the same areas on the ground.

The images were subset to the uMhlathuze municipal boundary as this represented the boundary of the study area. The sand on the coastline was not included into the study area, since this had undergone minimal changes during the study period and the low reflectance of the sand would have caused confusion with the urban land covers in the classification process. Similarly, the sand in the large rivers beds making up the boundaries of the study site were also not included.

Figure 4-1 demonstrates the process that was followed for the preprocessing stage.



**Figure 4-1** Flowchart of the steps undertaken during the preprocessing stage.

### **4.3. Change Detection**

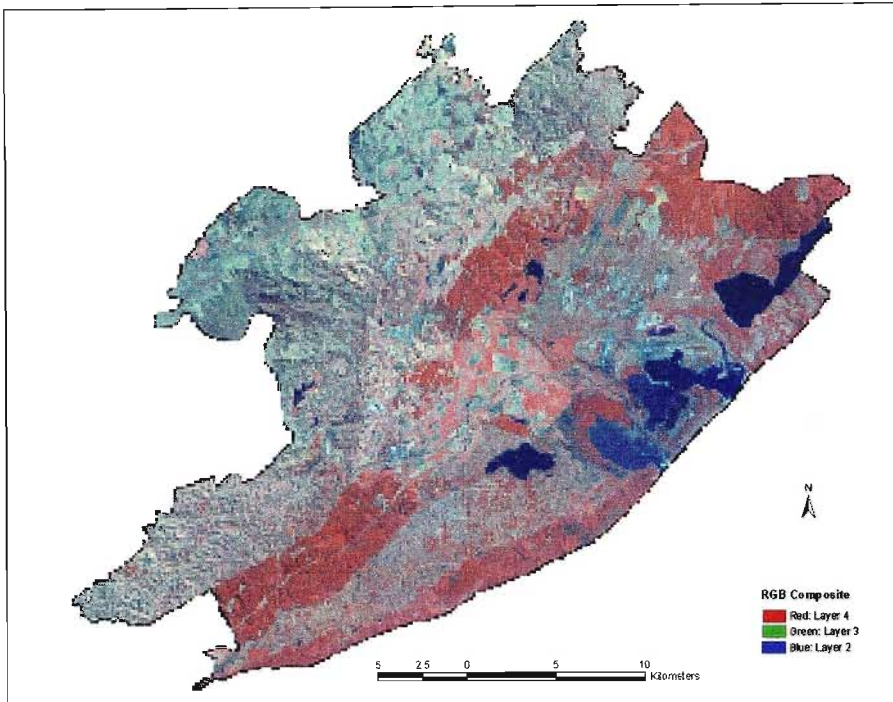
The change detection algorithm selected for this study was ‘post classification comparison’ (Singh, 1989), which involves the comparison of independently produced classified images. This method was chosen as the study utilised imagery from different Landsat satellite series and the study site experienced great variation in rainfall during the study years. This algorithm has proved favourable under such circumstances (Singh, 1989). Furthermore, by classifying the images separately, one minimises the problem of radiometric calibration between the different dates (Coppin *et al.*, 2004). However, this approach relies on the accuracy of the initial image classifications as misclassifications in this stage are compounded when multiple images are compared (Jensen, 2000). Emphasis was therefore placed on obtaining accurate initial image classifications.

#### **4.3.1. Image Classification**

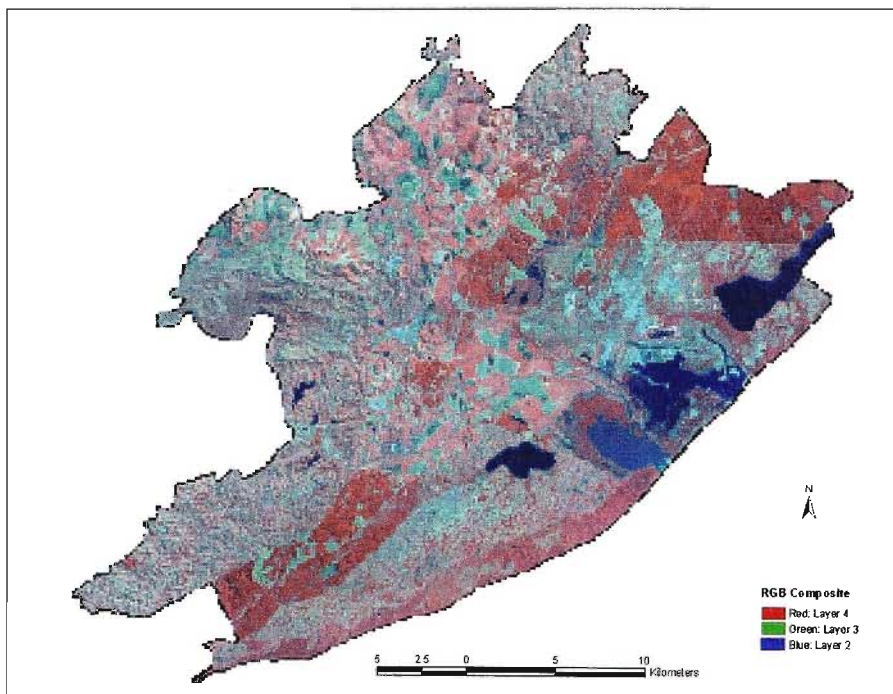
The images were viewed through a combination of bands 2 (green), 3 (red) and 4 (near infrared) (Figure 4-2, Figure 4-3 and Figure 4-4) as these were found to be the most suitable in other similar studies (Weng, 2002; Zha *et al.*, 2003), and gave the best visual distinction between the land covers used in this study. The profiles in Figure 4-5 illustrate the spectral differences of the broad land cover classes across the spectral bands. Although the variety is greatest across the bands three, four and five, the classes were found to be best distinguished using the above-mentioned band combination.

Polygons were drawn in areas representative of the different land covers to denote the training sites from which the class signature would be developed. A total of 60 training sites were selected for eleven land cover sub classes in each image. The large number of training sites increased the accuracy of the spectral signatures for each sub class.





**Figure 4-2** Landsat-5 image of study site in 1992 viewed through a combination of bands 2 (green), 3 (red) and 4 (near infrared).



**Figure 4-3** Landsat-7 image of study site in 1997 viewed through a combination of bands 2 (green), 3 (red) and 4 (near infrared).

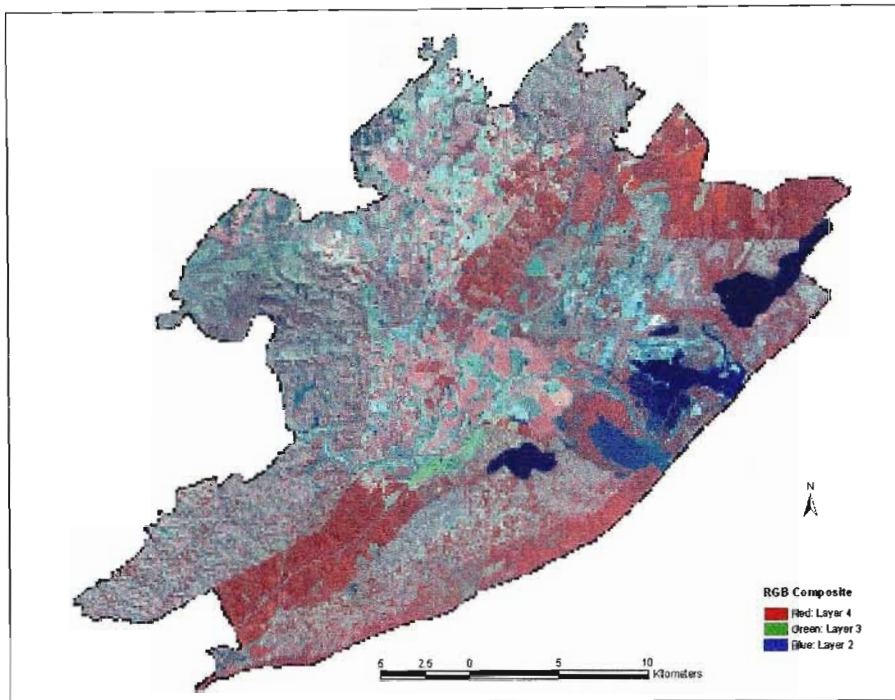


Figure 4-4 Landsat-7 image of study site in 2002 viewed through a combination of bands 2 (green), 3 (red) and 4 (near infrared).

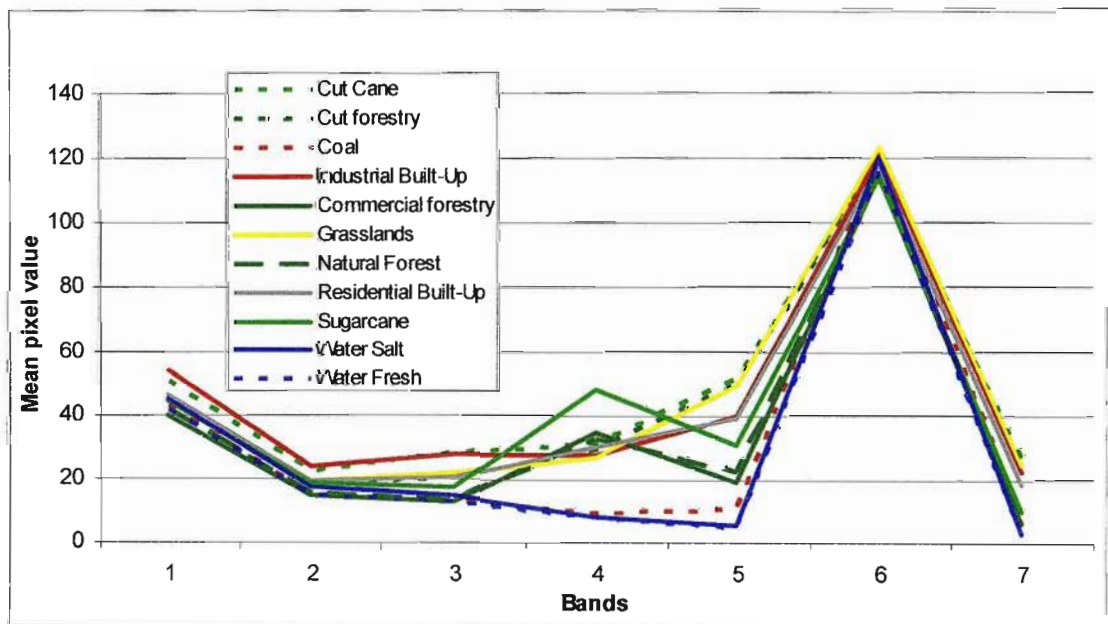


Figure 4-5 Spectral profiles of the 11 broad land cover classes in the study area, taken from the 1992 image.

Classification was carried out in ERDAS Imagine 8.7 (Leica Geosystems, 2003) and achieved through a ‘supervised classification’ process which divided the area into eleven initial land cover classes based on the spectral properties of the user defined training sites. The training sites for the different land cover classes were developed and verified with the aid of recent land use maps, aerial photographs and visits to the study area. Class signatures were evaluated using image alarms, spectral profiles, matrices and histograms (ERDAS, Inc, 1997).

The three satellite images were classified separately using consistent land cover classes developed from the South African classification system (Thompson, 1996). Certain categories of this system were combined together whilst other categories were modified to suit the purpose of the study. The classification was based on this system to allow the results to be viewed in the light of other studies as recommended by Jensen (2000).

Some of the initial eleven sub classes were combined to give a total of seven broad classes to avoid complications arising from too many classes whilst still depicting the relevant differences in land cover. The seven broad classes and descriptions of each are given in Table 4-1. The larger number of initial classes (eleven) was used as the land cover classes ‘*sugarcane*’ and ‘*forest and woodlands*’ contained patches with cover at different stages of growth depending on the life stage of the crops.

