LAND DEGRADATION AND SETTLEMENT INTENSIFICATION IN UMHLATHUZE MUNICIPALITY

SIFISO XULU

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

The multifaceted land degradation problem and its associated manifold impacts have attracted research from different disciplines, resulting in varying definitions of the concept. However, most researchers agree that human intervention that deteriorates the state of the environment is the central element. Among the anthropogenic activities that exacerbate land degradation, land cover has been singled out as the salient element. Rapid and unplanned land cover changes are primary manifestations of this problem. UMhlathuze Municipality, the study area which has superior biodiversity richness, is one of fastest growing municipalities in South Africa and is the locale of significant land modifications in recent decades because of a variety of industrial and residential developments.

Using Landsat TM imagery acquired for 1984, 1996 and 2004, this study mapped and quantified land cover change and manifestations of land degradation in the uMhlathuze Municipality in conjunction with settlement intensification computed from orthophotographs acquired for 1984 and 2004. Census population statistics were analysed as a reflection of population dynamics and further to gauge related causes of land cover change. Geographical information technology (GIT) was applied as an analytical tool.

The results revealed the anthropogenic influences that led to changes in land cover over the 20-year period between 1984 and 2004. The dominant natural cover classes in 1984 declined continuously and human-dominated land categories had increased sharply by 2004. Much of grasslands, forest and wetlands were converted to monotypical agroforestry (sugar cane and forestry plantations), built-up settlement and mining. These changes engendered complete loss of biodiversity (floral and migration of fauna). Bare ground, signifying land degradation, was noticeable although it exhibited a fluctuating trend which could be attributable to differences between the various imagery used. Along with population growth, the area of settlements increased over the study period and spatially sprawled from urban areas. Settlements showed a fairly stable spatial configuration over the 20-year period, but became magnified in medium- and high-density areas. Grassland and wetlands occurring around Richards Bay, as well as indigenous forest near Port Durnford, were identified as critically threatened ecosystems. The proposed industrial development zone and port expansion were recognized as having adverse ecological implications for wetlands. The study concluded that significant land cover changes occurred in the form of natural land cover giving way to monotypical agroforestry, built-up settlements and mining – all to the detriment of pristine natural habitat.

OPSOMMING

Die veelvlakkige probleem van omgewingsdegradasie en die gepaardgaande veelsoortige impakte lok navorsing uit verskillende dissiplines, wat lei tot verskillende definisies van die konsep. Tog is die meeste navorsers dit eens dat menslike invloede die sentrale element is wat die toestand van die omgewing verswak. Van die vele menslike aktiwiteite is grondgebruikverandering uitgesonder as die belangrikste beïnvloeder van agteruitgang van die omgewing. Veral vinnige en onbeplande grondgebruikveranderinge verteenwoordig die primêre manifestasies van hierdie probleem. UMhlathuze Munisipaliteit, die studiegebied met 'n hoë biodiversiteitsrykdom, is een van die vinnigste groeiende munisipaliteite in Suid-Afrika, waar 'n verskeidenheid nywerheids- en residensiële ontwikkelings beduidende grondgebruikverandering oor die afgelope dekades dryf.

Met behulp van Landsat TM beelde van 1984, 1996 en 2004, is hierdie studiegebied gekarteer en oppervlaktes gekwantifiseer om grondgebruikverandering en verwante manifestasies van die agteruitgang van landbedekking in die uMhlathuze Munisipaliteit te konstateer. Tesame hiermee is die verdigting van nedersettings ook met behulp van ortofoto's van 1984 en 2004 aangeteken. Bevolkingsensusstatistieke is ontleed as weerspieëling van die gepaardgaande bevolkingsdinamika en om moontlike oorsake van verandering in grondbedekking te bepaal. Vir hierdie doel is geografiese inligtingstegnologie (GIT) as analitiese instrument toegepas.

Die resultate toon antropogeniese invloede lei tot veranderinge in grondbedekking oor die tydperk van 20 jaar tussen 1984 en 2004. Die dominante natuurlike dekkingsklasse in 1984 het voortdurend verminder en menslik-gedomineerde kategorieë het teen 2004 skerp gestyg. Baie van die grasvelde, woude en vleilande is daadwerklik omskep tot monotipiese agro-bosbou (suikerriet- en bosbouplantasies), beboude nedersetting en mynbou. Hierdie veranderinge behels 'n volledige verlies van biodiversiteit (plantegroei en migrasie van fauna). Kaalgrond, wat dui op die agteruitgang van grondbedekking, was ook opvallend, hoewel dit 'n wisselende tendens toon wat ook kan wees as gevolg van die verskille tussen die beeldmateriaal wat gebruik is. Saam met die groei van die bevolking is bevind dat nedersettings oor die studieperiode toegeneem het en in tipiese spreipatrone weg van die stedelike gebiede uitbrei. Nedersettings het 'n redelik stabiele ruimtelike liggingsopset oor die tydperk van 20 jaar getoon, maar het in medium- en hoë- digtheid gebiedeverdeel. Die voorkoms van grasveld en vleiland rondom Richardsbaai, asook inheemse woud naby Port Durnford, is geïdentifiseer as krities-bedreigde ekosisteme. Die voorgestelde nywerheidsontwikkelingsone en hawe-uitbreiding is geïdentifiseer as ontwikkelings met nadelige ekologiese implikasies vir vleilande. Daar is dus tot die gevolgtrekking gekom dat beduidende voortgaande grondbedekkingveranderinge in die gebied voorkom, waarin natuurlike landdekking transformeer tot monotipiese agrobosbou, beboude nedersettings en mynbou – alles tot nadeel van die ongerepte natuurlike habitat.

ACKNOWLEDGEMENTS

A major research project of this nature is not at all the effort of anyone unaided. This translates into a call for thanking the following individuals and institutions who, with their diverse and significant contributions, contributed towards the completion of this thesis:

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I am very appreciative to my supervisor Prof JH van der Merwe[1] for his immeasurable comments, suggestions, encouragement and guidance throughout the duration of this research. Without his guidance, this research will not have been completed. I also thank him for countless words of advice that were not part of this orthodox syllabus; he unwittingly instilled confidence in whatever I do. All errors and limitations remaining in this thesis are mine alone.

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Finally, I extend a special thank you to my parents and family members concerned. Thank you for always believing in me and for your unlimited patience with me. I would not be where I am today if it were not for your love and support.

“[1] One thing that never stops to amaze me, along with the growth of vegetation from the earth and of hair from the head, is the growth of understanding”

Alice Walker

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ACRONYMS

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CDSM	Chief Directorate: Surveys and Mapping
CSIR (SAC)	Council for Scientific and Industrial Research (Satellite Application Centre)
DAERD	Department Agriculture, Environmental Affairs and Rural Development
DEAT	Department of Environmental Affairs and Tourism
DEM	digital elevation model
DPSIR	driver-pressure-state-impact-response
DWAF	Department of Water Affairs and Forestry
EMF	environmental management framework
FAO	Food and Agriculture Organization
GEF	Global Environment Facility
GIS	geographic information system
GIT	geographic information technology
IEA	International Energy Agency
IGBP	International Geosphere-Biosphere Programme
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KZN	KwaZulu-Natal
LADA	land degradation assessment in drylands
LCCS	land cover classification system
LULCC	land use land cover change
NAU	Natal Agricultural Union
NDVI	normalised difference vegetation index
SANBI	South African National Biodiversity Institute
SAWS	South African Weather Services
SFM	sustainable forest management
SFRA	stream-flow reduction activity
SRS	satellite remote sensing
SVM	support vector machine
TM	Thematic Mapper
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNECA	United Nations, Economic Commission Authority
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
USGS Glovis	United States Geological Survey Global Visualization Viewer

CHAPTER 1 INTRODUCTION

This introductory chapter gives background on land degradation as an environmental problem. It discusses the research problem identified and presents the aim and objectives of the study. It describes the study area under investigation and the general methodology employed. The last section gives the overall thesis structure.

1.1 LAND DEGRADATION AS A RESULT OF HUMAN ACTIVITY

Much has been said and written about human activities being a major factor causing and accelerating numerous environmental problems including land degradation. Land degradation is one, if not the most, serious global environmental problem (Wessels et al. 2007) often threatening food systems, water resources and biodiversity. Simply stated, land degradation is a process which entails a reduction of potential productivity of land, loss of biodiversity and it is accompanied by change of land-based ecosystems to perform and supply their goods and services (Kellner 2002). Moreover, Liu, Ni & Zha (1997) note that the occurrence of land degradation may possibly be everlasting, gradual, continual and even localized, depending on the nature and magnitude of causal factors in areas where it occurs.

Other themes noted by Hennemann (2001) relate to the complex nature of land degradation and he considers it as a collective degradation of different yet related fundamental environmental components such as land, water and biological resources. Hudson & Alcántara-Ayala (2006) remark that land degradation does not only result in deterioration of environmental components pointed out above, but also impacts severely on human development in areas where it occurs. Land degradation therefore constitutes far-reaching adverse environmental, economic and societal implications, making its detection and monitoring a useful undertaking toward the attainment of environmental sustainability and improved socio-economic welfare of communities.

A number of studies have been conducted to understand the possible causes of land degradation (Vrieling 2006; Wessels et al. 2007; Abbas 2009). Most have identified the causes of land degradation to include, inter alia, droughts, desertification and soil salinity (Ayoub 1999), conversion of rangelands to agricultural lands, and intensification of human settlements on ecologically sensitive environments (Khresat, Rawajfih & Mohammed 1998). These studies concur that the increased rates of land degradation are attributed to both human-induced activities and climate variability but clearly, these

factors do not have comparable magnitudes of effect. Reliable empirical evidence from several land degradation studies shows the greater extent to which human pressures accelerate the land degradation problem in many parts of the world due to growing population demands for land-based resources and space.

Among the anthropogenic activities said to exacerbate the land degradation problem, land cover change is singled out as being the most noticeable element. Several works have established that the primary manifestation of land degradation is hasty and extreme land cover changes. Confirming this, Barbier (2000) found a positive relationship between intensive land cover changes and the land degradation problem. A similar observation was reported by Maitima et al. (2004). Evidently, land cover change phenomena are a fundamental aspect in land degradation studies.

Alphan, Doygun & Unlukaplan (2009) cite extreme and fast land cover change phenomena arising from human pressures on the environment as having significant implications for sustainable resource use. Rapid changes in land cover are also the medium through which many human responses to global change occur (Lambin & Geist 2003). Alphan, Doygun & Unlukaplan (2009) add that this is commonly manifested as degradation of water- and land-based resources in many parts of the world. As Skidmore (2002) observes, changes in land cover can be persistent and can have severe impacts and implications at local, regional and global scales. He adds that changes, depending on human pressures, may be rapid (e.g. conversion of forest to agricultural land) or relatively slow (e.g. modification of forest land) yet all lead to severe land degradation problems.

Regarding South Africa, several related works have publicized the occurrence of land degradation (Hoffman et al. 1999; Wessels et al. 2004; Gibson 2007). Still, in South Africa, Hoffman & Todd (2000) argue that the country has decades of research efforts geared toward understanding and monitoring land degradation problems. Spatially, studies have shown that the occurrence of land degradation in South Africa is confined and severe within former homeland areas (Hoffman & Todd 2000). Similarly, Palmer & Ainslie (2002) have demonstrated that much of land the degradation in South Africa occurs in KwaZulu-Natal (KZN), Limpopo and the Eastern Cape.

Over the past 30 years, northern KZN has experienced two periods of prolonged drought (1981-1983) and (1992-1994) (Dube & Jury 2000, Tyson 2004). Steyl, Versfeld & Nelson (2000) also noted that the

uMhlathuze Local Municipality, specifically, is supporting a rapidly growing agricultural and industrial community. These events and activities could have led to the land modification found in a study by the Department of Water Affairs and Forestry (DWAF) which revealed that uMhlathuze estuary has been altered (DWAF 2004). Modification took the form of wetlands loss to agriculture, settlement expansion and loss of grazing lands.

More recent work done in uMhlathuze Local Municipality found several forms of land degradation. SRK (2009) found that wetlands occurring in uMhlathuze Local Municipality have been modified through disturbances relating to industrial developments and settlement expansion. McGinley (2008) pointed out that the area's original vegetation had been transformed by cultivation, urbanization and timber plantations, and that the greater portion of what remained has been degraded through the loss of woodlands, soil erosion and overgrazing. This empirical evidence that land degradation is indeed occurring in uMhlathuze Municipality draws attention to the need to establish the nature, impact and causes of this degradation.

In view of the foregoing, a study that maps land cover changes, more specifically land surface changes manifested as land degradation in uMhlathuze Local Municipality, in conjunction with spatial evidence of human settlement intensification over time is urgently called for. Because the variables involved occur spatially, their mapping and analysis using geographic information technology (GIT) are appropriate. These tools have been widely used in several disciplines to deepen our understanding of human influence on the environment. The nature of the problem to be researched, the aim and objectives, nature of the study area and research procedures are expounded in the following sections.

1.2 STATEMENT OF THE RESEARCH PROBLEM

The coastal belt of northern KZN is an ecologically sensitive area where land modifications have been occurring in recent decades due to increased agricultural, industrial and residential developments of a diverse nature. As Komlos (2008) states, it is well known that rapid development modifications can significantly degrade the surrounding environment. These development activities manifest as land modifications such as conversion of wetlands to settlement and alterations in the land cover in the area. As a result, major changes in the vegetation cover and surface waters occur with related implications for productivity and sustainable development in the area. Moreover, these activities result in more occurrences of severe land degradation. It is necessary to seek a detailed understanding of the linkages

between the manifestations of land degradation and human settlement intensification through the identification and areal quantification of land modifications associated with land degradation. To achieve this, land cover change detection from satellite imagery is an appropriate method.

This study is timely given that little empirical research on land degradation as a result of increased developments has been carried out in northern KZN and data on the spatial extent of land degradation is essential for sustainable development planning there.

1.3 RESEARCH AIM AND OBJECTIVES

The main aim of this study is to map, quantify and analyse the nature and extent of land cover change and manifestations of land degradation through settlement intensification in the study area over a 20-year period (from 1984 to 2004) using GIT. The focus of the land cover mapping is to estimate the extent of land cover changes to detect anthropogenic influence on natural class domains. Such changes will, it is hoped, reflect irreversible changes and, more importantly, changes that could lead to the establishment and even progression of land degradation problems in the area. The identification of threatened ecosystems also requires attention.

A secondary aim of this research is to map spatial evidence of human settlement growth over the same period based on a land cover classification in conjunction with census statistics, to determine the influence of population on land cover change. The proposed developments in the area must be identified and their implications for land cover investigated. On the conceptual and methodological front the study must define land degradation and operationalize its detection using satellite imagery.

These aims are reached through pursuing five objectives, namely:

1. Consult the literature to define land degradation and identify techniques for detecting land degradation and settlement intensification.
2. Map and quantify land cover distribution in 1984, 1996 and 2004.
3. Map and quantify land cover changes and manifestations of land degradation.
4. Map the spatial growth of human settlements and the socio-economic characteristics of the population.
5. Identify threatened ecosystems and land cover types likely to be impacted on by future industrial and residential developments.

These objectives record land degradation, settlement intensification and their associated themes and explain the methods applied in this study. The focus on land cover and land cover change detection, as well as evidence of land degradation and population growth and the concomitant socio-economic characteristics in the uMhlathuze Municipality are recorded and mapped. Also, threatened ecosystems and the types of land cover that are likely to be impacted by industrial and residential developments in the area identified.

1.4 THE STUDY AREA

This study was conducted in the uMhlathuze Local Municipality in KZN. Justification of the choice of uMhlathuze Municipality and descriptions of its location and biophysical environment are presented in the following subsections.

1.4.1 Selection of the study area

The problem of land degradation exists in the northern part of KZN and more specifically in the coastal zone. To allow a focused investigation, the study is limited to uMhlathuze Local Municipality, located in the coastal belt of the uMhlathuze catchment. In the whole catchment area, the uMhlathuze municipal area is a representative extract of environments experiencing notable land cover change due to multiple causes. This is an ecologically sensitive coastal area where significant land modifications have been occurring over the past years, due to increased developments in the area. The study area is a suitable size for exploratory research. Significantly, the demarcated area is a statutory unit within which representative data are compiled and in which administrative action can be taken once diagnostic conclusions on the state of the environment and solutions to problems have been formulated and acted upon. The prerequisite data sources for conducting a study of this nature are available from reputable sources for the targeted area.

1.4.2 Location and context

The uMhlathuze Local Municipality is one of six municipalities of the uThungulu District in the coastal belt of the uMhlathuze catchment in northern KZN (Figure 1.1), approximately 160 km north-east of Durban. Geographically, the area is located between latitudes of 28° 58´ 00´´ and 28° 39´ 30´´ south and between longitudes of 32° 45´45´´ and 32° 15´ 00´´ east. It covers a surface area of 796 km^2. The area is rich in sand mineral deposits (uMhlathuze Municipality 2002). It comprises urban settlements, traditional rural settlements, and nature reserves as shown in Figure 1.1. The major towns in the area

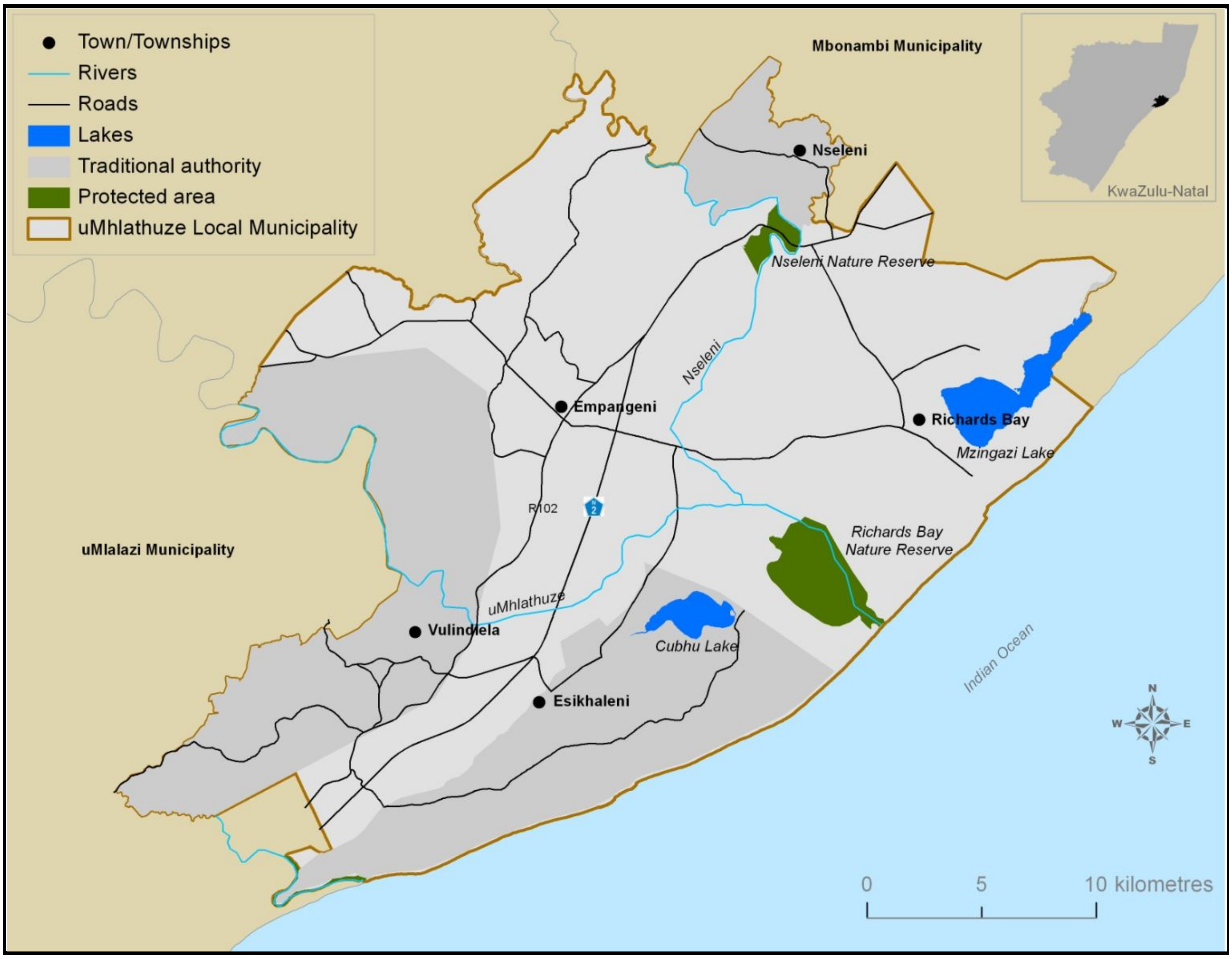


Figure 1.1 uMhlathuze Local Municipality in northern KwaZulu-Natal

are Empangeni and Richards Bay which are surrounded by large traditional authorities.

1.4.3 Biodiversity

The study area is located within the Maputaland-Pondoland-Albany Biodiversity Hotspot the wider location of which is shown in Figure 1.2. This plain is a transition zone characterized by a rich mix of floral species of local and proximate biogeographical origin (uMhlathuze Municipality 2002). The uMhlathuze Municipality has a heterogeneous landscape and is known to have high conservation status as a hotspot regarding regional biodiversity.

Amid this richness in biodiversity the study area is subject to severe human modification as a result of

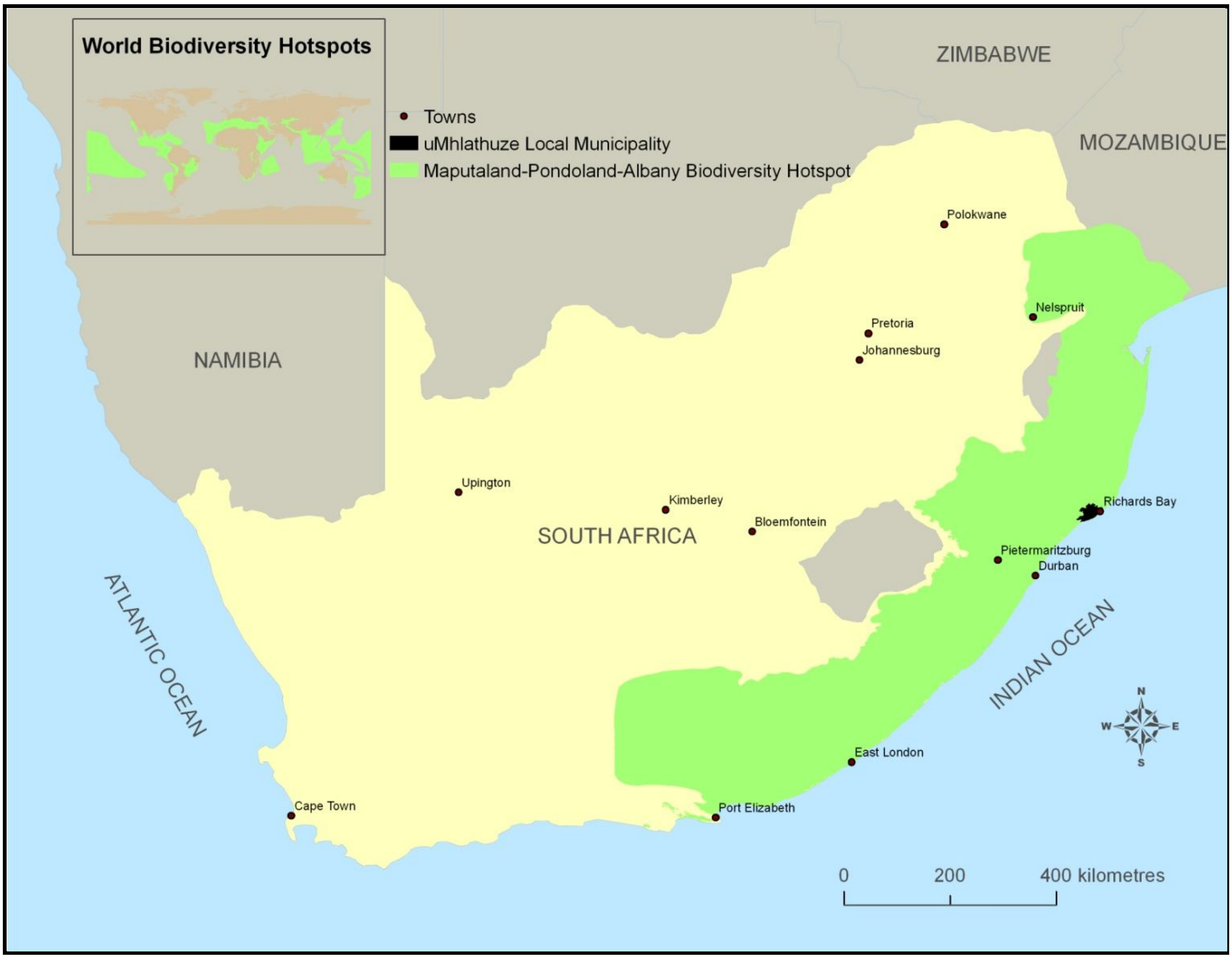


Figure 1.2 The Maputaland-Pondoland-Albany Biodiversity Hotspot in which the study area is located

population pressures and the economic development potential it holds. This is confirmed by McGinley (2008) who indicated that about 20% of the Maputaland-Pondoland-Albany Biodiversity Hotspot's original vegetation has been transformed by cultivation and urbanization, timber plantations and more than half of what remains has been degraded through the loss of woodlands, overgrazing and invasive species. Numerous endangered species such as sedges (*Cyperaceae*) have been recorded in the study area. There are two proclaimed protected areas in the study area which are under management of Ezemvelo KZN Wildlife, namely Nseleni Nature Reserve located on the north of the study area and Richards Bay Nature Reserve located near the coast along the uMhlathuze River (Figure 1.1).

1.4.4 Surface water resources

The hydrology of uMhlathuze Municipality is dominated by the uMhlathuze River which has a flow

averaging of 4.3 million cubic metres per month (http://www.dwaf.gov.za/hydrology/) and runs across the area into the Indian Ocean where it forms the Richards Bay estuary. The area is blessed with two major coastal lakes, Mzingazi and Cubhu, from which some adjacent communities partly derive their livelihoods (uMhlathuze Municipality 2002). The municipal area also features several wetlands ecosystems, most of which occur in the coastal zone.

1.4.5 Climate

The coastal belt of KZN has a humid subtropical climate with warm summers and generally hot winters (DWAF 2004). Compared to South Africa's annual average rainfall of 500 mm, the study region is a high rainfall area with annual rainfall ranging from 1200 mm in coastal areas to 1000 mm inland towards Empangeni (uMhlathuze Municipality 2002). Rainfall in the area is highly seasonal with a bimodal pattern and over 60% of annual rainfall is received during October to March as shown in Figure 1.3 (data recorded at Richards Bay weather station).

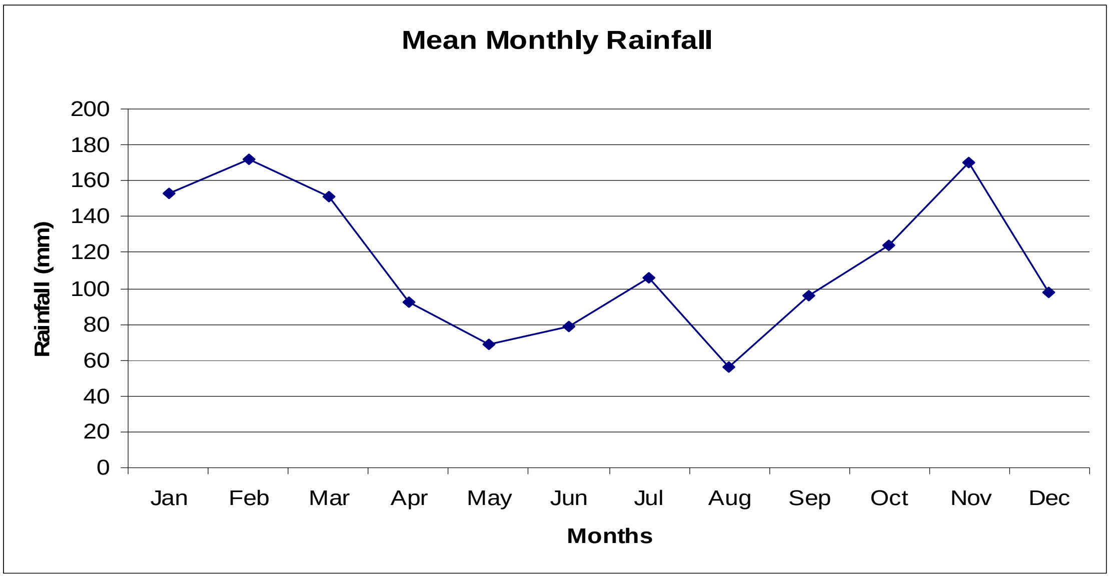


Figure 1.3 Mean monthly rainfall in uMhlathuze Municipality, 1984-2004

Winter rain is most often associated with frontal weather from the south or may result from the influx of moist air from the east associated with ridging Indian Ocean anticyclones (SAWS 2004). The northern coastal belt of KZN is frequently affected by severe weather events such as tropical cyclones (Blamey & Reason 2009). This could cause flooding and land degradation and shape the pattern of human settlement.

1.5 RESEARCH METHODS AND MATERIALS

This section overviews what and how different tasks were performed. The subsections present the components of the research, first the research design, then data sets used and their sources and finally descriptions of the methods used in investigating each objective.

1.5.1 Research design

This study consisted of two major components namely land cover change analysis and population analysis. Both these components are encapsulated in Figure 1.4 which is the framework within which the research unfolded. After determining the scope of the research and its target area, the various concepts and methods needed to tease out the theoretical basis for the work and perform the required analyses were sourced from relevant literature.

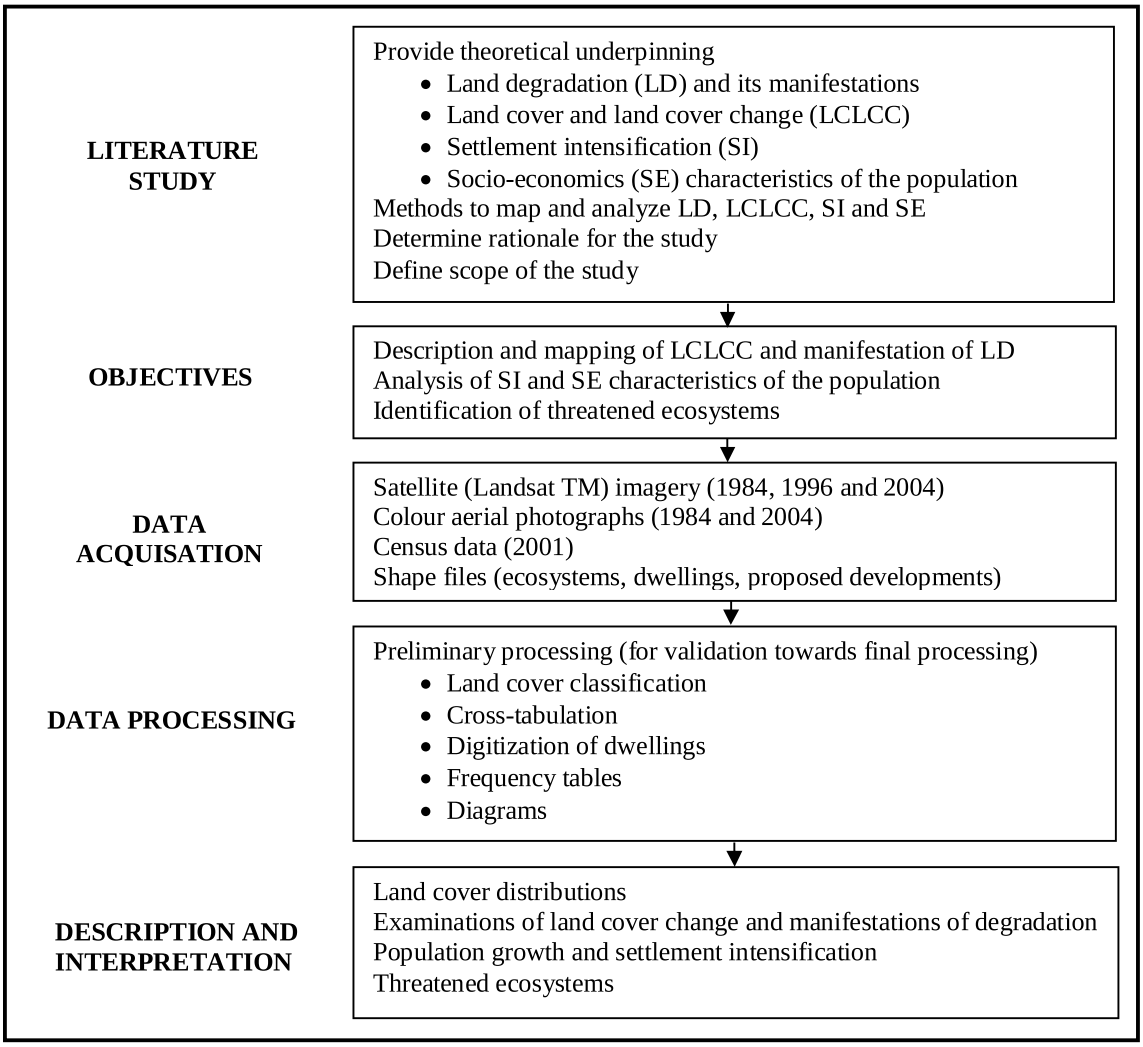


Figure 1.4 Schematic presentation of the research design

To map, quantify and analyse the nature and extent of change in land use and population from satellite imagery, digital orthophotographs and census data, the sources to map and analyse the variables were isolated. An analysis of three Landsat TM image sets resulted in three land cover maps from which land cover changes and land degradation were mapped. Spatial distributions of human settlements for 1984 and 2004 were computed from orthophotographs through on-screen digitization. Guided by related studies, key variables from Census 2001 data were identified and used to analyse socio-economic characteristics of communities. Owing to the spatial nature of the variables, GIT was applied to analyse them.

1.5.2 Description of data and data sources

The details of the data sets used in this study are presented in Table 1.1. The sources are reputable institutions as the table attests.

Table 1.1 Particulars of the data sources and types

<table>
<tr><th colspan="7">Satellite imagery</th></tr>
<tr><th>Platform</th><th>Sensor</th><th>Resolution</th><th>Date</th><th>Path/Row</th><th>Format</th><th>Source</th></tr>
<tr><td>Landsat 5</td><td>TM</td><td>30 m</td><td>01 June 1984</td><td>167/80</td><td>Electronic</td><td>USGS Glovis[1]</td></tr>
<tr><td>Landsat 5</td><td>TM</td><td>30 m</td><td>18 June 1996</td><td>167/80</td><td>Electronic</td><td>CSIR (SAC)[2]</td></tr>
<tr><td>Landsat 5</td><td>TM</td><td>30 m</td><td>23 May 2004</td><td>167/80</td><td>Electronic</td><td>CSIR (SAC)[2]</td></tr>
<tr><th colspan="7">Digital orthophotographs</th></tr>
<tr><th>Year</th><th>Date</th><th>Scale</th><th>Resolution</th><th>Format</th><th colspan="2">Source</th></tr>
<tr><td>1984</td><td>18 June</td><td>1:30 000</td><td>0.75 m</td><td>Electronic</td><td colspan="2">CDSM[3]</td></tr>
<tr><td>2004</td><td>06 April</td><td>1:30 000</td><td>0.3 m</td><td>Electronic</td><td colspan="2">uMhlathuze Municipality</td></tr>
<tr><th colspan="7">Census statistics</th></tr>
<tr><th>Year</th><th>Format</th><th colspan="2">Resolution</th><th>Format</th><th colspan="2">Source</th></tr>
<tr><td>2001</td><td>Shape file</td><td colspan="2">Subplace name</td><td>Electronic</td><td colspan="2">Statistics South Africa</td></tr>
<tr><th colspan="7">Vegetation map*, 2006 dwellings**, threatened ecosystems+ and proposed developments++</th></tr>
<tr><th>Year</th><th>Format</th><th colspan="2">Resolution</th><th>Format</th><th colspan="2">Source</th></tr>
<tr><td>2003*</td><td>Shape file</td><td colspan="2">Municipal area</td><td>Electronic</td><td colspan="2">uMhlathuze Municipality</td></tr>
<tr><td>2006**</td><td>Shape file</td><td colspan="2">National</td><td>Electronic</td><td colspan="2">Eskom</td></tr>
<tr><td>2009+</td><td>Shape file</td><td colspan="2">Municipal area</td><td>Electronic</td><td colspan="2">SANBI[4]</td></tr>
<tr><td>2012++</td><td>Shape file</td><td colspan="2">Municipal area</td><td>Electronic</td><td colspan="2">uMhlathuze Municipality</td></tr>
</table>

Sources: [1]United States Geological Survey, Global Visualization Viewer

[2]Council for Scientific and Industrial Research (Satellite Application Centre)

[3]Chief Directorate: Surveys and Mapping

[4]South African National Biodiversity Institute

Important aspects that must be considered when selecting *satellite imagery* for land cover mapping are: date of image acquisition, spectral responses of surface features, preprocessing stage and the area of interest (Yuan et al. 2005). These criteria were all considered in the selection of the satellite imagery suitable for this investigation. Considering the humid region in which the study is located and since cloud cover is particularly problematic during the wet season, cloud-free images acquired for winter coverage were selected. Matching imagery acquired for the same season was selected to minimize the influence of potential seasonal variations in displayed features on the imagery.

The baseline Landsat 5 1984 imagery with 30-metre resolution was obtained from the USGS Glovis online portal. This image was already in orthorectified format and required no detailed image correction. The 1996 and 2004 images with same resolution as that of the base imagery were obtained from the CSIR (SAC) in FAST format and referenced according to the orthorectified 1984 image and the United States Geological Survey (USGS) digital elevation model (DEM).

Colour digital *orthophotographs* were acquired gratis for two dates (1984 and 2004), for 1984 from Chief Directorate: Surveys and Mapping (CDSM), the government organization responsible for the national mapping programme, geodetic control network, collection of spatial information and aerial imagery in South Africa (Zakiewicz 2008), and for 2004 from uMhlathuze Local Municipality. The orthophotographs of 1984 have a coarser resolution (0.75 metre) compared to that of the 2004 orthophotographs (0.3 metre). The latter orthophotographs were in ready-to-use format but the base material (1984) had to be preprocessed in Erdas IMAGINE and georeferenced with the digital 2004 orthophotograph and other ancillary data.

Census data for 2001, obtained free of charge from Statistics South Africa, were used to map and determine a socio-economic profile of the population of uMhlathuze Municipality. Data were in a spatial resolution of subplace name and obtained in shape file format. The socio-economic variables were aggregated in subplace names which were spatially referenced as point geometry. Data were exported in Excel spread sheet where reclassification was performed and exported back to shape file format in GIS for analysis. This was done to show the variation and distribution of key variables considered in the study so as to link them with land cover and settlement distribution. Because human settlements were mapped from orthophotographs for 2004 and 1984, the census data for 2001 were used to compile the socio-economic profile that corresponds with the 2004 settlement map.

Unfortunately, 1985 census data to correspond with the 1984 settlement map were not spatially comparable and therefore not used.

1.5.3 Methods

The methods of analysis employed are outlined in conjunction with each of the study objectives. Each objective forms a chapter or a major part of one as suggested by Van der Merwe & De Necker (2013). More detailed descriptions of the method used to investigate Objectives 2 and 3 are given in Chapter 3 and for Objectives 4 and 5 in Chapter 4.

Objective 1: Consult the literature to define land degradation and identify techniques for detecting land degradation and settlement intensification

Topics in the literature were categorized according to defined thematic areas (see Figure 1.4) of the study. A synthesis of the literature is presented as Chapter 2. The review covered studies on land degradation as a ‘nexus problem’ (definition, impacts, and interventions to combat it). Examples reported in the literature on land degradation were studied to gain insights into the manifestations of land degradation elsewhere and in the study area. The features and application of land degradation mapping methods were compared to get direction about which methods to adopt in this study. Methods of population mapping were reviewed and the relationship between population settlement intensification and land degradation reported in the literature were surveyed.