**Table 4-1 Description of land cover classes used in the study**

<b>Class</b>	<b>Description</b>
<i>Commercial / industrial built up land</i>	Areas for the conduct of commerce and other mercantile business or including major industrial or transport related infrastructure.
<i>Residential built up land</i>	Areas where people reside on a permanent or near permanent basis. Includes both formal and informal settlement areas, ranging from high to low building density.
<i>Forest and woodlands</i>	All wooded areas with greater than 10% tree canopy cover. This category includes natural forests, mangrove forests and commercial plantations.
<i>Grasslands</i>	All areas of grassland with less than 10% tree and or shrub canopy cover and greater than 1% total vegetation cover, dominated by grass-like, non-woody, rooted herbaceous plants.

<i>Sugarcane</i>	Includes areas currently under sugarcane, fallow land and land being prepared for planting. Sugarcane is, by far, the dominant cultivated crop in the area and contained a relatively unique spectral signature.
<i>Waterbodies</i>	Areas of (generally permanent) open water. This category includes natural and man-made waterbodies, which are either static or flowing and contain fresh, brackish or salt water conditions.
<i>Mines and quarries</i>	Areas in which mining activity has occurred or is occurring. Includes both open cast mines and quarries, as well as surface infrastructure, mine dumps etc., associated with underground mining activities.

The sub classes included; *residential built up land, commercial / industrial built up land, commercial forestry, cleared commercial forestry, sugarcane, cleared sugarcane, natural forests, grasslands, fresh waterbodies, saline waterbodies, coal terminal and mining*. Many of these were then combined together after the classification process had been carried out, to give the seven broad classes as indicated in Table 4-2.

**Table 4-2 Broad classification classes with sub-classes**

<i>Broad Classes</i>	<i>Sub Classes</i>
1 <i>Commercial/industrial built-up land</i>	<i>Commercial/industrial built up land</i> <i>Coal terminal</i>
2 <i>Residential built-up land</i>	<i>Residential built up land</i>
3 <i>Forest and woodlands</i>	<i>Commercial forestry</i> <i>Cleared commercial forestry</i> <i>Natural forests</i>
4 <i>Grasslands</i>	<i>Grasslands</i>
5 <i>Sugarcane</i>	<i>Sugarcane</i> <i>Cleared sugarcane</i>
6 <i>Waterbodies</i>	<i>Fresh waterbodies</i> <i>Saline waterbodies</i>
7 <i>Mines and quarries</i>	<i>Mines and quarries</i>

The training site locations for the different categories remained as spatially uniform as possible across the different images, with only small alterations being made to the training site polygons of the categories; *cleared cane, cleared commercial forestry and grasslands*, where it was not possible to have uniform polygons. This uniformity ensured consistency in the spectral signatures between the three different images and minimised apparent false changes in land cover resulting from different signature selections for the same land cover categories.

The classification process used a 'maximum likelihood' decision rule, which is one of the most accurate of the common decision rules (Eastman, 2001). This decision rule uses the mean and variance/covariance data of the signatures to determine the likelihood that each pixel belongs to a specific class. The probability of a pixel belonging to a class is highest at the mean position of the class and decreases in an elliptical pattern away from the mean (Eastman, 2001).

The three classified images were filtered with a statistical filter comprising a 3×3 pixel window size and the function set to median. This reduced the problem of individual misclassified pixels within uniform land cover areas (Schneider & Pontius, 2001; Daryaei, 2003; De Kok *et al.*, 2003).

The major rivers within the study site contained large riverbeds with stretches of open sand. As with the rivers making up the boundary of the study site, the open sand was confused with urban areas in the classification process, thus these rivers were digitized and automatically classified as *waterbodies* reducing the problem of misclassification and increasing accuracy.

Figure 4-6 below provides a flow diagram of the steps undertaken during the image classification process.

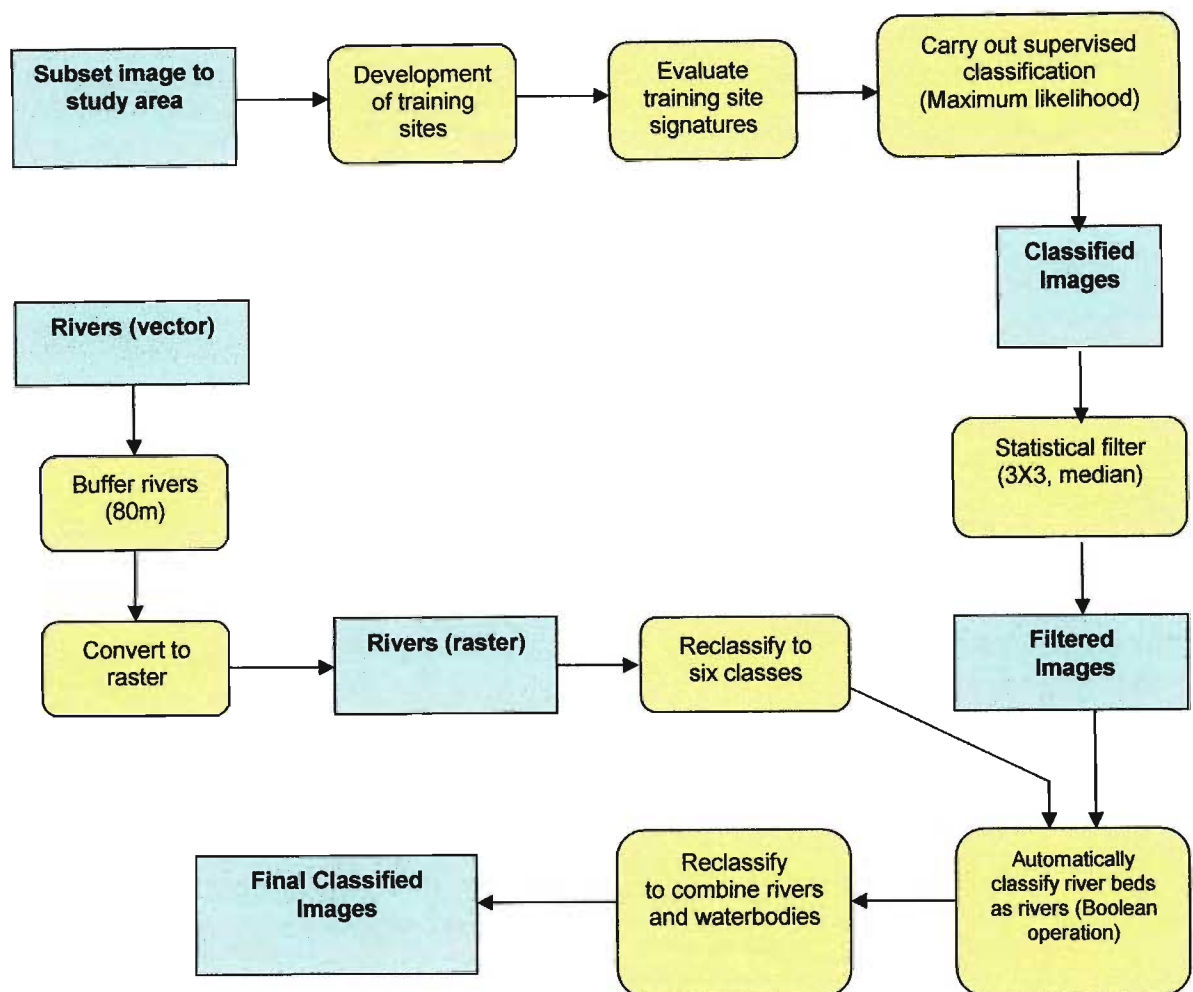


Figure 4-6 Flow chart of the steps undertaken during the classification process.

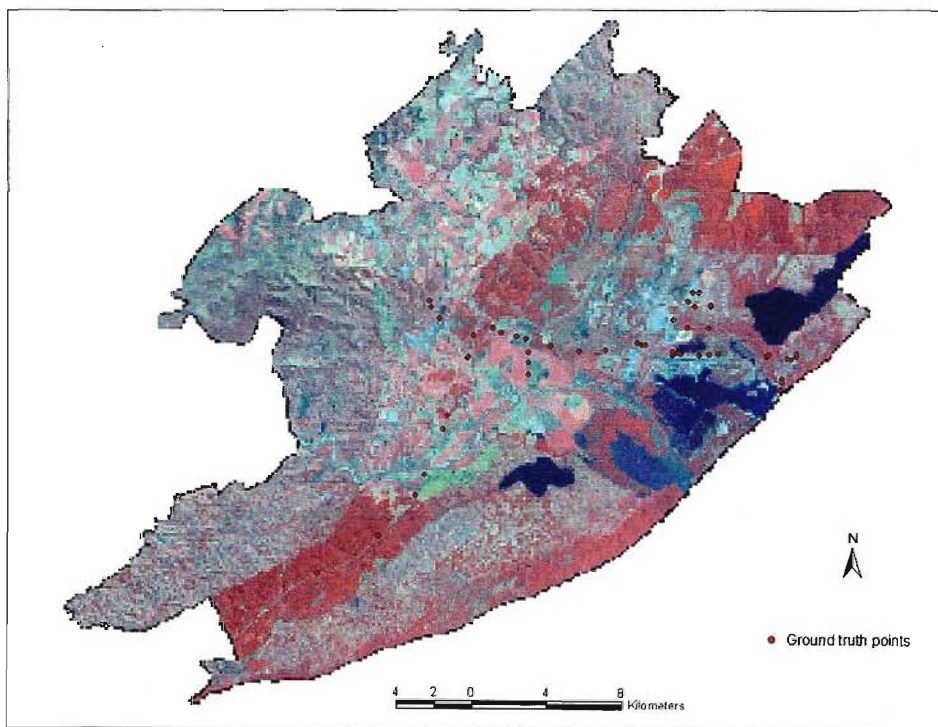
#### 4.3.2. Accuracy Assessment

An accuracy assessment was carried out to determine how accurately the classified images represent the true land cover of the uMhlathuze municipality (Dai & Khorram, 1998; Guild *et al.*, 2004). Such an assessment provides a means for the user to determine the confidence that one can gain from the classification results.

A lack of reference data for the years 1992 and 1997 rendered it impossible to carry out accuracy assessments of all three images. Consequently this was only attempted for the 2002 image, which although was also somewhat out of date (accuracy assessment points recorded in

early 2005), was considered, from personal observations, comparable to the present land covers in the uMhlathuze municipality. It was, however, essential that ground truth points were taken only in areas where there was a strong indication that the land cover had not changed since at least 2002. This lack of optimal reference data presented a limitation to the study but adequate measures were taken to reduce the impacts. It must also be noted that the study was as much about developing the techniques as it was about the accuracy of the final products.

With the use of a Global Positioning System (GPS), a total of 48 ground truth points were recorded in the uMhlathuze municipality where access was feasible (Figure 4-7). A larger number of points would have increased confidence in the accuracy assessment. However, time constraints prevented a larger number from being collected. At each point a true description of the actual land cover was recorded and compared to the land covers at these points on the classified image. Difficulty was experienced in attempting to obtain ground truth points for the land covers *waterbodies*, *commercial/industrial built-up land* and *mines and quarries*, as access to these areas was either restricted or problematic.



**Figure 4-7** Location of the ground truth points used in the accuracy assessment.

An error matrix was subsequently produced to compare the relationship between the known reference data (land cover recorded at the GPS points) and the corresponding pixels on the 2002 classified image on a category-by-category basis (Lillesand & Kiefer, 1994). From this, the errors of omission (exclusion), errors of commission (inclusion), and an overall accuracy were established.

#### **4.3.3. Change Detection**

Once the classification process was complete, the classified images were compared on a pixel-by-pixel basis to determine the quantity, location and direction of land cover changes. Firstly, all the pixels classified to each unique land cover class were summed to determine the changes in quantity and proportion during the two time periods, 1992 to 1997 and 1997 to 2002. Secondly, difference images were developed to establish the location of the changes and determine how many pixels changed from one land cover to another.

This was achieved through a layer subtraction in Image Calculator of the Spatial Analyst extension within ArcGIS 8.3 (ESRI, 2003) and gave unique values to all the possible class changes that could have taken place, This resulted in the creation of a change map consisting of pixel values ranging between 9 and 59, each number representing a different change from one land cover to another. From these results, change matrices were constructed to demonstrate the development of changes in the land cover classes.

#### **4.4. Land Use and Land Cover Change Modelling**

The final step of the analysis process involved the simulation of a predictive land cover image for the year 2012. This was achieved through the use of a land cover change simulation model named GEOMOD2, provided by Idrisi Kilimanjaro (Clarke Labs, 2003). The predicted image was based on the changes taking place between the 1992 and 2002 images. The 1992 image were chosen as this provided a ten year period and the model was set to predict changes over a



ten year period from 2002 to 2012. The years 1992 and 2002 also contained similar rainfall condition allowing readily comparable classification results.

GEOMOD2 simulates change between only two land cover classes, and therefore the land cover classes *forest and woodlands, grasslands, cultivated lands, waterbodies, and mining and quarries* were reclassified to *non-built-up* and the land cover classes *commercial / industrial built-up land* and *residential built-up land* were reclassified to *built-up*. A suitability image was created to stipulate where transformations could take place and was incorporated, along with other inputs, into the GEOMOD2 predictive change model.

It was assumed that the state in the year 2012 is dependant only on the state in the year 2002 and the transition probabilities, and that the history before the time period of the study has no effect. Secondly, it is assumed that transition probabilities remain stationary and are not random over the predicted time period between 2002 and 2012. These assumptions are necessary for all Markov based land cover change models (Baker, 1989; Cheng, 2000).

#### **4.4.1. Creation of the Suitability Image**

A suitability image was created to influence the spatial increase of the *built-up* land cover class. This image is used as a decision rule designed to guide the model to predict land cover changes according to realistic system behaviour (Wu & Webster, 2000).

The suitability image was developed from criteria deemed important in determining the appropriateness of a pixel to support the *built-up* land cover. It influences how, and in which areas, the *built-up* land cover will increase. The choice of criteria was based on previous studies (Hall *et al.*, 1995a; Deal, 2001; Parker *et al.*, 2003; Barredo *et al.*, 2004; Yang & Lo, 2003), the availability of data and the ability of the model itself. The criterion used was the uMhlathuze municipality's demarcation of urban zones, and the constraints, or areas to be excluded, included large waterbodies, areas within a proximity of 40 m to the centre of large rivers and areas zoned as either wildlife sanctuaries or other protected areas.

The suitability image was created using Multi-Criteria Evaluation (MCE) in the IDRIS software package, which incorporates the criteria and constraints to achieve a single composite raster image on which one can base a decision (Eastman, 2001). The image was then incorporated in to the GEOMOD2 model.

#### 4.4.2. GEOMOD2

The land cover change suitability model GEOMOD2 was used to predict a one-way change from the land cover state *non-built-up* to the land cover state *built-up*. The inputs for this model included:

- The beginning date (2002) and the end date (2012);
- An image containing the locations of the two land cover states in the year 2002 (created from the 2002 classified image);
- An image mask illustrating the boundary of the study area;
- A map of suitability for the transition from *non-built-up* to *built-up*; and
- An estimation of the quantity of land under the cover of *built-up* and *non-built-up* at the ending time.

The quantity of land predicted to be under *built-up* land cover in 2012 was developed from the expansion rate that took place during the previous ten years, from 1992 to 2002. The results of the classifications described in section 4.3.1 reveal that in 1992 the total number of pixels under *built-up* land cover was 83 658, and in 2002 it was 103 822 giving an expansion rate of 19.4% over the ten year period. It is presumed that a similar growth trend will continue, in which case the number of hectares under *built-up* land cover in the year 2012 can be expected to be 123 986 following the expansion rate of 19.4% over the ten year period, as illustrated in Table 4-3.

**Table 4-3 Number of pixels under *built-up* land during the relevant years**

Year	<i>Built-up</i> Pixels	Expansion Rate
1992	83658	
2002	103822	19.4
2012	123986	19.4

Figure 4-8 illustrates how the different processes involved in creating the predictive 2012 image fit together.

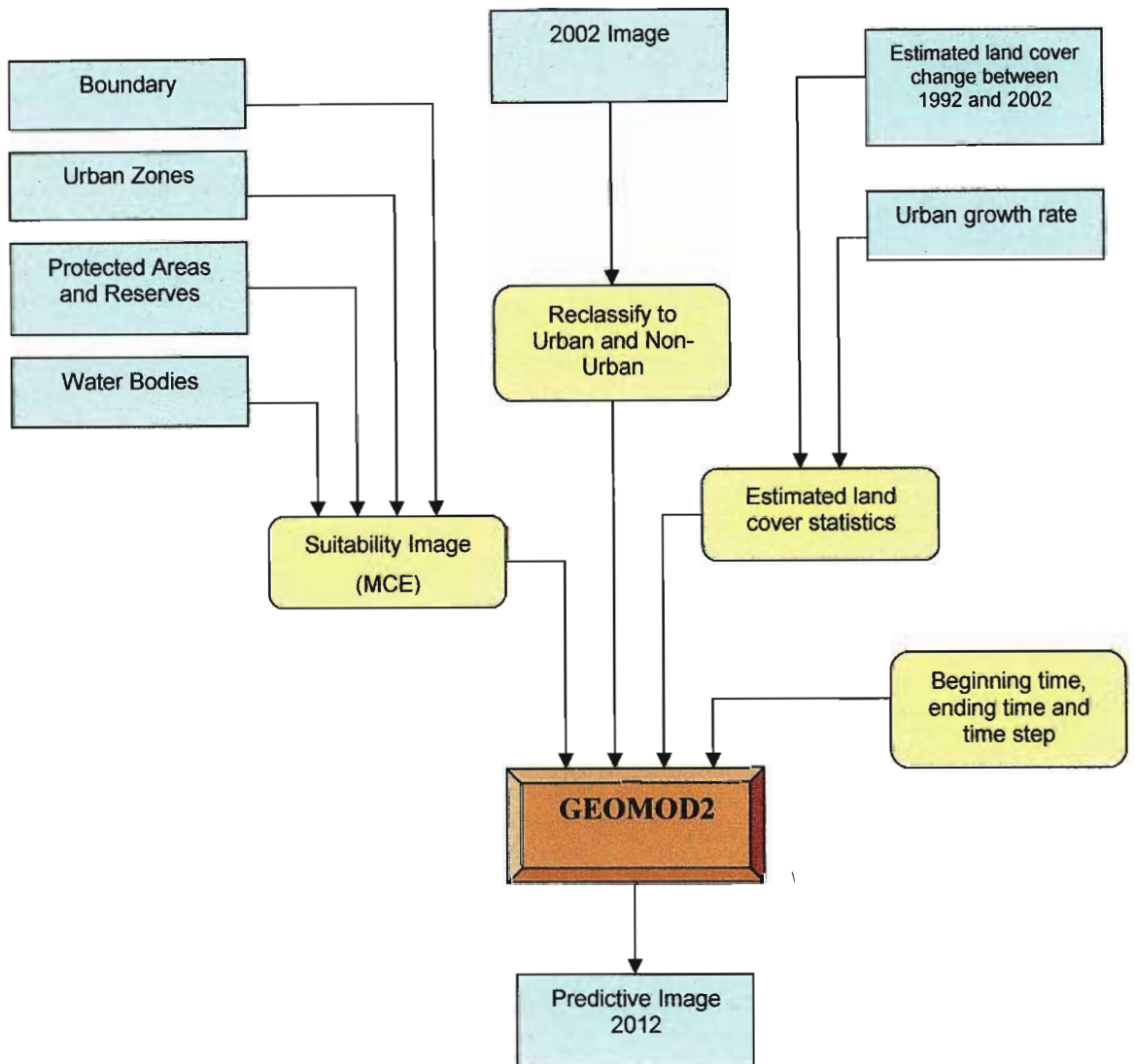


Figure 4-8 Flowchart of the steps undertaken during the predictive modelling section.

#### 4.4.3. Model Validation

Since there is no reference image available for the year 2012, the model was validated using the available images. A simulated image was created for 2002 using the 1992 image as the base image, the same suitability image used in the 2012 simulation and the known quantity of

changed pixels between 1992 and 2002. This image was compared to the empirical image of 2002 to determine the accuracy of the prediction. The VALIDATE function in Idrisi (Clarke Labs, 2003), was employed for this because it uses the Kappa statistic to compare the percent success of the image simulated through GEOMOD2, to the expected percent success as a result of change alone (Eastman, 2001; Pontius *et al*, 2001).

#### **4.5. Summary**

This chapter has described the data and data preprocessing, and the methods used to achieve the objectives of the research. Firstly, the three satellite images representing 1992, 1997 and 2002 underwent a preprocessed stage to ensure comparability in both the spectral and spatial domains. Secondly, the satellite images were classified through a supervised classification system, using predetermined land cover classes. The accuracy of the classification was assessed using an error matrix. Thirdly, the three classified images were applied to a 'post classification change detection' technique to determine the locations, extent and quantity of changes in land covers which had taken place in the study area during the duration of the study.

The final stage involved determining the likely future extent of built-up land cover in the year 2012 with the use of a Land Use and Land Cover Change (LUCC) model, GEOMOD2. This involved firstly, the creation of a suitability image through a MCE method to influence the location changed pixels, secondly, the estimation of the likely quantity of built-up land cover in 2012 derived from historical trends and population statistics and finally, running the model to produce an image showing the likely location of urban land cover in 2012.

It was intended that the processes outlined above will provide an indication of the land cover changes that took place within the uMhlathuze municipality between 1992 and 2002, and will provide a good simulation of the likely extent and location of the *built-up* land cover in the year 2012. It is also intended that the effectiveness of the methods to evaluate the land cover changes in the uMhlathuze municipality will be determined.