Objective 2: Map and quantify land cover distribution in 1984, 1996 and 2004

The Landsat TM images acquired for 1984, 1996 and 2004 were subjected to supervised classification and six preliminary land cover classes were identified in the uMhlathuze Municipality. Given that the study area is a heterogeneous landscape, land cover maps were overlaid with digital orthophotographs and the 2003 vegetation map in GIS to properly discriminate land cover classes (through digitizing) until satisfactory classification of nine final land cover classes was achieved. The areal extents of land cover classes were quantified in ArcMap and tabulated. Graphs showing trends over three sample years were created in Excel and interpreted.

Objective 3: Map and quantify land cover changes and manifestations of land degradation

A postclassification comparison technique was applied to detect land cover changes. For this purpose change detection statistics in the form of cross-tabulation matrixes were computed from ArcMap and

the attribute table was exported to Ms Excel. Land cover changes were first reported as an overall aggregated analysis and thereafter the changes in each interim period (1984-1996) and (1996-2004) were given. Net gains and losses were analysed to portray the broad increase/decrease of each category in each period. Spatial distribution of land cover changes were computed using the map algebra function in ArcMap. Land cover changes that manifested as land degradation were identified (i.e. proliferation of bare ground; biodiversity loss) and reported in sections on land cover change.

Objective 4: Map the spatial growth of human settlements and the socio-economic characteristics of the population.

Census statistics for 2001 in shape file format were used to describe socio-economic characteristics of the population in uMhlathuze Municipality. The data were subplace name resolution and spatially referenced as 81 x/y-locations, each with its unique statistics. The data were generalized to municipal ward scale to be comparable with settlement density. For this purpose, 81 subplace name locations were overlaid on the municipal wards shape file and all subplace names sited in each ward were merged to form one point. Because uMhlathuze Municipality has 30 wards, the resultant shape file had 30 points sited in each ward with aggregated statistics. Settlement growth was estimated through digitizing all individual dwellings computed from the 1984 colour orthophotograph and compared with the 2005 Eskom dwelling layer. Dwellings were distinguished as urban or rural to show areas where settlement growth was higher. From the digitized dwelling units, settlement density was computed at municipal ward level. The total number of settlements digitized in each ward was divided by the total area of each ward and the settlement densities were portrayed in a choropleth map showing five density classes.

Objective 5: Identify threatened ecosystems and land cover types likely to be impacted on by future industrial and residential developments

The shape files obtained from South African National Biodiversity Institute's (SANBI) online portal were overlaid with the 2004 land cover classification. This aimed to highlight threatened ecosystems in uMhlathuze Municipality. Likewise, the shape files of proposed industrial and residential developments were obtained from uMhlathuze Municipality and overlaid with 2004 land cover classification to portray land cover categories that may be impacted by these developments. The areal extents of the proposed industrial and residential developments were computed to estimate the land cover surface area these will consume.

1.6 THESIS OUTLINE

This thesis is organized in five chapters. This introductory chapter has provided a contextual foundation as well as justification for this study in uMhlathuze Local Municipality. It has set out the research aim, objectives and the methods to be used. Chapter 2 reviews literature on land degradation and land cover change and considers the relationships between human settlement distribution and socio-economic characteristics and land degradation. The quantification and mapping of these phenomena from aerial photographs and remotely sensed images using GIT are discussed. Chapter 3 gives an account of land cover change and the manifestations of land degradation in the study area. The spatial and areal extent of each land cover type and land conversions from one land cover type to another over time are examined. In Chapter 4 the spatial distribution of human settlement and their density are described in conjunction with the socio-economic characteristics of the study area's population. The threatened ecosystems and the proposed developments are identified and discussed. Chapter 5 summarizes the key findings and draws conclusions. Recommendations for further research are made.

This chapter provides introductory background to the land degradation problematic in the study area and explained how the research was conducted. In the next chapter literature on land degradation, settlement intensification and socio-economic characteristics of the population as well as methods used to investigate them are reviewed.

CHAPTER 2 LAND DEGRADATION, LAND COVER AND LAND COVER CHANGE AND POPULATION MAPPING: A REVIEW

To get a better understanding of land degradation (its definition, occurrence, impacts and monitoring), land cover and human settlement intensification, this chapter reviews the literature on these very relevant phenomena. The work on using GIT and other techniques to quantify and map these phenomena is given special attention.

2.1 LAND DEGRADATION: A COMPLEX NEXUS

The problem of land degradation as with numerous other environmental issues, is still widely debated. This is because land degradation contains elements of what Bai et al. (2008) asserts to be a ‘contentious phenomenon’. Land degradation is an alarming environmental problem that has multiple linkages which qualifies it as a nexus (linked) problem – as I call it. Therefore, the enhancement of our knowledge toward a better understanding of land degradation as an environmental problem depends on recognizing and appreciating the multiple linkages which constitute this complex nexus. Consequently, this section concentrates on reviewing the multiplex nature of land degradation.

2.1.1 The problem of land degradation

Land is probably the natural resource most vital to the survival and maintenance of terrestrial ecosystems (FAO & UNEP 1999). Land is a fundamental commodity on which people depend for survival and which support essential sectors such as agriculture, settlements and housing, industry and recreation (Mahabir & Al-Tahir 2008). Despite our reliance on land, alarming evidence exists that our interactions with the environment have caused serious degradation of land which detrimentally affects the people whose livelihoods are dependent on and derived from land through agriculture, and sustainable development, particularly the conservation of natural resources and their monitoring.

Several studies (IPCC 2001; LADA 2002; Abbas 2009) have claimed that land degradation and its attendant effects severely impact on rural communities since a large proportion of rural communities are dependent for their livelihoods on services derived from land-based ecosystems. Rural communities are thus particularly vulnerable to the consequences of land degradation. Land degradation also constitutes several socio-economic and environmental threats that lead to the phenomenon’s progression in many regions around the world. These threats include decline in land productivity resulting in reduction of agricultural production, loss of biodiversity and increased poverty levels.

According to Abbas (2009) land degradation is both a cause and a consequence of environmental changes that lead to losses of valuable land resources.

Most developing countries, of which South Africa is one, are singled out as being particularly vulnerable to the problems associated with land degradation. African communities and populations, for example, have less capacity to adapt so that they are more vulnerable to numerous environmental stresses, including those of land degradation (IPCC 2001). In Africa land degradation commonly manifests in soil degradation, rangeland degradation, loss of biodiversity and desertification and it has been linked to population pressures, mining, inappropriate agricultural technology, poor land management and droughts (UNECA 1999). It also involves a wide range of natural and human-induced factors affecting the productivity of land. These, together with other causal factors can exist in various non-unique and complex combinations in different environmental settings, often making detection and monitoring of land degradation difficult tasks (Mahabir & Al-Tahir 2008). Alas, no universal solution yet exists to eliminate the problem of land degradation!

To impede the encroachment of land degradation and to formulate the necessary conservation strategies, it is essential to know the phenomenon's spatial distribution and magnitude. Most importantly, land cover data can be used to derive information on ecosystem conditions. Censuses, settlement and population distributions and socio-economic attributes of communities provide information on human-induced pressure on the environment which is essential input for quantifying the nature, extent and projected effects of land degradation. In such studies, the application of GIT has been shown to become more appropriate because the occurrence of land degradation is spatial in nature. It is useful to define what land degradation is and what it entails. This is done in the next subsection.

2.1.2 Defining land degradation

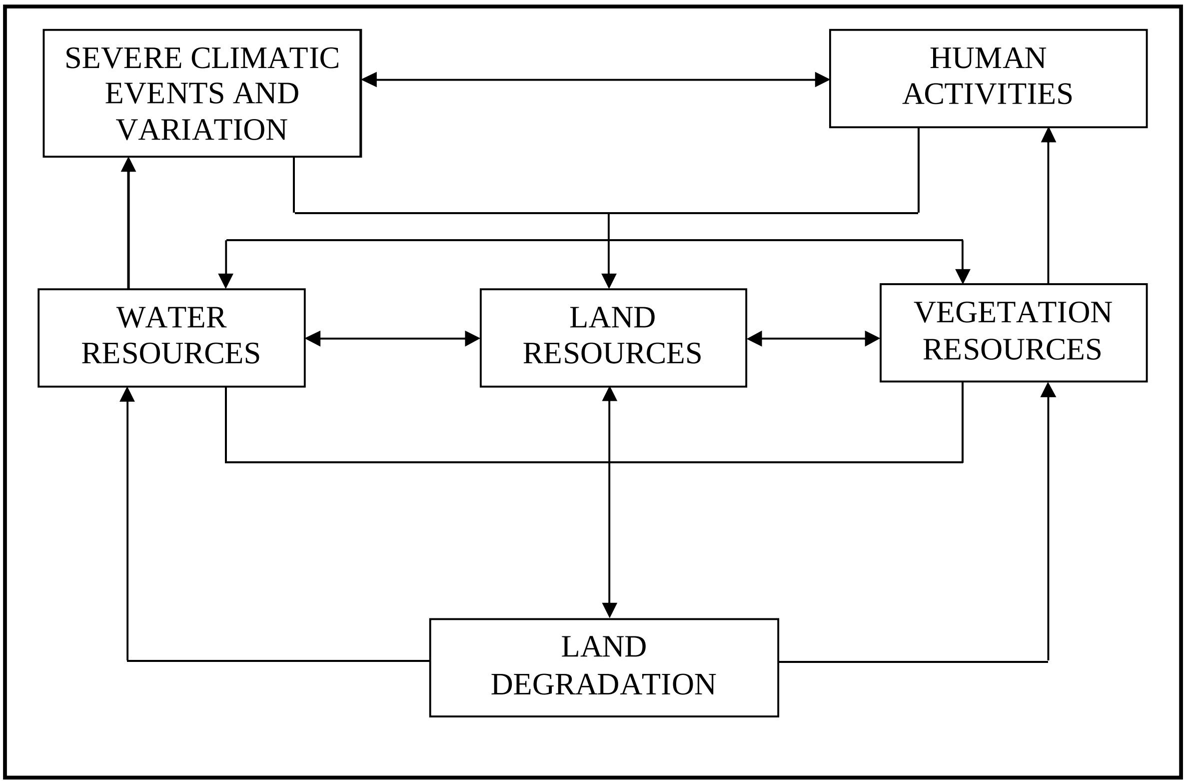
The common perception of land degradation is that it is exposed and barren lands where livelihoods are difficult to sustain. It is true that this is a defining characteristic of land degradation but there is ample evidence that land degradation is a far more complex phenomenon. Various definitions of land degradation exist and central to them is the impacts humans have on the quality of land and its productivity. Wasson (1987) refers to land degradation as a change to land that makes it less useful for human use and De Kimpe & Warkentin (1998) define it as a decrease in the optimum functioning of

soil in ecosystems. DEAT (2008) broaden the definition to land degradation being the reduction or loss of biological or economic productivity of agricultural land, woodlands and forests as a result of human pressures.

This study accepts the above definitions while embracing LADA's (2002) interpretation that land degradation is the reduction in the capacity of land to perform ecosystem functions and services that support society and development. In this study, losses in forest cover, wetland areas and grassland vegetation are considered to constitute land degradation. Closely related to the definition of land degradation are its causes which are discussed next.

2.1.3 Causes of land degradation

The prominence and prevalence of land degradation have led many authors to argue that it is a complex and multicausal process. Meadows & Hoffman (2003), Wessels et al. (2006) and Wuddivira, Ekwue & Stone (2010) all attribute land degradation to severe climatic events and human activities, as illustrated in Figure 2.1.



Source: Modified from Hoffman et al. (1999)

Figure 2.1 Feedback mechanism of the land degradation process

There is a preponderance of evidence that human activities are the main causers and accelerators of land degradation. Haberl (2004) contends that humans play a bigger role than naturally-induced factors in causing land degradation due to the greater extent to which humans dominate global environmental processes. McCloy (1995) has pointed out humans pose a greater threat owing to their inability to sustainably use and manage land because of increasing pressures emanating from population growth and economic development. From these views one can safely deduce that land degradation can be related to settlement intensification which is an indicator of population pressures on natural resources.

According to Davaasuren (2001), people in many affected regions who are driven by poverty and greed have a desire to derive as much benefit as possible from the land in a short period so leading to the initiation and progression of land degradation processes. However, it is vital to remember that land degradation is not confined to poor communities as it is often evident in other areas where it is a result of intense land use and land cover change driven by modern developmental pressures.

The major causes of land degradation according to Chikhaoui et al. (2005) are ecosystem changes, deforestation and human pressure through over cultivation. UNECA (1999) lists the causes of land degradation, among others, as clearance of vegetation for agricultural, industrial and residential development, overgrazing and inappropriate land use. Several land degradation studies (Thornes 1996; Barbier 2000; Bai et al. 2008) have linked the occurrence of land degradation to intense land cover change. For this reason, the detection of land degradation in this study will be done through analysis of land cover change revealed in multitemporal remotely sensed imagery. The spatial distribution of the population settlements will be related to land cover to establish causal linkages with land degradation.

Figure 2.1 illustrates a feedback relationship between climate variation and human activities in relation to land degradation (Hoffman et al. 1999). It is also evident that climate events and human activities can impact (negatively) on soil, vegetation and water resources and alterations to these environmental units can precipitate land degradation. Land degradation can impact on climate and on humans through soil, vegetation and water resources. Climatic events and human activities are thus causes and consequences of land degradation.

Van der Merwe (2005) has observed that all ecosystems are dynamic in time and space so requiring continuous monitoring. To promote multitemporal monitoring, it is useful to investigate the short- and

long-term variability of ecosystems so that land degradation can be documented and acted on.

Given the need for and significance of land degradation information, it is appropriate to identify indicators of the state and level of land degradation. Because land degradation, like most other environmental problems (e.g. biodiversity loss) is multifaceted, there is pressing need for selecting understandable, measureable and reliable indicators against which land degradation can continuously be assessed.

2.1.4 Indicators of land degradation

Dumanski & Pieri (2000) have asserted that indicators are measurable entities relating to a condition, change of quality and state of phenomena under investigation. They noted further that indicators are useful to monitor changes and provide means to compare trends and progress over time. Yet, according to LADA (2002) a demanding challenge in studying land degradation is to select indicators that are sufficiently representative and, at the same time, easy to understand and measure on a routine basis.

Rubio & Bochet (1998) emphasize that reliable land degradation assessment relies on the identification of relevant indicators. As with other environmental problems, a substantial amount of effort has been made to identify indicators with which land degradation can be measured and reported. Because land degradation is a complex problem, it is not surprising that the literature contains lists of land degradation indicators. The indicators and events used in the Driver-Pressure-State-Impact-Response (DPSIR) model assessment of land degradation are listed in Table 2.1. The model functions sequentially with land degradation indicators and associated activities or events from instigating driving forces to the eventual responses made after land degradation has occurred.

According to Ji (2008), indicators of driving forces are activities that directly or indirectly cause land degradation. If the activities in this category occur rapidly and ad hoc, then severe degradation can be established. Pressure indicators involve activities that result in increased pressure on natural resources and their consumption, for example the conversion of natural forest for agriculture and industrial development. State indicators reflect the conditions and status of degradation, as well as resilience to degradation. Through a state indicator, land degradation can be documented and reported, since it provides the status of the resources being investigated.

Table 2.1 Framework for indicators of land degradation in the DPSIR model

INDICATOR	ACTIVITIES OR EVENTS
Driving forces	▪ land use development ▪ population growth and poverty ▪ extreme climate events and variability ▪ macro-economic policies
Pressures	▪ population growth and overcultivation ▪ demand from agriculture and urban land use ▪ nutrient mining
State	▪ soil erosion and salinization ▪ loss of vegetation cover ▪ loss of biodiversity
Impacts	▪ changes in human population size and distribution ▪ loss of biodiversity and land productivity decline ▪ land goods and services
Response	▪ monitoring and early warning systems ▪ land policies and policy instrument ▪ conservation and rehabilitation ▪ investments in land and water resources

Source: LADA (2002)

Following the establishment of the status of degradation, it is vital to investigate the causes and effects of degradation, making the fourth indictor significant. The effects and impacts of land degradation on natural resources, human well-being and society are impact indicators. Last, when the impacts and effects of degradation are known, mitigation measures need to be implemented so that response indicators represent policies and actions taken toward proper control of degradation.

In sum, land degradation indicators are essential for documenting information regarding the phenomenon's potential causes, severity and impacts so that mitigating measures can be established expeditiously. In addition, increased understanding of these indicators remains critically important to inform researchers and governments about the adverse environmental conditions which may manifest as degradation that calls for alleviative measures. The following subsection overviews some major initiatives geared to arresting land degradation at global, regional and local scales.

2.1.5 Initiatives toward combating land degradation

As a response to mounting concerns shown in most, if not all, land degradation studies, several focused initiatives have been implemented to combat land degradation. The common objective of these

initiatives is to map, understand and suggest solutions to land degradation problems in as many countries as possible. Spatially, these initiatives range from global to local scales. Critically important is that these initiatives not only give the status of land degradation in areas where it occurs, but also offer different approaches to better assess the phenomenon and the socio-economic linkages relevant to it. This study has adopted some of the methods used in these initiatives and recognizes the same socio-economic pressures that have been linked to land degradation. Three projects are treated here.

To successfully drive and implement programmes intended to arrest all environmental problems requires sufficient funding. For this purpose the *Global Environment Facility (GEF)* was jointly established in 1990 by the United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP) and the World Bank (Gilpin 2000). The GEF is the largest public funder that support several initiatives aimed to improve global environments. The project has also been documented to unite 182 countries in partnership with international institutions, civil society organizations and the private sector to address global environmental issues while supporting national sustainable development initiatives (http://www.thegef.org/gef/whatisgef). Specifically, the GEF offers funding for projects associated with biodiversity, climate change, international waters, the ozone layer, persistent organic pollutants and land degradation (Gilpin 2000).

The *Land Degradation Assessment in Drylands (LADA)* project is a well-known United Nations environmental initiative to assess and curb land degradation problems. It is implemented by the Food and Agriculture Organization (FAO) and supported by the GEF, UNEP and United Nations Convention to Combat Desertification (UNCCD). The overarching goal is to establish and test effective methodologies that enable detailed assessment of land degradation, particularly in dryland environments. The project is undertaken at all spatial scales and considers the causes of land degradation, its status as well as the impact it has in areas where it occurs. In the context of land degradation, the LADA project is a platform from which integrated methodologies, indicators and other information relating to land degradation can be obtained (ftp://ftp.fao.org/docrep/fao/010/ai555e/ai555e00.pdf).

A substantial amount of work on land degradation has been undertaken in six pilot countries, namely South Africa, Argentina, China, Cuba, Senegal and Tunisia. It has been suggested that land degradation varies from place to place depending on the causal factors prevailing in the areas where it occurs.

Because South Africa is a LADA pilot country, it is hoped that the country will benefit from the project in that the extent, risk and causes of land degradation will be determined.

The *International Geosphere-Biosphere Programme (IGBP)* is a large project involving various earth and environmental science disciplines (http://www.igbp.net/about.4.6285fa5a12be4b403968000417.html). The main objective of the project is to study and understand the dynamics of global environmental change. Because global environmental change is complex, the project is a scientific collaboration which links the disciplines of geophysics and global ecology to enable the identification of changes and their causes to provide guidance on how these can best be monitored (IGBP 2006).

A major component of the IGBP project is land use and land cover change (LULCC). The central function of this unit is not only to provide the evidence of land cover change, but also to forecast scenarios so that various land management options can be explored. Recall that land cover change has often been cited as a primary manifestation of land degradation. Consequently, the IGBP project is spotlighted here because it is relevant to understanding and monitoring land degradation. Also vital is the publication of the state of land degradation through research which is discussed next.

2.1.6 Significance of land degradation studies

Many governmental and private organizations are involved in land management (particularly land degradation) research in several areas of the world. The common purpose of these research efforts is to assess and understand the extent and magnitude of land degradation in the areas where it occurs. Without the findings of these studies it would be difficult, if not impossible, to understand the nature and scale of land degradation occurrences and impacts.

Considering the above discussion, the critical importance of empirical studies of land degradation becomes evident, especially for land use planners and managers since they determine status as an indication of the extent of human pressures on natural resources. Studies have shown that knowledge of the spatial distribution of land degradation is as relevant as knowing the availability of a resource base (Torrion 2002). Sujatha et al. (2000) maintain that the information on the nature, extent, severity and geographic distribution of land degradation is essential for planning recovery strategies and setting up preventive measures for sustainable development in areas where land degradation is present.

Owing to diverse developments under way in uMhlathuze Municipality, it is deemed important that manifestations of land degradation be mapped and quantified so that mitigation measures can be implemented. Barrow (1994) has acknowledged that adequate information on the spatial distribution of land degradation facilitates strategies for its prevention and mitigation. Eswaran, Lal & Reich (2001) have emphasized that information acting as a warning indicator to degradation problems can galvanize collective efforts to determine mitigation measures. Given that land degradation and other environmental problems are proliferating and very likely have adverse impacts and implications at local, regional and global scales, such studies must be continuously conducted across all scales.

Because land degradation is complex and known to occur in various forms, some well-known documented examples of land degradation (some even in the study area) are discussed in the next section.

2.2 EXAMPLES OF LAND DEGRADATION

Since environmental settings are not all similar, the manifestation of land degradation will vary in different parts of the world. This section explores examples of land degradation under four rubrics that are pertinent to the study area.

2.2.1 Deforestation

Despite forests being able to provide a wide range of essential economic, social and environmental benefits, they are reported to be increasingly threatened by rising rates of forest conversion to different human land uses and degradations (Brown & Lugo 1990). There are also growing concern about the effects of deforestation which accelerate a number of problems like global climate change and biodiversity loss (Nelson & Geoghegan 2002). For instance, Newton et al. (2009) found that over the previous two decades sustainable forest management (SFM) had become a global environmental issue, reflecting widespread concern over high rates of forest loss and degradation.

It has been estimated that more than 15 million hectares of tropical forests are depleted every year to provide space for small-scale agriculture, cattle ranching and for use as fuel wood for household energy (UNCCD 2004). This and other critical issues such as the loss of wetlands and prime agricultural lands continue to receive growing attention from the academic and research communities.

Drummond & Loveland's (2010) recent work suggests that global forest loss is more common

than forest gain, although the characteristics and direction of change differ depending on the region and the driving forces. While decades of research conducted in several regions to facilitate forest conservation have revealed a number of causes, it was found that the central causal element is land use change. For example, Wunder (2000) revealed that a large number of hectares of forest have been transformed to agriculture and livestock keeping in Brazil. An earlier case reported that in the Sahel agricultural land use and livestock keeping substituted forested areas (Ahlcrona 1986). Rametsteiner & Simula (2003) alleged that the progress toward overall forest management has been inadequate and that high rates of forest loss and degradation were being reported in many regions around the world.

In South Africa, as elsewhere in the world, our limited forest ecosystems are facing a diverse array of growing threats and pressures. For example, the FAO (2010) revealed serious forest cover losses in South Africa, especially in the Eastern Cape and KZN. Findings from several studies (DEAT 2008; McGinley 2008) conducted on these areas suggest that agricultural and settlement intensification, grazing and direct use of forest products for energy are the chief causes of forest loss.

2.2.2 Degradation of surface water resources

The degradation of surface water resources occurs as a result of anthropogenic alterations to the quality of water entering, standing or flowing in a waterbody, and to the geomorphology of a waterbody itself (Snaddon 1998). Recent studies such as that of SRK (2012) indicate that land cover changes resulting from human land use practices may significantly impact on water resources regarding quantity and quality. Notably, surface water resources are subject to ever-increasing anthropogenic pressure manifesting as population growth and increased agricultural and industrial activities that may lead to the degradation of natural resources.

Surface water resources include wetlands, estuaries and rivers which in urban areas particularly, are frequently threatened by physical destruction owing to development pressures. From investigations in uMhlathuze Municipality (DWAF 2004) it is evident that the area’s surface water resources have also been altered. The following subsections review four elements of water resources relevant to this study.

2.2.2.1 Wetlands

Wetlands are transitional ecosystems (Grenfell, Ellery & Preston-Whyte 2005) that occur along a soil-saturation continuum between the extremes of dryland and permanently flooded areas too deep for

emergent plants to grow. They are among the most valuable and productive ecosystems in the world providing multiple ecological resources, products and services depending on their biological, chemical, and physical characteristics. Ecological services include (a) improving water quality by absorbing and filtering out pollutants and sediments; (b) storing floodwater and reducing flood levels; (c) retarding storm water flows downstream (Alvarez 2007); (d) offering habitat for wildlife; and (e) supporting biodiversity (Melesse et al. 2006).

Many wetlands around the world are being lost or are under threat. Due to their dependence on water (Brinson 1993), wetlands are highly susceptible to degradation by land surface developments on and around them (Gibbs 2000) and landscape management practices that alter their hydrological regime (Winter & Llamas 1993). The historical perception that wetlands were wastelands (Maltby 1986) has led to the exploitation, alteration and, in many cases, complete destruction of these valuable ecosystems, with an accompanying loss of associated ecosystem goods and services (Grenfell, Ellery & Preston-Whyte 2005).

These essential ecological units are faced with even more pressure because of increasing human populations and development activities. In many cases losses are caused by human impacts such as irrigation systems, conversion to agricultural land, reclaiming for urban expansion, pollution and habitat destruction (Schutter 2003). Likewise, Papastergiadou et al. (2007) observed that the common reason for wetland degradation is land use changes mainly caused by human activities. However, the ecological changes can also be natural as a result of erosion and drought. The area under investigation here, the uMhlathuze Municipality, is surrounded by several coastal wetlands. Studies conducted in this area (DWAF 2004) have indicated that these wetlands have been modified by agricultural and settlement expansion.

2.2.2.2 Impact of land degradation on rivers

Many human settlements in developing countries are near waterbodies such as lakes and rivers (Snaddon 1998) to ensure access to this resource. The activities of increasing populations near waterbodies impact directly and indirectly on these ecosystems. A wide range of human activities, like clearing of vegetation for agriculture, near waterbodies can significantly impact on the ecological functioning of these systems. Thus, it is critically important to map and monitor the spatial distribution of human settlements as well as land uses adjacent to waterbodies. Also important for mapping and

monitoring are quantifiable measures such as sedimentation and clearance of riparian zones which can further modify the ecological functioning of rivers, leading to their degradation.

2.2.2.3 Sedimentation

Sedimentation is the deposition of sediment loads from the water column onto the beds of rivers, leading to rivers becoming shallower and wider, thereby increasing water losses through evaporation (McCullum 1994). The extent of land degradation within catchments can be determined by measuring sediment accumulation in river catchments (Simms, Woodroffe & Jones 2003). Both erosion and sedimentation are directly influenced by the geology, topography, vegetation, soil characteristics and climate of a catchment (King 1996) and also by land use which indicates anthropogenic disturbance. As was documented long ago by Langbein & Schumm (1958) variation of sediment yield in a catchment is proportional to rainfall and inversely proportional to the density of vegetation coverage, while the type of vegetation is also an important determinant.

The most important determinant of fluvial sediment load is the amount of precipitation (McCormick & Cooper 1992). The clearing of vegetation for agriculture often results in the release of substantial quantities of nutrients by altering runoff patterns and by increasing soil erosion (Snaddon 1998). Overgrazing of grasslands contributes to excessive erosion and sedimentation (Hoffman & Todd 2000). Furthermore, the disturbance of surface slopes for the creation of roads, bridges, railway lines and cultivated lands can all lead to increased erosion and a high sediment load which can significantly degrade surface water resources (Hoffman & Todd 2000).

2.2.2.4 Clearance of riparian zones

The relationship between surface water ecosystems and the associated riparian vegetation has been noted as an intimate and dynamic one (Hoffman et al. 1999). Vegetation, according to Rowntree (1991), is an important control variable in the geomorphology of river channels while, in turn, river flow and sediment loads affect plant growth. Human activities within riparian zones have a direct influence on waterbodies. Riparian vegetation serves as a physical and biological filter for sediments and nutrients from catchment runoff and is important for the stabilization of banks and soils, thereby reducing erosion.

2.2.3 Vegetation degradation

In his study of vegetation degradation, Kakembo (2001) defined it as the worsening of healthy conditions of the vegetation articulated through changes in its composition, structure and function. Van der Merwe (2005) pointed out that vegetation is dynamic in responding to existing environmental conditions and these dynamics manifest in changes in the distribution of vegetation types and changes in the development stages of plant growth. Repeated observation and measurement of plant growth is important for monitoring changes (Van der Merwe 2005).

Singh (1998) has provided strong evidence to suggest that human-induced chronic disturbance is one of the major causes of vegetation degradation, especially in developing countries. Singh further notes that anthropogenic chronic disturbances can result in significant alterations to the structure and composition of vegetation and eventually initiate degradation processes. Horta (2002) found development activities in many developing countries to play a crucial role in vegetation degradation processes which are often related to global political and socio-economic forces. Often, forest degradation, especially at regional scales, has been linked to anthropogenic forces through subsistence farming, grazing and fuelwood collection, and as a result of development projects (Horta 2002). Undoubtedly, forest degradation levels will continue to increase as a result of these pressures, unless mitigation measures are implemented.

Horta (2002) has indicated that vegetation degradation, unlike deforestation, is not such a readily noticeable phenomenon. In the case of vegetation degradation, modifications and changes are revealed gradually, sometimes not as a decline in the area covered but characterized by qualitative losses, for example through the reduction of species diversity, increase of invasive species, decrease of the shrub layer, reduction of woody species and biomass decline (Horta 2002). Kakembo (2001) investigated the trends in vegetation degradation in relation to land tenure, rainfall and population changes in South Africa and found land tenure as the main controlling factor in the spatial and temporal variations of vegetation degradation. Vegetation degradation is thus a good indicator of land degradation. In this study, degradation is investigated though land cover changes rather than productivity.

2.2.4 Infestation of alien plants

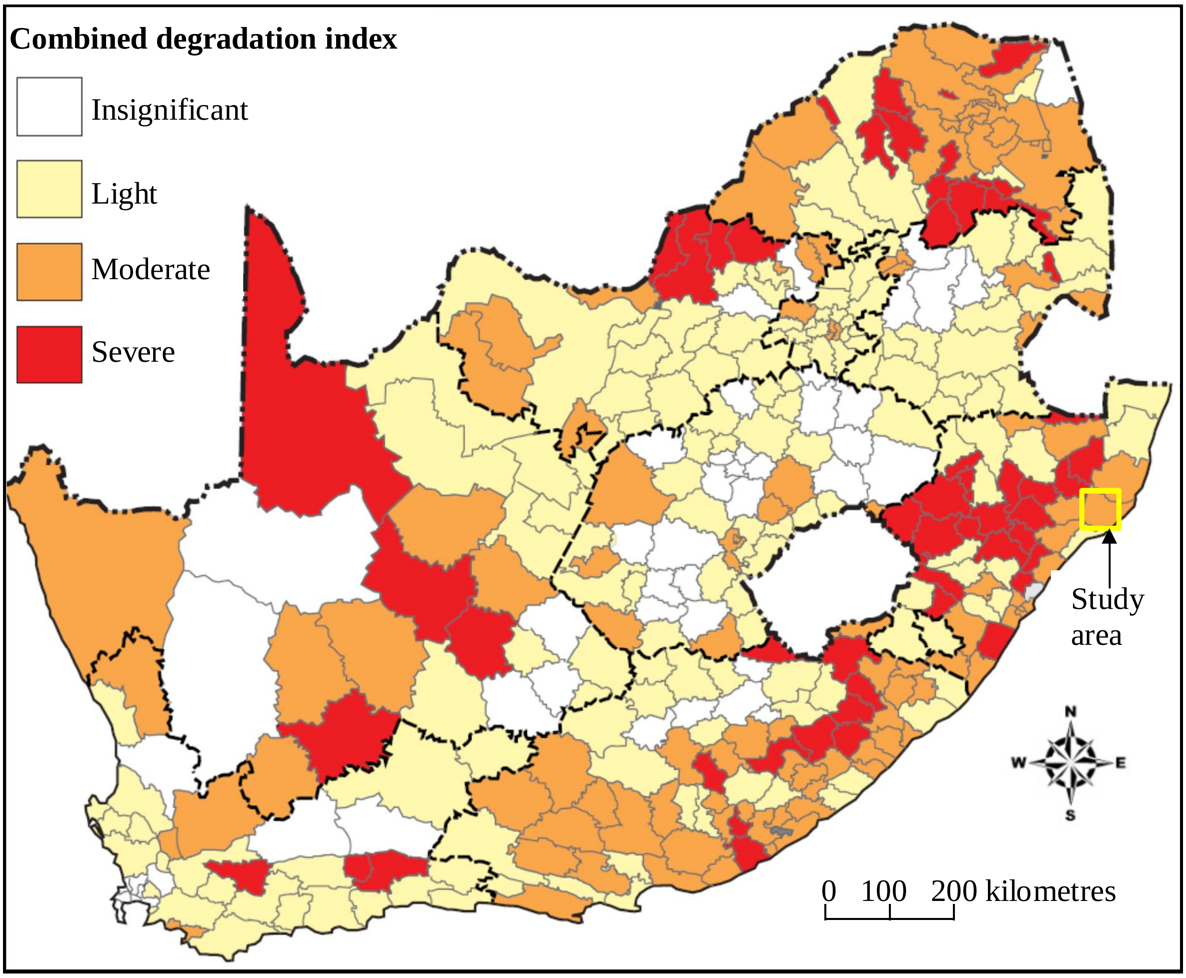
Another phenomenon affecting terrestrial environments worldwide is the infestation of alien plants. Heavy infestations of alien plants usually threaten indigenous biodiversity and ecosystem functioning in areas where it occurs. On the environmental impact of alien plants, Davis (2003) concluded that

some invasive species, commonly known as transformers, are capable of entirely changing the condition of an ecosystem. Perrings, Mooney & Williamson (2010) observed that invasive species dominate and cause severe consequences for indigenous vegetation survival in a wide range of habitats. A large body of research evidence suggests that South Africa has experienced decades of historical management of invasive alien plants (Van Wilgen 2009). Unfortunately, alien plants have been reported to occur in and constantly threaten the biodiversity of the uMhlathuze landscape (uMhlathuze Municipality 2002). Consequently, this study will pay attention to some of the pressures facing the biodiversity of the area. The next section overviews land degradation in South Africa.

2.3 LAND DEGRADATION IN SOUTH AFRICA

In line with several other affected countries, a fair amount of research work on land degradation has been undertaken in South Africa over the last number of decades. These studies (Hoffman & Todd 2000; Meadows & Hoffman 2003; Tafangenyasha et al. 2011) have raised concerns about the severity of land degradation in different parts of South Africa. As elsewhere in the world, different forms of land degradation in South Africa have been identified and studied. Among several forms of land degradation, Critchley & Netshkovela (1998) argued that soil erosion is a great concern in South Africa. Studies on land degradation have estimated that soil erosion is affecting more than 70% of South Africa at varying spatial resolutions (Garland, Hoffman & Todd 2000). Tafangenyasha et al. (2011) found the landscape of the Umfolozi catchment in KZN to be one of the most severely eroded areas in the country.

Hoffman et al. (1999) and Environmental Monitoring Group (2000) have demonstrated that many magisterial districts, especially in the Eastern Cape, KZN, Limpopo and Northern Cape, are severely degraded, as illustrated in Figure 2.2. These findings corroborate Hoffman & Todd's (2000) finding that land degradation in South Africa is very evident and severe in the former homeland areas. The extent of land degradation in South Africa is distinctively acute compared to most other countries subjected to land degradation. Meadows & Hoffman (2003) have reported that assessments of land degradation have not based on physical evidence acquired from instruments such as satellite imagery, rather substantial information on land degradation was gathered from a series of participatory workshops with agricultural extension officers, soil conservation technicians and other related professionals (Meadows & Hoffman 2003). The information used to profile land degradation was based on reliable informed opinion and observations of several professionals dealing with the nature, causes



Source: Modified from Hoffman et al. (1999)

Figure 2.2 Land degradation in South Africa and effects of land degradation.

Whether the methodology used to map land degradation in South Africa (as explained above) is appropriate to give an accurate picture of land degradation countrywide is debatable. This is because research has shown that land degradation studies have been almost entirely confined to agricultural areas and few, if any, have been conducted in the country's non-agricultural areas (Meadows & Hoffman 2003). This very likely implies that the full extent of land degradation in South Africa is far greater than represented by Figure 2.2. It is vitally important that more land degradation studies (using a range of techniques) be conducted in the country to give empirical accounts of the extent, magnitude and causal factors of land degradation in various locations. Figure 2.2 shows that land degradation is occurring in uMhlathuze Municipality, although at a moderate level. This current study is intended to help fill the lacuna in empirical research on land degradation in South Africa and particularly in uMhlathuze Municipality. The discussion now turns to an overview of techniques for mapping and

detecting land degradation.

2.4 LAND DEGRADATION MAPPING AND DETECTION TECHNIQUES

There is little agreement among researchers on the choice of a technique to best map land degradation phenomena. For this reason, various researchers have used a range of techniques to asses and document land degradation evident in several areas of the world. As summarized in Table 2.2, the most commonly used land degradation detection techniques are, in historical order: (a) field surveys, (b) aerial photograph interpretation and (c) satellite remote sensing techniques.

Table 2.2 Comparison of land degradation detection techniques

Technique	Strengths	Limitations
Field survey	• Very detailed information on vegetation and its spatial variability • Can provide information on subsurface conditions • Not weather dependent	• Labour intensive and significant cost implications • Attention required to ensure consistency • Not easily applied to extensive areas • Difficult in inaccessible areas and difficult terrain • Revisit to study landscape change can be impractical so limiting the temporal resolution
Aerial photograph interpretation	• High resolution and cost-effective solution over extensive areas • Likely to detect patterns not visible on the ground and infer land use from cover • Typically more accurate than automated classification	• Less detailed information in comparison to ground survey • Weather dependent (excluding radar system) • Weather dependency and capture costs can limit temporal resolution
Satellite remote sensing	• Multispectral and band ratios (vegetation indices) provide additional information about the surface • Wide area of coverage • Lower cost implications than ground survey or aerial photo capture • Variable spatial and temporal resolution	• Weather dependent (excluding radar systems) • Contextual information not easily obtained in automated classification • Land cover classes must be defined so that they are spectrally distinct • Ground data and aerial photography required to calibrate classification algorithms

Source: Modified from Wyatt (2000)

The advantages and disadvantages of each technique are presented in the subsequent subsections. Each technique has different strengths and limitations as outlined in Table 2.2. Note that both non-survey methods rely on remotely sensed imagery, namely aerial photography obtained from airborne photographically-derived (i.e. capturing reflection in the visible range of the light spectrum) imagery and satellite-borne scanned imagery derived from multispectral scanning of a much wider range of the (especially invisible) reflected spectrum. These methods have been used by myriad researchers in mapping land degradation on a range of spatial and temporal scales. A brief description of each follows.

2.4.1 Field surveys

Field surveys are conventional ground surveying methods of detecting and mapping land degradation making use of traditional observation of phenomena and mapping its location through conventional survey instruments or, of late making use of global positioning systems (GPS). This method is known to yield accurate results because it employs direct, subjective observation and is based on expert judgement and interpretation. Field surveys allow an opportunity for conducting interviews with local people to obtain personal accounts and observations about recent and historical events in the area. Most importantly, field surveys offer an opportunity of gathering information not available through secondary sources, at local level. However, there are documented drawbacks of using field surveys as summarized in Table 2.2. A principal limitation is the challenge of accessing all sites of interest, especially if the terrain is difficult to traverse physically. Because they are tedious to perform, it is not always feasible for field surveys alone to keep pace with the rate of land cover change over time, which is a fundamental aspect in land degradation studies (Osborne, Alonso & Bryant 2001). With such constraints, remote sensing has gained momentum in land degradation studies (De Jong 1994) and substantial amounts of work are now being done with this technology.

2.4.2 Remote sensing via aerial photography

Lillesand & Kiefer (1994) define remote sensing as a technique of obtaining information about an object or feature through analysis of data acquired by a device that is not in contact with the object or feature under investigation. Although there are several definitions of remote sensing, all centre on the sensing and recording of surface features by space- and airborne sensors without being in physical contact with them. This refers to a camera photographing the earth's surface on a film or signal medium sensitive to recordable light in the light spectrum or other portions of electromagnetic spectrum and yielding imagery in analogue or digital format. Aerial remote sensing also offers possibilities of understanding the association of mappable earth surface features and their historical trends as far back as the late 1930s. For this reason Cohen et al. (1996) maintain that aerial photographs are valuable sources for historical information on landscape dynamics and condition. Owing to its high spatial resolution (generally sub-metre), aerial photography has been widely used in ecological studies. Morgan, Gergel & Coops' (2010) empirical study on ecological management found aerial photography to be an ideal tool for mapping small ecosystem areas and fine-scale features. Similarly, Nichol, Shaker & Wong (2006) used aerial photography as one of the paramount sources for detailed environmental information.