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## APPENDICES

Appendix 1 Table showing the land covers represented by the accuracy assessment ground truth points  
(In the match column, a one symbolizes a correct match and a two symbolizes an incorrect match)

<b>WP no.</b>	<b>Ground Truth</b>	<b>Classification</b>	<b>Match</b>
5	forestry	forestry	1
6	forestry	forestry	1
7	grasslands	grasslands	1
8	sugarcane	sugarcane	1
9	forestry	grasslands	2
10	forestry	grasslands	2
11	forestry	grasslands	2
12	sugarcane	forestry	2
13	sugarcane	sugarcane	1
14	sugarcane	industrial	2
15	sugarcane	sugarcane	1
16	sugarcane	sugarcane	2
17	forestry	forestry	1
18	forestry	forestry	1
19	forestry	forestry	1
20	forestry	grasslands	2
21	grasslands	industrial	2
22	industrial	industrial	1
24	waterbodies	industrial	2
25	industrial	industrial	1
26	industrial	industrial	1
27	forestry	forestry	1
28	forestry	forestry	1
29	residential	residential	2
30	residential	residential	1
31	grasslands	residential	2
32	residential	residential	1
33	residential	residential	1
34	residential	residential	1
35	industrial	industrial	1
36	grasslands	residential	2
37	grasslands	grasslands	1
38	grasslands	grasslands	1
39	residential	residential	1
40	industrial	Industrial	1
41	industrial	Industrial	1
42	industrial	residential	1
43	grasslands	sugarcane	2
44	grasslands	grasslands	1
45	grasslands	residential	2
46	grasslands	grasslands	1

47	grasslands	grasslands	1
48	sugarcane	sugarcane	1
49	sugarcane	sugarcane	1
50	sugarcane	sugarcane	1
51	industrial	industrial	1
52	industrial	industrial	1
53	residential	grasslands	2

**An Assessment of Land Cover Changes Using GIS and Remote  
Sensing: A Case Study of the uMhlathuze Municipality, KwaZulu-  
Natal, South Africa**

**Thomas Robson, Fethi Ahmed, Trevor R. Hill**

## ABSTRACT

Rapid growth of cities is a global phenomenon exerting pressure on land resources and causing associated environmental and social problems. Addressing such problems through sustainable use of land resources has become a pertinent issue since the Earth Summit in Rio de Janeiro in 1992. An informed understanding of the processes and patterns of land cover change will aid urban planners and decision makers in guiding environmentally conscious development. The objective of this study was firstly, to determine the location and extent of land use and land cover changes in the uMhlathuze Municipality, KwaZulu-Natal, South Africa between 1992 and 2002 with the use of GIS and remote sensing, secondly, to predict the likely expansion of urban areas for the following ten years, and thirdly, to ascertain the usefulness of the techniques as tools for urban planners and policymakers. The uMhlathuze Municipality has experienced rapid urban growth since 1976 when the South African Ports and Railways Administration built a deep water harbour at Richards Bay, a town within the Municipality. Three Landsat satellite images were obtained for the years, 1992, 1997 and 2002. These images were classified into six classes representing the dominant land covers in the area. A post classification change detection technique was used to determine the extent and location of the changes taking place. Thereafter, a GIS-based land cover change suitability model, GEOMOD2, was used to determine the likely distribution of urban land cover ten years later, in 2012. The model was validated using the 2002 image. Sugarcane was found to have expanded by 129% between 1992 and 1997. Urban land covers had increased by an average of 24%, whilst *forest and woodlands* had decreased by 29% between 1992 and 1997. Variation in rainfall during the study years and diversity in sugarcane growth states had an impact on the classification accuracy. Overall accuracy in the study was 74% and the techniques gave a good indication of the location and extent of changes taking place within the study site, and show much promise in becoming a useful tool for regional planners and policy makers.



## 1. Introduction

### 1.1 Context

The United Nations Population Division (UNPD) (2002) estimate that the vast majority of population growth expected over the next 30 years will occur in urban areas; that half the world population will live in urban areas by 2007 and that the major population increase between the years 2000 and 2030 will be absorbed by the urban areas of less developed countries.

The expansion of urban areas brings dramatic changes in land cover and land use resulting in a wide range of environmental impacts. These include soil erosion, reduction in water quality, reduced plant biodiversity and pollution (Lubowski *et al*, 2003; Bergeron & Pender 1999). Land cover changes are also closely linked to global environmental change (Turner and Meyer, 1991), and can result in a decline or loss of spatial extent and connectivity of wildlife habitats (Leao *et al*, 2004), leaving landscapes fragmented, and reducing the distribution of many species to small isolated populations (Wu *et al*, 2003). Furthermore, many impacts of land cover change, such as land disturbance, formation of urban heat islands and modifications in nutrient dynamics, will alter local climates, often preventing re-habitation of the original species (Zipperer *et al*, 2000).

Although there is a paucity of detailed studies dealing with urban ecosystems (Wu *et al*, 2003), they play a number of important roles, such as air filtration, reduction of pollution, climate regulation and sewerage treatment (Elmqvist *et al*, 2004), all of which play a vital role in sustaining a healthy living environment and preserve ecological processes. Barredo *et al* (2004) point out that urban areas have to maintain an equilibrium between economic activities, population growth, and pollution and waste so that the urban system and its dynamic processes can evolve with minimal impacts on the environment. Deal (2001) extends this point and explains that ecological urban sustainability requires the implementation of ecologically sound alternatives to current practices.

Verburg *et al* (2004) discuss five dominant determinants of land use change: spatial policies, economic factors, biophysical constraints and potentials, social factors and spatial interactions. These factors interact to produce prevailing patterns of land uses and must be considered in determining the future course of land use changes.

Braissoulis (2001) notes that the relationship between land cover changes and large-scale environmental problems, such as climate change, has elevated the field as an important subject of policy disciplines. The expanding relevance of the field has also increased the need for research into the analysis of land use and land cover change as a step towards mitigating future environmental disasters. The development of both methods of analysis and data will lead to more informed decision-making for both planners and policy-makers alike (Herold *et al*, 2003).

Land use and land cover changes take place in response to a variety of factors stemming from human needs and wants. These influence the extent, pattern and rate of such changes at both the macro and micro level, and accordingly need consideration in any study of land use and land cover changes. Furthermore, studies should conceptualise the interactions among the driving forces of land-use change, their mitigating procedures and human behaviour and organisation (Verburg *et al*, 2004), and should not be viewed independently of the driving forces underlying the motivation for such changes.

### *1.2 Land Cover Change Detection*

The use of Geographic Information Systems (GIS) and remote sensing enables analysis of the spatial components of the earth's surface. Remotely sensed imagery, firstly, allows for detailed and consistent measurements on the earth's surface conditions at high temporal frequencies (Gibson, 2000), and secondly, allows for easy differentiation between land covers based on their reflectance values, and hence can reveal areas that have undergone changes in land cover over time. Remotely sensed imagery has been used extensively for land cover applications such as the analysis of land cover dynamics, damage mapping, risk assessment, urban

expansion assessment and ecosystem monitoring (Bruzzone & Cossu, 2002; Civco *et al* 2002; Weng 2002; Chen *et al* 2003; Coppin *et al*, 2004).

For temporal studies it is crucial that satellite imagery undergo a preprocessing stage to ensure consistency between the reflectance values and registration of the different images in the time sequence. This stage entails the corrections of radiometric and atmospheric deficiencies and the removal of flaws (Mather, 1989). For temporal change studies this stage involves image registration to ensure comparability between dates (Lu *et al*, 2004). Using similar dates for the anniversary images increases the comparability of the images by improving the likelihood of similar sun angles, soil moisture condition and plant phenological state (Singh, 1989; Jensen, 2000).

### *1.3 Predictive Change Modelling*

Land Use and Cover Change LUCC models are effective tools designed to analyse the consequences and causes of land use dynamics, to aid in investigating and understanding landscape processes and to analyse the underlying socio-economic processes (Verburg *et al*, in press). Most LUCC models are developed from a GIS base and have been applied to various applications. These include urban growth, the analysis of interactions of natural processes, the spatial consequences of policy decisions and proposed management strategies, agricultural expansion, deforestation and the effects of land use on the release of carbon into the atmosphere (Baker, 1989; White & Engelen, 1993; Hall *et al*, 1995; Pontius *et al*, 2001; Barredo *et al*, 2004).

Most LUCC models utilize Cellular Automata as a fundamental component allowing them to model changes on a spatial plane. The process of Cellular Automata is based on a lattice framework of congruent cells (Parker *et al*, 2003) relating well to spatial analysis. Land conversion takes place through a series of transitions in which pixels change from one land cover to another according primarily to the land cover of the neighbouring pixels (Toffoli & Margolus, 1987). All the pixels are interdependent relational entities updated simultaneously as the lattice develops in discrete time steps (Deal, 2001). Transition rules that reflect the

drivers such as land suitability, urban zones and protected areas, guide these conversion by determining the likelihood of each pixel to undergo change.

The majority of LUCC models, especially those designed for urban growth, have been produced in developed countries, particularly the United States, where there is both the expertise and the necessary data (Leao *et al*, 2004). As noted earlier, it is likely that the less-developed countries will experience the majority of urban growth and consequently such models have important application in these regions. However, Leao *et al* (2004) point out that urban growth in developed and developing countries often takes place in different patterns, which may impact the effectiveness of such models to developing countries.

This study used the GIS-based model GEOMOD2 (Pontius *et al*, 2001), which predicts the likely locations of land cover changes from one class to another. The model is primarily based on Markov Chain Analysis and Cellular Automata, and simulates the spatial patterns of land use change based on the patterns of biogeophysical attributes and existing land uses derived from digital raster maps. (Hall *et al*, 1995). The predictive model simulates the pattern and locations of land use change and not the quantity, which must be obtained from another source.

## 2. Study Site

The uMhlathuze Municipality is situated on the north coast of KwaZulu-Natal, South Africa between latitudes 28°37'S and 28°57'S, and longitudes 31°42'E and 32°09'E (figure 1). It comprises the towns and settlements of Richards Bay, Empangeni, Esikhawini, Ngwelezane, Nseleni, and Felixton (Anon, no date).

The uMhlathuze Municipality covers an area of 796 km<sup>2</sup>, with a population of 296 339 at an average of 372 people per km<sup>2</sup>. An estimated 169 008 of these people are resident in urban areas and 41% are between the ages of 15 and 34 years. The total unemployment rate in the area is 41%, although this figure only relates to the formal sector. (Anon, no date)

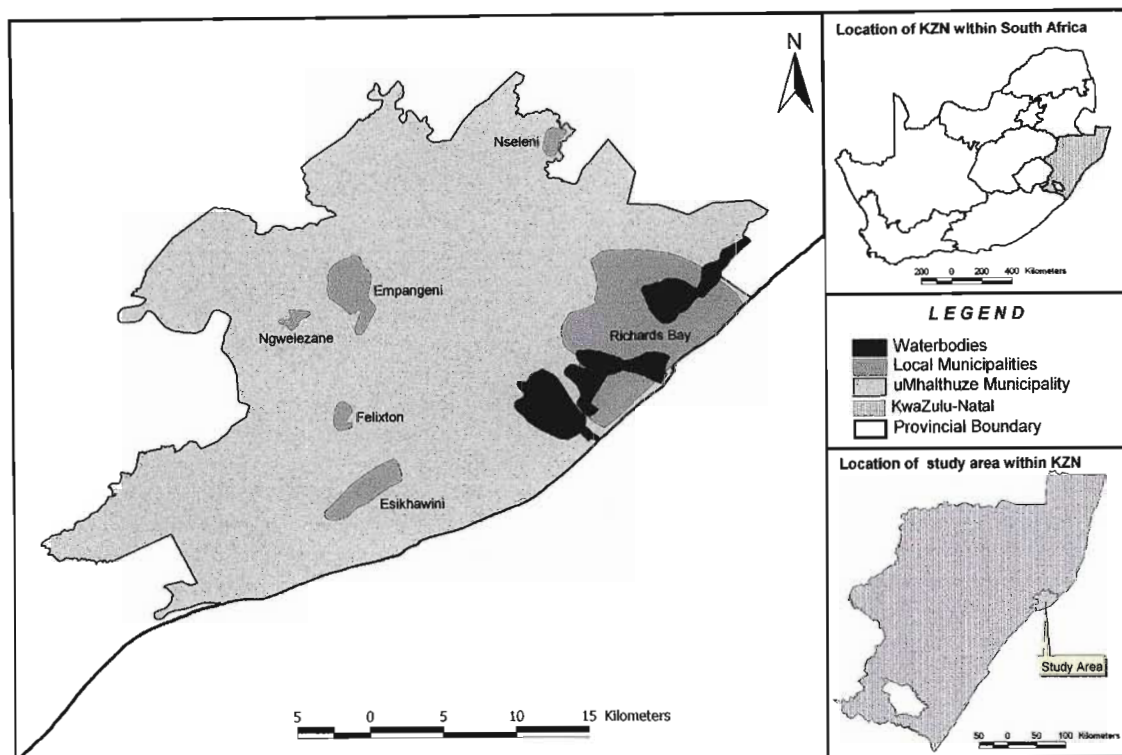


Fig 1. Location of urban areas, settlements and lakes in the uMhlatuze Municipality.

The uMhlatuze Municipality is recognised as having high conservation significance in terms of biodiversity (uMhlatuze IDP, 2002) and is situated within the Maputaland Centre of Endemism (van Wyk & Smith, 2001). The dune ridge running along the coast is considered a particularly important corridor for genetic exchange between members of certain species from different biogeographical units. This is the only remaining passageway as the majority of inland vegetation has been converted to sugar cane (uMhlatuze IDP, 2002).

The Town of Richards Bay has a scattered structure with many of the large industries sparsely distributed within areas of natural vegetation, lakes and wetlands. This allows for habitat connectivity between the industries. Similarly, the many settlement areas within the Municipality comprise well-spaced settlements with patches of subsistence crops and grassland between the dwellings. Often there are no streets and only footpaths between dwellings.

In the late 1960s, the town of Richards Bay was transformed from a small fishing village when South African Railways and Harbours Administration acted on the need to build a deep-water harbour on the eastern coast of South Africa to accommodate large vessels. The development of the town was part of a National Development Plan linking the harbour to inland developments by rail (Department of Planning, 1972). Following this, the area underwent rapid transformation with the growth of urban areas, containing large industrial, commercial and residential components. The town has become an important growth node as a consequence of several government-driven economic policies over the years, including the decentralisation policy during the Apartheid years and the Spatial Development Initiative (SDI) programme in more recent times (Hall, 2000).

Changes in the uMhlathuze Municipality are a consequence of both First and Third World processes. Richards Bay is based on an industrial foundation with large extractive industries as described above, supporting an affluent society in the formal sector. However, Richards Bay also contains a very large element of what Hall (2004) describes as a *city coping with informal hypergrowth*. Many cities in sub-Saharan Africa fall into this category and are characterised by rapid population growth from migration and natural increase and supporting economies heavily dependent on the informal sector. Such cities contain extensive informal housing areas, with widespread poverty and environmental and health problems. Richards Bay contains both the formal and informal sectors integrated together to provide the prevalent trajectories of growth.

The uMhlathuze Municipality has experienced much of its growth through urban sprawl with scattered low-density housing in informal settlements surrounding Richards Bay. The large industrial base attracts many people to the area with the prospect of possible jobs and they seek accommodation in the informal housing market. Barredo *et al* (2004) point out that when population growth takes place in loosely planned urban structures, environmental and social consequences can be significant, particularly in areas that have undergone rapid growth. Since, in most developing countries, urban development is concentrated on the needs of the poor (Robinson *et al*, 2004), environmental considerations are often neglected if not properly planned for.

### 3 Methods

#### 3.1 Data

Three Landsat satellite images representing the years 1992, 1997 and 2002 were obtained for the months of July, August and October respectively. Landsat -5 and -7 were used as they provide imagery at a 30m spatial resolution in the multi-spectral bands. The images were from as similar seasons as possible to maintain consistency of environmental variables and reduce problems resulting from seasonal changes, such as different sun angles and changes in plant phenology (Singh, 1989; Jensen, 2000). To ensure comparability and to prevent spatial errors occurring during the analysis process, the three images were re-projected to a Transverse Mercator projection with a Cape datum and a Clarke 1880 spheroid. They were then geometrically corrected and co-registered to represent precisely the same areas on the ground. Further pre-processing of the images, such as radiometric calibration has been carried out prior to my receiving them.

The images were subset to the uMhlathuze municipal boundary without including coastal sand, since this had undergone minimal changes during the study period, and the low reflectance of sand caused confusion with the urban land covers in the classification process. For the same reason, large riverbeds on the inland boundaries of the Municipality were excluded.

#### 3.2 Land Cover Change Detection

Several methodologies and algorithms have been devised for land cover change detection (Singh, 1989; Jensen, 2000; Coppin *et al*, 2004). Choice of these depends primarily on biophysical characteristics of the study site and the precision of the image registration (Jensen, 2000). For this Study, a 'post classification comparison' change detection technique (Singh, 1989) was used, due to the variability in rainfall in the study area and use of imagery from different Landsat satellite series. This technique involves the comparison of independently produced classified images, and hence reduces the impacts of the factors mentioned above.

Furthermore, by classifying the images separately one minimises the need for accurate radiometric calibration between different dates (Coppin *et al*, 2004). However, such an approach relies on the accuracy of the initial image classifications as misclassifications at this stage are compounded when multiple images are compared (Jensen, 2000).

A combination of bands 2 (green), 3 (red) and 4 (near infrared) were found to be the most suitable to distinguish between the relevant land features, and have been used for such land features in similar studies (Weng, 2002; Zha *et al*, 2003). Classification was carried out with a 'supervised classification' process using a 'maximum likelihood' decision rule, which divided the area into land cover classes based on the spectral properties of user defined training sites. The training sites were developed and verified with the aid of recent land use maps, aerial photographs and visits to the study area. The three satellite images were classified separately using consistent land cover classes developed from the South African land cover classification scheme (Thompson, 1996).

A total of seven classes was chosen to avoid complications arising from too many classes whilst still depicting the relevant differences in land cover. The categories were; *commercial / industrial built-up land*, *residential built-up land*, *forest and woodlands* (comprising both natural forest and commercial forestry), *grasslands*, *sugarcane*, *waterbodies*, and *mines and quarries*. The classified images were filtered with a 3 x 3 statistical filter to reduce individual misclassified pixels within uniform land cover areas. In addition, large rivers in the area were digitized and automatically classified as *waterbodies* as the sand in the river caused confusion in the classification as stated earlier.

An accuracy assessment was only attempted for the 2002 image due to a lack of earlier reference data. This image itself was to some extent out of date (study carried out in early 2005), but, from personal observations, it was considered comparable to the present land covers in the uMhlathuze Municipality. Consequently, it was critical that ground truth points were only taken in areas where it was presumed the land cover had not changed since 2002. A total of 48 ground truth points was recorded with the use of a Global Positioning System



(GPS). The sample was attempted to be both representative and random but was limited by access, security and time constraints.

Classified images were compared on a pixel-by-pixel basis, difference images and change matrices were produced to determine the locations, rate and extent of changes.

### 3.3 Predictive Change Modelling

A GIS-based land cover change model GEOMOD2 was used to produce a predictive image for the year 2012 showing the likely extent of urban land covers. The output image was based on the location of land covers in 2002 and the changes that took place between 1992 and 2002.

The model simulates change between only two land cover classes and therefore the classes used in the change detection section were combined together to form two appropriate classes. The classes *forest and woodlands*, *grasslands*, *sugarcane*, *waterbodies*, and *mining and quarries* were reclassified to *non-built-up* and the land cover classes *commercial / industrial built-up* and *residential built-up* were reclassified to *built-up*. The class *mining and quarries* was included in the *non-built-up* class, as it did not represent an urban land cover.

A suitability image was created to stipulate the areas most likely to undergo transformations. This image is an important decision rule in the model designed to guide the model to predict land cover changes according to realistic system behaviour (Wu & Webster, 2000). The choice of criteria was based on previous studies (Hall *et al*, 1995; Deal, 2001; Parker *et al*, 2003; Barredo *et al*, 2004; Yang & Lo, 2003), the availability of data and the ability of the model itself. The criterion used was the uMhlathuze Municipality's demarcation of urban zones, and the constraints included large waterbodies, areas within a proximity of 40 m to the centre of large rivers and areas zoned as protected. These factors were integrated with a Multi-Criteria Evaluation (MCE) process to produce a single composite raster image for input into the model.

The quantity of land predicted to be under *built-up* land cover in 2012 was calculated from the expansion rate that took place between 1992 and 2002 as observed in the classified images of these dates.

Model validation was carried out using a simulated image for 2002 since there was no reference image for 2012. This image was created using the 1992 image as the base image, the same suitability image used in the 2012 simulation and the known quantity of changed pixels between 1992 and 2002. This image was then compared to the 2002 reference image using the VALIDATE function in Idrisi (Clarke Labs, 2003).

## 4. Results

### 4.1 Classification

The classification results indicate the distribution of the land covers in the three years (figures 2 to 4). It is likely that seasonal differences in the images (1992 in July, 1997 in August and 2002 in October) impacted this process due to different growth states of the vegetation classes. Waterbodies in the study area generated a large variety of reflectance values, due to different depths, salinity and clarity levels and extent of vegetation cover. To avoid confusion with other classes, these areas were digitised and automatically classified as *waterbodies*.

In several areas sugarcane had been harvested, leaving fields with bare earth generating similar reflectance values to urban areas. To reduce this problem several sugarcane classes were created to represent the different levels of sugarcane cover, and these were grouped to form one single *sugarcane* class. Nevertheless, a few dispersed urban class pixels still remained in *sugarcane* areas and correspondingly a few dispersed *sugarcane* pixels appeared in urban areas.

### 4.2 Accuracy Assessment

An error matrix was created to determine the classification accuracy (table 1) of which the results are provided in table 2. The overall accuracy was 74% indicating that the accuracy was

moderately good and that 74% of the overall classification is likely to be correct. However, the result was not at the minimum standard stipulated by the USGS classification scheme of 85% (Anderson *et al.*, 1976).

The producer's accuracy had a wide range between the different classes from 100% for *sugarcane* and *residential built-up* to 55% for *grasslands*. The classes *sugarcane* and *residential built-up* were thus accurately interpreted and can be easily mapped on the earth's surface. The classes *grasslands* and *commercial/industrial built-up* can be mapped with less confidence. The user's accuracy also varied greatly between classes from 64% in the *forest and woodlands* class to 100% in the *commercial/ industrial built-up* class. This result indicates that the classes *commercial/industrial built-up* and *residential-built-up* successfully represent what users of the data can find on the ground (Story & Congalton, 1986).

Table 1 Classification error matrix for the 2002 classified image

		Classified image						
		F	S	G	R	C/I	W	Total
Reference image	F	7		4				11
	S	1	7			1		9
	G			6		4		10
	R			1	6			7
	C/I					9		9
	W					1		1
	Total	8	7	11	6	15	0	47

F -forest and woodlands                      R -residential built-up  
 S -sugarcane                                      C/I -commercial/industrial built-up  
 G -grasslands                                      W -waterbodies

Table 2 Statistical results from the classification error matrix of the 2002 classified image

Land cover	Producer's accuracy	User's accuracy
F	88%	64%
S	100%	78%
G	55%	60%
R	100%	86%
C/I	60%	100%

$$\text{Overall accuracy} = (7 + 7 + 6 + 6 + 9) / 47 = 74\%$$

#### 4.3 Post Classification Change Detection

Classified images of the study area cover a total of 79 026 ha and contain the classes *commercial/industrial built-up land*, *residential built-up land*, *forest and woodlands*, *grasslands*, *sugarcane*, *waterbodies* and *mines and quarries*. The 2002 image is the only one that contains the *mines and quarries* class, since mining in the area began after 1997. Figures 2, 3 and 4 illustrate the location and extent of the land cover classes in the years 1992, 1997 and 2002 respectively. The number of ha covered by each of the land covers and their respective proportions are presented in table 3. Figure 5 illustrates the land cover changes graphically.