Despite the considerably detailed information aerial photographs can provide, Morgan, Gergel & Coops (2010) maintain that this is not suitable for every mapping purpose, especially over broader spatial scales. However, aerial photographs do not keep pace well with landscape change arising from ever-mounting population demands. For this reason, more frequently available satellite remote sensing imagery becomes an alternative option given that satellite sensors are able to capture earth surface features at intervals that probably match the pace at which humans modify environments.

2.4.3 Remote sensing via satellite

Satellite remote sensing (SRS) has, over the past decades, gained wide acceptance in several research domains. SRS has been hailed as the prevailing practical tool for answering questions and understanding the ever-changing nature and dynamics of earth features at very large scales. Estimates provided by SRS are directly based on observation in both time and space. For example, SRS can give a regular indication of 'what happens where' and 'by how much'. SRS also offers great possibilities of understanding connections among mappable earth surface features and further allows historical trends since 1972 to be investigated. Shoshany, Kutiel & Lavee (1994) appraised the strengths of remote sensing over field surveys for providing regional descriptions of vegetation cover. Their research produced vegetation cover maps that provided new information at various spatial scales.

Because ground surveys, airborne and SRS techniques each have their strengths and weaknesses, they should be considered complementary rather than competitive techniques. The use of field surveys as a primary method for mapping manifestations of land degradation in the extensive uMhlathuze Municipality promised to be logistically problematic as opposed to the availability of data sets for mapping manifestations of land degradation using satellite imagery.

Capitalizing on these advantages and the more sophisticated possibilities of SRS, it was chosen for quantifying and mapping manifestations of land degradation in the uMhlathuze Municipality. SRS platforms were preferred for this study because these methodologies are related to advanced GIT which can integrate remote sensing and other spatial data sets. The next section reviews and discusses SRS applications in land degradation research.

2.5 APPLICATION OF SATELLITE REMOTE SENSING TO LAND DEGRADATION

Recent years have indeed witnessed growing recognition and acceptance of GIT applications in several

research fields tackling a range of socio-economic and environmental questions. More specifically, many studies have applied GIS and SRS to characterize land surface features and the extent to which these are being influenced and modified spatially and temporally by human activities.

With the aid of remotely sensed imagery, spatially distributed phenomena such as land degradation can be mapped and quantified (Prince, Guo & Stiles 2002). A good example is the study by Chikhaoui et al. (2005) who applied remote sensing to successfully map land degradation using ASTER (Advanced Space-Borne Thermal Emission and Reflection Radiometer), a high-resolution imaging instrument carried in the Terra satellite) data. Prince, Guo & Stiles (2002) confirm that the measurement of spatially continuous variables linked to land degradation and the spatial scale of land degradation can be done using SRS technology. SRS has also been proven useful for monitoring and assessing a wide range of phenomena related to land degradation like droughts, soil erosion and deforestation. Remote sensing technology has also long been recommended for its potential to detect, map and monitor degradation problems (Sujatha et al. 2000) including their spread and effects over time (Torrion 2002).

Owing to their distinctive capabilities outlined in Table 2.2, both remote sensing types have great potential for the collection of land degradation data at regular intervals and, moreover, its spatial and spectral resolutions allow for the detection of degraded areas (Torrion 2002). Metternicht & Zinck (1997) advise that for degradation mapping, whether features are directly or indirectly visible on the ground, SRS should be considered. Degradation features that must still be checked in the field are (a) manifestations of degradation on bare ground surface, (b) manifestations of degradation presented by vegetation and land use, and (c) manifestations of degradation provided by terrain morphology (King & Delpont 1993).

Several local-scale studies of land degradation and vegetation change have been conducted in South Africa using SRS (Kakembo 2001; Wessels et al. 2004; Gibson 2007). These studies used residual trends of biological productivity derived from satellite imagery to detect land degradation. The principal focus of these studies was on calculating vegetation indices such as the normalized difference vegetation index (NDVI) and doing time series analyses of rainfall to document land degradation. In particular, Wessels et al. (2004) concluded that moderate-resolution NDVI data integrated seasonally could be used to detect degraded areas. However, far less attention has been paid to integrating land cover change, population distribution and socio-economic characteristics with land degradation. This

study's import and intended contribution are to accomplish such integration.

Ample evidence exists that land degradation can be effectively assessed by using SRS in both temporal and spatial comparisons. Because there are several ways to map land degradation, this study elected to map and quantify land cover changes as representations of substantive land surface changes in the uMhlathuze Municipality. Consequently, land cover mapping and land cover change detection are dealt with next.

2.6 LAND COVER AND DRIVERS OF CHANGE

Much has been said about land cover change being a principal factor in environmental change. Several works have suggested that land cover change is significant to a range of themes and issues central to the study of global environmental change (Turner et al. 1995; Lu et al. 2004; Lowry et al. 2005; Abbas 2009), including land degradation. A more recent observation by Chunxiao, Zhiming & Nan (2008) is that changes in land cover is mostly attributable to changes in human land use activities which ultimately bring about global environmental change. In similar vein, Riebsame, Meyer & Turner (1994) confirm that human influences on shifting patterns of land use are a primary component of many current environmental concerns because land cover change is gaining recognition as a key driver of environmental change. To structure this discussion, it is appropriate to distinguish between land cover and land use as concepts. The following section is dedicated to explaining the difference between these terms, before the driving forces of land cover change are distinguished, land cover mapping and change detection practices and procedures are introduced and the relationship between land cover change and land degradation is brought into focus.

2.6.1 Distinction between land cover and land use

Land cover and land use are inseparably interrelated and some researchers tend to use these terms interchangeably. However, there is a clear distinction between land cover and land use. Di Gregorio & Jansen (2000) describe land cover as the observed biophysical attributes that cover the earth's surface such as vegetation, waterbodies and built-up areas. They describe land use as the manner in which humans use biophysical attributes such as mining, agriculture and settlement. It implies that land cover is visually (especially remotely) observed, but all observation is to be understood for the (human) usage that land cover is being put to – that is land use. The latter mostly needs to be established through direct observation or further enquiry and this distinction is universally accepted. Following Waite

(2009), it is essential that before a researcher commences with analyses, a decision must be made whether to focus on land use or land cover. In this thesis the term land cover is used because remotely sensed land cover is what was studied.

2.6.2 Driving forces of land cover change

Certainly, there are numerous factors that drive changes in land cover and these vary from place to place and time to time. It is quite evident from literature that human-induced factors cause most land cover change and override naturally-induced factors. There is evidence (Lowry et al. 2005; Abbas 2009) that significant land cover changes are most evident in areas experiencing developmental and agricultural demands along with natural pressures. It is not surprising that much of land cover change research has concentrated on areas of high natural- and human-induced pressures to assess and quantify the extent, magnitude and consequences of land surface changes driven by these pressures. Examples of such driving pressures are given below.

Agricultural intensification has been cited by many studies as one, if not the most widespread, human activities that has driven land cover change and resulted in the transformation of ecosystems worldwide. A well-documented example is Maitima et al. (2009) who found that agriculture in many parts of East Africa has transformed land cover from pristine conditions to reflecting agro-ecosystems. They established that the changes were caused by a growing demand for agricultural products essential to optimizing food security and revenues, not only for the rural poor but for large-scale investors in the commercial farming sector too.

Stoate et al. (2001) also noted that environmental problems such as land degradation, biodiversity loss, environmental pollution and climate change arise from increased agricultural practices associated with land cover changes. Added to this, several ecologically sensitive ecosystems and biodiversity hotspots such as in Maputaland-Pondoland (where the study area is located) have been reported to be among the vulnerable regions of the world facing significant land cover change because of agricultural intensification. Of course, agriculture alone cannot be blamed for this, as there are other human-induced drivers of the processes of land cover change.

Like agricultural intensification, researchers have also attributed land cover changes to human *developmental pressures*. More generally, Bai et al. (2008) conclusively suggested that human-induced

pressures such as economic development and population increase are significantly driving rapid, unsustainable land cover changes. Among several human developmental pressures, urbanization is probably the main driver of land cover change worldwide with concomitant detrimental impacts on ecosystems (Long et al. 2008). Although total urban area covers a very small fraction of the earth's land surface, urban expansion is believed to have significantly impacted on the natural landscape, producing enormous changes in the environment and associated ecosystems at all geographical scales (Lambin & Geist 2001).

Moreover, Stow & Chen (2002) have presented evidence that land cover change is more noticeable in urban areas because of 'hard' developmental forces there and therefore they rightly concluded that most attention has recently been directed toward urban land cover change. While a considerable amount of work has been done on this aspect in many parts of the world, the extent of urban encroachment on natural ecosystems remains to be determined, especially in developing nations. Mohan et al. (2011) found land cover change driven by urbanization to proceed more rapidly in developing countries than in the developed world and remarked further that urban sprawl (a virulent type of urbanization) is the major contributor to land cover change noted in developing nations. Similarly, Maitima et al. (2009) noted significant expansion of developments in several parts of Africa causing substantial changes in land surface cover and land degradation in the recent past.

These findings and sentiments partly justify why this study was conducted in uMhlathuze Municipality. Moreover, Steyl, Versfeld & Nelson (2000) have pointed out that uMhlathuze Municipality experienced rapid developments of a diverse nature in the recent past. As a result of these pressures, frequent observation to track land cover change, especially using SRS and GIS accounted for elsewhere in this study, has become more appropriate for efficacy monitoring of remaining natural resources in the study area.

This section has reviewed the main drivers of land cover change and has shown that agricultural intensification and human developmental pressures are most prevalent among these. The following section explores land cover mapping because of its central role in monitoring change.

2.6.3 Land cover mapping

Recent studies have consistently shown the importance of land cover mapping for monitoring global

environmental change. Lowry et al. (2005) have pointed out that land cover mapping is generally executed by segmenting the landscape into areas of relative homogeneity that correspond to the land cover classes of an existing or purpose-developed land cover classification. In this study, geospatial techniques (remote sensing and GIS) are the indispensable tools to identify, locate and map various types of land use associated with different landform units (Khan, Gupta & Moharana 2001). Seto et al. (2002) have indicated that medium-resolution Landsat TM is the most suitable and popular satellite data source for land cover mapping exercises and consequently this platform was adopted in this study.

According to Shi et al. (2006), land cover mapping, characterization, monitoring and forecasting are ingredients of several environmental monitoring projects, including land management programmes. They further emphasize that land cover data and information give indications of the effects of land use impacts on natural resource conditions as well as environmental and human well-being. Most importantly, the combined use of land cover and land use data for environmental monitoring allows the detection of where certain changes are occurring, what type of changes they are, as well as how the land is changing over time (Jansen & Di Gregorio 2002). Several studies have successfully demonstrated that remotely sensed data can be processed and classified into actual existing land cover classes (Turner et al. 1995; Jensen 2005; Abbas 2009). Remote sensing is said to be the only practical method for mapping historical land cover and changes that occurred in different parts of the earth (Turner et al. 1995).

According to Levin (1999), the surface or landscape properties measured with remote sensing techniques relate to land cover from which land use can be inferred, particularly with ancillary data or a priori knowledge. Keeping in mind that remote sensing does not directly measure land use, this (land use) is a function of social, political and economic factors (Treitz & Rogan 2004). Moreover, remote sensing only captures spectral properties of surface features on earth, thus it is far more suitable for gathering land cover information (Treitz & Rogan 2004).

Remote sensing technology, along with GIS, offer an opportunity to identify, locate and map various types of lands associated with different landform units (Khan, Gupta & Moharana 2001). To accomplish this, landscape features on the earth's surface must be classified from remotely sensed imagery so that land cover maps can be created. Various approaches can be applied to classify the pixels of remotely sensed imagery into actual land cover classes depicting the earth's surface. Ten

categories of image classification techniques, examples of each and their properties have been summarized by Jensen (2005) as shown in Table 2.3. Some are defined by the statistical properties of the classification procedure and each is characterized by its underlying classificatory assumptions. Supervised and unsupervised methods have been widely accepted and applied.

Table 2.3 Summary of remote sensing classification techniques

Technique	**Examples of methods**	**Properties**
Parametric	Maximum likelihood classification (MLC) and unsupervised classification	Assumptions: Data are normally distributed A priori generation of class density functions
Non-parametric	Nearest neighbour classifier, fuzzy classifiers, support vector machines (SVM), and neutral networks	No prior assumptions are made
Non-metric	Rule-based decision tree classifiers	Can operate on both real-valued data (i.e. reflectance values) and nominal-scaled data (i.e. class 1 = forest)
Supervised	Maximum likelihood classification (MLC), minimum distance (MD)	Analyst identifies training sites to represent classes and each pixel is classified by statistical analysis
Un-supervised	ISODATA, K-means	A priori ground information not known Pixels with similar spectral characteristics are grouped according to specified statistical criteria
Hard (parametric)	Supervised and unsupervised classification	Classification using discrete categories
Soft (non-parametric)	Fuzzy set classification logic	Considers heterogeneous nature of real world Each pixel is assigned a proportion of the land cover types
Per-pixel		Classification of the image pixel by pixel
Object-orientated		Image segmented into homogeneous objects Classification performed on each object vs. each pixel
Hybrid approaches		Includes expert systems (e.g. decision tree) and artificial intelligence (e.g. neural network)

Source: Modified from Jensen (2000)

A supervised classification technique was selected to classify existing land cover in the uMhlathuze Municipality from Landsat TM imagery. Reasons for its selection are given in the next chapter. Because land cover mapping is performed mostly to detect land cover changes, change detection as technique receives attention next.

2.6.4 Change detection

Change detection has progressively become a more important component of environmental change

research as evidenced by its extensive and ever-increasing application. Singh (1989) defined change detection as the process of identifying differences in the state of an object or phenomenon by observing it at different times. Similarly, Karanja (2002) describes change detection as a technique used to highlight conversions of land from one use to another within a given time frame. Change detection exercises have from early on been one of the most popular applications of remote sensing (Singh 1989) and also as a more sound and effective way to monitor environmental changes (Howarth & Wickware 1981). Timely and accurate change detection of earth surface features provides the foundation for greater understanding of the relationships and interactions between human and natural phenomena (Berberoglu & Akin 2009). Ramachandran et al. (1998) advise that multitemporal Landsat TM data are eminently suitable for the identification and tracing of the major changes in land cover, such as deforestation and wetland loss.

Four important aspects to consider in change detection exercises are specified by Macleod & Congalton (1998) as: (a) detecting the changes that have occurred, (b) identifying the nature of the change, (c) computing the areal degree of the change, and (d) measuring the spatial pattern of the change. In this study, all four aspects are examined in uMhlathuze Municipality as reported Chapter 3. This study considers these aspects of change detection sequentially to map and quantify land cover changes, population distribution and manifestations of land degradation over a study period. Given that severe land cover changes can lead to land degradation problems (as indicated in Section 1.1), the next section discusses the relationship between land cover change and land degradation as background to this study's aim to map land cover changes to reveal changes manifested as land degradation.

2.6.5 Land cover change in relation to land degradation

Anthropogenic pressures like economic development and population increase are inexorably driving land use change and, in turn, unsustainable land use is driving land degradation (Bai et al. 2008). In short, land degradation is often manifested as land cover changes, but it is essential to emphasize that not all land cover changes necessarily imply land degradation. However, several land modifications driven by a variety of socio-economic causes can result in land cover changes that may significantly affect biodiversity and water resources (Riebsame, Meyer & Turner 1994) and the altered in the functioning of these components may manifest as land degradation. Thornes (1996) has drawn attention to the issue of land use and land cover change and the direct or indirect relationship these changes might have with land degradation.

Since human modifications of land cover are common in present-day society, these human-induced changes in land cover have reciprocal implications for both society and the environment. Hence, access to historical as well as current and reliable data that reflect land cover changes that have occurred and the direction of change are vital so that informed remedial and planning decisions can be made. Information on changes in land cover is crucial when such changes can lead to land degradation. Although remote sensing has the capability of capturing land cover changes, including degraded areas and their spatial distribution, the extraction of change information from remotely sensed data requires effective and automated change detection techniques (Roy, Lewis & Justice 2002) as discussed above.

Equally important in land degradation mapping and detection is an understanding of population dynamics which can significantly contribute to land degradation processes. The remainder of this chapter is devoted to an overview of population mapping using commonly applied techniques. The next section considers the physical presence of population and the last one concentrates on their socio-economic characteristics.

2.7 GIT APPLICATION FOR MAPPING PHYSICAL POPULATION CHARACTERISTICS

Some useful studies in remote sensing application to population dynamics such as that of Lo (1995) have shown that such applications to estimating human population settlement location and size are not new. According to Lo (2008), population estimation using remotely sensed data has a long history traceable to the 1970s for satellite imagery and even before that for aerial photography. Liu, Clarke & Herold (2006) pointed to advances in two interrelated directions, namely (a) the use of remote sensing to provide accurate estimates of population numbers and (b) the use of remote sensing as ancillary information to refine census reportage of the spatial distribution of population. The following section expounds the need for spatially recording population distribution, advocates the use of satellite imagery to get the job done and concludes with an example of mapping dwellings from high-resolution imagery.

2.7.1 Need for spatial population mapping

Similar to all human–nature interactions, land cover change signifies a response to socio-economic and environmental conditions generally characterized by the nature and extent of population pressures (He et al. 2008). Because these interactions, conditions and pressures are typically spatial in nature, there is a compelling need for mapping the spatial distribution of human populations. Liu, Clarke & Herold (2006) for example, have alerted us that knowledge of the size and distribution of human population is

essential for understanding and responding to many social, political, economic as well as environmental problems.

Considerable research has been done into environmental change with the intention of understanding causal factors at scales ranging from local to global (Lowry et al. 2005; Liu, Clarke & Herold 2006; Maitima et al. 2009). Osborne, Alonso & Bryant (2001) found that human-induced factors are the leading drivers of environmental change compared to naturally-induced factors. Wilkie & Finn (1996) found natural resource consumption and degradation to be prevalent in many areas because of human-induced pressures. Poor and fragmented environmental planning has often been blamed for this condition. The lack of technological expansion, especially in developing communities and nations, will continue to accompany a gradually degraded natural resource base as people fight for survival with ultimate far-reaching implications for environmental quality and human health (Amissah-Arthur, Mougenot & Loireau 2000).

The issues highlighted above have, inter alia, resulted in the devising and improvement of several research tools and methodologies to spatially map and link population dynamics with a wide range of environmental features. The rationale behind these is to enhance our understanding of population pressures on the environment. Some available methods for mapping aspects of population are reviewed in the following three subsections.

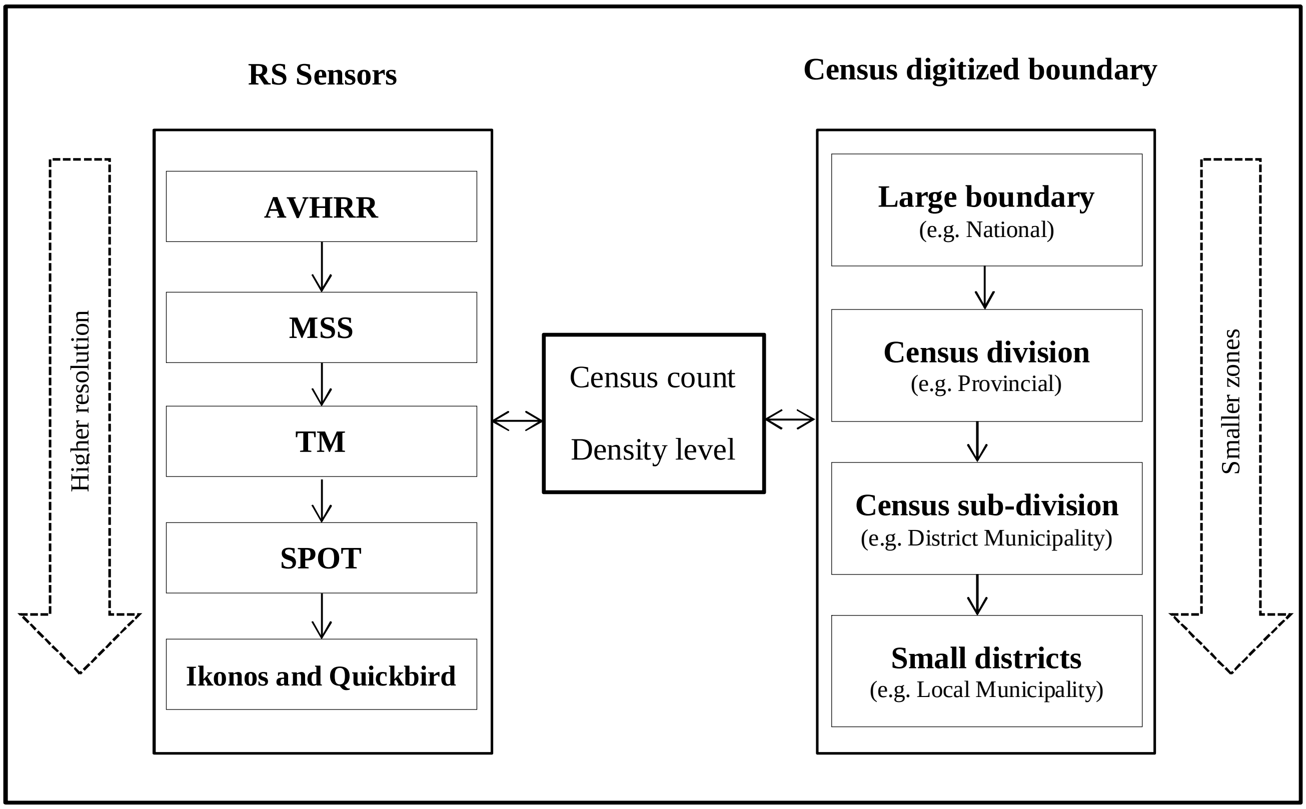
2.7.2 Population mapping using GIT

A number of different measures have been used to estimate aspects of human populations from remotely sensed imagery. The strengths of each may vary but broadly produce similar population patterns. Lo (1986) has described four yardsticks, namely (a) individual dwelling counts, (b) measurements of urbanized land areas, (c) estimates from land use classifications, and (d) automatic image analysis based on spectral features. The most accurate of the remote sensing approaches to estimating the population of a local area is to count individual dwellings (Jensen & Cowen 1999). Lo (1986) has noted that high-resolution imagery is most suitable for this task. The following subsection advocates the use of high-resolution satellite imagery.

2.7.3 High-resolution satellite imagery

Figure 2.3 shows the relationship between imagery resolutions and census scales. It is clear that not all

population features can be mapped using satellite imagery, the main reason being spatial resolution (Lo 2008). This constraint makes high-resolution imagery such as Ikonos, Quickbird (0.8-1m) and aerial photography (0.3-0.5m) an appropriate alternative for mapping smaller features (i.e. dwellings) in smaller districts as Figure 2.3 depicts. Despite these (Ikonos and Quickbird) imageries' ability to acquire detailed earth surface information, they cannot yield comparably detailed information on the ground as high-resolution aerial photographs do.



Source: Modified from Jensen (2005)

Figure 2.3 Hierarchical linkages of census scales and remote sensing sensors

Satellite imagery appropriate for population mapping must show features in enough detail for the required analysis (Lo 2008). The hierarchical linkages between census scales and remote sensing sensors illustrated in Figure 2.3 make it clear that high-resolution imagery such as aerial photographs are more suitable for mapping population settlements at smaller scales, since ground features can be clearly observed. This is confirmed by Avelar, Zah & Tavares-Correa (2009) who suggested that high spatial resolution makes it possible to distinguish among small constructions, thus facilitating a survey of small built-up elements. Lo (1995) advise further that the imagery must be of sufficient spatial

resolution to identify individual structures even through tree cover and irrespective of whether they are residential, commercial or industrial buildings. An example is given in the following section.

2.7.4 Mapping spatial settlement distribution through digitizing dwellings

Cowen & Jensen (1998) established that by means of remote sensing one can measure landscape spatial attributes such as dwelling units. Unfortunately this task (measuring dwelling units) cannot be achieved by using remote sensing as an isolated tool. A system that can integrate remotely sensed data is required to analyse earth surface features. GIS is such a tool in geographical research because of its distinctive capabilities to manipulate, integrate and analyse remotely sensed spatial data sets.

Hand in hand with the innovations in computer technology, GIS has developed capabilities to handle massive data sets such as high-resolution imagery and to enable the abstraction and complex analyses of spatially distributed features. Because high-resolution imagery permits the identification of above-ground features, it is possible in a GIS environment to digitize individual dwelling units to give overviews of the distribution and patterns of settlements along with settlement densities which are essential to land use planners, especially in changing environments.

In this study, settlement growth and density were estimated as explained in Chapter 4. Because the mapping of human settlement alone is not enough to fully portray human pressures on the environment it was necessary to map key socio-economic variables from census data (e.g. access to energy). By overlaying maps of these variables on land cover maps, some driving factors of land cover could probably be identified. The next section reviews GIS as a tool to map socio-economic variables to uncover their possible roles as drivers of land cover change.

2.8 GIS MAPPING OF SOCIO-ECONOMIC CHARACTERISTICS

Studies that investigate and depict socio-economic and demographic characteristics of areas and populations remain essential to empirical social science (O'Sullivan 2004). In such studies census data are often relied on as the main source of information (Fiedler, Schuurman & Hyndman 2006). The presentation of census statistics requires a fast method with spatial-analytical capabilities to map and enhance the visualization of socio-economic characteristics of communities. GIS is such a spatial tool that best handles census data and enables users to create outputs in identifying spatial relationships among and patterns in socio-economic variables. Maps, long used in geography as tools to portray and

describe spatial features, are now more widely used in other fields and disciplines (Johnston 1998).

In the following subsections, the application of GIS to map socio-economic characteristics is overviewed and four socio-economic variables frequently used in land degradation studies are described.

2.8.1 GIS application in mapping socio-economic characteristics

GIS is a spatial tool with capabilities for storing, manipulating and displaying spatial and non-spatial information. With GIS it is possible to generate graphic displays, usually maps and diagrams, as well as tabular reports, from which statistics representing derived information products can be generated (Ji 2008). GIS also allows a number of useful applications such as seamless data import from Microsoft Excel (the format in which census data is mostly distributed). In GIS data on socio-economic variables of population can be statistically manipulated and combined with other spatially related information to exploit relationships beyond census data only (Fiedler, Schuurman & Hyndman 2006). Leading from this ability, Crampton (2001) has suggested that the reintroduction of dasymetric mapping practices to socio-economic GIS can significantly improve the representation of population data. A dasymetric mapping approach uses ancillary data sources like land use and remotely sensed imagery in conjunction with high-resolution census data to produce more meaningful spatial units for mapping (Eicher & Brewer 2001). Added to this, census data in the GIS environment can be updated from time to time so facilitating comparisons and analysis of trends over time.

A host of variables can be investigated to measure socio-economic characteristics of human populations. Guided by the literature, key socio-economic variables linked to land cover change and degradation were identified and they are discussed in the following subsections. These variables were used in the analysis of the population of uMhlathuze Municipality as presented in Chapter 4.

2.8.2 Population growth and density

The connection between population growth and land cover change has been shown beyond doubt in most environmental change studies. For instance, Nagamani & Ramachandran (2003) observed human population growth to exert pressure on biodiversity and natural ecosystems through activities such as agriculture, industry, forestry and settlement. These activities have been blamed for rapid and magnified land cover change and land degradation in many parts of the world. Conversely, Eswaran,

Lal & Reich (2001) are of the opinion that high population growth and densities are not essentially related to land degradation. In their view, it is what the population does that determines the degree of land degradation. This implies that population growth alone is perhaps not sufficient to engender population pressures that could instigate land degradation. This notion is explored in this research to understand how the population in the study area is distributed and growing over time and these are related to land degradation.

2.8.3 Unemployment status of communities

Coupled with poverty and lack of workable regulatory strategies, unemployment has been positively associated with land degradation problems (Hoffman & Todd 2000). As a major poverty indicator, the focus in this study is on the unemployment status of communities. The assumption is that in areas where unemployment rates are high, communities will resort to natural resource exploitation to derive their daily livelihoods because these are ‘cheaper’ or even ‘free’. These two notions can easily lead to dependencies on and overexploitation of resources resulting in land degradation. Depending on the rate and extent of natural resources use, environmental problems such as land degradation and biodiversity loss are likely in such settings. In Liberia for example, Booth (2012) found increased unemployment rates to be linked with the spatial occurrence of deforestation, signifying that communities where high unemployment reigns opt for cheaper fuelwood over other available sources of energy which they cannot afford. Of course, manifold social variables (like poor education standards) may be related to unemployment.

2.8.4 Access to energy sources

The prevalence of poverty in communities is a major deterrent to the sustainable development of most countries, but particularly so in developing countries (Kanagawa & Nakata 2008). One possible way to overcome this malaise, as suggested by the World Bank (2001), is to stimulate economic opportunities through improved access to modern energy sources such as electricity. Dasappa (2011) underlines this by pointing out that access to energy or electricity in a society is a critical factor in its development.

While access to electricity is essential to reducing pressures on natural resource consumption, evidence (IEA 2009) indicates that Africa registers the lowest levels of electricity access compared to other continents. Even among developing regions, Africa has an electrification rate of merely 25% compared to East Asia (90.8%), South Asia (62.2%), Latin America (93.4%) and the Middle East (89.5%) (IEA

2009). It is not surprising that a larger proportion (more than 80%) of the African population relies on biomass for energy needs (UNECA 2006). No doubt, heavy dependence on biomass energy promotes deforestation and other forms of land degradation. Access to electricity is used as an explanatory variable in this research to determine whether it is a significant socio-economic factor leading to land cover change in the form of deforestation.

Chapter 2 has provided insights on various aspects of land degradation and most importantly offered comparisons of methods to map and detect land degradation and human settlements. It was shown that remote sensing and GIS are most suitable for mapping these phenomena because of their capabilities to handle spatial data. The narrative showed that land cover change and population growth, together with their socio-economic characteristics, are essential explanatory features in land degradation studies. The next chapter uncover land cover distributions and land cover changes empirically in the study area from which manifestations of land degradation are tracked over the study period.

CHAPTER 3 ANALYSIS OF LAND COVER AND DEGRADATION

This chapter first details the classification system adopted and the methods used to map land cover. It then turns to a discussion of the extent of land cover and the patterns that developed over time, discerns land cover changes and concludes how these changes have manifested as land degradation in the study area.

3.1 LAND COVER MAPPING METHODS

For meaningful analysis of land cover change, an accurate land cover map must be created for each time period involved. To realize this, Waite (2009) advises that the selection of an appropriate classification method is of paramount importance. The following subsections describe the land cover classes decided upon and explain the classification method used. The section ends with a short report on how the area of each land cover class was quantified.

3.1.1 Classification system

A primary requirement for all land cover and land cover change studies, as expounded by Mohan et al. (2011), is to choose a suitable land cover classification system (LCCS). Anderson et al. (1976) long ago declared that there was no ideal LCCS and that it was doubtful whether one would ever be developed. Thompson (1996) ascribed this difficulty to LCCSs being largely influenced by geographical location and environmental settings being globally very diverse. Consequently, a number of classification systems have been developed around precise user objectives but few are directly comparable (Thompson 1996).

This study has adopted the LCCS defined by Thompson (1996) as it is one of the most used in South Africa to date. It is used along with a land cover field guide developed by the Chief Directorate: Surveys and Mapping (CDSM) and the Council for Scientific and Industrial Research (Satellite Application Centre) (CSIR (SAC)) which is now SANSA (South African National Space Agency) and vegetation maps of the study area. A copy of the land cover field guide was obtained from the Department of Geography and Environmental Studies at Stellenbosch University. After reviewing the aforesaid sources, the nine classes described in Table 3.1 were selected.

These land cover classes reflect human pressures on the uMhlathuze landscape which manifest in land

Table 3.1 Description of land cover classes for identification in uMhlathuze Municipality

Land cover class	**Description**
Forest	Multistrata community of indigenous tree species with interlocking canopies growing under natural condition; excludes planted forests
Grassland	Dominated by grass-like, non-woody, rooted herbaceous plants; associated with grassland and savanna biome
Wetlands	Includes woody riparian vegetation, freshwater swamp forests, mangrove forests, pans and floodplain
Waterbodies	Includes natural lakes, rivers and estuaries
Bare ground	May comprise unvegetated lands, visible erosion and fine rock
Built-up areas	Built-up areas where people live on a permanent or semi-permanent basis; includes rural dwellings
Plantations	Planted trees (e.g. *Eucalyptus*) requiring human activities to maintain; can be temporarily without vegetative cover
Sugar cane	Only sugar cane plantations; can temporarily be without vegetation seasonally; can be regularly modified by humans, for example during harvest period
Mining	Active mine and areas used to stockpile waste material created during extraction of sand or minerals during mining activities

degradation. These classes include (a) natural classes (natural forest, wetlands, grasslands) which should give an indication of how natural resources and biodiversity are changing or lost spatially and temporally, and (b) human-induced classes (built-up area, plantations, sugar cane, mining) which should reflect land use and intensity that may drive land cover change in the study area.

Briassoulis (2006) has emphasized that the environmental impacts of land use modifications and their influence on ecosystems functioning are mediated to a larger degree by land cover change. For this purpose, better understanding the cause and effect of land cover change necessitates the separate consideration of human-induced activities and natural land cover types.

3.1.2 Classification method

Mapping land cover requires specific or typical land cover classes to be distinguished and delimited from remotely sensed imagery. Various classification methods exist to perform this action. Classification methods refer to technique(s) used for categorizing and grouping similar land cover classes based on their spectral relationships from remotely sensed imagery (Jansen & Di Gregorio

2002). Several methods for the classification of patterns observed on images exist and the selection of the most suitable method is determined by the characteristics of the imagery used and the nature of the analyses being performed (Eastman 2006). In this study a supervised classification was applied. In a supervised classification, the analyst identifies homogenous and clearly defined samples of different surface cover types of interest, often referred to as training areas (Levin 1999). The classifier is then used to attach labels to all the image pixels based on the trained parameters.

Each remotely sensed image of the study area was segmented in the software programme Definiens 7.0 and subjected to a supervised classification. Segmentation entailed the automatic recognition and delineation of (small) image areas showing dissimilarity in pattern (colour) and hence different land cover types. Training areas (areas of clearly recognizable land cover types) were identified onscreen, and the procedure of classification and training area modification was iterated until a satisfactory classification was obtained. Ancillary orthophotographs operated as ground verification information that aided the verification of training areas. The nine class samples were exported as a raster file (.tif) and the segmentation (the objects) was exported as a shape file (ArcMap .shp). The classification raster was converted into a polygon shape file in ArcMap and intersected with the objects shape file for error correction.

The resultant classification only clearly identified six land cover classes. Previous studies, such as uMhlathuze Municipality (2002), have classified the landscape of uMhlathuze Municipality as a biodiverse and heterogeneous area. Sommer, Hill & Megier (1998) have maintained that the resemblance in spectral responses of natural surfaces, especially in spatially heterogeneous landscapes, usually precludes the consistent identification and mapping of actual land cover classes. As such, the preliminary classification was considered inadequate for this type of investigation. For instance, bare ground had similar white reflectance as built-up areas and mining areas. Similar confusion was observed between natural forest and wetlands. While fewer classes are less complicated and easier to analyse, Jansen & Di Gregorio (2002) caution that fewer land cover categories limit the identification of precise conversions from one class to another. Moreover, the land cover change analysis would not yield meaningful results if larger land cover classes were not separated into smaller actual classes occurring in the area. The further purpose of separating broader classes was to create a land cover map which stratifies the study area into meaningful environmental units. It was thus decided to enforce the discrimination of the six classes into the nine classes described in the classification system (Table 3.1).

To effect this decision, the 2004 colour orthophotographic mosaic, the 2003 digital vegetation map as well as the 1984 orthophotographs were used to aid the discrimination of land cover classes into actual classes occurring in the area. Classified polygon shape files were overlaid with orthophotographs and all similar class polygons were merged and others were manually separated until satisfactory classification was attained and thereafter each layer was exported as a shape file. All nine intended land cover classes were distinguished from the original six, as shown in Figure 3.1.

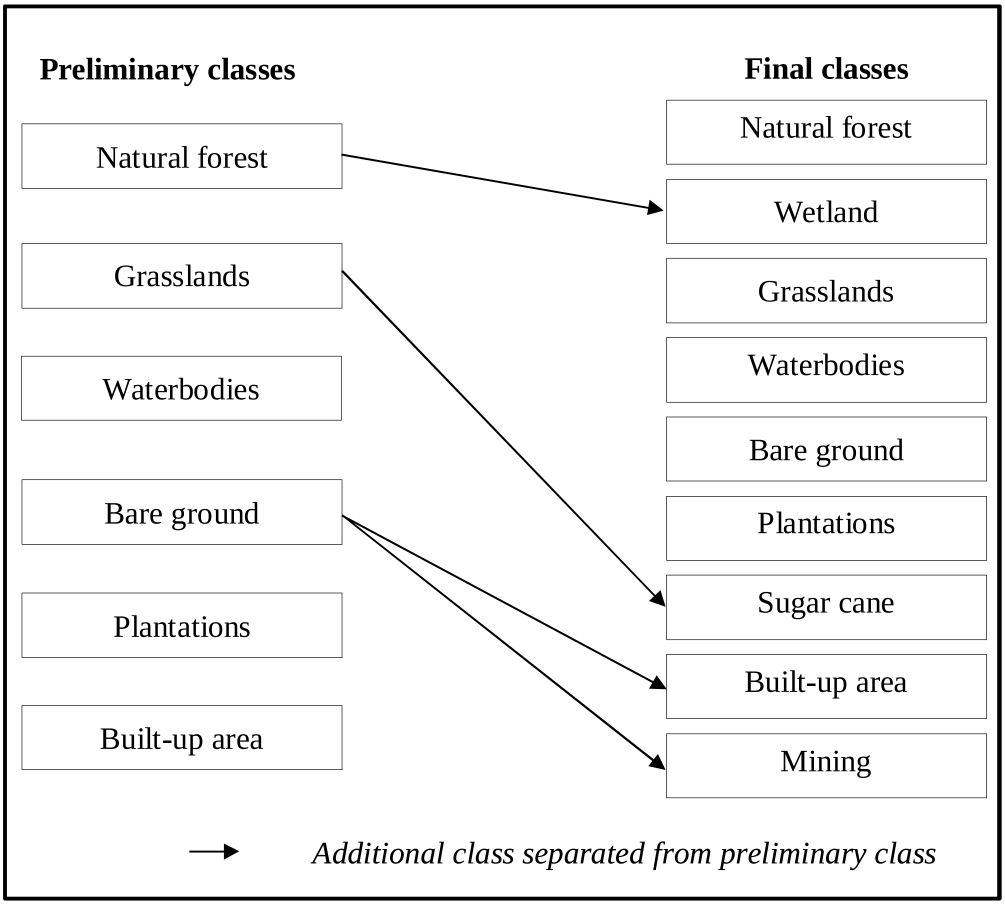


Figure 3.1 Separation of six preliminary classes into nine final land cover classes

This procedure was followed to allow a limited focus into actual environmental units within which degradation could be mapped and quantified, since various land cover types impact differently on the environment.

3.1.3 Quantification of areal land cover extent

Without quantifying individual land cover types in a given time span, it might be difficult to understand land cover dynamics. This is confirmed by Mengistu & Salami (2007) who pointed out that tabulations and surface area calculations provide a comprehensive data set of the overall landscape condition including the type and extent of changes that have occurred. In this study, land cover statistics were computed from ArcMap in a GIS environment, and then exported to Excel and presented as areal extent and percentages.

3.2 ANALYSIS OF LAND COVER DISTRIBUTIONS

Having addressed the classification system, the narrative now turns to the results of the analyses. The discussion of results first (Section 3.2.1) reports the quantitative and spatial trends observable in the land cover maps of 1984, 1996 and 2004, followed by an overview of the trends in the same years of the land cover classes according to use intensity (Section 3.2.2.). The intensity of a land cover class is assumed to be related to potential environmental stresses that can be mapped and reported. Some of the discussions relate to prominence of land cover in uMhlathuze Municipality.

3.2.1 Land cover overview

Here an overview is given of land cover distribution, first areally and then spatially for each of the three years studied. Only salient observations are recorded to set the scene for the change analysis that follows in Section 3.3.

3.2.1.1 Total land cover areal distribution

The areas covered by each land cover class in the study area of almost 800 square kilometres are listed in Table 3.2 – an item to which discussions in subsequent sections will of necessity refer back as required. The dominant (>50%) land cover class in 1984 was natural vegetation domain (grassland, forest and wetland), but by 2004 that had decreased to below 40% of total coverage. This trend was apparently due to the expansion of agroforestry (forest and sugar cane plantations) from near 30% in 1984 to almost 40% by 2004. These agroforestry cover types are of medium ‘hardness’, since they can, if eventually abandoned, revert to a natural condition although biodiversity loss is complete at the outset and unlikely to be re-established. The increases in built-up areas (10%) and to a growing extent mining (0.4%) are noteworthy. These two raise concern because they represent extremely ‘hard’ and irreversible coverage types that fully obliterate the original natural landscape and are unlikely to be

Table 3.2 Area of land cover types in uMhlathuze Municipality in 1984, 1996 and 2004

Land cover type	**1984**		**1996**		**2004**	
	Area (km^2)	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
Natural forest	70	8.8	67	8.4	51	6.4
Grassland	358	45.1	293	36.8	243	30.5
Wetland	17	2.1	9	1.1	8	1.0
Waterbodies	44	5.5	44	5.5	44	5.5
Bare ground	21	2.7	33	4.1	15	1.9
Built-up areas	43	5.4	101	12.7	124	15.6
Forestry plantations	89	11.1	117	14.8	141	17.7
Sugar cane plantations	153	19.2	131	16.5	166	20.9
Mining	1	0.1	1	0.1	4	0.5
Total area	**796**	**100.0**	**796**	**100.0**	**796**	**100.0**

converted back to the original natural condition. As such they attest to complete loss of biodiversity.

Given the growth of these artificial land cover types, the decline in the area of natural coverage classes is inevitable. To provide spatial perspective to the information provided in this section, the following subsections describe some salient spatial features of the land cover types at three synoptic moments in turn.

3.2.1.2 Land cover distribution in 1984

Land cover in the uMhlathuze Municipality in 1984 as shown in Figure 3.2 had a definite yet fairly simple configuration. Grassland was the prominent and most widespread feature of the uMhlathuze landscape. It also presented as remnant matrix patches among developed agroforestry fields particularly around Empangeni and Richards Bay. Natural forest occurred along a narrow coastal strip and along some waterbodies and watercourses. An assemblage of wetlands existed in the north-eastern areas adjacent to waterbodies. Notably, some of these sensitive systems were situated in and flanked by built-up areas around Richards Bay. Agroforestry concentrated in large blocks: sugar cane predominantly in the central interior and forest plantations in two large, linear and continuous stands in the south-western and north-eastern interior (between Vulindlela-Esikhaleni and Richards Bay-Nseleni respectively).

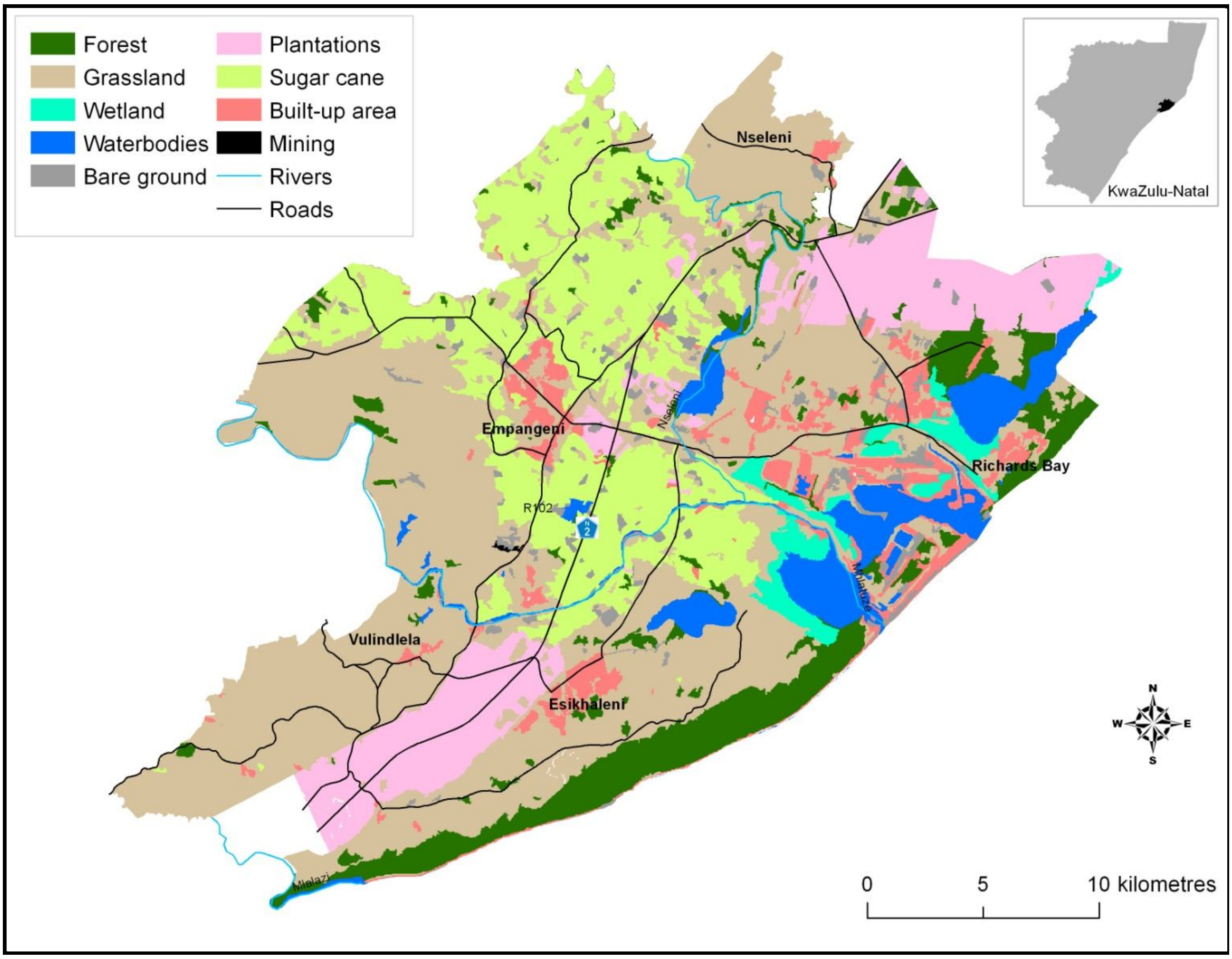


Figure 3.2 Land cover in uMhlathuze Municipality, 1984

The smaller urban built-up areas showed a patchy distribution spread across the study area, but appear relatively prominent adjacent to the coastal waterbodies in the Richards Bay area. Very small patches of bare ground appeared in isolated and scattered locations. Mining (Ninians quarry) was only present in very small area surrounded by grassland along the R102 south of Empangeni.

3.2.1.3 Land cover distribution in 1996

In 1996 (Figure 3.3), given the relatively short passage of time (12 years), the broad land cover distribution remained relatively the same as in 1984. However, and this might be partly due to the difference in imagery used for classification, the general picture of land cover occurrences appears more patchy as if landscapes were becoming more fragmented. The prevalence of small settlements (built-up areas) largely contributed to this fragmented manifestation, while the larger urban centres

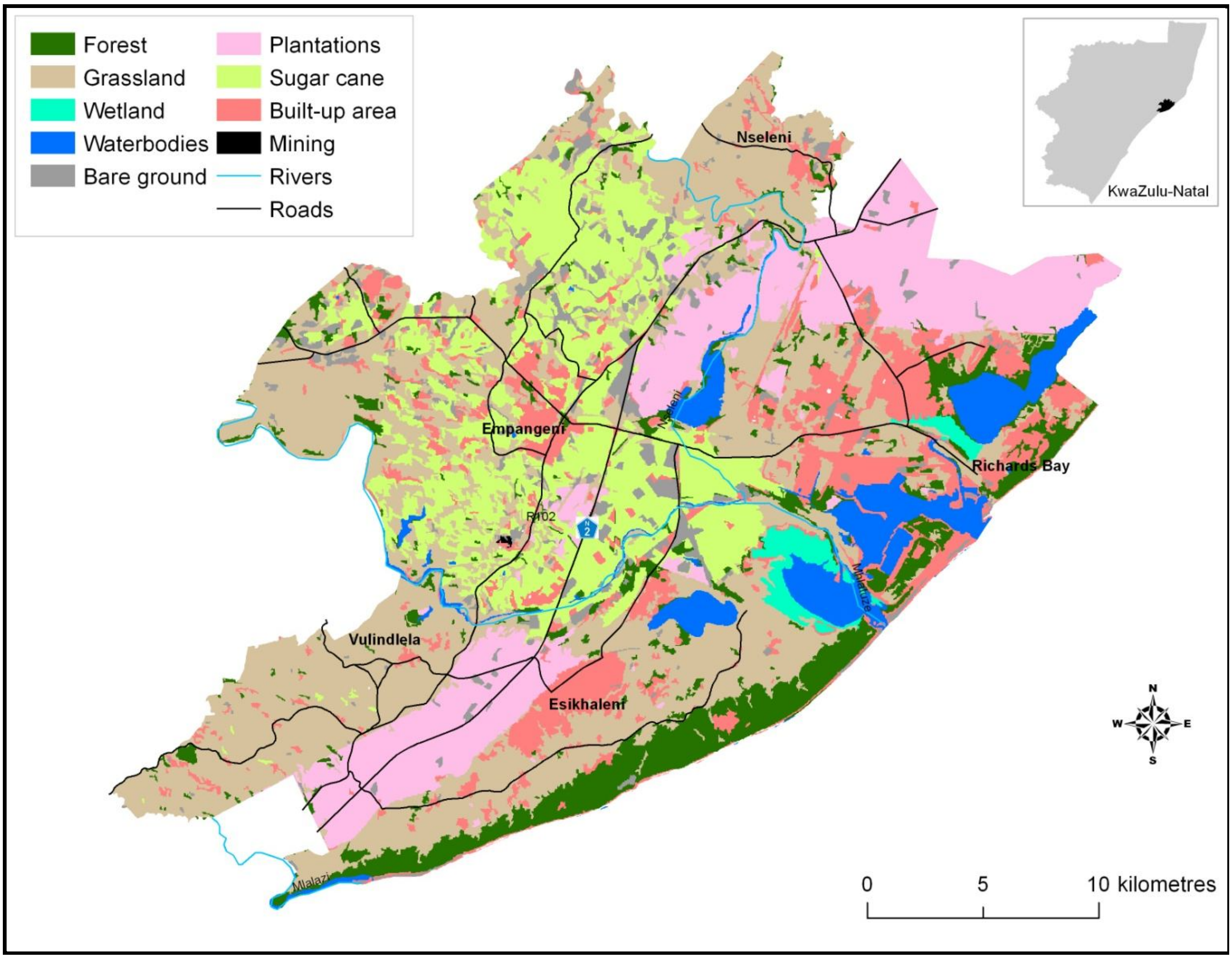


Figure 3.3 Land cover in uMhlathuze Municipality, 1996

seemed to have consolidated into urban monodominant landscapes. The north-eastern forestry block had extended south-westward and grassland had become scarcer, almost disappearing with the spread of sugar cane fields west of the R102 southwest of Empangeni.

Some built-up patches were now evident in the natural forest along the coast, suggesting an upsurge of coastal developments. There is a proliferation of bare patches of increased size to point to a foothold for land degradation and interspersed with sugar cane fields.

3.2.1.4 Land cover distribution in 2004

Eight years later in 2004 – after an even shorter passage of time – the land cover scene (see Figure 3.4) had solidified the overall distribution and trends pointed out in the previous two stages.

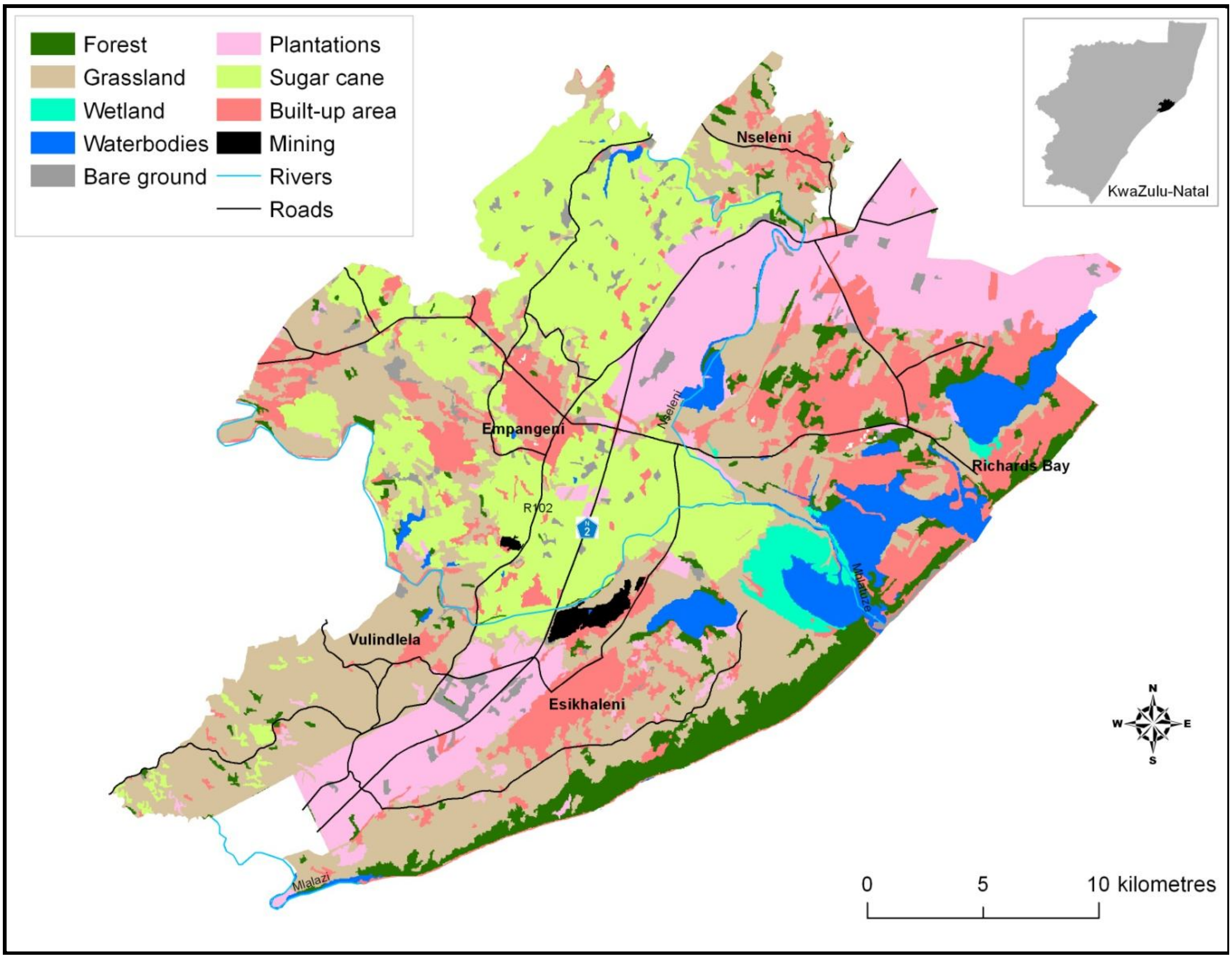


Figure 3.4 Land cover in uMhlathuze Municipality, 2004

The overall impression in 2004 pointed to a number of landscape scenarios with definite implications for environmental development planners in the uMhlathuze Municipality. They are:

- Dominance of the major land cover classes (like urban built-up) in their original settings, but becoming even more cemented in their various locations;
- Virulent growth of new and expansion of existing human settlements and formal urban areas;
- Further consolidation of the north-eastern forestry plantations;
- Consolidation of the central sugar cane plantations;
- Perilous thinning of coastal forest lines;
- Further disappearance of grasslands;
- Ominous appearance of large mining activity east of the N2 along the uMhlathuze River; and
- Many bare patches have apparently acquired the appearance of and consequently been classified

as built-up areas. Clearly, changes in land cover and probable landscape degradation affected large areas of the uMhlathuze municipal area by 2004.

In land cover and land cover change studies, chronological trends and the ecological significance of each land cover is important because they reflect environmental stresses leading to land degradation. These are discussed next.

3.2.2 Overview of land cover class trends

Having considered the broad historical occurrences of land cover at three time slices, attention now turns to accounts of the land cover type in greater detail. For the sake of discussion the classes are grouped in logical and meaningful ensembles of similar origin and state, closeness to ecological pristineness and degree of reversibility (i.e. potential to return to a natural setting or remain altered). Consequently, the discussion begins with the natural cover types, then turns to agroforestry (potentially rehabitable), followed by the irreversible cover types (human settlement and mining) and ends with the manifestations of land degradation.

3.2.2.1 Salient trends in the natural vegetation classes

About terrestrial ecosystem dynamics, Kerr & Ostrovsky (2003) found habitat loss and degradation to implicate ecosystem functioning and reduction of the value of ecosystem services for humans. This is probably a common predicament in fast-growing municipalities where natural vegetation is imperiled by rapid conversion to intensive human land use activities. UMhlathuze Municipality is no exception to this trend. Before entering this discussion, it is worth noting that Richards Bay is the single most studied area in uMhlathuze Municipality, largely because much of the environmentally sensitive land cover occurs there and it is an area of concentrated developmental activity. So, it is not surprising that the significant alterations have stemmed from noticeable trends in the natural vegetation classes in this area.

Owing to their economic value and despite their ecological significance, natural forests are among the most rapidly disappearing ecosystems the world over. As in several other developing countries, South Africa is vulnerable to this extinction, with no more than 2% of its total land surface area being classified as occupied by indigenous forest (Van der Zel 2000). This valuable ecosystem, most of which is in the Maputaland-Pondoland-Albany Biodiversity Hotspot, is presently being increasingly subjected to diverse developmental pressures.

Some of the remaining natural forest in this biodiversity hotspot is found in uMhlathuze Municipality. Figure 3.5 shows that natural forest area declined from 70 km^2 to about 50 km^2 or from 9% to 6% of the total study area. This is serious.

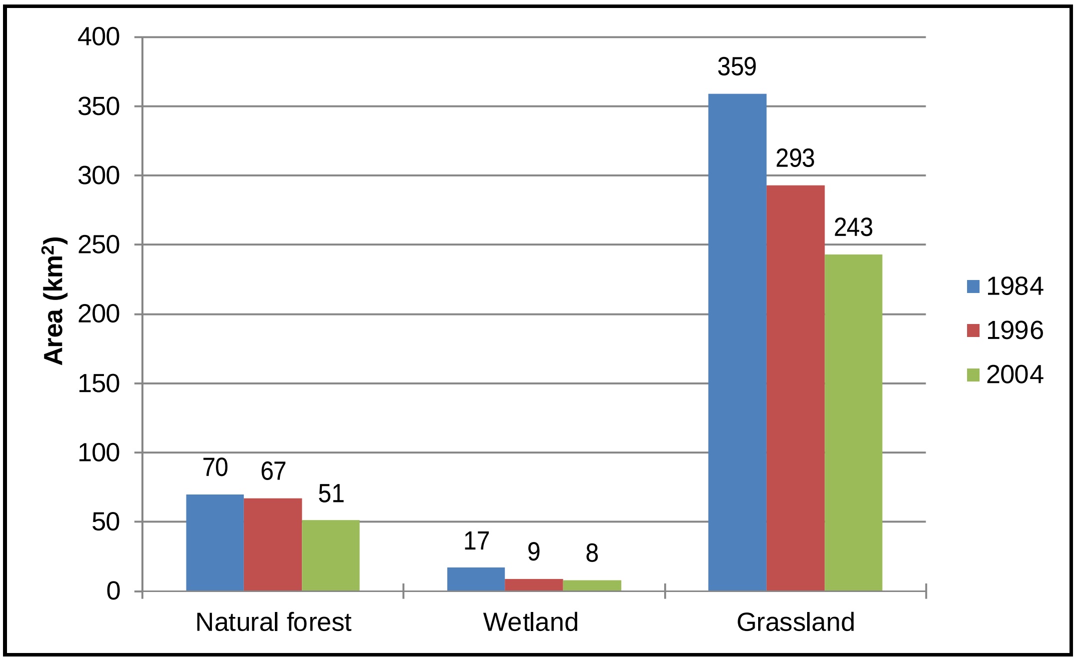


Figure 3.5 Natural vegetation classes in uMhlathuze Municipality, 1984, 1996 and 2004

Natural forest occurs along the coast and in a few patches inland around Richards Bay where there is a concern about its existence following diverse developmental pressures. Whatever the real estimates are at present, it would not be out of place to expect estimates lesser than of 2004 (the latest imagery date) because of on-going developments taking place there. From an environmental perspective, it has been acknowledged that the alteration of the spatial distribution of natural forest affects wildlife habitat and biodiversity (Virgos 2001). Regrettably, much of the critical biodiversity and endemic richness in the study area is found in this habitat where it is presently under serious threat. This gradually diminishes the natural attractiveness of the area.

A notable feature in the uMhlathuze Municipality is its wetlands. As a signatory to the Ramsar Convention, South Africa is committed to optimize the protection and sustainable use of wetland systems. Because the value of wetland systems has been spotlighted the predicament of declining and degrading wetlands cannot be ignored. Wetlands are known to provide a plethora of goods and services to societies and the environment (as explained in Chapter 2). Costanza et al. (1997) estimated the value

of a hectare of wetland to be as high as £24 100 per year, nearly double that of forest and six times that of grasslands ecosystems. Among the empirical studies of these systems, Lande (2008) pointed out that the wetlands in the uMhlathuze Municipality are internationally important as the southern destination of many migratory wading birds.

According to uMhlathuze Municipality (2002) the uMhlathuze landscape contained considerable wetland systems over the past decades, exceeding the size of the Isimangaliso Wetland Complex (formally known as the Greater St. Lucia). At present, less than half of the area's original wetlands remain (SRK 2009). This study has found that the size of wetlands in the area has decreased over the 20 years between 1984 and 2004 by approximately 53%.

Unfortunately, the remaining wetlands are mainly along the coast around Richards Bay where they are close to or bordered by major (smelter and phosphate) industries (Figure 3.6). This collocation is likely to place even greater pressure on these ecologically sensitive systems, especially if expansion by adjacent industries occurs in the future. This is why conservation authorities have set a '100%

Figure 3.6 A wetland in Richards Bay located in close proximity to industrial activities

protection' target for all wetlands in the area (Thornhill & Thornhill 2010). Conservation targets are largely determined by rarity and the extent of landscape alteration (Kuyler 2006) so that the target of 100% acknowledges the status and vulnerability of wetlands in uMhlathuze Municipality. According to Thornhill & Thornhill (2010) the Ezemvelo KZN Wildlife has pledged support for such a programme.

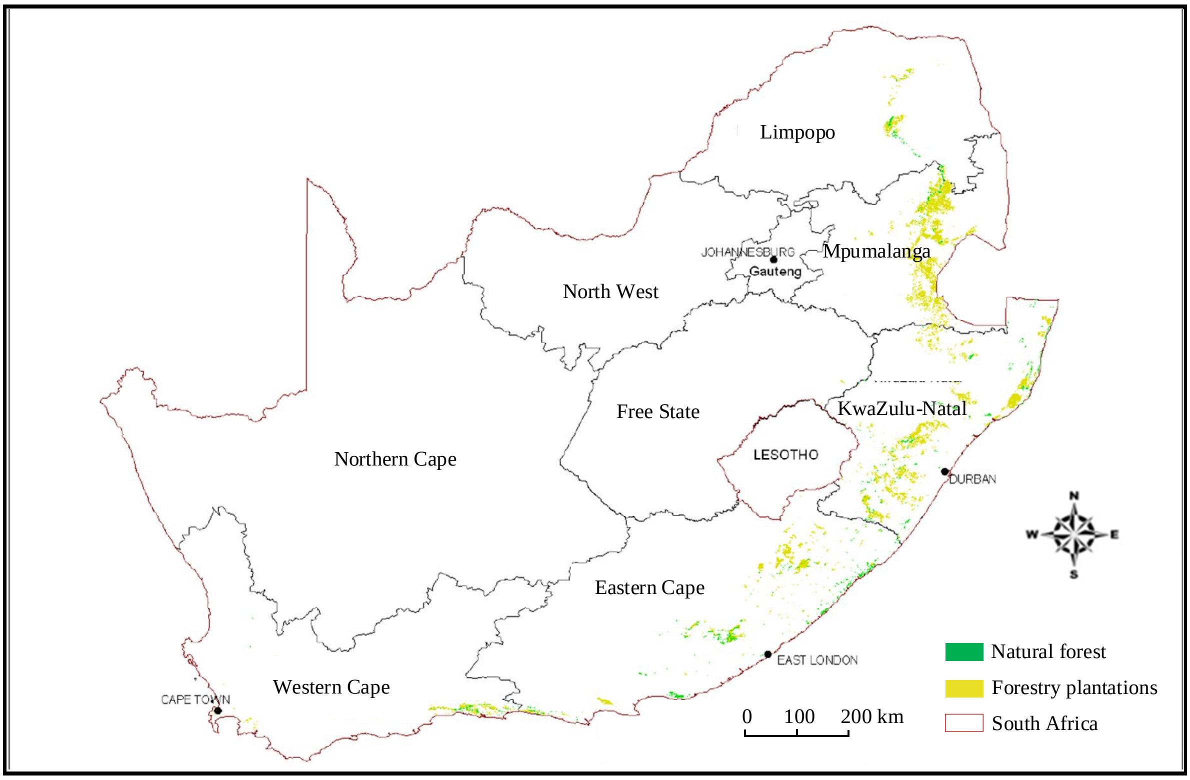
UMhlathuze Municipality is geographically located in a savanna biome and its landscape consists of bushveld grassland, valley thicket and sand forest (Low & Rebelo 1998). Despite its 32% decline in size over 20 years, grassland still had the largest land cover extent in 2004 and was extremely important vegetation cover type in the uMhlathuze landscape. This importance is confirmed by Reyers et al. (2005) who pointed out that the area covered by the grassland biome in South Africa has great prominence for aquatic and terrestrial biodiversity. DEAT (1997) has documented that less than 3% of the total surface area of this vegetation type has been placed under formal protection: far less than the figure of 10% recommended by the International Union for Conservation of Nature (IUCN).

Grassland is significant in many respects and its value is well established in the literature. For example, O'Conner & Bredenkamp (1997) maintain that grassland vegetation is resource wealthy and delivers a range of ecological services that support human populations. Important among these services is soil stabilization, water and nutrient cycling, energy supply, provision of sustenance through present-day agricultural activities and forage for livestock (Reyers et al. 2005). Therefore, a decline or disappearance of grasslands will endanger or even lead to the eternal loss of these essential ecological services.

Owing to the extent of its transformation in the uMhlathuze Municipality, grassland vegetation has been recognized as a priority and critically in need of high conservation action (uMhlathuze Municipality 2002). This vegetation type is at risk of being destroyed, especially in the Richards Bay area where numerous industrial and commercial developments are occurring. Grasslands declined from 45% to 30% of all land cover area in the study period. This corroborates McGinley's (2008) conclusion that grassland vegetation was the prominent feature of the Maputaland Coastal plain (where uMhlathuze is located) before substantial conversion to forestry and sugar cane plantations transpired. This is not unique to uMhlathuze Municipality seeing that Scholes & Biggs (2005) found that globally the grasslands terrestrial ecosystem has exhibited the largest degree of habitat loss.

3.2.2.2 Salient trends in agroforestry

Agroforestry in uMhlathuze Municipality comprises two notable sectors, namely commercial forestry and sugar cane plantations. Both plantation types are practiced extensively in this area and, with exception of grassland, they individually and together exceed the area covered by any of the other land cover classes. Most indigenous tree species are slow-growing and therefore unsuitable for meeting the increasing demands for timber (Grundy & Wynberg 2001). Consequently, exotic plant species, largely from Australia, were introduced in South Africa to provide more timber. Many of these plantations are located along over coasts as shown in Figure 3.7.



Source: Modified from Van der Zel (2000)

Figure 3.7 Natural forest and forestry plantations in South Africa

The commercial forestry plantations follow dry-land cropping practices and grow more productively in environments receiving more than 800 mm of rainfall per annum (DWAF 2004). Fortunately, the eastern seaboard of KZN where uMhlathuze Municipality is situated receives an annual rainfall ranging from 1000 mm to 1200 mm and the overall climate and soils of the region offer favorable conditions for forestry plantations.

Analysis of remotely sensed imagery provided evidence that uMhlathuze municipal area is substantially covered by forestry plantations. The observed areas increased from nearly 90 km^2 to over 140 km^2 in the period 1984 to 2004 (Figure 3.8). That represents a significant increase of 58%.

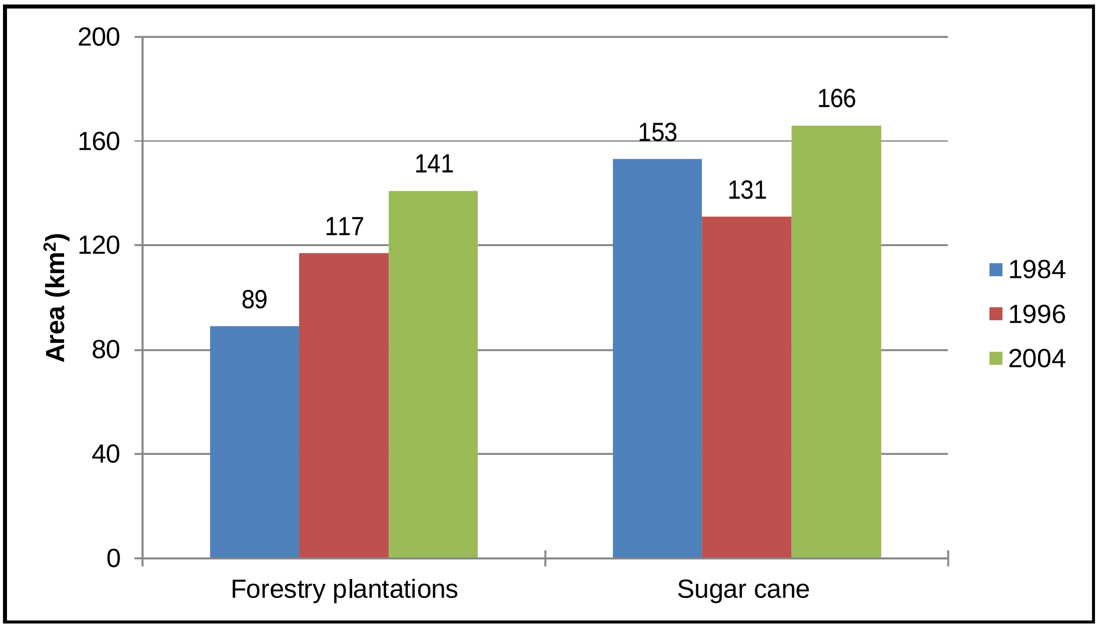


Figure 3.8 Agroforestry in uMhlathuze Municipality, 1984, 1996 and 2004

Empirical studies such as that of Karumbidza (2006) and SRK (2009) have expressed serious concerns over the spatial expansion of forestry plantations in the area. More specifically, they argued that *eucalyptus* plantations are not sustainable in the uMhlathuze environment as they have cumulative impacts especially, on water resources which are a continuous threat to the natural ecosystems in the area principally because, as Dye & Versfeld (2007) claim, forestry plantations act as a major stream-flow reduction activity (SFRA). SFRA, according to DWAF (1999), entails any activity that is likely to reduce the availability of water in a watercourse to the reserve level and to other water users as declared by the National Water Act (36 of 1998). Similarly, Armstrong et al. (1998) found commercial forestry plantations to have severe effects on biodiversity – particularly in coastal regions of South Africa. The internationally recognized Maputaland-Pondoland-Albany Biodiversity Hotspot is no exception, given that a large part of these plantations is in this region. Therefore, if the serious detrimental ecological effects of forestry plantations are to be avoided, environmentally less disruptive alternative options must be promoted to sustain the remaining biodiversity of the uMhlathuze municipal area.

It has widely been shown, for example, that the coastal strip of KZN (where uMhlathuze is located) is an important sugar cane region in South Africa, the others being Mpumalanga and the Eastern Cape. UMhlathuze Municipality (2002) noted that sugar cane is the foremost cultivated crop in the uMhlathuze landscape, mostly concentrated around Empangeni town (see Figure 3.9 for its appearance on remotely sensed imagery).

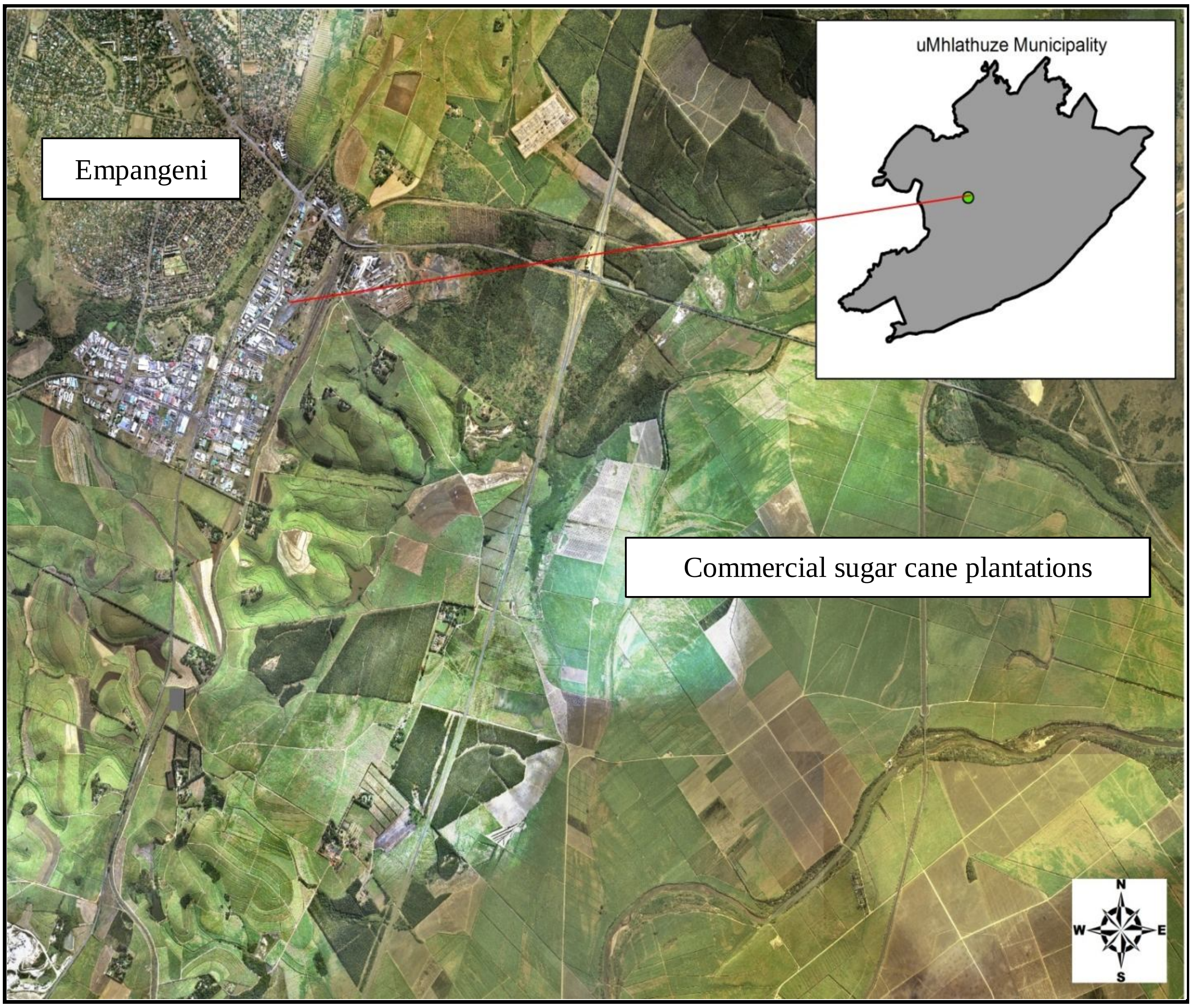


Figure 3.9 Sugar cane plantations around Empangeni in uMhlathuze Municipality, 2004

Sugar cane plantations constituted the greatest share (see Figure 3.8) of agroforestry land cover and grew by approximately 5% between 1984 and 2004. This growth (although relatively small) might be attributable to growth factors pointed out by Watts (1983) that the growth of sugar cane plantations from an infancy period relied first on the establishment of sugar mills for cane processing, and second

on good transport infrastructure to move the commodity. In the study area, sugar cane expansion has been spurred by the existence of Felixton Sugar Mill (one of the 14 operational mills in South Africa) and good road and railway transport infrastructure (Watts 1983).

Ecologically, sugar cane is a monotypic land cover (Figure 3.9) and its expansion could have serious implications for ecological functioning of ecosystems in the area. For example, the biodiversity prevalent around Empangeni prior to the introduction of sugar cane is now largely lost. Expansion of sugar cane plantations is a cause of concern because it entails continuous loss of biodiversity and impediment to migration of fauna of this area (McGinley 2008). The focus next shifts to trends in 'hard' land cover types in the area.

3.2.2.3 Salient trends in irreversible land use

Built-up areas and mining are some of the most intense and 'hard' land use activities that are responsible for significantly altering the functioning of ecological systems. In this study these land use activities are recognized and discussed as irreversible human land use activities. Conversion of land to built-up area and mining is a one-way process because there generally is no reverting to an initial or more natural land cover category. Lyson & Olson (1999) claim that land use change is irreversible when the ecological elements necessary for ecological functioning have deteriorated. The counter-claim for site rehabilitation done post-mining does not hold because such areas can never be restored to their *original* natural state – hence mining is ecologically irreversible.

Despite its relatively small coverage of the earth's land surface, urban land use has extensively impacted natural landscapes worldwide (Lambin & Geist 2001). Kuyler (2006) adds that urban developments are associated with complete losses of biodiversity integrity of the landscape and there are limited chances of reversing this loss. Kuyler (2006) advises that urban expansion should preferably be directed toward areas that have 'little or no' natural resources and that are least significant regarding biodiversity integrity. He argues further that urban policy should promote intensification of density and make allowance for more open space systems instead of encouraging low-density developments. Such actions can safeguard the biodiversity in dynamic urban environments like uMhlathuze Municipality. This helps to realize the objectives of sustainable development. Biodiversity will enhance the natural attractiveness of uMhlathuze Municipality which can benefit several domains, particularly the fast-growing tourism sector and specifically ecotourism. But these merits must be seen in light of the

tripling in size of the built-up area in the uMhlathuze Municipality from 43 km^2 in 1984 to 124 km^2 in 2004 (Figure 3.10). While this increase may be economically beneficial, what is worrying is that sensitive ecosystems could have been compromised, especially if growth took place haphazardly.