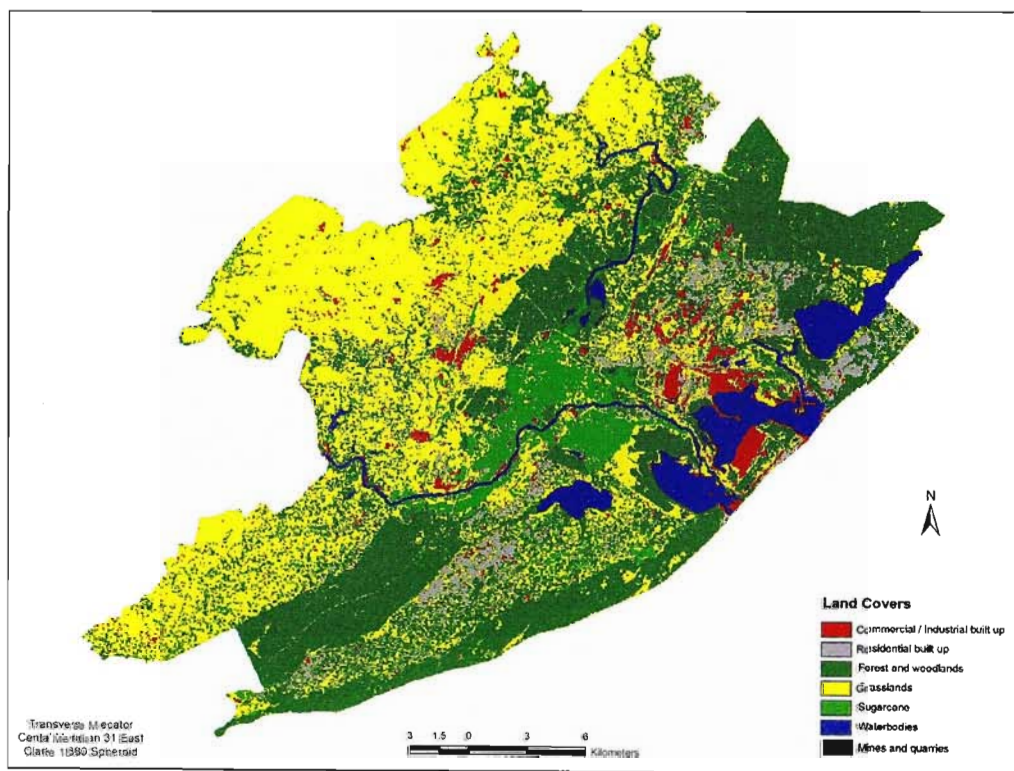


Fig. 2. Classified image of the uMhlathuze Municipality in 1992.

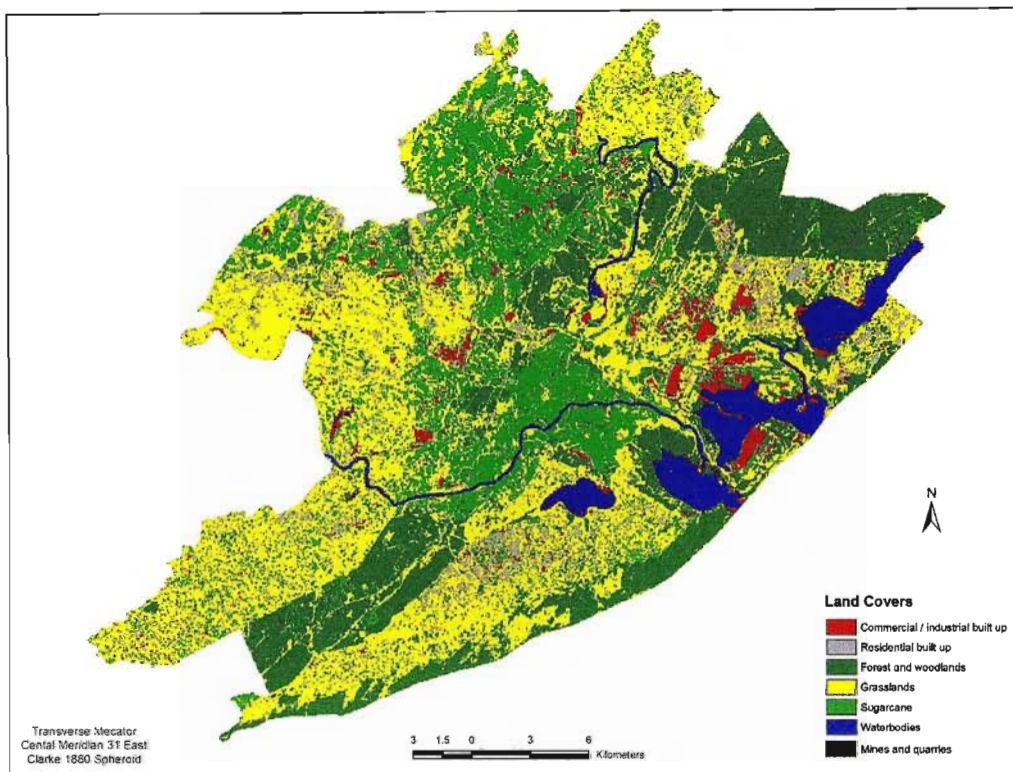


Fig. 3. Classified image of the uMhlathuze Municipality in 1997.

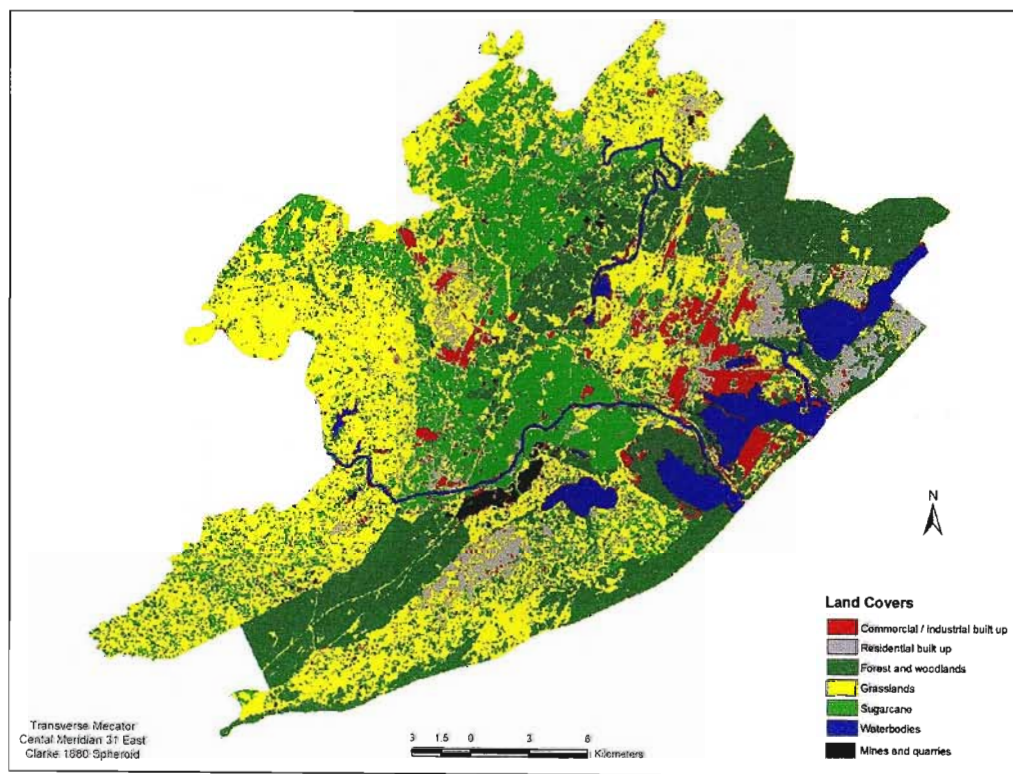


Fig. 4. Classified image of the uMhlathuze Municipality in 2002.

Figure 3 clearly shows that the uMhlathuze Municipality has undergone considerable change during the ten years of the study and most of this change occurred between 1992 and 1997. The biggest change was found in the *sugarcane* class, which increased by 8114ha (129%) between 1992 and 1997 but then decreased by 1146 ha (8%) between 1997 and 2002. *Commercial/industrial built-up land* experienced an overall increase from 1992 to 2002 of 611ha, a growth of 23%. *Residential built-up land* increased between 1992 and 2002 by 1204 ha, a growth of 25%. The *forest and woodlands* class underwent a large decrease from 1992 to 1997 of 8098 ha (29%). It then increased by 838 ha (4%) from 1997 to 2002. *Grasslands*, although shifting spacially, remained fairly constant in terms of overall quantity with a small decrease of 2206 ha (7%).

Table 3 Area, change and percentage change of the land covers in the three study years

	1992	Change (92-97)		1997	Change (97-02)		2002	Change (92-02)	
	(ha)	Change (ha)	% of 1992	(ha)	Change (ha)	% of 1997	(ha)	Change (ha)	% of 1992
C/Industrial built-up	2653	-103	-4	2550	714	28	3264	611	23
Residential built-up	4876	460	9	5336	744	14	6080	1204	25
Forest & woodland	27930	-8099	-29	19832	838	4	20670	-7260	-26
Grasslands	32855	-228	-1	32628	-1979	-6	30649	-2206	-7
Sugarcane	6314	8113	128	14428	-1146	-8	13282	6967	110
Water bodies	4397	-144	-3	4253	263	6	4516	119	3
Mining	0	0		0	565		565	565	
Total	79026			79026			79026		

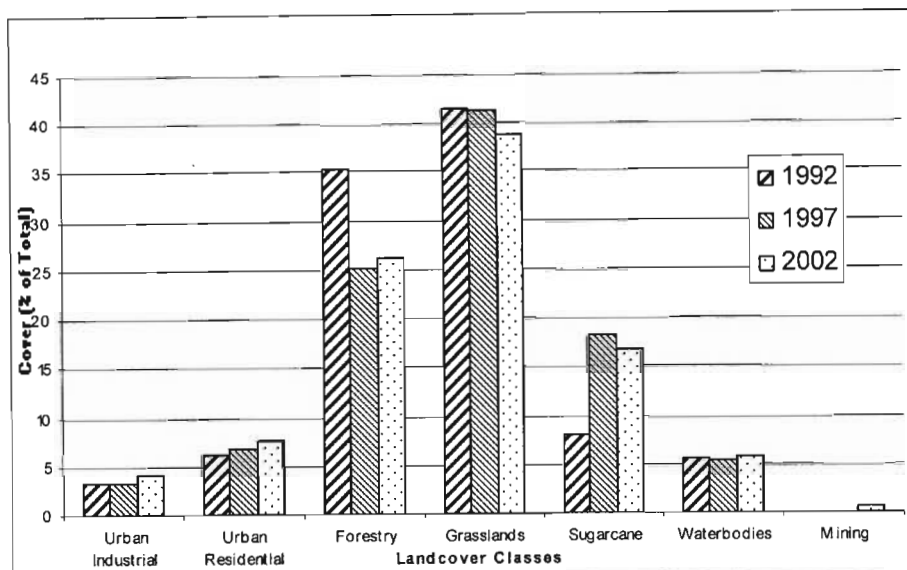


Fig. 5. Graphical representation of the land cover changes in the uMhlathuze Municipality between 1992 and 2002.

The large increase in *sugarcane* between 1992 and 1997 (129%) is concentrated in the area to the north of Empangeni. It is primarily a consequence of the Heatonville irrigation scheme, developed by Tongaat-Hulett's in 1994, which allowed for a large area previously under the rain shadow of a mountain range to be irrigated cost effectively (Fortman, 2005 pers comm.). Agriculture that relies on irrigation has many environmental impacts in terms of water resources, such as the depletion of supplies to downstream areas, modified flow regimes and re-channeling of stream networks. An increase in small-scale cane growers in South Africa in recent years (Maloa, 2001) may have impacted on this result.

The results of the change matrices (Appendix A) reveal that much of the land converted to *sugarcane* was formerly *grasslands* (7 704 ha) and *forest and woodland* (1 782 ha). This suggests that the expansion of sugarcane has reduced the extent of Coastal Bushveld-Grassland vegetation type, which had already been greatly transformed by agriculture (Low & Rebelo, 1998).

The *commercial/industrial built-up* and *residential built-up* land covers showed average increases of 23% and 25% respectively over the ten year period. There is clear evidence of expansion of *residential-built up* areas in the northern parts of Richards Bay and in the township areas of Esikhawini and Felixton, in the southern part of the Municipality. The

industrial nature of Richards Bay demands large labour resources, which, when coupled with high levels of poverty in surrounding areas, draws many people to the area. The increase in *commercial industrial built-up* is mainly concentrated around the harbour and the town centre of Richards Bay. Industries are attracted by economic policy, the deep-water harbour and good industrial infrastructure.