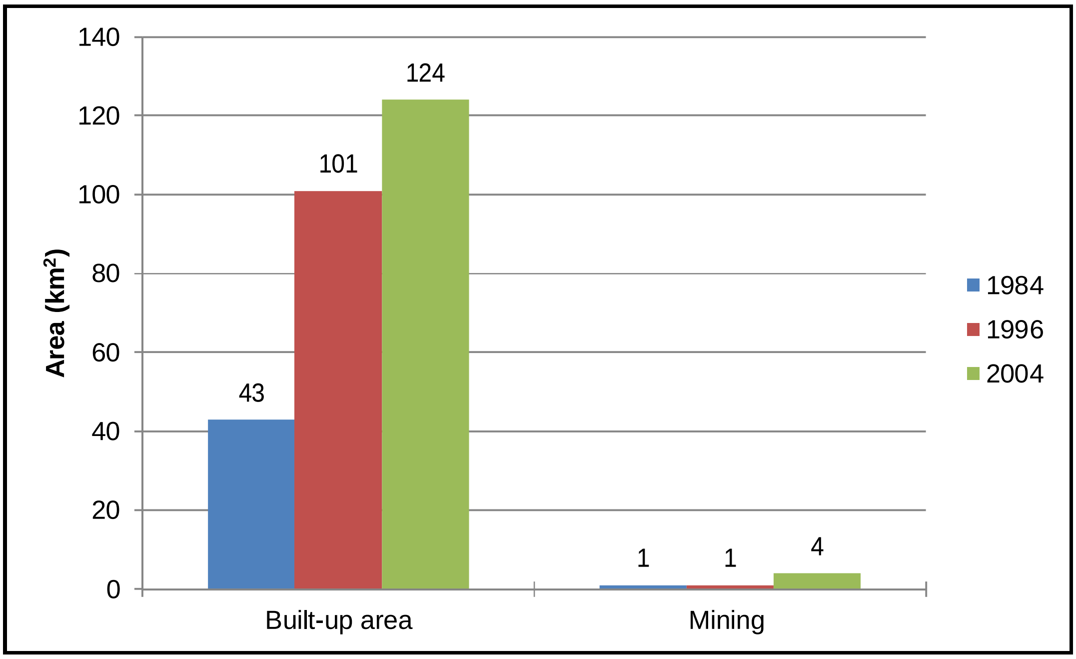


Figure 3.10 Irreversible land use types in uMhlathuze Municipality, 1984, 1996 and 2004

UMhlathuze Municipality (2002) has documented the study area as having rich mineral resources. Apart from Ninians Quarry that has been operating in the area since before the base year for this study (Watts 1983), there was no substantial mining activity in uMhlathuze Municipality until the middle of the 1990s when Exxaro KZN Sands (the then Ticor SA) emerged. According to Kotzé, Bessinger & Beukes (2006), a detailed feasibility study was initiated in 1995 which moulded a design phase for the mine. Full operation commenced in 1997 in the central south of the area (see Figure 3.4). The large extent of the mining operation is shown in Figure 3.11.

Although mining has the smallest land cover footprint of all the classes (4km^2 or 0.5% of all classes in 2004), it is an extremely intensive and destructive human land use in the study area and it increased fourfold in size between 1996 and 2004.

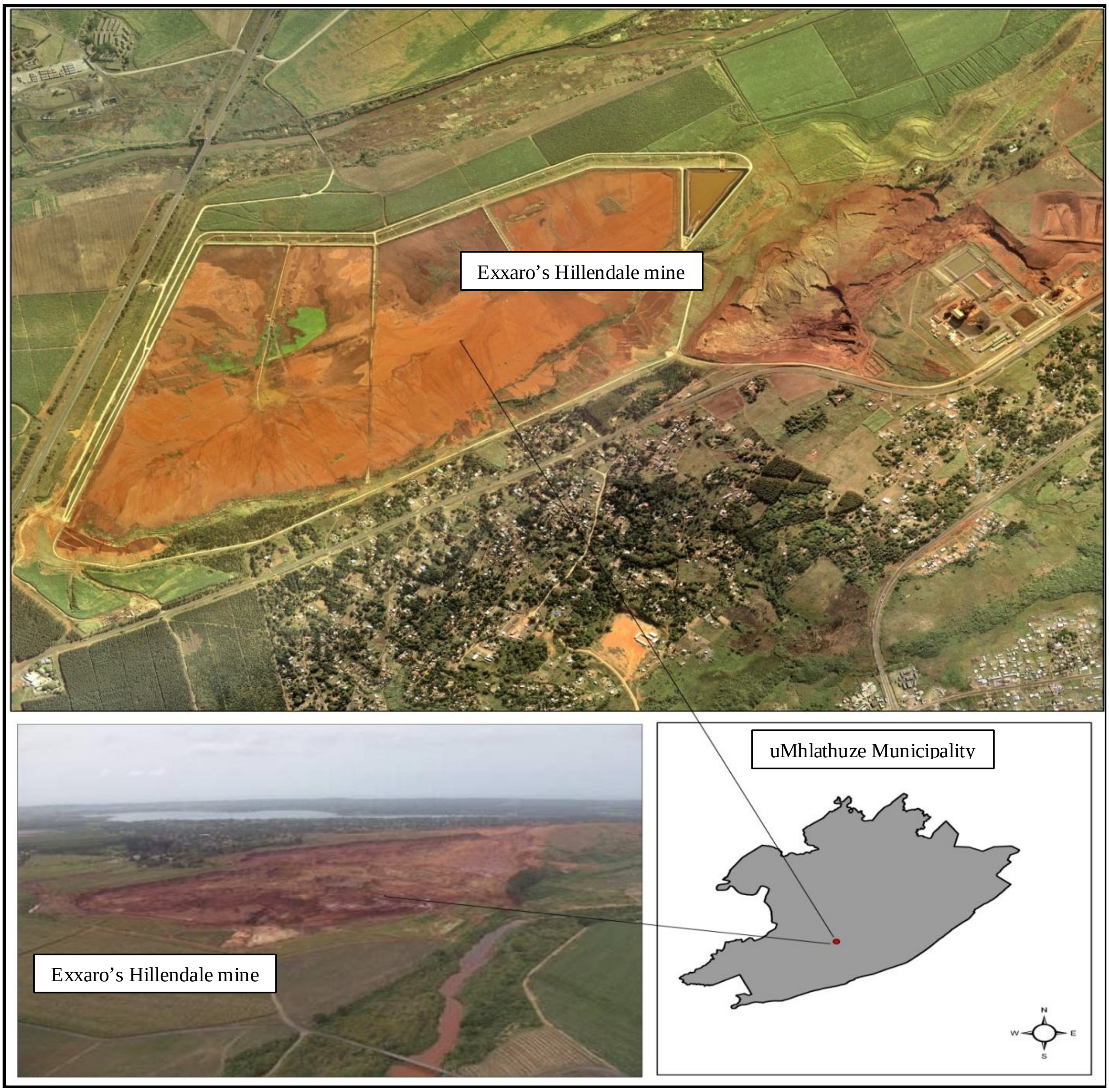


Figure 3.11 Exxaro's Hillendale mine in uMhlathuze Municipality

A number of environmental impacts emanating from the Hillendale mining site have already been reported. For instance, Thornhill & Thornhill (2010) found increased sand erosion from the mining site to cause sediment accumulation in the uMhlathuze River course. This may not only impact on the nearby river section that is exposed to the mining site, but could also be detrimental to the ecologically sensitive uMhlathuze estuary further downstream.

3.2.2.4 Salient signs of land degradation

Islam & Ahmed (2011) have established that extreme land cover change can degrade biodiversity and generate hardships for human livelihoods. While evidence of such degradation does exist, Mortimore & Adams (1999) caution that not all land cover changes amount to land degradation. Yet, it is imperative to be aware that areas of bare ground should be vegetated to avoid aggravating land degradation. Patches of bare ground were mostly observed around Richards Bay, although there were difficulties in distinguishing them from sugar cane fields (this is a notable problem during the sugar cane harvest period). Should more bare ground areas be classified as sugar cane or built-up area, land degradation will appear to affect the larger part of uMhlathuze Municipality. The next section is devoted to documenting and explaining the land cover changes that have occurred in uMhlathuze Municipality during the study period.

3.3 EXAMINATION OF LAND COVER CHANGE

Extreme and rapid changes in land cover resulting from anthropogenic pressures potentially have serious implications for the ecological functioning of the environment which can lead to land degradation. It is relevant here to enquire about the extent to which land cover changed in the interim periods and what the drivers of change were. Because uMhlathuze Municipality is a fast-growing municipality, it is not inconceivable that significant land cover changes and examples of land degradation are evident in the study area.

A prerequisite for analysis of land cover change is a statistical change detection exercise. Change detection offers an account of areal changes that have occurred during a given period (Kareddula 2011). Owing to the growing international attention given to environmental change, a number of land cover change detection methods have been developed. These are, inter alia, image regression and image differencing as summarized in Jensen (2005). The choice and selection of a land cover change detection method depends on user needs and the purpose of the investigation. In this section the technical aspects of the change detection method applied in this study are described first, followed by a discussion of the results of analyses of land cover change in the study area.

3.3.1 Methods of change detection

Several methods exist for investigating and executing land cover change. The selection of an appropriate method depends largely on user objectives but it is important to note that existing change detection methods vary and each one cannot provide change information at the same

analytical level (Munday 2010). Comparisons of these methods have been made by Jensen (2005). Lu et al. (2004) have reported that some methods, such as image differencing, can only deliver change and non-change information. This is inadequate, because a proper study of land cover change should also consider time-series analysis. For this reason Lu et al. (2004) consider the postclassification comparison method to be more appropriate for in-depth analysis of land cover because it provides a complete matrix of change and also detects where changes have occurred. Postclassification comparison is the commonly used and effective technique that was applied in this study because it provides ‘from-to’ information (Pontius, Shusas & McEachern 2004). ArcMap’s Map algebra function was also applied to identify changed and no-change areas in uMhlathuze Municipality.

In this study postclassification comparison was performed through land cover cross-tabulation matrixes constructed in ArcMap. This procedure has been used extensively in postclassification comparison and Ahadnejad (2002) recommended it as a suitable exercise for comprehensive land cover change analysis. The method for investigating land cover change is summarized in Figure 3.12.

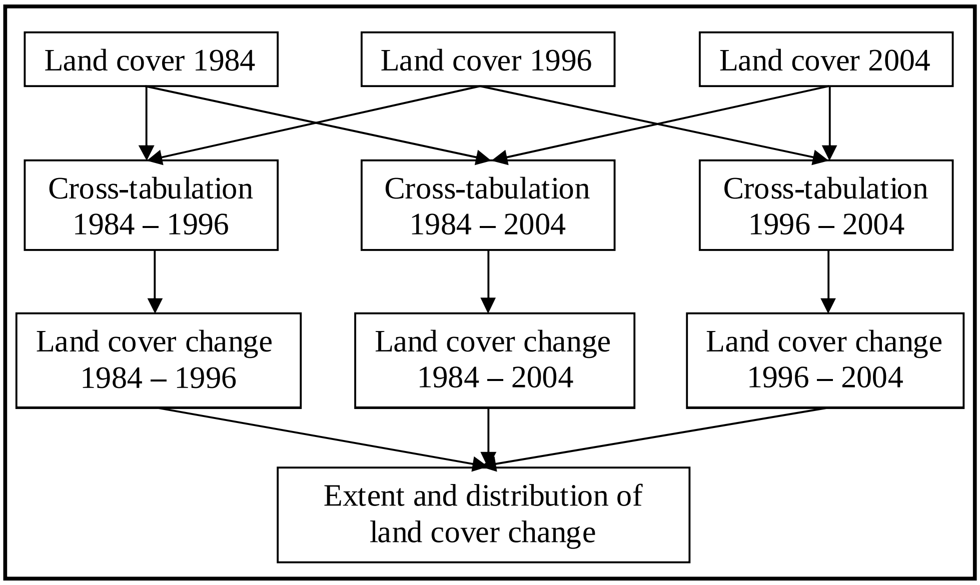


Figure 3.12 Flow diagram of the analysis of land cover change in uMhlathuze Municipality

A requirement of this task was that all three vector land cover maps be converted to raster format because GIS computes and compares areal conversions of classes pixel by pixel. The nature of land cover changes were classified into four levels of reversibility: very high, high, medium and low. This was done to indicate which changes can revert in intensity and which are permanent. In a change matrix table, values for areas that remained unchanged are placed along the diagonal of the cross-

tabulation while all other cells signify change.

3.3.2 Analysis of land cover change

The previous section gave a general picture of land cover dynamics in the study area over the study period. This section details a time-series account of proximate influences responsible for significantly changing the area's landscape. The first subsection reports the overall change of land cover during the study period and grades the reversibility of the changes from very high to low. Thereafter, account is given of detailed 'from-to' analyses of changes in each interim period.

3.3.2.1 Overall land cover change from 1984 to 2004

The aggregated land cover change values for uMhlathuze Municipality over the entire study period are presented in Table 3.3, classified according to the potential 'hardness' of change or degree of permanent damage and hence irreversibility affected on the natural environment. It is apparent that the landscape was subjected to anthropogenic influences that led to significant changes in land cover. The analysis showed that nearly one fifth (19%) of the study area's total size changed over a 20-year period between 1984 and 2004.

Table 3.3 Overall land cover change in uMhlathuze Municipality among aggregated classes, 1984 to 2004

(Row percentage)	2004					**Area total (km²) (% of total)**
1984	Forest	Grassland	Wetland/water-body	Agroforestry	Built-up/Mining/ Bare ground	
Forest	30 (42.9)	16 (22.8)	2 (2.9)	11 (15.7)	11 (15.7)	**70 [100.0] (8.8)**
Grassland	14 (3.9)	193 (54.1)	4 (1.1)	83 (23.1)	64 (17.8)	**358 [100.0] (45.0)**
Wetland/waterbody	2 (3.3)	7 (11.5)	43 (70.5)	4 (6.6)	5 (8.1)	**61 [100.0] (7.6)**
Agroforestry	1 (0.4)	18 (7.5)	1 (0.4)	198 (81.8)	24 (9.9)	**242 [100.0] (30.4)**
Built-up/ Mining/ Bare ground	4 (6.3)	9 (12.5)	2 (3.1)	11 (17.2)	39 (60.9)	**65 [100.0] (8.2)**
Area total (km²) (% of total)	**51 (6.4)**	**243 (30.5)**	**52 (6.5)**	**307 (38.6)**	**143 (18.0)**	**796 (100.0)**

Change 'hardness' or damage irreversibility — *Stable* (yellow) *Low* (dark green) *Medium* (light green) *High* (orange) *Very high* (red)

While the shift in natural land cover to human-induced commercial land use is an inevitable element of economic growth, this process is generally accompanied by many devastating penalties. Table 3.3 provides evidence that the three natural land cover categories lost their initial areal prevalence by dwindling from 61.4% in 1984 to 43.4% in 2004. This was expected because the study area is tied to agricultural (agroforestry) and non-agricultural (built-up, mining) use so that the shift of these land covers from below 40% in 1984 to over 55% in 2004 in the study area is thus not surprising.

According to the values in the diagonal cell line in Table 3.3, all the land cover categories with exception of forest remained stable for more than 50% of their areal coverage over the study period. This means that forest was the least stable category with only about two fifths of its area remaining unchanged from 1984 to 2004. The remaining three fifth was transformed to other categories, of which nearly one fifth was converted to grasslands. The latter is a type of conversion with low irreversibility because there is latitude for the lost forest area to be reversed because the area is still natural and covered by grassland. The fairly small conversion (2.9%) of forest to wetlands also has a low irreversibility rating.

Another 15.7% of forest area was transformed to agroforestry and because agroforestry is a monotypical practice, the ecological functioning of this ecosystem was indisputably modified. The conversion of natural forest to agroforestry is therefore classified as having high irreversibility. The expansion of the built-up, mining and bare ground categories also consumed 15.7% of forested land during the study period. This type of conversion does not occur without adverse environmental effects as it causes a complete loss of forest biodiversity which must be cause for concern among environmental managers because the irreversibility level is very high.

Grassland was rated as the second least stable category over the study period with 54% of this land cover being unchanged from 1984 to 2004. Of the 46% of grasslands lost, 23% was converted to agroforestry which is awarded a high irreversibility rating. In a similar case in Drakensberg catchments where forestry plantations substituted grassland vegetation, the Natal Agricultural Union (NAU) in 1996 reckoned a high (82%) streamflow reduction in rainfall runoff over a period of two decades resulted (Karumbidza 2006). Likewise, grassland to commercial forestry in the study area has no doubt threatened local water resources.

Also ominously, almost one fifth of grassland was lost to built-up and mining areas and little, if any, chances exists that this vegetation type is restorable to its natural state because the conversion has a very high if not totally irreversible grading. Declines of grassland vegetation as a result of ongoing developments in the area are documented in previous studies of the area (uMhlathuze Municipality 2002; McGinley 2008). Relatively small proportions of grassland vegetation were transformed to forest or wetland both of which have low irreversibility status.

The study area experienced more than twofold increase in the area of built-up, mining and bare ground land cover from 1984 (8.2%) to 2004 (18%) (Table 3.3). This increase is mostly attributable to population growth and economic developments as will be shown in Chapter 4. However, the greater portion (61%) of this category remained stable between 1984 and 2004. While it is unlikely that built-up area can be transformed to another land cover types because it is a ‘swallowing’ type of change, surprisingly such changes were recorded. Some 39% was shown as converted to agroforestry, grassland, forest or to wetland. This unexpected result can probably be ascribed to edge effects in the original land cover mapping, overlaying inaccuracies and the clearance or abandonment of informal rural settlements to formalized and serviced urban locations. Except for the conversion to agroforestry which represents medium irreversibility the others all have very high irreversibility.

The wetland/waterbody category retained 70% of its area from 1984 to 2004. Almost 15% of the remaining area changed to forest and grassland, yet small, but significant areas were lost to the human-intensive land use agroforestry and built-up area. Because of the dearth of wetland and waterbodies, even small conversions raises concerns about developments being allowed to continue occupying such vanishing and highly-sensitive systems.

As expected, the agroforestry class remained largely stable with more than 80% of its areal extent unchanged from 1984 to 2004. With only minor changes from agroforestry to other land cover types there was a noteworthy change of an almost 10% shift to the built-up, mining and bare ground categories. The 7.5% conversion to grasslands represents areas where sugar cane had been harvested shortly before imaging.

Having discussed the overall land cover changes in the area from 1984 to 2004, the focus now narrows to a detailed from-to analysis of change in each individual interim period, namely 1984 to 1996 and

1996 to 2004. The major changes in the natural land cover categories are treated first and then the human-induced categories.

3.3.2.2 Land cover change from 1984 to 1996

The most notable change by area in this period, as set out in Table 3.4 was in the grasslands category. Although 63% of the grassland remained stable from 1984 to 1996, the loss of 37% is significant because its areal coverage declined from 45% of the total to just over 36%.

Table 3.4 Land cover change in uMhlathuze Municipality between 1984 and 1996

(Row percentages) **1984**	**1996**									**Area total (km^2) (% of total)**
	Forest	Grasslands	Wetlands	Waterbodies	Bare ground	Built-up area	Plantations	Sugar cane	Mining	
Forest	39 (55.7)	12 (17.1)	1 (1.4)	-	1 (1.4)	10 (14.3)	4 (5.7)	3 (4.3)	-	**70 [100] (8.8)**
Grasslands	16 (4.5)	226 (63.0)	1 (0.3)	-	9 (2.5)	44 (12.3)	20 (5.6)	42 (11.7)	-	**358 [100] (45.0)**
Wetlands	2 (11.8)	5 (29.4)	6 (35.3)	-	-	1 (5.9)	1 (5.9)	2 (11.8)	-	**17 [100] (2.1)**
Waterbodies	-	1 (2.3)	1 (2.3)	40 (90.8)	-	1 (2.3)	1 (2.3)	-	-	**44 [100] (5.5)**
Bare ground	1 (4.8)	4 (19.0)	-	1 (4.8)	2 (9.5)	6 (28.6)	3 (14.3)	4 (19.0)	-	**21 [100] (2.7)**
Built-up area	3 (7.0)	7 (16.3)	-	2 (4.7)	2 (4.7)	28 (65.1)	-	1 (2.3)	-	**43 [100] (5.4)**
Plantations	1 (1.1)	3 (3.4)	-	-	2 (2.2)	2 (2.2)	79 (88.8)	2 (2.2)	-	**89 [100] (11.2)**
Sugar cane	5 (3.3)	35 (22.9)	-	1 (0.7)	17 (11.1)	9 (5.9)	9 (5.9)	77 (50.3)	-	**153 [100] (19.2)**
Mining	-	-	-	-	-	-	-	-	1 (100)	**1 [100] (0.1)**
Area total (km^2) (% of total)	**67 (8.4)**	**293 (36.8)**	**9 (1.1)**	**44 (5.5)**	**33 (4.2)**	**101 (12.7)**	**117 (14.7)**	**131 (16.5)**	**1 (0.1)**	**796 (100.0)**

The magnitude of grassland conversion to other categories varied, with the most (12%) changed to built-up areas. Such change is generally permanent. Table 3.4 also offers evidence of a trend toward agroforestry developments in the study area. Nearly 12% of grassland was transformed to sugar cane plantations and nearly 6% to commercial forest plantations in this period. Another undesirable change was the 2.5% of grassland modified to bare ground. However, some positive (as for the environment)

changes were observed too. These are the 4.5% conversion of grassland to natural forest and a marginal (0.3%) conversion to wetland. Regrettably, wetlands dropped from 2.1% to 1.1% in this period. Wetlands showed the least stability among essentially natural land cover classes with slightly more than one third of its area remaining the same. Fortunately, the larger proportion of the wetlands area transformation was to natural categories (nearly 30% to grasslands and almost 12% to forest). The remainder was lost to human-intensive land cover categories (sugar cane, forestry plantations and built-up area). This might be attributable to the closeness of these ecologically sensitive systems to built-up areas which elevates their susceptibility to conversion as found by SRK (2009). The transformation of wetlands to built-up area is a worrying loss because of the slight chances of reversibility and the significant detrimental ecological alterations.

Forest exhibited a similar trend of deterioration to that of the aforementioned natural categories, dwindling from 8.8% to 8.4%. In view of its paucity, this means a significant loss. While about 56% of the natural forest area remained stable during this period, 44% was lost. The largest portion (17.1%) was transformed to grasslands, 14.3% was converted to built-up area. 10% was lost to agroforestry with 5.7% and 4.3% to forest plantations and sugar cane respectively. The remaining losses to wetlands and bare ground area were small.

Concomitant with the decreases in the areas of the natural land cover classes were increases in human-induced land cover categories. As expected, built-up area more than doubled in size. Most of this category (65%) remained stable between 1984 and 1996. Change of built-up area to other types of land cover is a rare conversion but contrary to expectation this period did witness such changes. About one third of built-up areas changed to five other land cover categories. Grasslands accounted for about 16% and 7%, probably informal structures that disappeared. Some 4.7% changed to waterbodies, most likely around Richards Bay harbour where expansion took place. Other transformations of built-up area were 4.7% to bare ground and a small change (2.3%) to sugar cane plantations. From an environmental standpoint, these changes are gains rather than losses.

There was limited expansion of forestry plantations (11.2% to 14.7%) during the period while most (88.8%) of its areal extent remained unchanged. Much of the forestry expansion came at the expense of grassland vegetation. This corroborates Karumbidza’s (2006) observation that uMhlathuze Municipality – particularly the area adjacent to Richards Bay – experienced a substantial expansion of

forestry plantations steered by Sappi and Mondi during the 1980s. Apart from the generally favorable biophysical environment, the cited study argued that the expansion of commercial plantations was largely due to accessibility through road and rail infrastructure and the harbour at Richards Bay.

Contrary to expectation, sugar cane plantations declined slightly from 19.2% to 16.5% over this period. The 11.1% change to bare ground area is perhaps erroneous because the satellite imagery represents a sugar cane harvesting season and the 1996 imagery particularly was captured at the height of these activities. Under-classification of sugar cane plantations very likely took place because of the spectral similarities with bare ground area. Regrettably, no ancillary high-resolution imagery for 1996 was available to verify this. Fortunately, there was a favourable 23% shift of sugar cane plantations to grasslands. The two other notable changes were similar (6%) conversions to built-up area and forestry plantations. Overall one half of the sugar cane plantations remained stable.

Having discussed the land cover changes that took place in the first interim study period, the focus now turns to reveal the nature of land cover change that occurred in the latter period.

3.3.2.3 Land cover change from 1996 to 2004

During the eight years following 1996, the study area again witnessed fragmentation of natural land cover categories which mostly gave way to growing human-induced activities. Table 3.5 shows that grassland area declined to just less than one third of all land cover although more than 70% of its area recorded the unchanged class membership during this period. Much of the grassland shift (21.5%) was caused by expansion of built-up area (7.8%) and agroforestry (sugar cane 10% and forestry plantations 3.8%). This signals an uMhlathuze landscape that was gradually becoming more artificial.

The share of natural forest in the study area's total declined in this interim period. Almost 60% of forested land remained stable in this eight-year period and about 42% was forfeited to other land cover categories. Of the total forest area lost, more than 16% became grasslands and 12% was converted to built-up area. Regarding this period, SRK (2012) reported widespread invasion of coastal indigenous forest by informal settlements. Matthews et al. (2000) also concluded that natural forest losses are primarily attributable to intense human land use activities such as agricultural and settlement intensification.

Nearly 14% was offered to agroforestry, that is sugar cane plantations (7.5%) and forestry

Table 3.5 Land cover change in uMhlathuze Municipality between 1996 and 2004

(Row percentages 1996	2004									**Area total (km^2) (% of total)**
	Forest	Grasslands	Wetlands	Waterbodies	Bare ground	Built-up area	Plantations	Sugar cane	Mining	
Forest	39 (58.2)	11 (16.4)	-	-	-	8 (11.9)	4 (6.0)	5 (7.5)	-	**67 (8.4) [100]**
Grasslands	10 (3.4)	212 (73.0)	-	1 (0.3)	4 (1.4)	23 (7.8)	11 (3.8)	29 (9.9)	1 (0.3)	**293 (36.8) [100]**
Wetlands	-	1 (11.1)	6 (66.7)	-	-	2 (22.2)	-	-	-	**9 (1.1) [100]**
Waterbodies	-	-	1 (2.3)	41 (93.2)	-	-	1 (2.3)	1 (2.3)	-	**44 (5.5) [100]**
Bare ground	1 (3.0)	5 (15.2)	-	-	1 (3.0)	5 (15.2)	5 (15.2)	15 (45.4)	1 (3.0)	**33 (4.2) [100]**
Built-up area	1 (1.0)	1 (1.0)	1 (1.0)	2 (2.0)	2 (2.0)	79 (78.2)	7 (6.9)	8 (7.9)	-	**101 (12.7) [100]**
Plantations	-	2 (1.7)	-	-	1 (0.9)	3 (2.5)	110 (94.0)	1 (0.9)	-	**117 (14.7) [100]**
Sugar cane	-	9 (6.9)	-	-	7 (5.3)	4 (3.1)	3 (2.3)	107 (81.6)	1 (0.8)	**131 (16.5) [100]**
Mining	-	-	-	-	-	-	-	-	1 (100)	**1 (0.1) [100]**
Area total (km^2) (% of total)	**51 (6.4)**	**243 (30.5)**	**8 (1.0)**	**44 (5.5)**	**15 (1.9)**	**124 (15.6)**	**141 (17.7)**	**166 (20.9)**	**4 (0.5)**	**796 (100.0)**

plantations (6%). These conversions are distressing for ecological conservation as they have very likely led to migrations of fauna and (complete) loss of biodiversity. Two thirds of wetlands remained stable during this period, the diminution of the one third being brought about by the expansion of built-up areas (22%) and transformation to grasslands (11%).

The non-natural land cover classes gained at the expense of natural land cover classes. Most notable was an expansion of sugar cane plantations to more than one fifth of the area, making it the most prevalent cultivated crop in the area. Previous studies (uMhlathuze Municipality 2002; McGinley 2008) also singled out sugar cane plantations as the dominant feature of the uMhlathuze landscape. This class was very stable over this period with nearly 82% remaining undisturbed. The principal contributors to sugar cane plantations were grasslands (7%) and bare ground (5%). Forestry plantations recorded the highest stability with 94% of area remaining unchanged. Its share of the total area

increased from almost 15% to almost 18%. The contributors to the forestry plantation gains were built-up areas (20.5%), grasslands (1.7%), and bare ground and sugar cane plantations (1% each). Forestry plantations filled the second position in agriculture practiced in uMhlathuze Municipality and it is a positive element in establishing conservation in the area.

The expansion of built-up area continued relentlessly, growing from about 13% to nearly 17% of the total area. The expansion of built-up area consumed grassland, forested land, wetland and bare ground. SRK (2012) established that much of grasslands sprinkled with developed fields (built-up) were showing signs of fragmentation and degradation. Mining activity became more visible in this period as it increased from 0.1% to 0.5% of the total area. This activity consumed grasslands (0.3%), sugar cane plantations (0.8%) and bare ground (3%).

Further quantitative evidence of these changes is discussed in the next section where the changes are reported as net increases and decreases for each land cover over the whole study period. This is done to reveal the land use categories that were affected most or least.

3.3.3. Land cover net gains and losses

An analysis of land cover net gains and losses affords an overall portrayal of land cover shifts. A ‘gain’, denoted as (+), shows that a land cover’s area in the latest imagery had increased as a result of conversion from another land cover and a ‘loss’, denoted as (-), means that a land cover’s area in the latest imagery is less than that in earlier imagery. So, the total loss is equal to the total gain. In essence, this analysis offers a proportional look at the extent of gain and loss between two time slices and does not depict the total coverage of each class. The gains and losses are displayed in Figure 3.13.

With the exception of waterbodies, all the land cover categories were affected. The most noticeable loss is by grassland. Owing to its large extent, it was reduced by 116 km^2, most (57%) of which took place during the period 1984 to 1996. A total of 19 km^2 natural forest was changed, most (16 km^2) of which was during the second period. Wetland area diminished by 9 km^2, most of the loss happened during the first period. Recall that there were some apparent difficulties in the classification of bare ground and sugar cane. Bare ground decreased only in the second period by 18 km^2 while the loss of 22 km^2 in sugar cane took place in the first period.

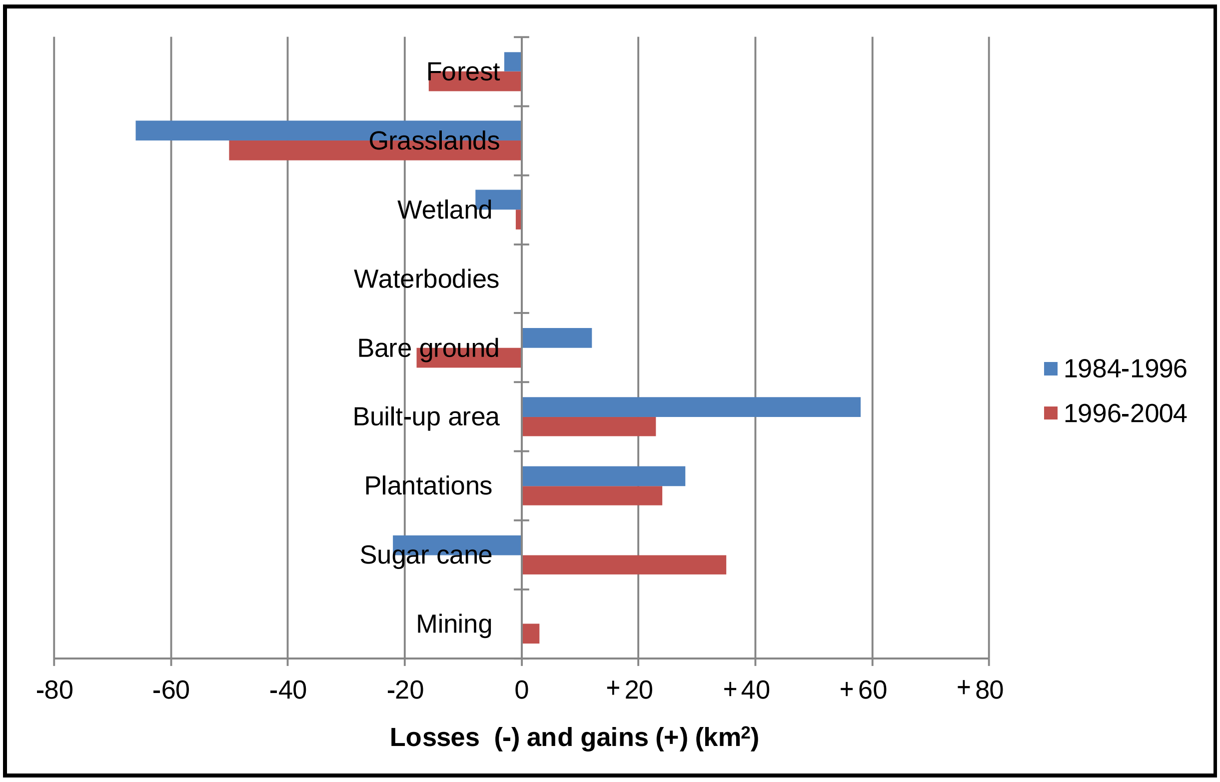


Figure 3.13 Land cover gains and losses in uMhlathuze Municipality, 1984 to 1996 and 1996 to 2004

As for land cover gains, built-up areas are the most conspicuous in Figure 3.13 with a total of 81 km^2 over the whole study period and most (58 km^2) of this expansion having occurred in the first period. Much of this increase centred in formal urban areas, particularly around Richards Bay where most developmental activities were concentrated. The smaller more recent gains are probably attributable to greater control of planned formal urban expansion, compared to uncontrolled informal urbanization earlier on. The expansion of forestry plantations is noteworthy. The first period witnessed a slightly higher increase (54%) of the overall 52 km^2. Further gain in forestry plantations is distressing because of their eminent negative impacts on local ecosystems. The gain in sugar cane area must be interpreted with caution as it was distorted by the problematic classification of bare ground in the 1996 imagery. Sugar cane increased by 35 km^2 in the second period and bare ground attained 12 km^2 in the first period. The smallest gain was recorded for mining and it all occurred in the second period following the start of the Exxaro's Hillendale sand mining operation.

Light has now been shed on the nature and extent of temporal land cover changes in uMhlathuze Municipality. Agroforestry and built-up area developments, and to a growing extent mining activity,

were the main triggers of land cover change. The focus now shifts to a spatial perspective on land cover change.

3.3.4 Spatial distribution of land cover change

Given that significant land cover changes occurred in the study area over a 20-year period, a spatial portrayal of the areas where land cover change occurred was deemed necessary. A map was constructed showing all the areas that changed in 1984-2004 period against a background of non-changed land cover. Figure 3.14 is the result.

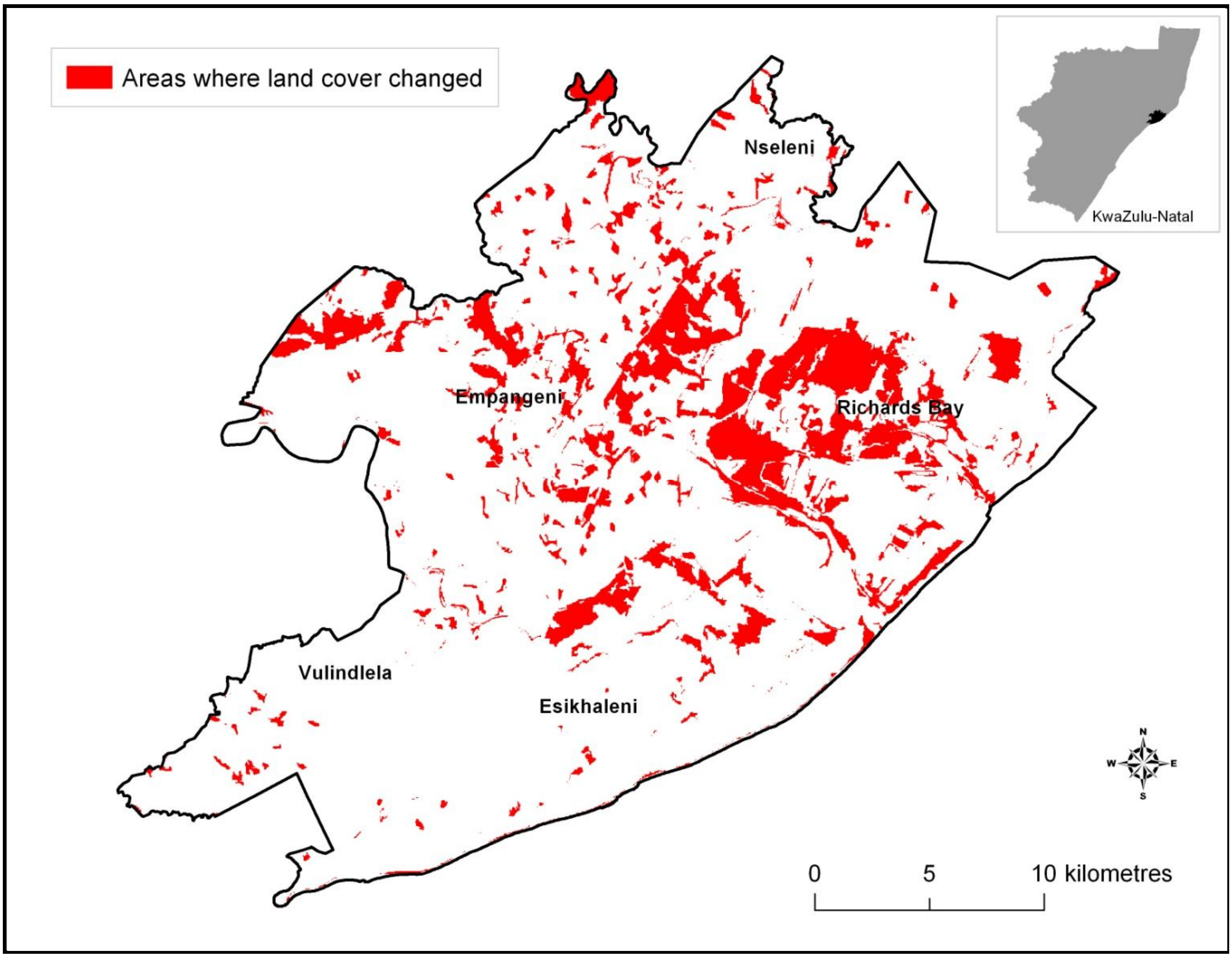


Figure 3.14 Spatial distribution of areas where land cover changed between 1984 and 2004 in uMhlathuze Municipality

The central section of the study area adjacent to Empangeni and extending north-eastwards to around

Richards Bay was the most affected as to land cover changes. It is noteworthy that the changed areas around Richards Bay correspond with the locations earmarked by the South African National Biodiversity Institute (SANBI 2009) as critically threatened ecosystems (see Section 4.3.1). Comparison of Figure 3.14 with the land cover distribution in 2004 (Figure 3.4) shows that the disappearing grassland vegetation around Richards Bay is the most threatened land cover element as it has suffered severe modification. Wetlands bordering the developed fields are a cause of concern as well (Figure 3.4). One must note that some of the changes portrayed around Empangeni are perhaps attributable to the technical difficulty of distinguishing between sugar cane and bare ground in the mapping process (as alluded to in Section 3.1.2). The total of changed areas (red polygons) in Figure 3.14 covers nearly one fifth (150 km^2 or 18.8%) of the study area.

The changes concentrated around the Richards Bay urban area and to a lesser extent Empangeni, point to numerous and varied implications for the conservation and environmental planning bodies in the uMhlathuze Municipality. The safeguarding of the remaining natural systems from change cannot be ignored.

This chapter has established that significant land cover changes have occurred in the uMhlathuze Municipality. It revealed that land cover changes were attributable to anthropogenic influences. Thus, it was deemed necessary to investigate the spatial growth of the population and their socio-economic characteristics so that more credence is offered about anthropogenic influence being the primary driver of land cover change. These elements are discussed in the next chapter.

CHAPTER 4 POPULATION GROWTH AND IMPLICATIONS FOR LAND COVER

Recent foci in research on land cover and land degradation have extended beyond the identification and mapping of land cover change and degradation events to incorporate independent variables to establish causal linkages. The objective of this chapter is threefold: first, to analyses the population characteristics and structure of uMhlathuze Municipality; second, to map human settlement growth between 1984 and 2004; and third, to overview the threatened ecosystems and identify land cover classes that will be implicated by proposed developments in the area.

4.1 POPULATION STATISTICS

Since one cannot divorce human population aspects from environmental change studies, human population analysis was considered significant in this study. Radeloff et al. (2000) maintain that landscapes are moulded by multifaceted interactions between human populations, social structures and environmental conditions. They pointed out that these factors have usually been studied separately within their respective domains. This section examines the growth of population numbers in uMhlathuze Municipality, the socio-economic characteristics of the population and their access to basic services and infrastructure. The spatial dimension of population distribution and density are explored in in Section 4.2.

4.1.1 Method

An analysis of population census data that corresponds in time with the imagery used in this work is appropriate. Unfortunately, such comparisons of South African population census data are fraught with problems. Statistics South Africa & Human Sciences Research Council (2007) identified several factors that impede comparative population analysis using South African census data. Most important is that ongoing and broad changes of administrative (hence statistical) boundaries must be contended with. Moreover, Statistics South Africa has historically collected data on a geographical basis using manifold unit types, among which are named places (settlements) in the recent past and enumeration areas prior to 1996.

With the exception of the examination of population growth which used 1996, 2001 and 2011 census data, only 2001 census data in shape file format from Statistics South Africa was used in this study. This was dictated by the 2001 census data which differs from those of previous censuses as the

former is based on a GIS platform, hence its products are spatially referenced.

To facilitate a comparative enquiry, this study used municipal wards as the unit of analysis. Municipal wards are the smallest statutory administrative units in South Africa (see Figure 4.1 for the official hierarchy) and they are sufficiently large to permit meaningful analysis. Because 2001 census data was collected by place names, some data generalization was required. To this end, 81 subplace names (points), each with its own location (x/y coordinates) and statistics, were overlaid with the municipal wards layer. Subsequently, all subplace names (points) sited in each ward were merged to form one point with its collated data (see Appendix A). Because uMhlathuze Municipality has 30 wards, the resultant shape file had 30 points sited in each ward with aggregated statistics.

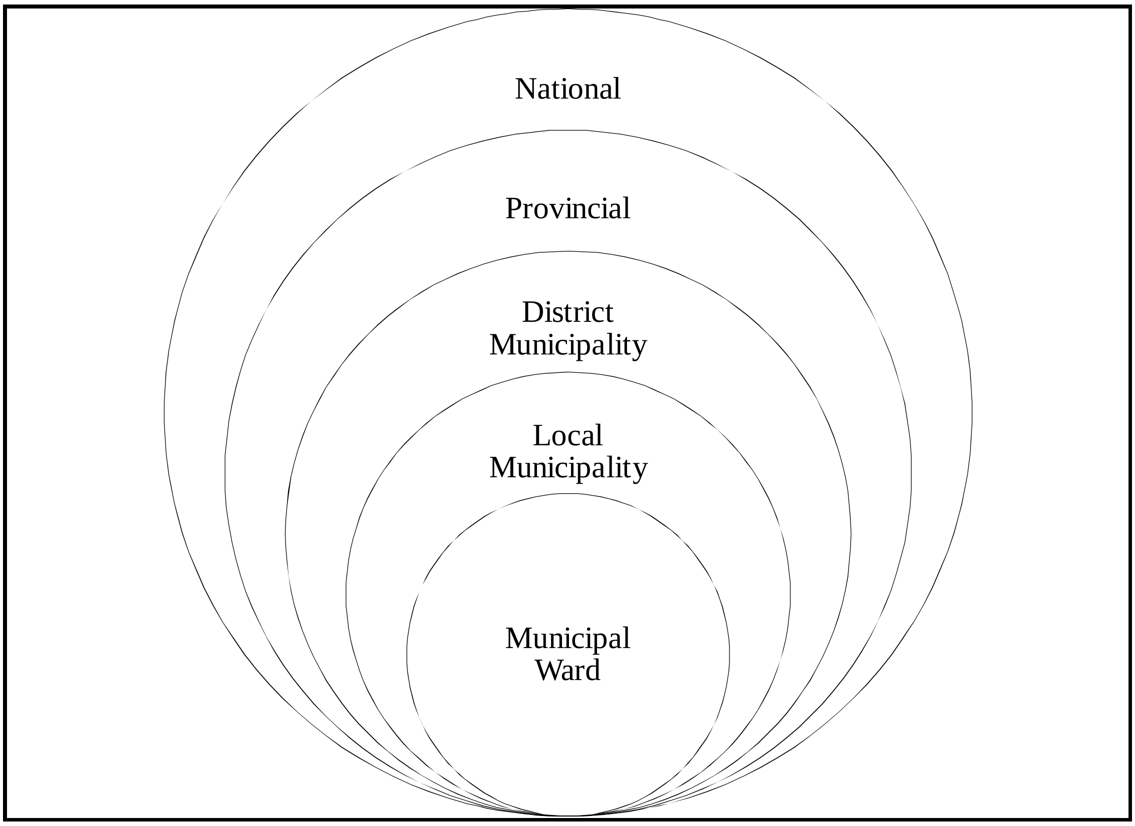


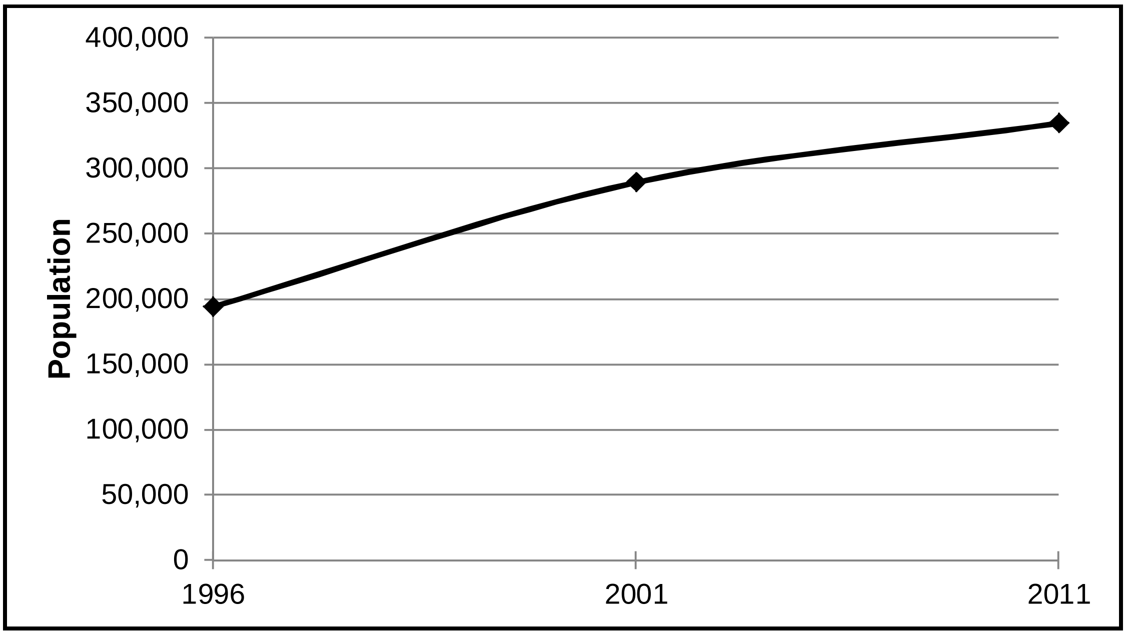
Figure 4.1 Hierarchical arrangement of South Africa’s administrative units

The settlement density analysis discussed in Section 4.2.2 was computed at municipal ward level and the generalization of census data at ward scale made possible comparisons of socio-economic variables with settlement characteristics.

4.1.2 Population growth

The census data for 1985 contains anecdotal records for the uMhlathuze population since it comprised numbers (46 000 inhabitants) for Lower Umfolozi which included Richards Bay and Empangeni. The 1985 census data was not used in this analysis because it covered certain areas and excluded others (Statistics South Africa 2000). The actual 1985 population numbers for areas now in uMhlathuze Municipality are no doubt incorrect. Furthermore, the Human Sciences Research Council (HSRC) estimated a 33.6% undercount of the total population (Statistics South Africa 2000). Consequently, only population statistics for 1996, 2001 and 2011 were analysed to report population growth trends.

The study area, which comprises a fast-growing municipality, experienced rapid growth of population over the period 1996 to 2011. The 1996 census recorded the population of uMhlathuze Municipality as 193 972 people (Figure 4.2). It then grew by 95 217 people to reach 289 189 in 2001. During the intercensal interval, the annual population growth rate was 7.7% – placing uMhlathuze Municipality as one of the fastest growing municipalities with a growth rate nearly triple that of KZN (2.2%). During the decade 2001-2011, the population of uMhlathuze Municipality increased from 289 189 to 334 456 at a far slower growth rate of 1.5%. Such growing human populations escalate the demand for residential, recreational and commercial land.



Source: Modified from Statistics South Africa (2012)

Figure 4.2 Population growth of uMhlathuze Municipality, 1996 to 2011

Moreover, Hietel, Waldhardt & Otte (2007) have established that rapid population increases are primary drivers of land cover change in the contemporary world. It is conceivable that this applies in the study area too. It is important that socio-economic characteristics of this growing population are uncovered, hence the next section.

4.1.3 Socio-economic characteristics of the population

The maps of three socio-economic variables for uMhlathuze Municipality, as shown in Figure 4.3, portray relatively similar spatial configurations.

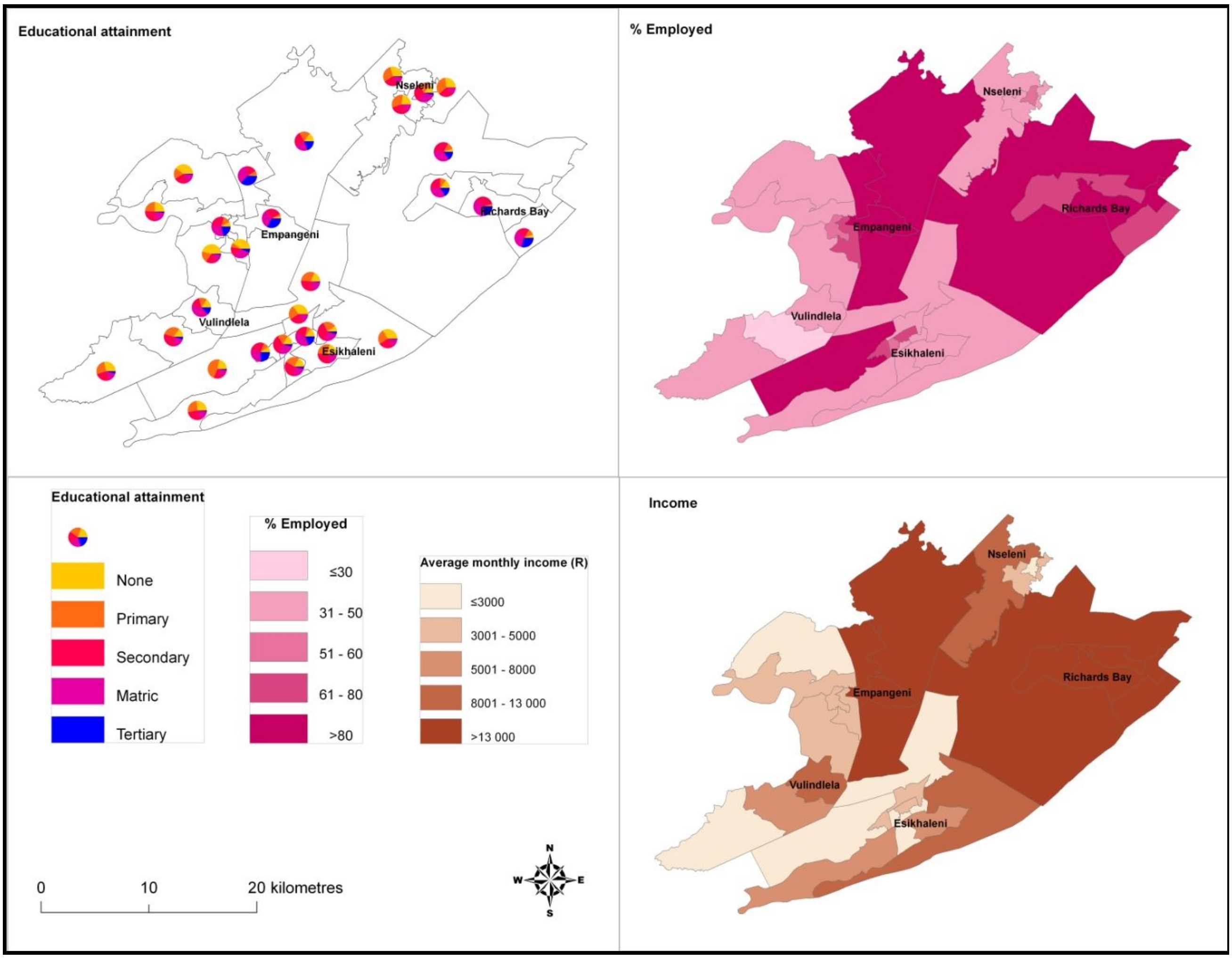


Figure 4.3 Socio-economic characteristics of population in uMhlathuze Municipality, 2001

Areas with higher values for all three variables cluster around the main urban centres. The population in these areas generally have higher levels of educational attainment, higher employment rates and higher average monthly income. Much of the surrounding traditional rural areas exhibit lower values

for the socio-economic characteristics compared to the urban areas. The average monthly income of the population living around Empangeni and Richards Bay was more than R13 000. This is not surprising because on average more than 80% of these populations were employed and the better educated and skilled population live in and around the urban areas. It is widely accepted that education level, employment status and average monthly income are spatially correlated. Taylor & Yu (2009) contend that educational attainment is often instrumental in overcoming most social ills and for positioning workers in a competitive labour market. They also argue that educational attainment is a rudimentary and a good proxy for performance in the labour market.

One expects that the distribution of occupational type will reflect the distribution of employment status, that is, workers in higher positions (i.e. managers, professionals) concentrate in urban areas. For example, the 2001 census shows that 73% of the managers in the study area lived in Empangeni and Richards Bay. Table 4.1 presents the occupational types of the population of uMhlathuze Municipality and also shows that unemployment (at more than 40%) was higher than the national average and that a high proportion (20.4%) of the employed population is classified as doing elementary work.

Table 4.1 Occupations of the population in uMhlathuze Municipality, 2001

Status	**Occupation**	**Total**	**Percentage**
Employed		67 390	59.4
	Manager	3 239	4.8
	Professional	4 953	7.3
	Technical	7 437	11
	Clerk	7 666	11.4
	Service	6 459	9.6
	Agricultural work	1 099	1.6
	Craft trade	9 532	14.1
	Plant machinery operator	6 518	9.7
	Elementary	13 737	20.4
	Unspecified	6 750	10
Unemployed		46 067	41.6
TOTAL		**113 456**	**100**

Source: Statistics South Africa (2001)

One can assume that the minority of the population is engaged in advanced types of employment, even in high density areas (see Section 4.2.2). This may be significant in light of the claim (Wang & Zhang

2001) that a population's employment status is significantly associated with degrees of landscape change experience – the relationship which remains to be determined in the study area.

In population studies the age dependency ratio is an indispensable measure of burden on the employed by their unemployed dependants. Khattry & Rao (2002) have, for example, established that less-developed nations are generally subjected to high dependency ratios. The dependency ratio for uMhlathuze Municipality has decreased from 59% to 48% between 1996 and 2011 which is heartening. The proportion of children aged 14 or younger declined slightly but that of the eldest increased (Table 4.2).

Table 4.2 Age distribution by gender in uMhlathuze Municipality, 1996, 2001 and 2011

(values in parenthesis is the percentage of the total)

Age group (years)	**1996**			**2001**			**2011**		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
≥14	33 003 (49.4)	33 773 (50.6)	**66 776 (34.4)**	47 567 (49.8)	47 916 (50.2)	**95 483 (33.0)**	49 341 (50.3)	48 768 (49.7)	**98 109 (29.3)**
15 - 34	36 284 (46.7)	41 414 (53.3)	**77 698 (40.1)**	56 429 (47.9)	61 340 (52.1)	**117 769 (40.7)**	69 594 (48.5)	73 850 (51.5)	**143 444 (42.9)**
35 - 64	22 161 (50.1)	22 110 (49.9)	**44 271 (22.8)**	33 225 (48.9)	34 656 (51.1)	**67 881 (23.5)**	40 097 (48.8)	42 127 (51.2)	**82 224 (24.6)**
≤65	2 020 (38.6)	3 207 (61.4)	**5 227 (2.7)**	2 749 (34.1)	5 307 (65.9)	**8 056 (2.8)**	3 909 (36.6)	6 770 (63.4)	**10 679 (3.2)**
Total	**93 468 (48.2)**	**100 504 (51.8)**	**193 972 (100)**	**139 970 (48.4)**	**149 219 (51.6)**	**289 189 (100)**	**162 941 (48.7)**	**171 515 (51.3)**	**334 456 (100)**

Source: Statistics South Africa (2012)

Overall, the gender distributions remained quite balanced (females in 1996 (52%), 2001 (52%) and 2011 (51%)) but in the oldest age group the proportion of females stayed greater than 60%. A large proportion of female-headed households (reaching 41% in 2011) was recorded. The reality of child-headed households remained, but it declined from 1.7% to 0.7% (see Appendix B) – an encouraging trend for parental support. The proportion of children aged 14 or younger declined consistently from 34% to 29% in the period 1996 and 2011. This implies that birth rates dropped, due to several factors, among which effective family planning.

Having highlighted salient aspects of the socio-economic characteristics of the population in uMhlathuze Municipality, the focus now turns to the inhabitants' access to basic services and

infrastructure – both significant indicators of the population's welfare.

4.1.4 Access to basic services and infrastructure

The population's access to basic services and infrastructure reflects the level of socio-economic development and well-being. In this section, access to electricity and water services were considered and trends from 1996 to 2011 are uncovered.

4.1.4.1 Electricity

Electricity generated by Eskom is distributed to the population of uMhlathuze Municipality by the municipality. UMhlathuze Municipality (2012) confirmed that the urban areas are serviced by the municipality and the rural surroundings by Eskom directly. More than 80% of the total population had access to electricity by 2001 and in 2011 all the urban areas serviced by the municipality had 100% access. Figure 4.4 shows the purposes for which households used electricity. The figure illustrates the increased use of electricity over the years and underlines the increasing burden on the municipality to keep pace with provision.

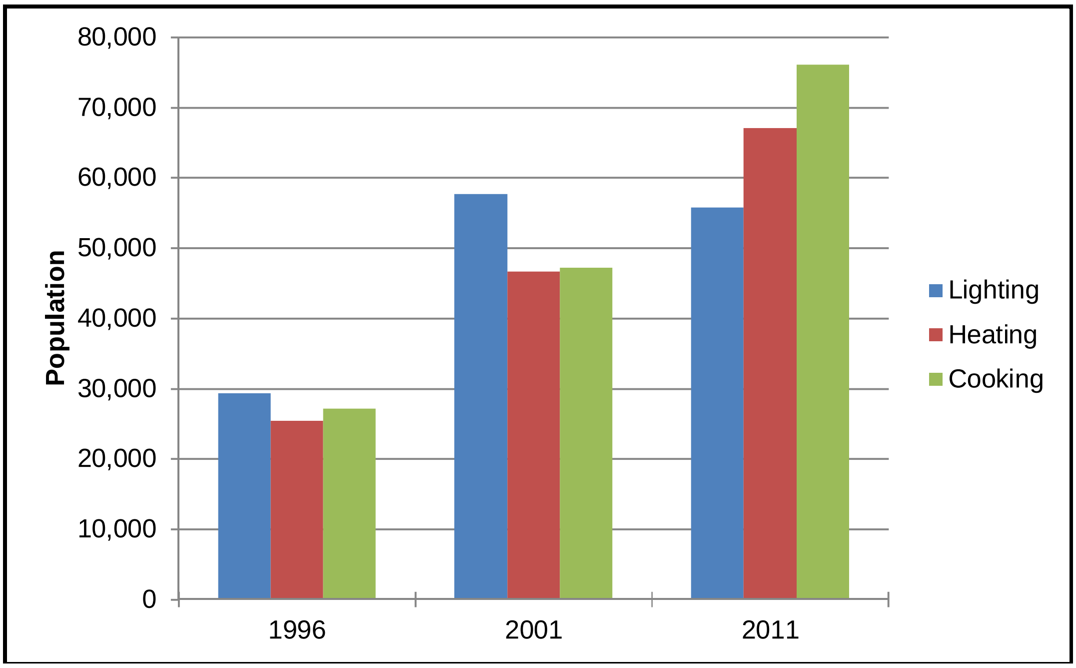


Figure 4.4 Household uses of electricity in uMhlathuze Municipality, 1996, 2001 and 2011

There is a trend toward more sophisticated usage, that is heating and cooking, rather than simple lighting. This represents a positive development in human well-being and uMhlathuze Municipality

(2012) has announced an Eskom undertaking to further increase the electrification rate in the area. Empirical research, such as that of Ayenagbo, Kimatu & Rongcheng (2011), have shown that an indirect relationship exists between access to electricity by communities and the rates of deforestation – where electricity is provided, deforestation declines because less firewood needs to be harvested. This relationship could not be confirmed quantitatively for this study, but it can safely be assumed to exist.

4.1.4.2 Water

The improvement in access to water services or networks by the population of uMhlathuze Municipality over time is demonstrated in Figure 4.5. Census 2001 put the population with in-house water connection at 68% of 67 100 households.

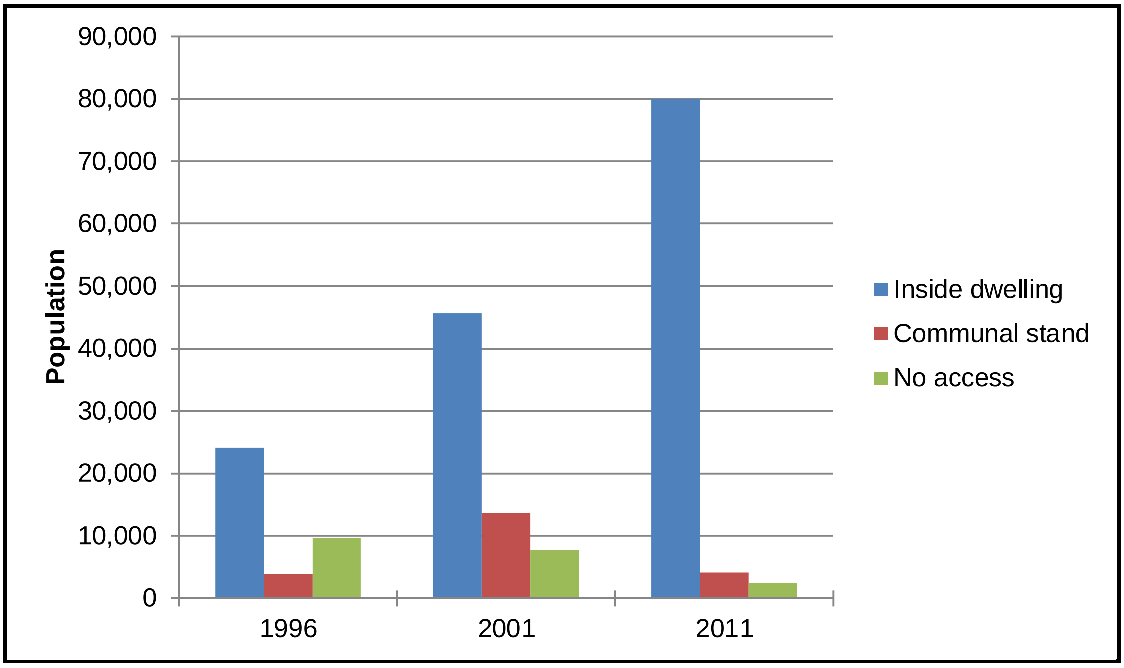


Figure 4.5 Access to water in uMhlathuze Municipality, 1996, 2001 and 2011

Concomitant declines in access via communal water stands (after an increase in 2001) and the absence of service connections are evident – to the extent that these two categories had nearly disappeared by 2011. What is especially notable is that serviced population numbers increased fourfold over a 15-year period and only 3.1% had no access to water services by 2011. These trends in service provision and access raise questions about spatial distribution of the population and where the connections are. The next section details the spatial distribution and density of settlements in uMhlathuze Municipality.

4.2 SPATIAL SETTLEMENT GROWTH IN UMHLATHUZE MUNICIPALITY

This exercise was done because knowledge of the spatial distribution, patterns and densities of South Africa's population is a fundamental requirement for understanding human pressures on natural resources. Trends in these features are usually uncovered through bitemporal or multitemporal comparative analyses aided by maps. The maps help to track the directions, magnitudes and concentrations of the spatial growth of settlement all of which are indispensable components of socio-economic and environmental planning. In this study the spatial distribution and density of settlements were mapped in a GIS, a commonly used and effective tool for analysing population dynamics. This discussion is structured to give a conceptual background, then to outline the methods used and to conclude with a presentation and interpretation of settlement distributions and dwelling densities over time.

4.2.1 Settlement distribution

An understanding of spatial distribution of settlements is essential as the distributions undergird administrative planning and are a source of data for forecasting spatial patterns of population growth (National Institute of Statistics 2009). In addition, UNECE (2008) insists that it is a government's duty to devise spatial plans and champion human settlement strategies directed toward sustainable socio-economic development. The mapping of settlements was hence done to portray human settlement growth over time in uMhlathuze Municipality. The methods used are explained next.

4.2.1.1 Digitizing dwellings

The most widely used and rudimentary technique for mapping human settlements is through digitizing individual dwellings in a GIS environment and plotting them to show their spatial distribution from which settlements pattern can be recognized. The technique requires the imagery from which settlements are digitized to be of high spatial resolution so that dwellings can be identified accurately (Lo 1986). Owing to their higher resolution of 0.75 m and 0.3 m respectively, colour orthophotographs of 1984 and 2004 were used to digitize dwellings in the uMhlathuze Municipality.

Georeferenced orthophotographs covering the study area were loaded into ArcMap and overlaid with a blank multipoint geometry shape file. All dwelling units were then identified and digitized using on-screen digitizing. This technique, according to Imam (2011), gives a greater level of accuracy and provides a zoom facility to aid clear identification of individual dwelling structures. Before final maps

were created, the 1984 and 2004 dwelling layers were overlaid on the base orthophotographs until satisfactory results were confirmed by visual comparison. The screen-print shown in Figure 4.6 is an example of how dwelling locations were digitized in this study.

Each dwelling was mapped as an element of settlement form. A distinction was made between settlements falling in urban and those in rural areas to enable comparison of the distribution and growth

Figure 4.6 Example of digitizing dwellings using high-resolution orthophotography

in these two environments. In the South African context this is a difficult task because Statistics South Africa (2003) maintains that the classification of the country into urban and rural areas yields a fuzzy distinction because these settlement forms lie on a density continuum. To avoid this problem, the definition and classification of urban and rural areas in uMhlathuze Municipality was done by reviewing their environmental and town-planning documents. Then boundaries for these classes were created and overlaid with the dwelling layer in GIS to identify and select dwellings located in each area. To distinguish between these two types on the maps, urban dwellings were coloured red and rural dwellings yellow.

4.2.1.2 Settlement distribution in 1984

The settlement distribution in uMhlathuze Municipality in 1984 (Figure 4.7) showed a pattern of clustering in urban environments and relatively low densities in rural wards. The pattern of dwelling distribution is fairly simple in the municipal space with concentrations in urban areas and some rural areas but with the central area being largely vacant. There was a total of 17 189 dwellings in 1984 and the number of dwellings tended to be greater in the larger rural areas than in the smaller urban areas.

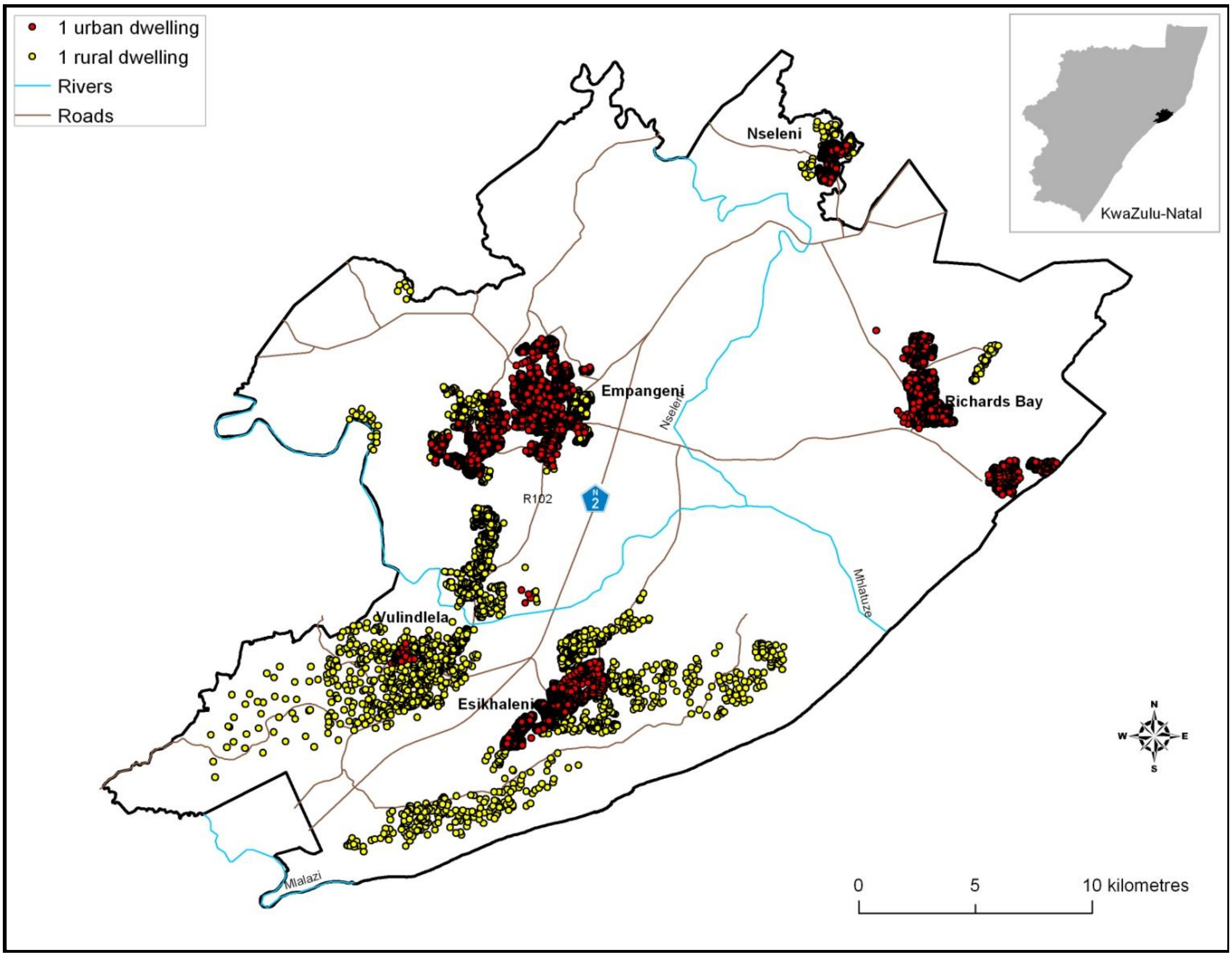


Figure 4.7 Distribution of urban and rural dwelling in uMhlathuze Municipality in 1984

Nearly 60% of the dwelling units were located in rural surroundings. For most of the preceding period, Empangeni was the main town (Watts 1983), but Figure 4.7 suggests that Esikhaleni township had begun to rival it in size by 1984.

The largely vacant central space was mainly occupied by sugar cane fields and forestry plantations (as was noted in Section 3.2.1.2). UMhlathuze Municipality (2002) ascribes this prevalence of agroforestry to much of the land in the central area being privately owned.

4.2.1.3 Settlement distribution in 2004

Twenty years later, the pattern of settlement distribution in the uMhlathuze Municipality had generally been preserved, although evidence of extensive dwelling intensification was distinctly evident (Figure 4.8). Remarkably, the central land space remained vacant while dwelling numbers grew explosively in peripheral areas that had few dwellings in 1984. In total, the number of dwellings increased more than twofold during the study period – from 17 189 in 1984 to 47 490 in 2004. The number of urban dwellings only marginally exceeded those in rural areas with 51% of the identified dwellings being in

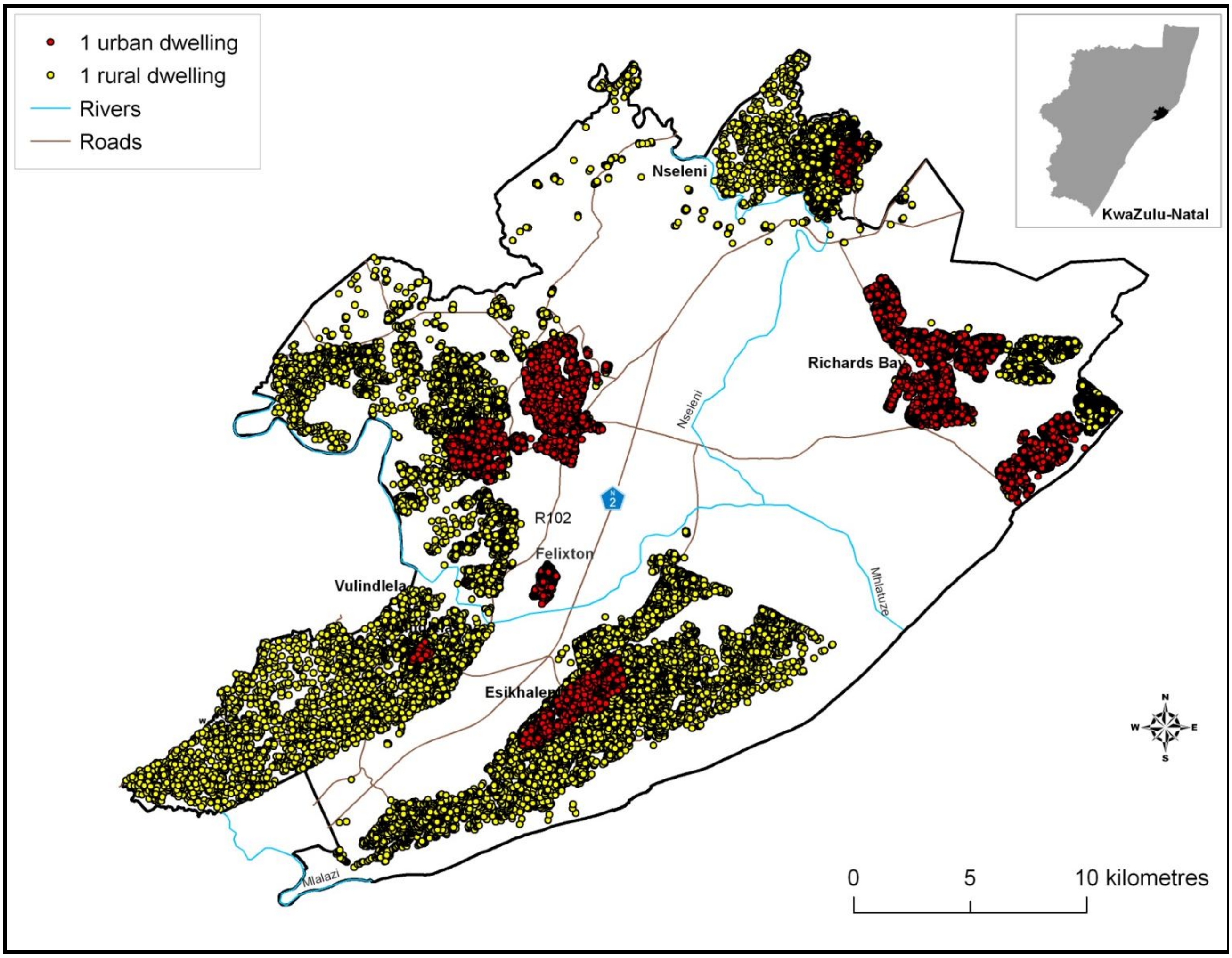


Figure 4.8 Distribution of urban and rural dwellings in uMhlathuze Municipality in 2004

urban areas compared to only 40% in 1984. Urbanization evidently occurred in the interim.

Overall, the settlement pattern points toward efficient settlement planning management given that the settlement structure is spatially uniform, and no patchy settlement spread (or sprawl) was evident, particularly around Empangeni and Richards Bay. Notwithstanding this observation, incidents of expansion of informal settlements into indigenous coastal forest were observed – an ominous threat to the maintenance of biodiversity.

This has given rise, inter alia, to untenable usage of forested land near Port Durnford (uMhlathuze Municipality 2012). This accord with Balchin, Kieve & Bull's (2000) conclusion that rapid population increases exacerbate the problem of unplanned development or haphazard expansion of settlements. This normally results in greater demand for urban land space that many governments find difficult, if not impossible, to provide because it can tamper with integrated development planning (Balchin, Kieve & Bull 2000). By awarding 'settlement' rather than 'rural' status to wards with high dwelling concentrations, the growth in settlement size is captured in Figure 4.9. It makes the extensive growth of

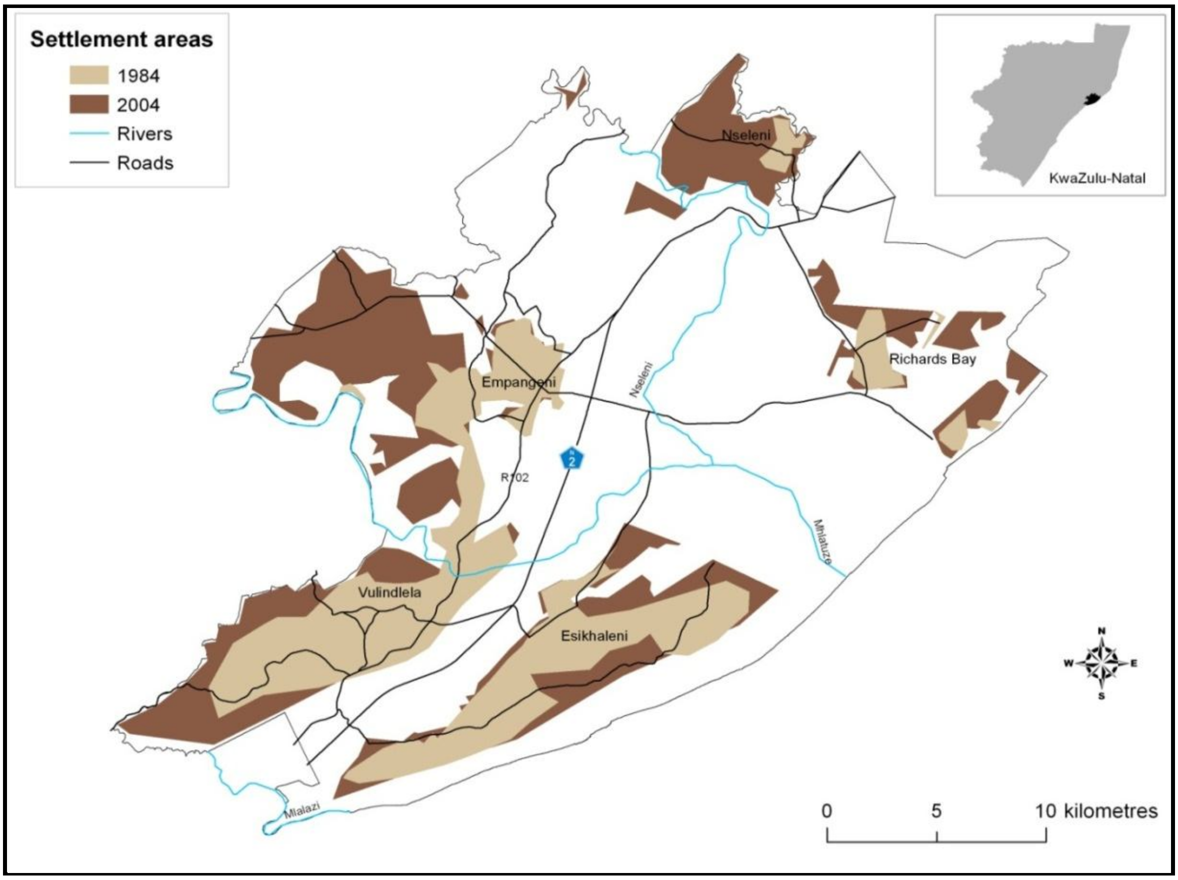


Figure 4.9 Settlement size in 1984 and 2004

settlements over the 20-year study period abundantly clear. The combined size of settlements increased

from nearly 130 km^2 to 252 km^2 (94%) between 1984 and 2004. Much of the growth has occurred west of Empangeni and Nseleni.

Figure 4.9 gives credence to the aforementioned discussion that settlements have grown rapidly in uMhlathuze Municipality over the study period. The next section analyses settlement densities in the area to distinguish areas of low and high density and to determine how densities changed between 1984 and 2004.