In the case of *forest and woodlands*, this class demonstrated a substantial decrease between 1992 and 1997 of 8 098 ha (29%), followed by a small increase of 838 ha (4%) between 1997 and 2002. The change matrices (table 4) confirms that most of the forest and woodland areas were converted to grasslands (8 367 ha) and sugarcane (1 782 ha) during the study period. There is clear evidence, along the coast in the southern regions of the uMhlathuze Municipality, that large tracts of natural forest have been converted to grasslands. Clearing of forest patches is common practice in South Africa where wood is cut for fuel and to increase grazing capacity.

The change matrices (table 4) revealed that many areas changed from both *grasslands* to *forest and woodlands* (119 ha) and from *forest and woodlands* to *grasslands* (279 ha). This indicates that spatial shifting has occurred. In some areas, forest patches have expanded into the grasslands while in others, forests patches have either died back, been cleared or converted to grasslands. Forest expansion in South Africa is often the result of the invasion of alien trees such as *Eucalyptus* and *Acacia* species. These plants negatively transform ecosystems by consuming resources excessively and altering microclimates, in turn changing biochemical cycles (Richardson & van Wilgen, 2004).

Open cast titanium mining began in the Municipality in 2001 and therefore is only evident in the 2002 image. The mining operations cover an area of 565 ha (0.7% of the total Municipality), which was previously sugarcane or and grasslands (198 ha and 224 ha respectively).



#### 4.4 Predictive Change Modelling

The model appears to have simulated the spread of *built-up* land in a logical manner consistent with the spread of the *built up* classes in the 1992, 1997 and 2002 images (figures 6 to 8). Figure 9 displays regions where GEOMOD2 predicted the change to take place in black. The majority of change has occurred around existing urban areas, spreading out into the adjacent land covers. The model has also predicted a densification of the existing *built-up* areas where there is much undeveloped land within *built-up* areas.

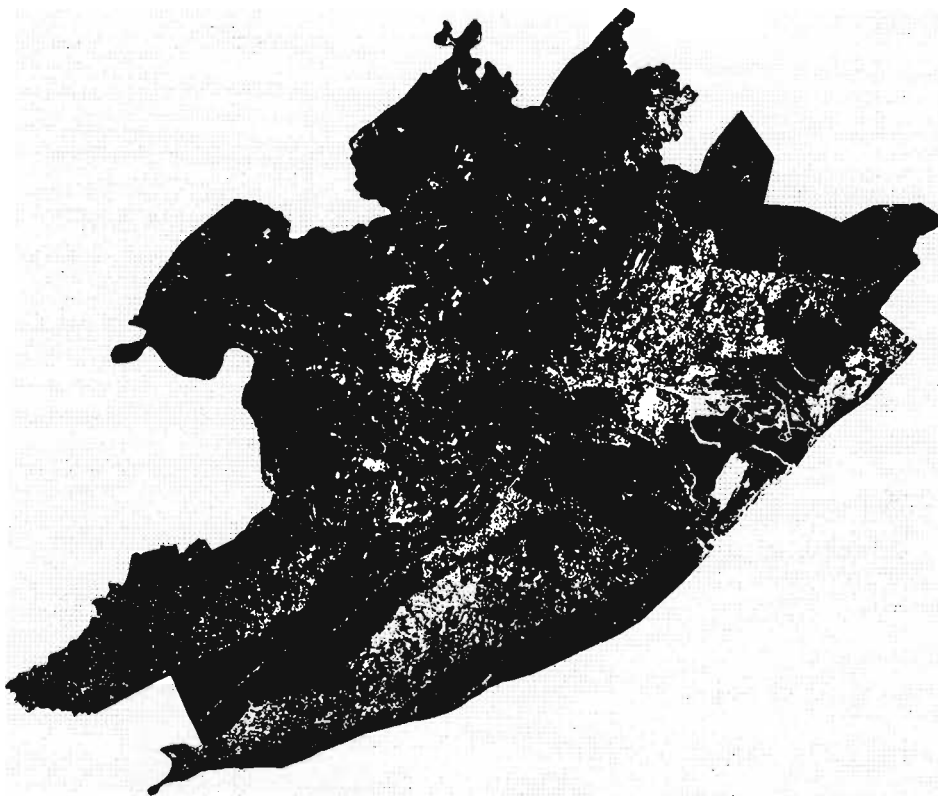


Fig. 6. Location of built-up land cover (white areas) in 1992 [1cm = 5km].

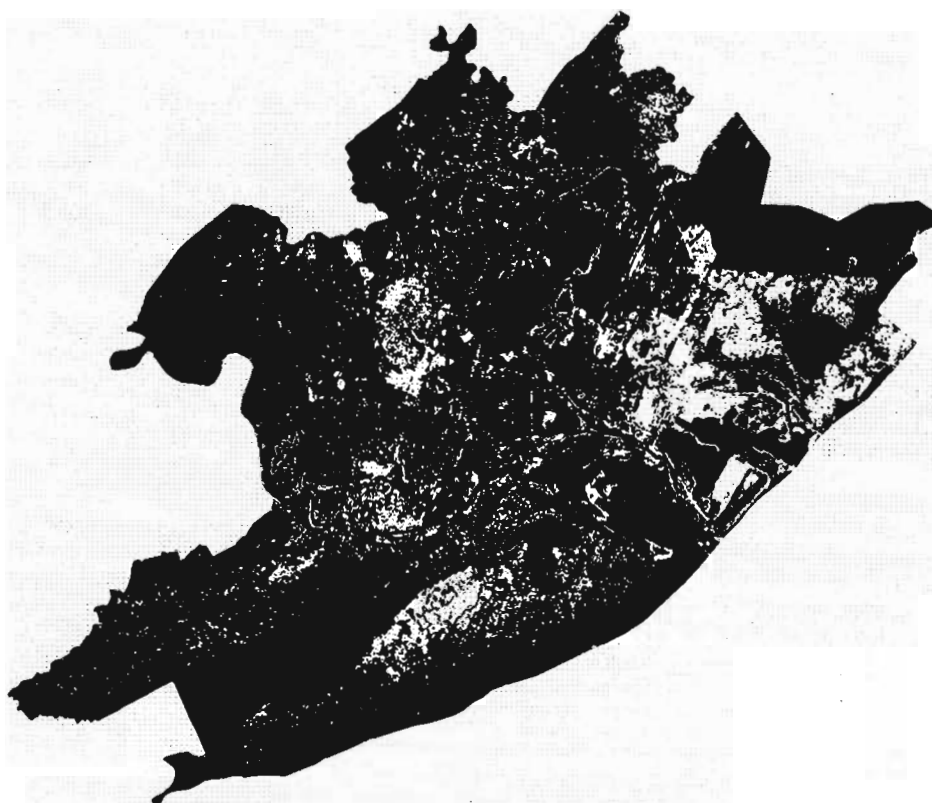


Fig. 7. Location of built-up land cover (white areas) in 2002 [1cm = 5km].

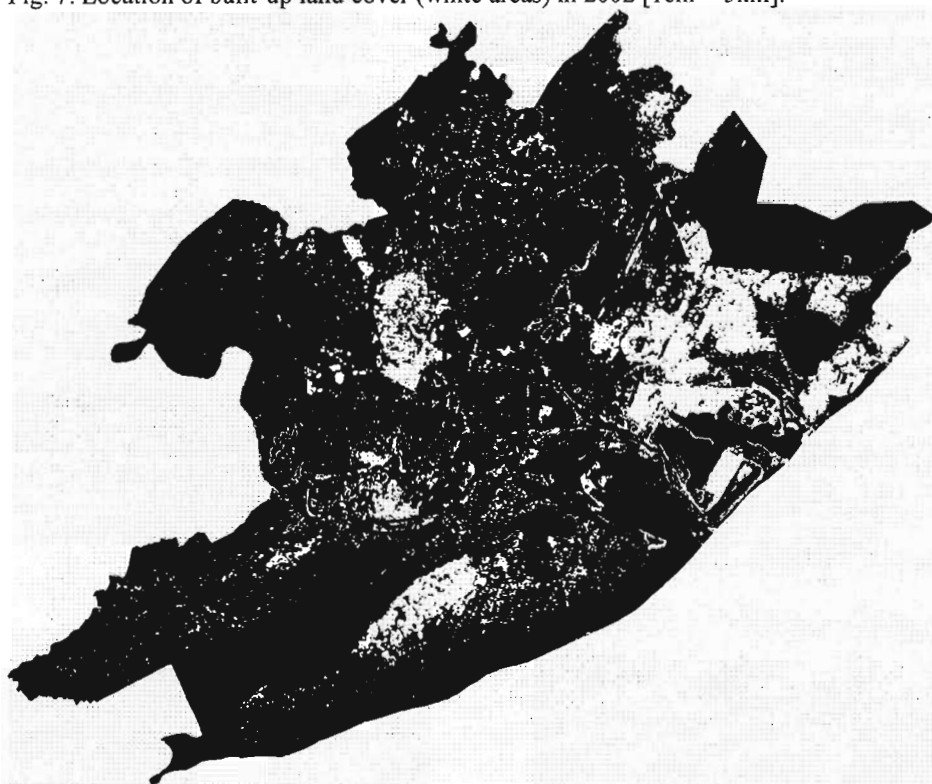


Fig. 8. Location of predicted built-up land cover (white areas) in 2012 as derived from GOEMOD2 [1cm = 5km].

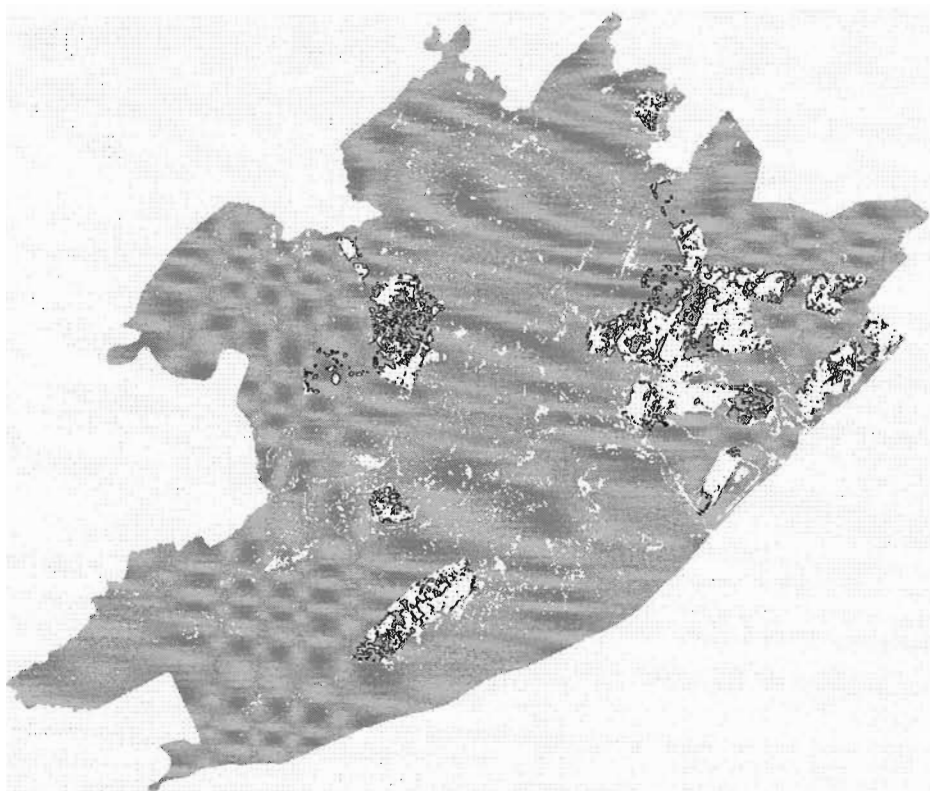


Fig. 9. Image illustrating the locations where GEOMOD2 predicted the increase in built-up land cover to take place (Illustrated by black regions) [1cm = 5km].

#### *4.5 Model Validation*

The results of the model validation quantify the positional differences between the 2002 model output and the reference image. Figure 10 displays (in black) the areas classified differently between the model output image and the reference image. Much of the difference is not in close proximity to the urban centres of Richards Bay, Empangeni, Esikhawini, Ngwelezane, Nseleni, and Felixton. This is a consequence of the 2002 classified image (reference image) containing small pockets of incorrectly classified built-up pixels within the non-built-up land covers resulting from patches of bare earth within cultivated lands, rather than the model having produced an inaccurate prediction.

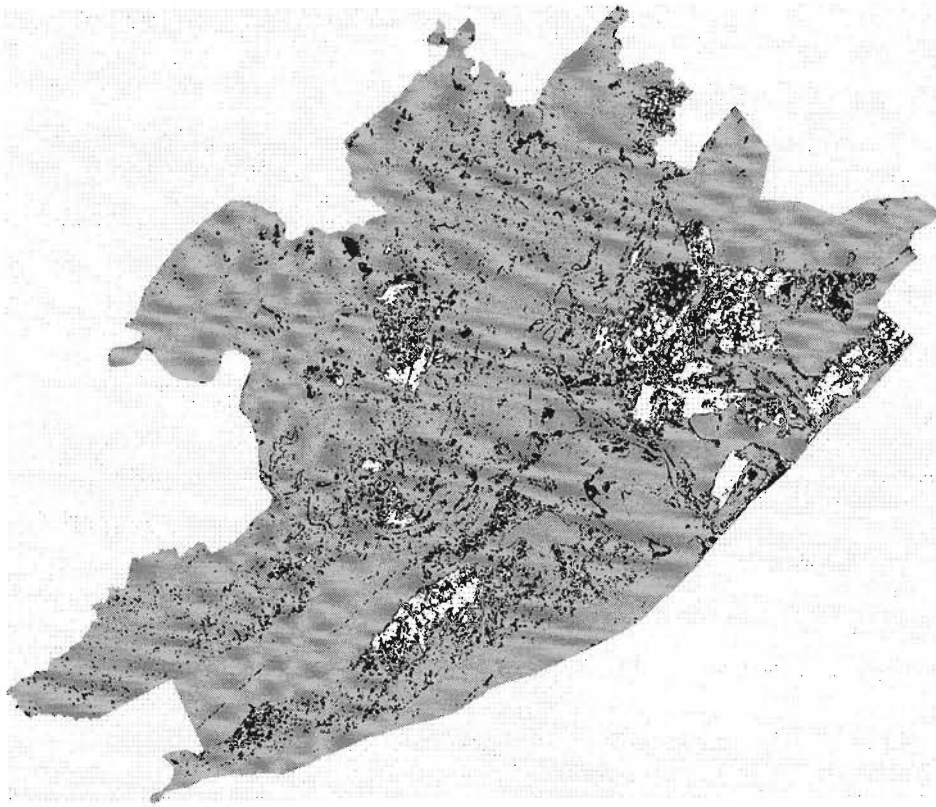


Fig. 10. Image illustrating the difference in location of built-up between the GEOMOD2 produced image and the reference image (areas of difference shown in black) [1cm = 5km].

The relevant results from the validation process included a Kappa for no information (indicating the proportion of pixels classified correctly relative to the expected proportion classified correctly by a simulation with no ability to specify accurately quantity or location) and a Kappa for grid-cell level location (indicating how well the grid cells are located on the landscape), both providing a result of 0.9121. This result proves the images to be a very near match. However, the result is rather misleading as the 'VALIDATE' process incorporates the entire image, rather than simply the cells in which GEOMOD2 had predicted change. Since the area that underwent change was a very small proportion of the whole image, this result is largely inconclusive in terms of providing an indication of the accuracy of GEOMOD2 to this application. A simple visual analysis of figure 10 may provide a clearer indication of the effectiveness of GEOMOD2 in predicting the location of change in this study.

#### 4. 6 Limitations to the Study

Rainfall had an impact on this study as it affects the growth state and quantity of vegetation, altering the spectral response of vegetation land covers. The three years of this study experienced rather varied rainfall. In 1992 the total was 753.9 mm, 58% of the annual average, in 1997 the total was 2154.5 mm, 167% of the average and in 2002 the total was 986.2 mm, 76% of the average (South African Weather Services, 2005). Ideally, the three images need to contain consistent growth states, but with such varied rainfall between image dates this was difficult to achieve. Accordingly, the use of a 'post classification comparison' change detection technique reduced the impacts of such variability across dates.

The difference in rainfall quantity during the study years is presumed to have impacted the classification process in several ways. Firstly, higher rainfall increases the areas of all the vegetation classes and thus decreases the area of the non-vegetation classes such as *commercial/industrial built-up* and *residential built-up*. This trend was prevalent in the results as the urban industrial class decreased from 1992 to 1997 by 4% (103 ha) and then showed a large increase of 28% (714 ha) from 1997 to 2002. Similarly in the Urban Residential class only increased by 9% (460 ha) from 1992 to 1997 and then increased by 14% (744 ha) from 1997 to 2002. The impact of this trend on the waterbodies class is inconclusive since a mask was used to remove the main waterbodies from the analysis. Nonetheless, this class did show a decrease in size in the 1997 image, resulting from changes in unmasked waterbodies.

During the 1997 image it is likely that the grassland training sites contained a larger amount of bare earth and dry grass giving these areas a higher reflectance value. This caused some *residential built-up* areas to be classified as *grasslands*.

The high vegetation growth in the suburbs and spatially dispersed nature of both the large industries around Richards Bay and the settlement areas also negatively impacted on the classification accuracy giving a 'salt-and-pepper' type classification result. In these situations approaches such as object-oriented classification, which takes the form, textures and spectral information into account (Oruc *et al*, 2004), may produce more accurate results. Various

filtering techniques can also reduce such problems. Furthermore, imagery with a finer resolution would also reduce this effect.

Shadows also affected the classification process. Where plantations were very tall, adjacent areas would lie under shadow and have reflectance values similar to *commercial/industrial built-up* or *waterbodies*. This was another source of pixel misclassification.

## **5. Conclusion and Recommendations**

### *5.1 Changes in the uMhlathuze Municipality*

The most significant change in the uMhlathuze Municipality was the increase in sugarcane, which increased by 6 967 ha (110%) between 1992 and 2002. This transformation may have improved the economy of the region but has, at the same time, reduced the extent of Coastal Bushveld-Grassland vegetation type, which is already greatly transformed by such agricultural practices (Low & Rebelo, 1998). Mitigation measures may include the provision of corridors of natural vegetation allowing for species migration between conserved areas. The rapid rate of many of the changes exemplifies the need for such measures.

Since many of the built up areas around Richards Bay are industrial in nature, the increase in this land cover is of particular concern. The spread of large industries results in environmental problems such as air, groundwater and riparian pollution. Consequently, it is imperative that planning strategies incorporate such considerations to guide the development in a way to minimise these impacts in the future.

The loss of coastal forest in the southern parts of the uMhlathuze Municipality is of concern because the coastal dunes of KwaZulu-Natal are prime areas for residential development, and the vegetation is being destroyed at an alarming rate. Moreover, the uMhlathuze IDP (2002) notes that the dune ridge along the coast is a particularly important corridor for genetic exchange between certain species from different biogeographical units. It is the only remaining passageway as the majority of inland vegetation has been converted to sugarcane.

## 5.2. Success of the Study

The various stages of growth of the sugarcane fields including fallow fields, the large amount of vegetation in the suburbs, the spatially distributed nature of both the industrial areas and the townships, and the shadows along the edges of plantations, all caused confusion in the classification results, and therefore contributed a low classification accuracy (74%). This is considered detrimental to the Post Classification Comparison algorithm as the final accuracy is a multiplication of the accuracies of the individual classified images (Coppin *et al*, 2004).

Notwithstanding these problems, the change analysis provided a good indication of the changes that have taken place in the Municipality between 1992 and 2002. The techniques can be considered successful as the large scale of the study site meant that, in spite of certain inaccuracies, the general locations and rates of changes were clearly demonstrated.

Policy, economic fluctuations and large industrial projects have all had a significant impact on the growth and development of urban areas, especially around Richards Bay (Hall, 2000). GEOMOD2 was not designed as an urban growth model but rather as a LUCC model and thus unable to incorporate such factors. Other models such as the SLEUTH urban growth model (Herold *et al*, 2003) may have been better suited to the urban growth part of this study as they better facilitate the incorporation of such factors. However, such models require additional data that was available for this study.

Furthermore, the model did not include representation of some important socio-economic factors such as human decision-making (Parker *et al*, 2003), which, in Richards Bay where development is guided through a Structure Plan framework, would improve the accuracy of the model.

Overall the study provided valuable results for both the study site and the techniques used. In determining the change in land cover between 1992 and 2002, the method indicated clearly where the major changes were taking place, and the extent and nature of the changes, while

the GEOMOD model produced a good prediction of the extent of urban land covers that can be expected in 2012.



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## Appendix A. Change matrices for the different time periods analysed in the study

Change Matrix 92 - 97								
	C/R Built-up	R Built-up	Forest & Woodland	Grass-lands	Sugar-cane	Water-bodies	Mines & Quarries	1992 Total
C/R Built-up	902	179	248	604	608	112	0	2653
R Built-up	150	928	516	2860	412	11	0	4877
Forest & Woodland	334	1063	14943	9431	2097	63	0	27931
Grasslands	757	2707	3355	17936	8035	66	0	32856
Sugarcane	143	457	748	1698	3265	4	0	6315
Waterbodies	265	2	22	98	11	3999	0	4397
Mines & Quarries	0	0	0	0	0	0	0	0
<b>1999 Total</b>	<b>2551</b>	<b>5336</b>	<b>19832</b>	<b>32627</b>	<b>14428</b>	<b>4255</b>	<b>0</b>	<b>79029</b>

Change Matrix 97-02								
	C/R Built-up	R Built-up	Forest & Woodland	Grass-lands	Sugar-cane	Water-bodies	Mines & Quarries	1997 Total
C/R Built-up	1187	280	177	312	298	291	4	2549
R Built-up	121	1566	376	2559	684	3	29	5338
Forest & Woodland	344	492	14203	3387	1279	16	110	19831
Grasslands	759	2890	4733	20616	3324	108	198	32628
Sugarcane	775	838	1118	3765	7697	10	224	14427
Waterbodies	78	14	63	11		4088	0	4254
Mines & Quarries	0	0	0	0	0	0	0	0
<b>2002 Total</b>	<b>3264</b>	<b>6080</b>	<b>20670</b>	<b>30650</b>	<b>13282</b>	<b>4516</b>	<b>565</b>	<b>79027</b>

Change Matrix 92-02								
	C/R Built-up	R Built-up	Forest & Woodland	Grass-lands	Sugar-cane	Water-bodies	Mines & Quarries	1992 Total
C/R Built-up	1245	369	151	463	286	109	30	2653
R Built-up	186	1831	511	1947	352	23	26	4876
Forest & Woodland	455	1371	15762	8367	1782	102	92	27931
Grasslands	992	1947	3575	18275	7704	82	280	32855
Sugarcane	282	544	612	1571	3157	12	137	6315
Waterbodies	104	17	60	26	0	4190	0	4397
Mines & Quarries	0	0	0	0	0	0	0	0
<b>2002 Total</b>	<b>3264</b>	<b>6079</b>	<b>20671</b>	<b>30649</b>	<b>13281</b>	<b>4518</b>	<b>565</b>	<b>79027</b>