4.2.2 Settlement density in uMhlathuze Municipality

Guo, Li & Jia (2006) successfully mapped population growth and quantified density per unit area. By employing defined geographical boundaries, all spatial population features can be mapped as densities (Okabe, Satoh & Sugihara 2009). Density mapping is an effective way to identify locations where population is most and least densely concentrated in a geographical space. Population density mapping was used in this study to track the spatial growth of settlement in uMhlathuze Municipality between 1984 and 2004.

4.2.4.1 Computing dwelling density

To permit the computation of and comparisons between the dwelling densities of 1984 and 2004, electoral municipal wards, for which boundaries were available in shape file format were used as spatial units. Although these wards had polygons of varying extent, Radeloff et al. (2000) maintain that these provide the finest spatial resolution for census statistics. The square kilometer area of each ward was calculated in ArcMap. Then, a ‘definition query’ function was used to separate each ward and a ‘select by location’ was performed to compute the total number of dwellings in each ward. The total number of dwellings was divided by the area to give dwelling density per ward.

Dwelling density classes were separated by Jenks’ natural breaks classification method resulting in five classes. This accords with Guo, Li & Jia’s (2006) recommendation that four to seven classes are appropriate for mapping population density. This was the most suitable classification method because it reduces within-class variance while enhancing between-class variance (Jiang 2013) as the density values for the study area varied widely. Density classes were named high, medium-high, medium, medium-low and low.

It must be noted that when the number of dwellings increases over time in a given

geographical area and boundaries remain stable, the dwelling density count increases correspondingly. The situation prevailing here is that the boundaries remained fixed so that increasing dwelling concentration denotes increased settlement intensity.

4.2.4.2 Dwelling density in 1984

The landscape of uMhlathuze Municipality was classified into five qualitative categories of dwelling density (low, medium-low, medium, medium-high and high). The dwelling densities in uMhlathuze Municipality in 1984 are mapped in Figure 4.10. There were five urban core areas with densities ranging from medium-low to high in a large sea of low density. The highest densities (high and medium-high) were registered in Esikhaleni, Nseleni and Empangeni, and Richards Bay and Vulindlela had-medium low dwelling densities only.

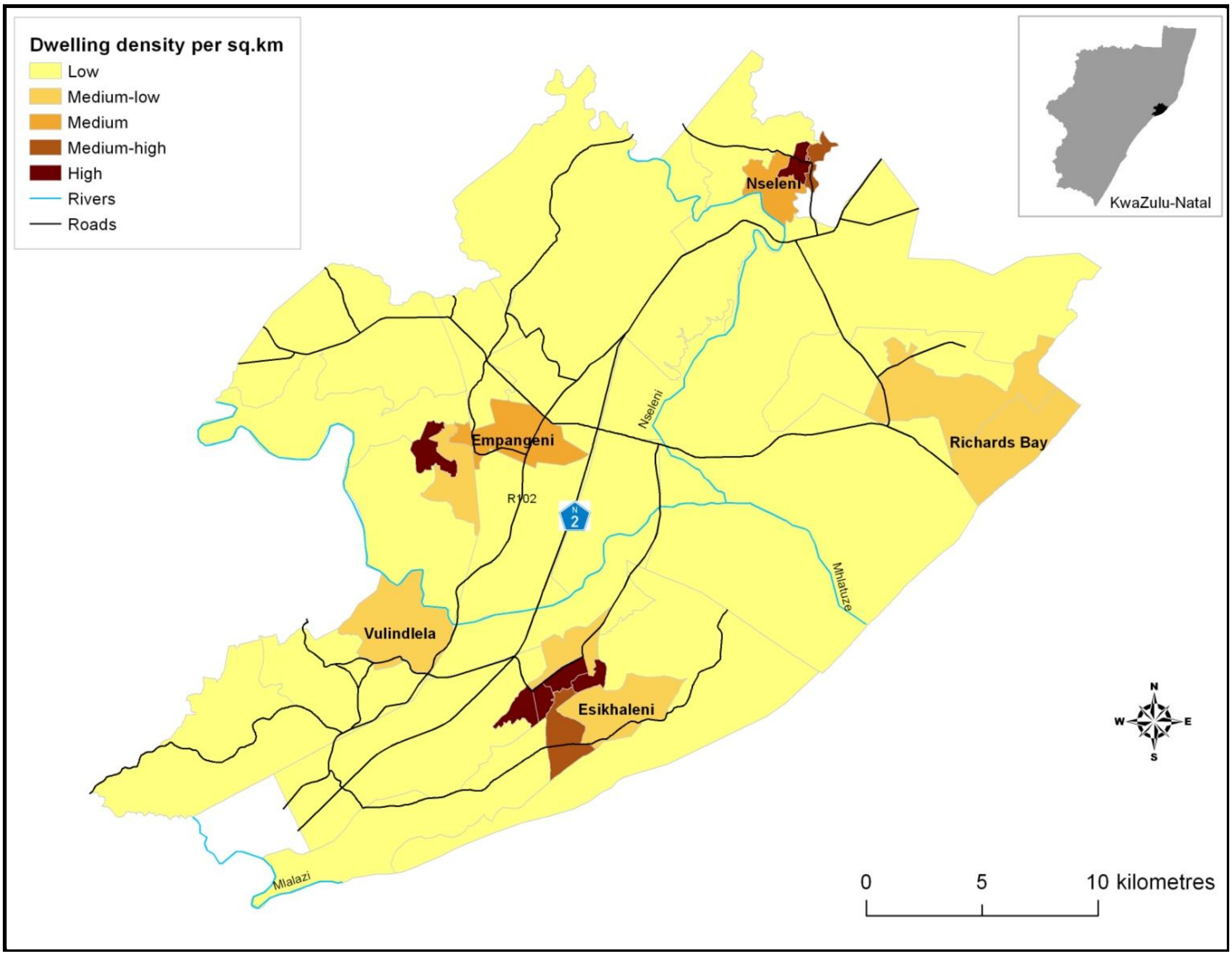


Figure 4.10 Dwelling density in uMhlathuze Municipality, 1984

4.2.4.3 Dwelling density in 2004

Figure 4.11 reveals that the distribution of dwelling densities maintained a relatively similar configuration as in 1984 with the same five urban core areas but notably they densified at relatively different rates. Also, settlement density increased significantly in areas previously classified as medium and high density, namely Esikhaleni and Nseleni rather than in areas with low density.

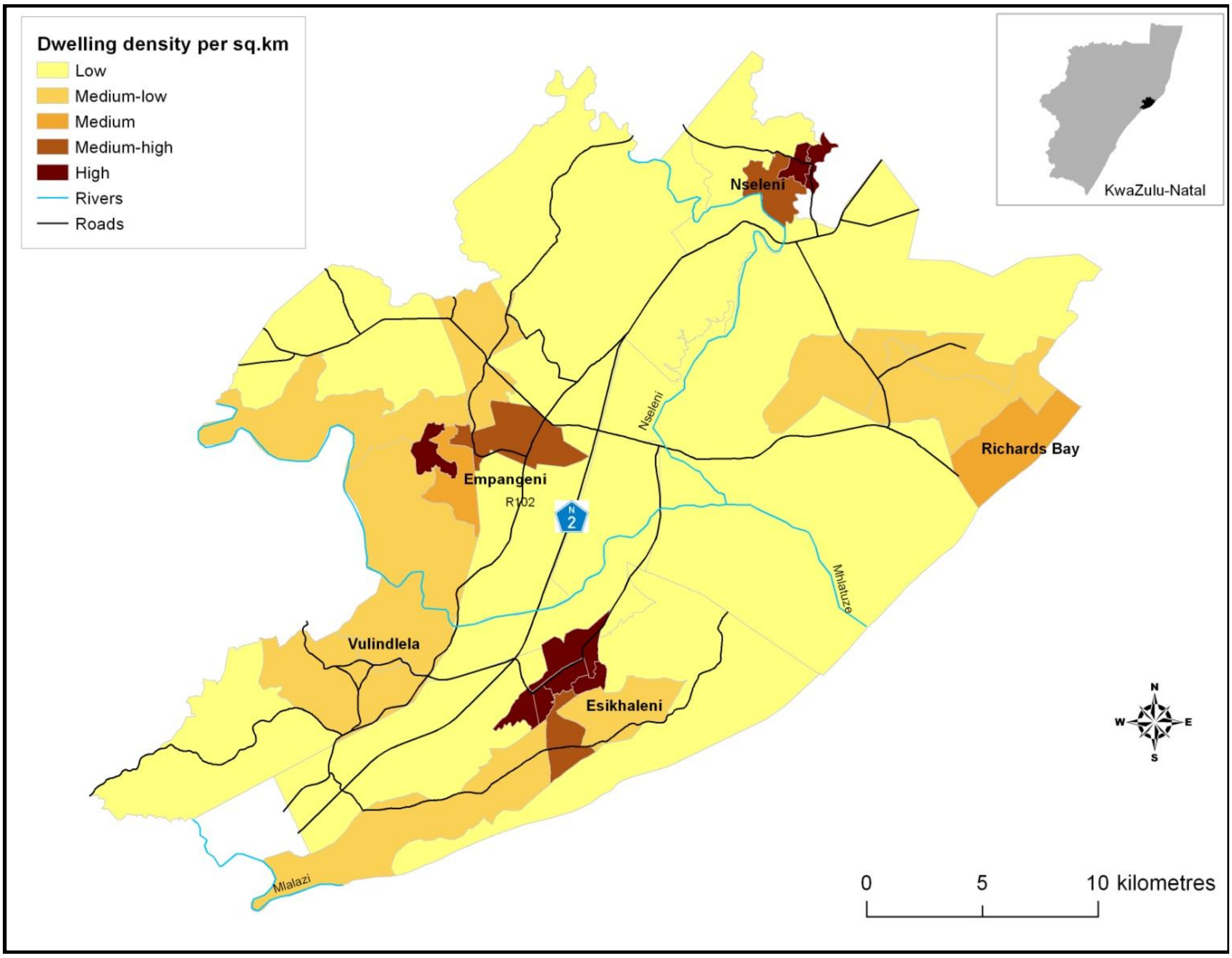


Figure 4.11 Dwelling density in uMhlathuze Municipality, 2004

The varying size of the units of analysis (ward polygons) could of course have affected the calculated densities. Empangeni's dwelling densities remained high, Esikhaleni township had an even larger concentration of the highest density than 20 years before.

With the exception of Nseleni, which remained relatively stable, the prevalence and spread of dwellings adjacent to high-density areas is a notable trend. Much of this spread manifested in

areas outside Empangeni southwards to Vulindlela and westwards and also south-westwards from Esikhaleni. There was an increase in dwelling density around Richards Bay (which is considered to be the fastest growing town in uMhlathuze Municipality), particularly so in the coastal block which is classified as having medium-density dwelling occupation. There is a notable westward-trending axis of dwellings that spread from Richards Bay. Even with many industrial and commercial developments reported to have taken place in Richards Bay, the dwelling density in this ward was unexpectedly low compared to other urban areas in the area. This is presumably because the residential developments were relatively smaller than other types there or that sufficient planned open space was allowed.

Figure 4.12 shows that in 2004 a large proportion (72%) of the study area (mostly rural) had a low settlement density of 50 or fewer dwellings per sq.km. High dwelling densities (>300 dwelling per km^2) were concentrated in only 2% of the surface area of the uMhlathuze Municipality, as expected in a well-planned urban environment. The population and dwelling numbers in the uMhlathuze Municipality was clearly growing and spreading out from already established places, and larger vacant central spaces remained largely occupied by agroforestry plantations.

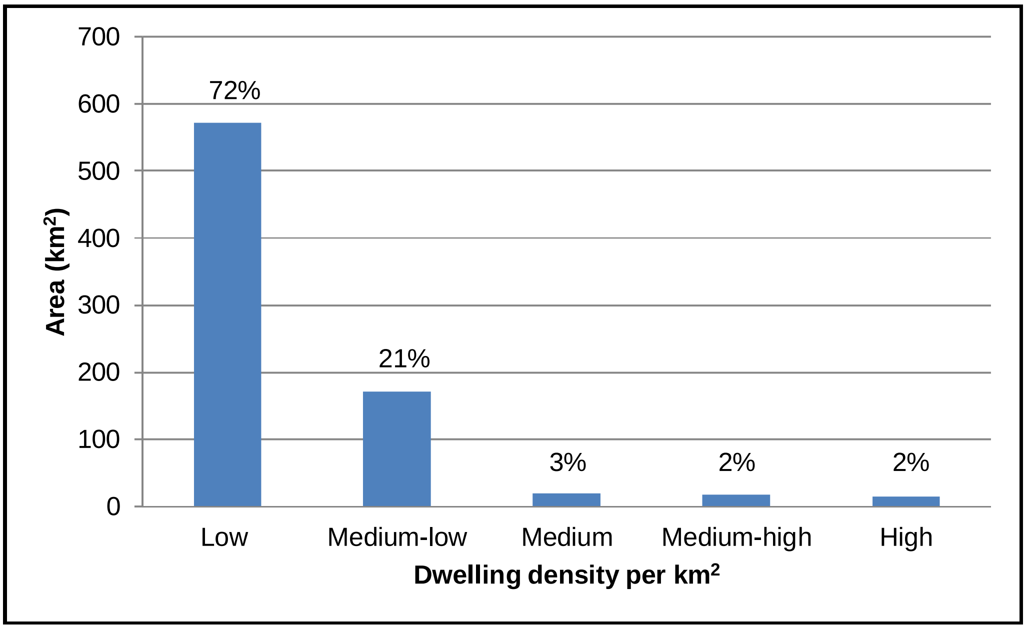


Figure 4.12 Dwelling densities in uMhlathuze Municipality, 2004

Having considered the dwelling densities in uMhlathuze Municipality, the attention is now devoted to the identification of threatened ecosystems and land cover that are likely to be impacted by industrial

and residential development.

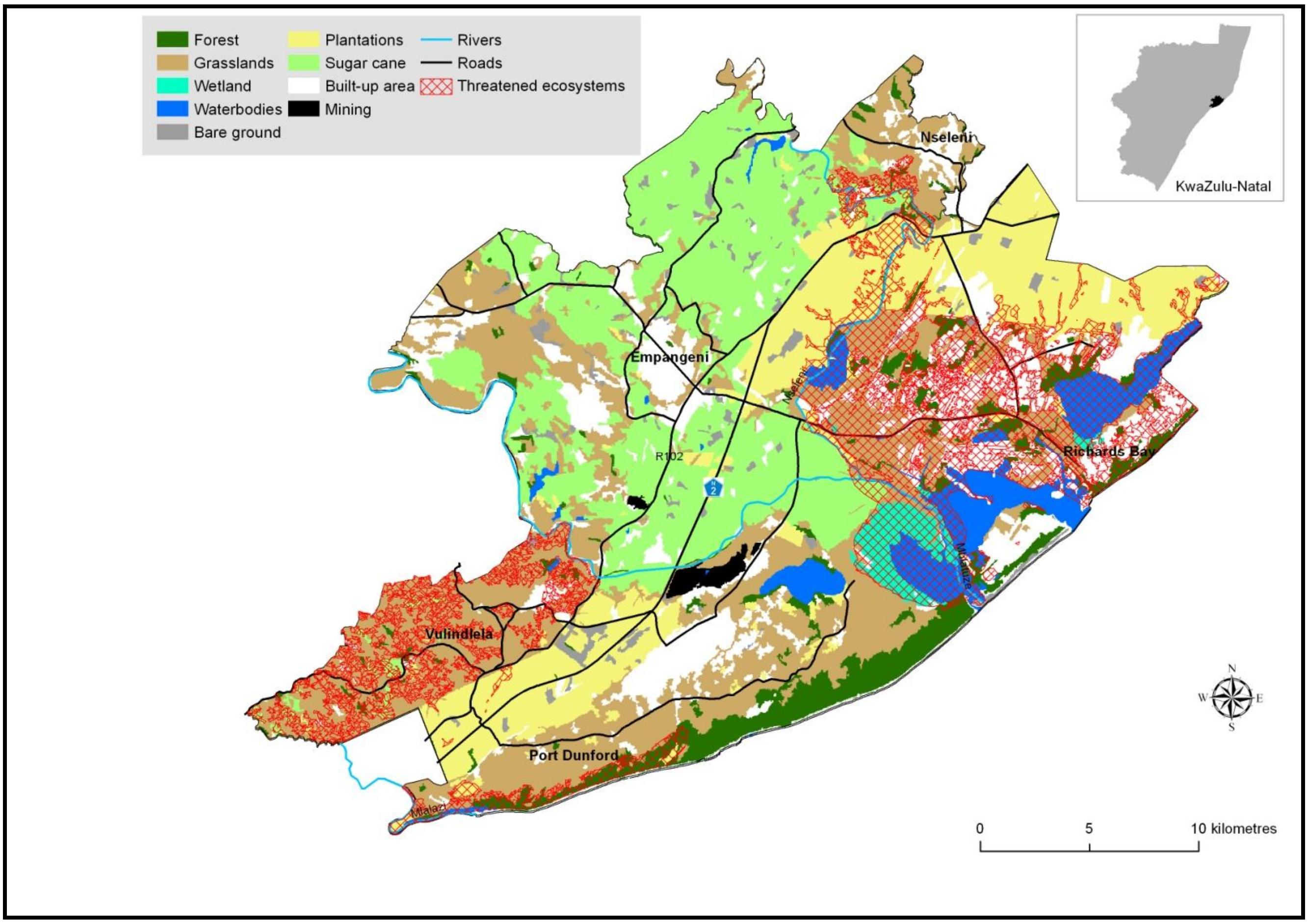
4.3 THREATENED ECOSYSTEMS AND PROPOSED DEVELOPMENTS

Over the past few decades, there has been an intensifying curiosity among environmental planners about how urban form (e.g. size, layout) contributes to the sustainability of urban environments Williams (2007). The situation becomes especially complicated especially when developments are earmarked for areas with exceptional biodiversity value. Given that uMhlathuze Municipality is an area of outstanding biodiversity richness, while simultaneously experiencing excessive development impacts of varied nature, this section identifies areas in uMhlathuze Municipality where biodiversity is most threatened and then distinguishes the land cover types most likely to be affected by future developmental activities.

4.3.1 Threatened ecosystem hotspots

By knowing where specific ecosystems that are under threat and what the agents of the threats are, it is possible to develop monitoring frameworks to optimize the protection of the remaining biodiversity in affected areas. Owing to their mandate declared in Chapter 2 of the National Environmental Management Biodiversity Act 10 of 2004, SANBI (South African National Biodiversity Institute) collects, processes and disseminates information about biodiversity in South Africa. This section thus relies heavily on empirical work reported in SANBI (2009) and their effective mapping of threatened ecosystems in selected South African municipalities – of which uMhlathuze Municipality is one. The criteria applied to identify and map threatened ecosystems were: (a) ecosystem degradation and irreversible loss of both natural environment and integrity; (b) rate of loss of natural habitat; (c) limited extent and imminent threat; (d) threatened flora and fauna species associations; (e) fragmentation; and (f) priority areas for meeting explicit biodiversity targets as defined in a systematic biodiversity plan. Fortunately, the GIS shape files for this work were available (from SANBI online portal (http://bgis.sanbi.org/ecosystems/project.asp) and these were manipulated to portray the threatened ecosystems in the study area (see Figure 4.13).

Wetland and grassland ecosystems occurring in the Richards Bay area were identified by SANBI (2009) as being critically endangered and Thornhill & Thornhill (2010) have reiterated that grassland and wetland are crucially significant ecosystems being seriously threatened by manifold developmental pressures. This is not surprising in the study area where various and hastily implemented developments



Source: Modified from SANBI (2009)

Figure 4.13 Land cover and threatened ecosystems in uMhlathuze Municipality

are located in this town so that ecosystems in its ambit are undeniably under threat of being altered and degraded. This study has also pointed out the conversion of wetlands and grassland – mostly to built-up usage. This is more distressing because built-up area is an all-consuming, destructive type of land use and transformations of these invaluable ecosystems to built-up area are irreversible. Much of the remaining stands of these indispensable natural systems are scattered among developed domains and this will no doubt accelerate their disappearance if care is not taken to conserve them.

Further, Figure 4.13 attests to the serious concerns about the grassland ecosystem in the Vulindlela area in the south-western section of uMhlathuze Municipality. Unlike the grasslands around Richards Bay, this ecosystem is under serious pressure from extensive grazing and natural fire regimes (Mucina et al. 2006). These adverse elements increase the potential for soil erosion which engenders further deterioration of this highly valued biodiversity ecosystem. Moreover, the sustainability of the all-

important livestock economy of the local traditional community will be severely affected (Karumbidza 2006).

Figure 4.13 also shows that an already disappearing strip of coastal forest around Port Durnford along the far southern coastal belt is critically endangered. Studies such as uMhlathuze Municipality (2002) have indicated that this area is rich in mineral deposits and the Richards Bay Minerals (RBM) company already had mining endorsement granted in 1995 (SRK 2012). In their environmental impact assessment report, SRK (2012) indicated that RBM began small-scale mining in 2002 with full operation commencing in 2016, and extractions will continue for almost 25 years. SRK (2012) pointed out a number of ramifications that endanger high-value biodiversity ecosystems in the area, namely:

- Loss and degradation of indigenous coastal forest that contains red-data species;
- Further fragmentation and degradation of communal grassland adjoining the lease area; and
- Impacts on soils with high agricultural potential.

There is no doubt that all the threatened ecosystems discussed in this section critically need urgent conservation action. It is essential that environmentally sound alternatives be found for all the activities that threaten these vulnerable ecosystems.

4.3.2 Proposed residential and harbour developments and affected land covers

There are a number of proposed developments in uMhlathuze Municipality, most of which are residential and industrial developments. This section discusses some possible implications these developments may have for land cover in the area.

4.3.2.1 Residential developments

All the proposed developments are fully built-up in nature – mostly residential and some commercial (uMhlathuze Municipality 2012). The proposed development areas were identified as suitable for human settlements following a series of environmental suitability evaluations in uMhlathuze Municipality (uMhlathuze Municipality 2012). It is important to recall that built-up areas are an all-consuming type of land use and land conversions to built-up are considered to be irreversible.

The significance of the interaction between towns and their surroundings is documented in the National Urban Development Framework (Van Niekerk et al. 2010). At present, the spatial integration of

Esikhaleni, Nseleni and Vulindlela with Empangeni and Richards Bay towns does not seem possible (uMhlathuze Municipality 2012). Therefore, a key advantage of the proposed residential developments is their linking function for the urban centres shown in Figure 4.14. These expansions are seen as vital corridors that will link these townships and the surroundings rural areas with two major commercial urban centres in the area. As documented in uMhlathuze Municipality (2012), these developments are primarily aimed at enhancing the access of low-income communities to economic opportunities by improving access to services.

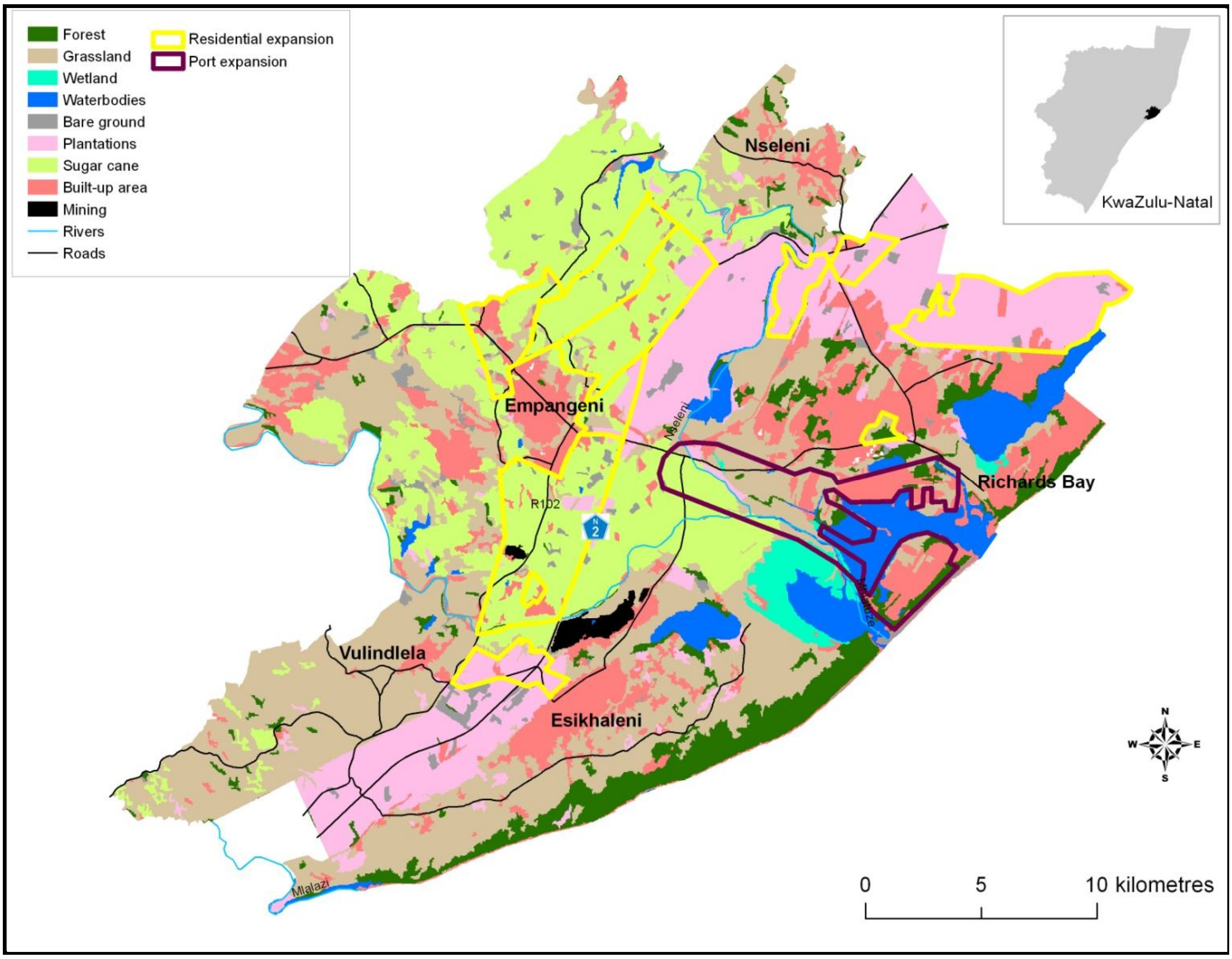


Figure 4.14 Proposed physical developments in relation to land cover in uMhlathuze Municipality, 2004

It is clear from Figure 4.14 that the proposed developments are earmarked to occupy and spatially affect the monotypic agroforestry land use category. Because the allocated tracts of lands are no longer

in a natural state, these residential expansions should have limited ecological impacts. Note, however, that the uMhlathuze Municipality landscape is becoming more spatially contiguous, without consuming high-value land currently undeveloped or natural areas and natural ecosystems that can be rehabilitated in the area. Calculations in ArcMap determined that these planned residential developments will consume approximately 96 km^2 of which the larger proportion (59%) will consume sugar cane fields and the rest commercial forestry plantations – both land use types having serious limiting effects on rainfall runoff yields. But the non-residential developments proposed in the form of port expansion appear to be more serious. The possible implications are discussed in the following section.

4.3.2.2 Port expansion and the Industrial Development Zone

The paramount initiative for the development-led economic boom centred on Richards Bay town came in 1976 when the harbour was constructed (Watts 1983). This action was amplified by a series of policies that influenced and channeled major developments toward Richards Bay to support the harbour (uMhlathuze Municipality 2002). It's not surprising that Richards Bay has been and still is the economic hub of the uMhlathuze Municipality as well the uThungulu District (uMhlathuze Municipality 2012). To further strengthen economic development in Richards Bay, an Industrial Development Zone **(**IDZ) was designated by the Minister of Trade and Industry in 2002 (Thornhill & Thornhill 2010) so becoming one of South Africa's four IDZs, besides Port Elizabeth (Coega IDZ), East London (ELIDZ) and Gauteng (OR Tambo International Airport). IDZs are commonly cited as important vehicles to facilitate investment, create jobs and boost exports (Tang 2008).

For all the opportunities promised by the IDZ, it is lamentable that the proposed IDZ and port expansion have to be located in an environmentally sensitive wetland area that will no doubt be severely modified (Thornhill & Thornhill 2010). To limit the effects, the Department of Agriculture, Environmental Affairs and Rural Development (DAERD) in partnership with uMhlathuze Municipality cooperatively initiated a Port and IDZ Environmental Management Framework (EMF) in 2009. The main goal of this EMF is to support decision-making practices to safeguard the area's remaining natural ecosystems. According to the EMF, the remaining wetlands constitute the most significant land use constraint for industrial development in the area. This is commensurate with Hosking & Bond's (2000) finding that IDZs pose major threats to the existing biodiversity in the respective IDZs.

This chapter has explored socio-economic trends of the population in the study area and has shown

rapid growth over the study period. This growth has led to the expansion of human settlements both in terms of size and density mostly in medium-high and high density settlement zones. Planned residential expansion was shown to have been earmarked as strategy to integrate the main urban areas in the area. Industrial developments were noted to have serious implications for wetland stability in the coastal zone around Richards Bay. Wetland, grassland and natural forest were identified as threatened ecosystems. The next chapter concludes this study summarizes the research by revisiting each objective in terms of its achievement, and culminates in recommendations for development planning and some ideas for future research.

CHAPTER 5 EVALUATION AND CONCLUSIONS

In this chapter, the evaluation and conclusions of the research findings are made. The conclusions made here follow the structure of the thesis objectives. Consequently, the first section revisits and provides an evaluation of each research objective. Thereafter, the conclusions of the study are drawn, while the last section offers recommendations and suggestions for further research.

5.1 EVALUATION OF RESEARCH OBJECTIVES

The aim of this study was to map, quantify and analyse the nature and extent of land cover distribution, change and manifestations of land degradation parallel to settlement intensification in the uMhlathuze Municipality over a 20-year period from 1984 to 2004, mainly using geographic information technology (GIT). Census data were analysed to better profile the socio-economic characteristics of the population. In this section each objective is revisited to reflect on how they were achieved through the results generated.

Objective 1: ***Consult the literature to define land degradation and identify techniques for detecting land degradation and settlement intensification***

The first objective was to review the literature for an understanding of the phenomenon of land degradation and to highlight its associated elements. Vital issues about land degradation and existing techniques to detect it were explored. It was established that land degradation is a multifaceted problem the manifold impacts of which have been studied by numerous researchers from various disciplines. This has led to several definitions of this environmental problem, yet most researchers agree that a central element of this environmental condition is the negative impacts that human intervention has in causing the deterioration of landscapes and ecosystems. Hence, there is no single universally accepted technique to arrest land degradation, instead a multicriteria approach has been advocated.

Hand in hand with the pace at which humans transform and degrade environments, has been an upswing in the implantation of computer-based techniques to detect land degradation. Recent studies have declared that land degradation is manifested through changes in land surface cover and its incidence is always spatial in nature. This is why GIT has replaced traditional manual detection and analysis techniques and gained wide acceptance and application in land degradation research. Deforestation, degradation of vegetation and surface water and loss of wetlands were tracked over time

using GIT, so allowing the comparison of trends. For settlement mapping, most studies used high-resolution orthophotographs because individual dwellings can be clearly distinguished.

Some recent applications in land degradation studies have gone beyond the mapping of land cover and land degradation to incorporate persuasive variables (i.e. population growth) to estimate causative linkages. The literature revealed that modern population censuses in several countries, including South Africa, use GIT and this allows land–population dynamics to be linked with degradation.

Objective 2: ***Map and quantify land cover distribution in 1984, 1996 and 2004.***

The landscape of uMhlathuze Municipality was divided into nine land cover classes which were summarized into three broad categories (natural, agroforestry and irreversible change). It was found that land cover in the landscape maintained a fairly constant spatial pattern in the district for the study period. Generally, the consolidated natural land cover category was predominant in the landscape with grassland being most prominent with its distribution across the study area along with remnant spots sprinkled in urban environments. Wetlands existed in the northern coast areas and along major watercourses. Natural forest formed a strip extending from the south to the north along the coastline with small patches occurring in the central north. With exception of waterbodies, all natural land cover waned in size over the study period to be matched by a concomitant surge in the growth of artificial land cover.

The spread of agroforestry in the form of sugar cane plantations which prevailed in the central section of the study area and a band of commercial forest occurring in the central-south extending northwards of Richards Bay was a major land cover feature. Built-up terrain was prevalent in and around designated urban areas and it expanded over time. These land cover types extensively fragmented the natural ecosystems.

Objective 3: ***Map and quantify land cover changes and manifestations of land degradation.***

It was established that uMhlathuze Municipality witnessed significant anthropogenic influences which led to land cover changes so that the natural land cover domains declined in comparison to human-induced categories. Overall, natural land cover was predominant in 1984 in uMhlathuze Municipality, but by 2004 human land uses dominated the landscape. The most noticeable changes were the expansion of agroforestry, built-up area and to a lesser extent the mining category – the all-consuming

types of land use. Their stability and dominance over other groups was therefore not surprising. Most of the changes observed were given irreversibility ratings of medium and high.

Grasslands and wetlands suffered from manifold built-up activities, especially around Richards Bay. The expansion of both sugar cane and forestry plantations consumed grassland vegetation. Mining activity showed an increasing and exceptionally ominous trend to 'consume' grasslands. The biodiversity in the natural ecosystems was virtually wiped out. If not carefully planned, the expansion of these monotype land uses will seriously threaten the remaining biodiversity. Patches of bare ground were observed, although they were often misclassified as built-up and sugar cane. Land degradation was found to affect a large proportion (15 km^2) of the study area.

Objective 4: ***Map the spatial growth of human settlements and the socio-economic characteristics of the population.***

The documented population growth over the study period was rapid. A 15-year intercensal period from 1996 to 2011 witnessed a significant increase of population numbers in the area. The greatest increase was in the five years between 1996 and 2001, followed by a slower increase during the decade 2001-2011. Analysis of socio-economic variables revealed the expected configurations with lower levels in employment, education and income being recorded in rural areas compared with urban areas. A noteworthy decline in the age-dependency ratio was evident, signifying a decreased burden on the economically active and employed cohorts.

While settlements maintained a stable spatial distribution, increased size and concentration was observed in five core areas of the municipality (Esikhaleni, Empangeni, Nseleni, Vulindlela and Richards Bay) where consistent urban spread was typical. Similar features and patterns were noted regarding settlement density, densities increasing mostly in medium- and high-density areas over time.

Objective 5: ***Identify threatened ecosystems and land cover types likely to be impacted on by future industrial and residential developments.***

Because it is difficult to link and integrate with one another the core settlement areas in uMhlathuze Municipality, proposed residential developments are institutionally planned in nature. This development type is earmarked for areas occupied by sugar cane and forestry plantations. These developments are intended to enhance access to employment and livelihood opportunities that are

currently concentrated in Richards Bay and Empangeni towns. Expansions to the Richards Bay port and the designated industrial development zone (IDZ) have been proposed. Critically, these expansions are located in an environmentally sensitive section of the landscape where they threaten the remaining wetlands. This is why the South African National Biodiversity Institute (SANBI) identified wetlands and grasslands in the Richards Bay vicinity as being critically threatened. Other threatened ecosystems include forest in the southern coastal section where Richards Bay Minerals is currently operating.

5.2 CONCLUSION

This work found that significant changes in land cover occurred in uMhlathuze Municipality over the study period. The observed changes took the form of natural-to-human-induced shifts and much of these were classified to be of medium to high intensity. Forest, wetlands and grassland contributed to significant expansions of monotype agroforestry, built-up areas and mining activity. Ecologically, these changes are grave because they entail an eternal loss of biodiversity (flora and migration of fauna). The natural ecosystems are altered so that grassland, wetlands and forest are showing signs of degradation.

Population numbers in uMhlathuze Municipality have grown rapidly, accounting for the increase of total built-up area. The age-dependency ratio has shown a welcome decreasing trend, implying less pressure on the economically active population and greater potential for general socio-economic improvement. This may also reduce the population’s dependency on and over-use of natural resources. Settlement size and density increased over the study period as did their sprawl. These increases in built-up area do not bode well for the maintenance of biodiversity in uMhlathuze Municipality.

5.3 RECOMMENDATIONS

In view of the research conclusion, the following recommendations regarding practical spatial planning measures can be made:

- Critically threatened grasslands and wetlands around Richards Bay need continuous monitoring and mapping so as to keep track of their spatial extent and integrity with a view to designing a sustainable conservation framework.
- The settlements that are interspersed with or expanding into indigenous forest should be restrained, and growth reallocated and protection measures strengthened.
- Continuous mapping of land use is vital for detecting trends in agroforestry and built-up area influences over natural land cover classes.

- The assessment of land degradation using field surveys in the area should be implemented.

Certain limitations to the study could be addressed through further and refined research avenues. Some limitations were rooted in the nature of the data available (different census units) that impeded the comparison of historical changes of socio-economic characteristics and their connection to land cover change since the base year. Research topics that can be probed further include:

- Investigation of the role of socio-economic characteristics in accompanying and influencing land cover change. The linkages between socio-economic characteristics and change can offer answers to planning for and preventing land cover change.
- Examination of the socio-economic impact of agroforestry and their effects on water resources especially run-off volumes and availability of potable quantities to service local community needs.
- Determining the role and value of ecotourism as a strategy for conservation of remaining natural resources in the study area.
- Investigation of opportunities and modes for the cooperation between conservation bodies, environmental planners and land managers. This may unravel the political nature of communication and decision-making guiding appropriate use of land in biodiverse areas.
- Examination of the nature and practices of land use management systems so that ‘hard’ land use activities are properly channelled to the least sensitive areas.
- Refining mapping methods and a classification system design to efficiently monitor the spatial and temporal extent of threatened ecosystems and facilitate long term conservation frameworks.

Several environmentally punitive land use activities emanate from poor understanding of proximate and underlying land use dynamics and their causes, and management inability to coordinate environmental planning programmes properly. It is thus vital to find an appropriate balance between conservation and economic development through integrated environmental planning.

[31 978 words]

REFERENCES

Abbas II 2009. An overview of land cover changes in Nigeria, 1975-2005. *Journal of Geography and Regional Planning* 2: 62-65.

Ahadnejad M 2002. *Environmental land use change detection and assessment using with multi-temporal satellite imagery*. Bangkok: Mapasia.

Ahlcrona E 1986. Monitoring the impact of climate and man on land transformation – study in arid and semi-arid environments in central Sudan. Lund: University of Lund, Naturgeografiska Institution.

Alphan H, Doygun H & Unlukaplan YI 2009. Postclassification comparison of land cover using multi-temporal Landsat and ASTER imagery: The case of Kahramanmaraş, Turkey. *Environmental Monitoring and Assessment* 151: 327-336.

Alvarez JAG 2007. Effects of land cover changes on the water balance of the Polo Verde wetland, Costa Rica. MSc thesis. Enschede: University of Twente, Department of Water Resources and Environmental Management.

Amissah-Arthur A, Mougenot B & Loireau M 2000. Assessing farmland dynamics and land degradation on Sahelian landscapes using remotely sensed and socio-economic data. *International Journal of Geographical Information Science* 14: 583-599.

Anderson JM, Hardy EE, Roach JT & Witmer RE 1976. *A land use and land cover classification system for use with remote-sensor data*. Washington DC: United States Government Printing Office.

Armstrong AJ, Benn G, Bowland AE, Goodman PS, Johnson DN, Maddock AH & Scott-Shaw CR 1998. Plantation forestry in South Arica and its impact on biodiversity. *Southern African Forestry Journal* 182: 59-65.

Avelar S, Zah R &Tavares-Correa C 2009. Linking socio-economic classes and land cover data in Lima, Peru: Assessment through the application of remote sensing and GIS. *International Journal of Applied Earth Observation and Geoinformation* 11: 27-37.

Ayenagbo K, Kimatu JN & Rongcheng W 2011. A model for a sustainable energy supply strategy for the social-economic development of Togo. *Journal of Economics and International Finance* 3: 387-398

Ayoub AT 1999. Land degradation, rainfall variability and food production in the Sahelian zone of the Sudan. *Land Degradation & Development* 10: 489-500.

Bai ZG, Dent DL, Olsson L, & Schaepman ME 2008. Proxy global assessment of land degradation. *Soil Use and Management* 24: 223-234.

Balchin PN, Kieve JL & Bull GH 2000. *Urban economics – a global perspective.* 1st ed. New York: Palgrave Publishers.

Barbier EB 2000. Links between economic liberalization and rural resource degradation in the developing regions. *Agricultural Economics* 23: 299-310.

Barrow CJ 1994. *Land degradation: Development and breakdown of terrestrial environments*. Cambridge: Cambridge University Press.

Berberoglu S & Akin A 2009. Assessing different remote sensing techniques to detect land use/cover changes in the eastern Mediterranean. *International Journal of Applied Earth Observation and Geoinformation* 11: 46-53.

Blamey RC & Reason CJC 2009. Numerical simulation of a mesoscale convective system over the east coast of South Africa. *Tellus* 61: 17-34.

Booth J 2012. How deforestation could further destabilize Liberia [online]. Available from http://www.policymic.com/articles/14582/how-deforestation-could-further-destabilize-liberia. [Accessed 15 October 2012].

Briassoulis H 2006. Analysis of land use change: Theoretical and modeling approaches [online]. http://www.rri.wvu.edu/WebBook/ Briassoulis/contents.htm [Accessed 18 May 2010].

Brinson MM 1993. A hydrogeomorphic classification for wetlands [online]. US Army Corps of Engineers Technical Report WRP-DE-4. Vicksburg. Available from http://el.erdc.usace.army.mil/wetlands/pdfs/wrpde4.pdf. [Accessed 18 July 2011].

Brown S & Lugo AE 1990. Tropical secondary forests. *Journal of Tropical Ecology* 6: 1-32.

Chikhaoui M, Bonn F, Bokoye AI & Merzouk A 2005. A spectral index for land degradation mapping using ASTER data: Application to a semi-arid Mediterranean catchment. *International Journal of Applied Earth Observation and Geoinformation* 7:140-153.

Chunxiao Z, Zhiming L & Nan Z 2008. Using remote sensing and GIS to investigate land use dynamic change in western plain of Jilin province. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science* 37: 1685-1690.

Cohen WB, Kushla JD, Ripple WJ & Garman SL 1996. An introduction to digital methods in remote sensing of forested ecosystems: Focus on the Pacific Northwest, USA. *Environmental Management* 20: 421-435.

Costanza R, D'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J, Raskin R, Sutton P & Van den Belt M 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.

Cowen DJ & Jensen JR 1998. Extraction and modeling of urban attributes using remote sensing technology. In Diana L (Ed.) *People and pixels: Linking remote sensing and social science*, 164-188. Washington DC: National Academy Press.

Crampton JW 2001. Maps as social constructions: Power, communication and visualization. *Progress in Human Geography* 25: 235-252.

Critchley WRS & Netshikovhela EM 1998. Land degradation in South Africa: Conventional views, changing paradigms and a tradition of soil conservation. *Development Southern Africa* 15: 449-469.

Dasappa S 2011. Potential of biomass energy for electricity generation in sub-Saharan Africa. *Energy for Sustainable Development* 5: 203-213.

Davaasuren N 2001. Information system design for land degradation assessment, in particular for pasture areas: A case study of West Mongolia. MSc thesis. Enschede: University of Twente, Department of Earth Systems Analysis.

Davis MA 2003. Biotic globalization: Does competition from introduced species threaten biodiversity? *Biological Science* 53: 481-489.

De Jong SM 1994. Applications of reflective remote sensing for land degradation studies in a Mediterranean environment. Utrecht: The Royal Dutch Geographical Society.

De Kimpe CR & Warkentin BP 1998. Soil functions and the future of natural resources. In Blume HP, Eger H, Fleischhauer E, Hebel A, Reij C & Steiner KG (eds) Towards sustainable land use: Further cooperating between people and institutions. *Advances in Geo-Ecology* 31: 3-10.

DEAT (Department of Environmental Affairs and Tourism) 1997. *White paper on the conservation and sustainable use of South Africa's biological diversity*. Pretoria: Department of Environmental Affairs and Tourism.

DEAT (Department of Environmental Affairs and Tourism) 2008. Agriculture-induced land degradation: A consideration of key emerging issues that may impact the state of the environment. Emerging Issues Paper: Land degradation. Pretoria: Department of Environmental Affairs and Tourism.

Di Gregorio A & Jansen LJM 2000. *Land cover classification system (LCCS): Classification concepts and user manual*. Rome: Cooperazione.

Drummond MA & Loveland TR 2010. Land-use pressure and a transition to forest-cover loss in the eastern United States. *Biological Science* 60: 286-298.

Dube LT & Jury MR 2000. The nature of climate variability and impacts of drought over KwaZulu-

Natal, South Africa. *South African Geographical Journal* 82: 44-53.

Dumanski J & Pieri C 2000. Land quality indicators: Research plan. *Agriculture, Ecosystem & Environment* 81: 93-102.

DWAF (Department of Water Affairs and Forestry) 1999. Stream flow reduction activities combined licensing and authorisation guidelines. Pretoria: Department of Water Affairs and Forestry.

DWAF (Department of Water Affairs and Forestry) 2004. Water resource protection and assessment policy implementation process. Resource directed measures for protection of water resource: Methodology for the determination of the ecological water requirements for estuaries. Version 2. Pretoria: Department of Water Affairs and Forestry.

Dye P & Versfeld D 2007. Managing the hydrological impacts of South African plantation forests: An overview. *Forest Ecology and Management* 251: 121-128.

Eastman JR 2006. *IDRISI 15.0: The Andes edition.* Worcester: Clark University.

Eicher CL & Brewer CA 2001. Dasymetric mapping and areal interpolation: Implementation and evaluation. *Cartography and Geographic Information Science* 28: 125-138.

Environmental Monitoring Group 2000. Land degradation - A resource of the EMG, Cape Town [online]. Available from http://www.botany.uwc.ac.za/inforeep/land1.htm [Accessed 10 October 2011].

Eswaran H, Lal R & Reich PF 2001. Land degradation: An overview. In Bridges EM, Hannam ID, Oldeman LR, Pening de Vries FWT, Scherr SJ, & Sompatpanit S (eds) *Responses to land degradation*. Proceedings of the 2nd International Conference on Land Degradation and Desertification. New Delhi: Oxford Press.

FAO (Food and Agriculture Organization) 2010. Guide to implementation of phytosanitary standards in forestry [online]. Rome: FAO. Available from http://www.fao.org/forestry/23643-07ff049b3790ef1967dfbdb966c54d 2c6.pdf . [Accessed 20 March 2011].

FAO & UNEP (Food and Agriculture Organization & United Nations Environment Programme) 1999. The future of our land facing the challenge. Guidelines for integrated planning for sustainable management of land resources [online]. Rome: FAO. Available from http://www.fao.org/docrep /004/x381e/x3810e00.htm [Accessed 03 June 2009].

Fiedler R, Schuurman N & Hyndman J 2006. Improving census-based socio-economic GIS for public policy: Recent immigrants, spatially concentrated poverty and housing need in Vancouver. *International Journal for Critical Geographies* 4: 145-171.

Garland GG, Hoffman MT & Todd S 2000. Soil degradation. In Hoffman MT, Todd S, Ntshona Z &

Turner S (eds) *A national review of land degradation in South Africa*. Pretoria: South African National Biodiversity Institute.

Gibbs JP 2000. Wetland loss and biodiversity conservation. *Conservation Biology* 14: 314-317.

Gibson DJD 2007. Land degradation in the Limpopo province, South Africa. MSc thesis. Johannesburg: University of the Witwatersrand, School of Animal, Plant and Environmental Sciences.

Gilpin A 2000. *Environmental economics: A critical overview*. Chichester: John Wiley.

Grundy I & Wynberg R 2001. Integration of biodiversity into national forest planning programs: The case of South Africa. Proceedings of the Integration of Biodiversity in National Forestry Planning Programme held 13-16 August 2001. Bogor: Center for International Forestry Research.

Grenfell MC, Ellery WN & Preston-Whyte RA 2005. Wetlands as early warning (eco)systems for water resource management. *Water SA* 31: 465-472.

Guo Q, Li L & Jia Y 2006. Quality evaluation of statistical data classification considering spatial autocorrelation. *Geomatics and Information Science of Wuhan University* 31: 240-243.

Haberl H 2004. Land use and sustainability indicators: An introduction. *Land Use Policy* 21:193-198.

He C, Okada N, Zhang Q, Shi P & Li J 2008. Modelling dynamic urban expansion processes incorporating a potential model with cellular automata. *Landscape and Urban Planning* 86: 79-91.

Hennemann R 2001. Land degradation, assessment, monitoring and modeling. Enschede: University of Twente, Soil Science Division.

Hietel E, Waldhardt R & Otte A 2007. Statistical modeling of land-cover changes based on key socio-economic indicators. *Ecological Economics* 62: 496-507.

Hoffman MT, Todd S, Ntshona Z & Turner S 1999. Land degradation in South Africa [online]. Cape Town: SANBI. Available from www.sanbi.org/landdeg [Accessed 18 October 2008].

Hoffman MT & Todd S 2000. A national review of land degradation in South Africa: An influence of biophysical and socio-economic factors. *Journal of South African Studies* 26:742-758.

Horta MB 2002. Assessment of human and physical factors influencing spatial distribution of vegetation degradation - environmental protection area Cachoeira das Andorinhas, Brazil. MSc thesis. Enschede: University of Twente, Department of Natural Resources.

Hosking S & Bond P 2000. Infrastructure for SDIs or basic needs? Port Elizabeth's prioritisation of the Coega port over municipal services. Johannesburg: University of the Witwatersrand, Graduate School of Public and Development Management.

Howarth PJ & Wickware GM 1981. Procedures for change detection using Landsat digital data.

International Journal of Remote Sensing 2: 277-291.

Hudson PF & Alcántara-Ayala I 2006. Ancient and modern perspectives on land degradation. *Catena* 65:102-106.

IEA (International Energy Agency) 2009. World energy outlook policy database [online]. Available from www.iea.org/textbase/weo/. [Accessed on 01 November 2011].

IGBP (International Geosphere-Biosphere Programme) 2006. Science plan and implementation strategy. IGBP Report No. 55. Stockholm: International Geosphere-Biosphere Programme [online]. Available from http://www.igbp.net/download/18.1b8 ae20512db692f2a680006388/report_55-IGBP.pdf [Accessed 10 June 2011].

Imam E 2011. Use of geospatial technology in evaluating landscape cover type changes in Chandoli National Park, India. *Computational Ecology and Software* 1: 95-111.

IPCC (Intergovernmental Panel on Climate Change) 2001. Climate change 2001: Impacts, adaptation and vulnerability [online]. Available from http://www.grida.no/climate/ipcc_tar/wg2/index.htm [Accessed 26 May 2009].

Islam MS & Ahmed R 2011. Land use change prediction in Dhaka City using GIS and aided Markov chain modeling. *Journal of Life and Earth Science* 6: 81-89.

Jansen LMJ & Di Gregorio A 2002. Parametric land cover and land-use classifications as tools for environmental change detection. *Agriculture, Ecosystems and Environment* 91: 89-100.

Jensen JR 2000. *Remote Sensing of the Environment: An earth resource perspective*. New Jersey: Prentice Hall.

Jensen JR 2005. *Introductory digital image processing: A remote sensing perspective*. New Jersey: Prentice Hall.

Jensen JR & Cowen DC 1999. Remote sensing of urban/suburban infrastructure and socio-economic attributes. *Photogrammetric Engineering and Remote Sensing* 65: 611-622.

Ji CY 2008. Land degradation in central Asia. *Central Asian Countries Initiative for Land Management Multicountry Partnership Framework Support Project* [online]. Available from http://www2.adb.org/Documents/CACILM/Land-Degradation-CentralAsia.pdf. [Accessed 26 May 2009].

Jiang B 2013. Head-tail breaks: A new classification scheme for data with a heavy-tailed distribution. *The Professional Geographer* 65: 482-494.

Johnston CA 1998. *Geographic information systems in ecology*. 1st ed. Victoria: Blackwell Science.

Kakembo V 2001. Trends in vegetation degradation in relation to land tenure, rainfall and population changes in Peddie District, Eastern Cape, South Africa. *Environmental Management* 28: 39-46.

Kanagawa M & Nakata T 2008. Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries. *Energy Policy* 36: 2016-2029.

Karanja FN 2002. *Use of knowledge based systems for the detection and monitoring of unplanned developments*. Hannover: Universität Hannover, Vom Fachbereich Bauingenieur-und Vermessungswesen.

Kareddula S 2011. Monitoring and quantifying the environmental change detection of Lake Kolleru and the surrounding Mandals using Remote sensing techniques. MSc thesis. Carbondale: Southern Illinois University, Department of Geography and Environmental Resources.

Karumbidza JB 2006. *A study of the social and economic impacts of industrial tree plantations in the KwaZulu-Natal province of South Africa*. Montevideo: World Rainforest Movement.

Kellner K 2002. *Desert Margins Program*. Proceedings of a National Workshop: Appropriate Restoration Technologies in South Africa. Potchefstroom: Potchefstroom University for Christian Higher Education.

Kerr JT & Ostrovsky M 2003. From space to species: Ecological applications for remote sensing. *Trends in Ecology and Evolution* 18: 299-305.

Khan MA, Gupta VP & Moharana PC 2001. Watershed prioritization using remote sensing and geographical information system: A case study of Guhiya. *Indian Journal of Arid Environments* 49: 465-475.

Khattry B & Rao JM 2002. Fiscal Faux Pas: An analysis of the revenue implications of trade liberalization. *World Development* 30: 1431-1444.

Khresat SA, Rawajfih Z & Mohammed M 1998. Land degradation in north-western Jordan: Causes and processes. *Journal of Arid Environments* 39: 623-629.

King AS 1996. Water pollution and management. In Chenje M & Johnson P (eds) *Water in Southern Africa*. Harare: Southern African Research and Documentation Centre.

King C & Delpont G 1993. Spatial assessment of erosion: Contribution of remote sensing, a review. *Remote Sensing Reviews* 7: 223-232.

Komlos L 2008. Examination of land use/land cover changes in the vicinity of Playa del Carmen, Mexico and their impact on groundwater quality. MA thesis. Fayetteville: University of Arkansas, Department of Geography.

Kotzé H, Bessinger D & Beukes J 2006. Ilmenite smelting at Ticor South Africa. Pretoria: The South African Institute of Mining and Metallurgy.

Kuyler P 2006. Application of multi-criteria analysis in land use decisions. PhD thesis. Bloemfontein:

University of the Free State, Centre for Environmental Management.

LADA (Land Degradation Assessment in Drylands) 2002. Land Degradation in Drylands. Proceedings of the FAO workshop held 5-7 December 2002. Rome: Food and Agriculture Organisation.

Lambin EF & Geist HJ 2001. Global land use and land cover change: What have we learned so far? *Global Change News Letter* 46: 27-30.

Lambin EF & Geist HJ 2003.The land managers who have lost control of their land use: implications for sustainability. *Tropical Ecology* 44: 15-24.

Lande D 2008. Mondi wetlands project management: A review of principles, contexts, experiences and opportunities. *Agricultural Systems* 55: 173-193.

Langbein WB & Schumm SA 1958. Yield of sediment in relation to mean annual precipitation. *Transactions of the American Geophysical Union* 39: 1076-1084.

Levin N 1999. *Fundamentals of remote sensing, 1st Hydrographic data management course*, International Maritime Academy. Trieste: Tel Aviv University, Geography Department [online]. Available from http://geography.huji.ac.il/personal/Noam%20Levin/1999-fundamentals-of-remote-sensing.pdf [Accessed 10 June 2009].

Lillesand TM & Keifer RW 1994. *Remote sensing and image interpretation*. 4th ed. New York: Wiley.

Liu X, Clarke KC & Herold M 2006. Population density and image texture: A comparison study. *Photogrammetric Engineering & Remote Sensing* 72: 187-196.

Liu Y, Ni S & Zha Y 1997. Land degradation mechanism and management of countermeasures in the sand-blow area of northern Shaanxi Province. *Journal of Natural Resource* 12: 357-362.

Lo CP 1986. Accuracy of population estimation from medium-scale aerial photography. *Photogrammetric Engineering and Remote Sensing* 52: 1859-1869.

Lo CP 1995. Automated population and dwelling unit estimation from high-resolution satellite images: a GIS approach. *International Journal of Remote Sensing* 16: 17-34.

Lo CP 2008. Population estimation using geographically weighted regression. *GIScience and Remote Sensing* 45: 131-148.

Long H, Wu X, Wang W & Dong G 2008. Analysis of urban-rural land-use change during 1995-2006 and its policy dimensional driving forces in Chongqing, China. *Sensors* 8: 681-699.

Low AB & Rebelo AG 1998. Vegetation of South Africa, Lesotho and Swaziland. Pretoria: Department of Environmental Affairs and Tourism.

Lowry JH, Ramsey RD, Boykin K, Bradford D, Comer P, Falzarano S, Kepner W, Kirby J, Langs L, Prior-Magee J, Manis G, O'Brien L, Pohs K, Rieth W, Sajwaj T, Schrader S, Thomas KA, Schrupp

D, Schulz K, Thompson B, Wallace C, Velasquez C, Waller E & Wolk B 2005. The Southwest regional gap analysis project final report on land cover mapping methods [online]. Available from http://ftp.nr.usu.edu/swgap/swregap_landcover_report.pdf [Accessed 06 August 2009].

Lu D, Mausel P, Brondizio E & Moran E 2004. Change detection techniques. *International Journal of Remote Sensing* 12: 2365-2407.

Lyson TA & Olson RK 1999. *Under the blade: The conversion of agricultural landscapes*. Boulder: Westview Press.

Macleod RD & Congalton RG 1998. A quantitative comparison of change detection algorithms for monitoring eelgrass from remotely sensed data. *Photogrammetric Engineering & Remote Sensing* 64: 207-216.

Mahabir R & Al-Tahir R 2008. The role of spatial data infrastructure in the management of land degradation in small tropical Caribbean Islands. Proceedings of the 10th International Conference for Spatial Data Infrastructure held 25-29 February 2008. St. Augustine: The Centre for Caribbean Land and Environmental Appraisal Research.

Maitima JM, Gachimbi LN, Mugatha S, Mathai, Olson J, Mutugu R, Kamau P & Otuoma J 2004. The linkages between land-use change, land degradation and biodiversity in Embu –Mbeere. LUCID Working Paper Series No. 5 [online]. Available from www.lucideastafrica.org. [Accessed on 10 December 2010].

Maitima JM, Mugatha SM, Reid RS, Gachimbi LN, Majule A, Lyaruu H, Pomery D, Mathai S & Mugisha S 2009. The linkages between land use change, land degradation and biodiversity across East Africa. *African Journal of Environmental Science and Technology* 3: 310-325.

Maltby E 1986. *Waterlogged wealth: Why waste the world's wet places?* London: Earthscan.

Matthews E, Payne R, Rohweder M & Murray S 2000. *Pilot analysis of global ecosystems (PAGE): Forest ecosystems.* Washington DC: World Resources Institute.

McCloy R 1995. *Resource management information system*: *Process and practice*. London: Taylor & Francis.

McCormick S & Cooper JAG 1992. Fluvial sediment yield to the Natal coast: A review. *Southern African Journal of Aquatic Sciences* 18: 74-88.

McCullum J 1994. Freshwater Resources. In Chenje M & Johnson P (eds) *State of the Environment in South Africa*. Harare: Southern African Research and Documentation Centre.

McGinley M 2008. Biological diversity in Maputaland – Pondoland – Albany [online]. Available from www.eoearth.org/article/Biological_diversity_in_Maputaland-Pondoland-Albany. [Accessed on 19

September 2009].

Meadows ME & Hoffman MT 2003. Land degradation and climate change in South Africa. *The Geographical Journal* 169: 168-177.

Melesse AM, Oberg J, Nangia V, Beeri O & Beumgartner D 2006. Spatiotemporal dynamics of evapotranspiration at the Glacial Ridge prairie restoration in the northern Minnesota. *Hydrological Processes* 207: 1451-1464.

Mengistu DA & Salami AT 2007. Application of remote sensing and GIS inland use/land cover mapping and change detection in a part of south western Nigeria. *African Journal of Environmental Science and Technology* 1: 99-109.

Metternicht G & Zinck JA 1997. Spatial discrimination of salt and sodium affected soil surfaces. *International Journal of Remote Sensing* 18: 2571-2586.

Mohan M, Pathan SK, Narendrareddy K, Kandya A & Pandey S 2011. Dynamics of urbanization and its impact on land-use/land-cover: A case study of Megacity Delhi. *Journal of Environmental Protection* 2: 1274-1283.

Morgan JL, Gergel SE & Coops NC 2010. Aerial photography: A rapidly evolving tool for ecological management. *Biological Science* 60:47-59.

Mortimore M & Adams WM 1999. *Working the Sahel: Environment and society in northern Nigeria*. London: Routledge.

Mucina L, Scott-Shaw R, Rutherford MC, Camp KGT, Matthews WS, Powrie LW & Hoare DB 2006. Indian Ocean coastal belt. In Mucina L & Rutherford MC (eds) *The Vegetation of South Africa, Lesotho and Swaziland*. Pretoria: South African National Biodiversity Institute.

Munday P 2010. Downscaling scenarios to local landscapes: a case study of the Norfolk Broads. PhD thesis. Norwich: University of East Anglia.

National Institute of Statistics 2009. General population census of Cambodia 2008: National report on final census results. Phnom Penh: National Institute of Statistics.

Nagamani K & Ramachandran S 2003. *Landuse /Land Cover in Pondicherry using remote sensing and GIS*. In Bunch MJ, Suresh VM & Kumaran TV (eds) Proceedings of the Third International Conference on Environment and Health held 15-19 December 2003. Chennai: University of Madras and Faculty of Environmental Studies, Department of Geography.

Nelson GC & Geoghegan J 2002. Deforestation and land use change: Sparse data environments. *Agricultural Economics* 27: 201-216.

Newton AC, Cayuela L, Echeverría C, Armesto JJ, Del Castillo RF, Golicher D, Geneletti D,

Gonzalez-Espinosa M, Huth A, López-Barrera F, Malizia L, Manson R, Premoli A, Ramírez-Marcial N, Rey Benayas J, Rüger N, Smith-Ramírez C & Williams-Linera G 2009. Towards integrated analysis of human impacts on forest biodiversity: Lessons from Latin America. *Ecology and Society* 14: 20-61.

Nichol JE, Shaker A & Wong MS 2006. Application of high-resolution stereo satellite images to detail landslide hazard assessment. *Geomorphology* 76: 68-75.

O'Conner TG & Bredenkamp GJ 1997. Grassland. In Cowling RM, Richardson DM & Pierce SM (eds) *Vegetation of South Africa.* Cambridge: Cambridge University Press.

O'Sullivan D 2004. Too much of the wrong kind of data: Implications for the practice of micro-scale spatial modeling. In Goodchild M & Janelle DG (eds) *Spatially integrated social science*. New York: Oxford University Press.

Okabe A, Satoh T & Sugihara K 2009. A kernel density estimation method for networks, its computational method and a GIS-based tool. *International Journal of Geographical Information Science* 23: 7-32.

Osborne P, Alonso J & Bryant R 2001. Modeling landscape-scale habitat use using GIS and remote sensing: A case study with great bustards. *Journal of Applied Ecology* 38: 458-471.

Palmer A & Ainslie A 2002. Country pasture/forage resources profile: South Africa. Rome: Plant Production and Protection Division, United Nations Food and Agriculture Organisation [online]. Available from www.fao.org/agricult/agp/agpc/doc/counprof /southafrica.htm. [Accessed on 20 November 2010].

Papastergiadou ES, Retalis A, Kalliris P & Georgiadis T 2007. Land use changes and associated environmental impacts on the Mediterranean shallow lake Stymfalia, Greece. *Hydrobiology* 584: 361-372.

Perrings C, Mooney HA & Williamson M 2010. *Bioinvasions and globalization: Ecology, economics, management, and policy*. Oxford: Oxford University Press.

Pontius RG, Shusas S & McEachern M 2004. Detecting important categorical land changes while accounting for persistence. *Agriculture, Ecosystems and Environment* 101: 251-268.

Prince K, Guo X & Stiles JM 2002. Optimal Landsat TM band combinations and vegetation indices for discrimination of six grassland types in eastern Kansas. *International Journal of Remote Sensing* 23: 5031-5042.

Radeloff VC, Hagen AE, Voss PR, Field DR & Mladenoff DJ 2000. Exploring the spatial relationships between census and land cover data. *Society and Natural Resources* 13: 599-609.

Ramachandran S, Sundramoorthy S, Krishnamoorthy R, Devasenapathy J & Thanikachalam M 1998. Application of remote sensing and GIS to coastal wetland ecology of Tamilnadu and Andaman and Nicobar group of islands with special reference to mangroves. *Current Science* 75: 101-109.

Rametsteiner E & Simula M 2003. Forest certification – An instrument to promote sustainable forest management? *Journal of Environmental Management* 67: 87-98.

Reyers B, Nel J, Egoh B, Jonas Z & Rouget M 2005. Grassland biodiversity profile and spatial biodiversity priority assessment. South African National Biodiversity Institute-National Grassland Biodiversity Programme. Pretoria: South African National Biodiversity Institute.

Riebsame WE, Meyer WB, Turner BL 1994. Modeling land use and cover as part of global environmental change. *Climatic Change* 28: 45-64.

Rowntree KM 1991. An assessment of the potential impact of alien invasive vegetation on the geomorphology of river channels in South Africa. *South African Journal of Aquatic Science* 17: 28-43.

Roy DP, Lewis PE & Justice CO 2002. Burned area mapping using multi-temporal moderate spatial resolution data – A bi-directional reflectance model-based expectation approach. *Remote Sensing of Environment* 83: 263-286.

Rubio JL & Bochet E 1998. Desertification indicators as diagnosis criteria for desertification risk assessment in Europe. *Journal of Arid Environments* 39: 113-120.

SANBI (South African National Biodiversity Institute) 2009. Biodiversity Summary - uMhlathuze Local Municipality [online]. Available from http://bgis.sanbi.org/municipalities/show-muni-summaries.asp?muni=KZN282. [Accessed 10 January 2011].

SAWS (South African Weather Services) 2004. Atmospheric circulation systems, synoptic climatology and weather phenomena of South Africa. Technical Report 32 – part 6. Pretoria: South African Weather Services.

Scholes RJ & Biggs R 2005. A biodiversity intactness index. *Nature* 34: 45-49.

Schutter JD 2003. *Wetland management*. Washington DC: The World Bank.

Seto KC, Woodcock CE, Song C, Huang X, Lu J & Kaufmann RK 2002. Monitoring land-use change in the Pearl River Delta using Landsat TM. *International Journal of Remote Sensing* 23: 1985-2004.

Shi Y, Snyder JD, Asher J, Bartholic JB & O'Neil G 2006. The fundamental role of land cover data in a web-based decision support system to assist local natural resource managers [online]. North American land cover summit. Reston, Virginia. Available from www.aag.org/books/nalcs

/chapters/CH14.pdf. [Accessed on 30 May 2009].

Shoshany M, Kutiel P & Lavee H 1994. Monitoring temporal vegetation cover changes in Mediterranean and arid ecosystems using a remote sensing technique: Case study of the Judean Mountain and Judean Desert. *Journal of Arid Environments* 33: 9-21.

Simms AD, Woodroffe CD & Jones BG 2003. Application of RUSLE for erosion management in a coastal catchment, southern NSW [online]. Available from http://ro.uow.edu.au/scipapers/34 [Accessed 18 October 2008].

Singh A 1989. Digital change detection techniques using remotely sensed data. *International Journal of Remote Sensing* 10: 989-1003.

Singh SK 1998. Vegetation structure under north and south aspects in the temperate zone of Tirthan valley, western Himalaya. *Indian Journal of Forestry* 21: 217-223.

Skidmore AK 2002. *Land use and land cover*. New York: Marcel Dekker.

Snaddon CD 1998. Some of the ecological effects of a small inter-basin water transfer on the receiving reaches of the Upper Berg River, Western Cape. MSc thesis. Cape Town: University of Cape Town, Department of Zoology.

Sommer S, Hill J & Megier J 1998. The potential of remote sensing for monitoring rural land use changes and their effects on soil conditions. *Agriculture, Ecosystems and Environment* 67: 197-209.

SRK (Stephen, Robertson & Kirsten) 2009. Proposed Grindrod terminals expansion: Richards Bay–biodiversity assessment [online]. Available from http://www.srk.co.za/files/file/southafrica/publicdocuments/grindrod/eia/appendices/appendix%2016%20-%20biodiversity%20Assessment.pdf [Accessed 10 January 2011].

SRK (Stephen, Robertson & Kirsten) 2012. Zulti south mining lease area: Draft environmental impact assessment and environmental management programme for the mine’s services. Johannesburg: Stephen, Robertson & Kirsten Consulting.

Statistics South Africa 2000. *Population Census 1985*. Pretoria: Statistics South Africa and National Research Foundation.

Statistics South Africa 2001. *Census 2001: Key results.* Pretoria: Statistics South Africa.

Statistics South Africa 2003. *Census 2001: Investigation into appropriate definitions of urban and rural areas for South Africa*. Pretoria: Statistics South Africa.

Statistics South Africa 2012. *Census 2011 municipal report for KwaZulu Natal*. Pretoria: Statistics South Africa.

Statistics South Africa and Human Sciences Research Council 2007. *Using the 2001 census: Approaches to analyzing data*. Pretoria: Statistics South Africa.

Steyl I, Versfeld DB & Nelson PJ 2000. Strategic environmental assessment for water use – uMhlathuze Catchment-KZN. Report No SEA-01/2000. Pretoria: Department of Water Affairs and Forestry.

Stoate C, Boatman ND, Borralho RJ, Rio Carvalho C, De Snoo GR & Eden P 2001. Ecological impacts of arable intensification in Europe. *Journal of Environmental Management* 63: 337-365.

Stow DA & Chen DM 2002. Sensitivity of multi-temporal NOAA AVHRR data of an urbanizing region to land use/cover changes and misregistration. *Remote Sensing of Environment* 80: 297-307.

Sujatha G, Dwivedi RS, Sreenivas K & Venkataratnam L 2000. Mapping and monitoring of degraded lands in parts of Jaunpur District of Uttar Pradesh using temporal spaceborne multispectral data. *International Journal of Remote Sensing* 21: 519-531.

Tafangenyasha C, Mthembu AT, Chikoore H, Ndimande NP, Xulu S & Gcwensa N 2011. Rangeland characteristics of a supercritically degraded landscape in the semi-arid area of South Africa. *Journal of Soil Science and Environmental Management* 2: 80-87.

Tang V 2008. Zoning in on South Africa's Industrial Development Zones [online]. Available from http://www.tips.org.za/files/Tang_Final_Zoning_in_on_SAfrica_IDZs_24_Oct_2008.pdf. [Accessed on 01 June 2010].

Taylor S & Yu D 2009. *The importance of socio-economic status in determining educational achievement in South Africa*. Stellenbosch: Stellenbosch University, Department of Economics.

Thompson M 1996. A standard land cover classification scheme for remote sensing applications in South Africa. *South African Journal of Science* 92: 34-42.

Thornes J 1996. Desertification in the Mediterranean. In Brandt J & Thornes J (eds) *Mediterranean desertification and land use*. Chichester: Wiley.

Thornhill M & Thornhill H 2010. Environmental risk evaluation and guidelines for the Richards Bay Industrial Development Zone. Status Quo Report prepared for the Richards Bay industrial development zone. Report No. TX2010/C015-5. Pietermaritzburg: Richards Bay Industrial Development Zone.

Torrion JA 2002. Land degradation detection, mapping and monitoring in the Lake Naivasha Basin, Kenya. MSc thesis. Enschede: University of Twente, Department of Natural Resources.

Treitz P & Rogan J 2004. Remote sensing for mapping and monitoring land cover and land use - An introduction. *Progress in Planning* 61: 269-279.

Turner BL, Skole D, Sanderson S, Fischer G, Fresco LO & Leemans R 1995. Land-use and land cover change science research plan. IGBP Global Change Report No. 35. Stockholm: International Geosphere–Biosphere Programme/Human Dimensions of Environmental Change Programme.

Tyson PD 2004. *Weather and climate of Southern Africa*. 2nd ed. Cape Town: Oxford University Press.

uMhlathuze Municipality 2002. *Integrated development plan (IDP)*. [Online]. Available from http://devplan.kzntl.gov.za/Municipal/IDPs/uMhlathuze/idp_uMhlathuze_list.asp [Accessed 17 February 2009].

uMhlathuze Municipality 2012. *Integrated development plan 2012/2017*. Richards Bay: uMhlathuze Municipality.

UNCCD (United Nations Convention to Combat Desertification) 2004. A carrying pillar in the global combat against land degradation and food insecurity. Proceedings of the San Rossore meeting on climate change: A new global vision. Held 15 – 16 July 2004. Pisa: United Nations Convention to Combat Desertification.

UNECA (United Nations Economic Commission for Africa) 1999. Study on soil erosion and destruction of land resources: Issues and trends in Africa: Addis Ababa: United Nations Economic Commission for Africa.

UNECA (United Nations Economic Commission for Africa) 2006. Energy for sustainable development in Africa [online]. Available from http://wwww.eneca.org./csd.csd4_report_on_energy_for_sustainable_development.htm. [Accessed 02 August 2010].

UNECE (United Nations Economic Commission for Europe) 2008. *Spatial planning: A key instrument for development and effective governance with special reference to countries in transition*. Geneva: United Nations Economic Commission for Europe Services.

Van der Merwe JH & De Necker PH 2013. *Requirements and guidelines for research reporting*. Stellenbosch: Stellenbosch University, Department of Geography and Environmental Studies.

Van der Merwe JPA 2005. Spatial monitoring of natural resource condition in Southern Africa. MSc thesis. Stellenbosch: Stellenbosch University, Department of Geography and Environmental Studies.

Van der Zel DW 2000. Forest policy. In Anon (eds) *South African forestry handbook*. Menlo Park: South African Institute of Forestry.

Van Niekerk A, Donaldson R, Du Plessis D & Spocter M 2010. A revision of the 2004 growth potential of towns in the Western Cape study. Stellenbosch: Stellenbosch University, Centre for

Geographical Analysis.

Van Wilgen BW 2009. The evolution of fire and invasive alien plant management practices in fynbos. *South African Journal of Science* 105: 335-342.

Virgos E 2001. Role of isolation and habitat quality in shaping species abundance: A test with badgers (*Meles meles*) in a gradient of forest fragmentation. *Journal of Biogeography* 28: 381-389.

Vrieling A 2006. Satellite remote sensing for water erosion assessment: A review. *Catena* 65: 2-18.

Waite H 2009. Detecting land cover change over a 20-year time period in the Niagara Escarpment plan using satellite remote sensing. MSc thesis. Waterloo: University of Waterloo, Department of Geography and Environmental Management.

Wang Y & Zhang X 2001. A dynamic modeling approach to simulating socio-economic effects on landscape changes. *Ecological Modeling*140: 141-162.

Wasson R 1987. Detection and measurement of land degradation processes. In Chisholm A & Dumsday R (eds) *Land degradation: Problems and policies*. Cambridge: Cambridge University Press.

Watts HL 1983. A socio-economic baseline regional survey of the Richards Bay – Empangeni region. University of Natal: Durban, Centre for Applied Social Sciences.

Wessels KJ, Prince SD, Frost PE & Van Zyl D 2004. Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. *Remote Sensing and the Environment* 91: 47-67.

Wessels KJ, Prince SD, Malherbe J, Small J, Frost PE & Van Zyl D 2007. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *Journal of Arid Environments* 68: 271-297.

Williams K 2007. Can urban intensification contribute to sustainable cities? An international perspective [online]. Available from http://unpan1.un.org/intradoc/groups/public/documents/apcity/unpan026009.pdf. [Accessed on 15 June 2011].

Wilkie DS & Finn JT 1996. *Remote sensing imagery for natural resources monitoring: A guide for first -time users*. New York: Columbia University Press.

Winter TC & Llamas MR 1993. Hydrogeology of wetlands. *Journal of Hydrology* 141: 1-269.

World Bank 2001. World Development Report 2000/2001. Washington DC: The World Bank.

Wuddivira MN, Ekwue EC & Stone RJ 2010. Slaking sensitivity to assess the degradation potential of humid tropic soils under intense rainfall. *Land Degradation and Development* 2: 48-57.

Wunder S 2000. *The Economics of deforestation: The examples of Ecuador*. London: Macmillan.

Wyatt BK 2000. Vegetation mapping from ground, air and space – competitive or complementary techniques? In Alexander R *&* Millington AC (eds) *Vegetation mapping: From patch to planet* 3-15. Chichester: Wiley.

Yuan F, Sawaya K, Loeffelholz B & Bauer M 2005. Land cover classification and change analysis of the Twin Cities (Minnesota) metropolitan area by multi-temporal Landsat remote sensing. *International Journal of Remote Sensing* 98: 317-328.

Zakiewicz T 2008. Mapping South Africa with a digital aerial camera from the perspective of the national mapping agency. Mowbray: Chief Directorate: Surveys and Mapping.

APPENDICES

Appendix A Generalization of subplace names to municipal wards

Ward no	Sub_place name				Province	Municipality
1	Meer-en-See	53812001	53812001	Meer-en-See	KWAZULU-NATAL	uMhlathuze
	Meer-en-See	53810010	53810010	Meer-en-See	KWAZULU-NATAL	uMhlathuze
	Meer-en-See	53811001	53811001	Meer-en-See	KWAZULU-NATAL	uMhlathuze
	Mzingazi	53812002	53812002	Mzingazi	KWAZULU-NATAL	uMhlathuze
2	Tuzi-Gazi	53812004	53812004	Tuzi-Gazi	KWAZULU-NATAL	uMhlathuze
	Aquadene Ext 32	53810003	53810003	Aquadene Ext 32	KWAZULU-NATAL	uMhlathuze
	Alton	53810001	53810001	Alton	KWAZULU-NATAL	uMhlathuze
	NONE	53806000	53806000	NONE	KWAZULU-NATAL	uMhlathuze
	Brackenham	53810007	53810007	Brackenham	KWAZULU-NATAL	uMhlathuze
3	Arboretum	53810004	53810004	Arboretum	KWAZULU-NATAL	uMhlathuze
	Arboretum Ext	53810005	53810005	Arboretum Ext	KWAZULU-NATAL	uMhlathuze
	Veld-en-Vlei	53812005	53812005	Veld-en-Vlei	KWAZULU-NATAL	uMhlathuze
4	Richards Bay Central	53812003	53812003	Richards Bay Central	KWAZULU-NATAL	uMhlathuze
	Alton North	53810002	53810002	Alton North	KWAZULU-NATAL	uMhlathuze
	Wildenweide	53812006	53812006	Wildenweide	KWAZULU-NATAL	uMhlathuze
	Bird Wood	53810006	53810006	Bird Wood	KWAZULU-NATAL	uMhlathuze
	Mandlazini	53810009	53810009	Mandlazini	KWAZULU-NATAL	uMhlathuze
5	Bhejane	53805001	53805001	Bhejane	KWAZULU-NATAL	uMhlathuze
	Ezikhaleni	53805002	53805002	Ezikhaleni	KWAZULU-NATAL	uMhlathuze
	Mkhoma	53805004	53805004	Mkhoma	KWAZULU-NATAL	uMhlathuze
6	Nkhanangu	53805006	53805006	Nkhanangu	KWAZULU-NATAL	uMhlathuze
	Nkhanangu	53801003	53801003	Nkhanangu	KWAZULU-NATAL	uMhlathuze
	Nthunzi	53801004	53801004	Nthunzi	KWAZULU-NATAL	uMhlathuze
	Mzipofu	53801002	53801002	Mzipofu	KWAZULU-NATAL	uMhlathuze
	Mzipofu	53805005	53805005	Mzipofu	KWAZULU-NATAL	uMhlathuze
	Mazimazana	53805003	53805003	Mazimazana	KWAZULU-NATAL	uMhlathuze
7	Ovondlo	53805007	53805007	Ovondlo	KWAZULU-NATAL	uMhlathuze
	Mkhoma	53801001	53801001	Mkhoma	KWAZULU-NATAL	uMhlathuze
8	Nseleni	53809001	53809001	Nseleni	KWAZULU-NATAL	uMhlathuze
9	Grantham Park	53803003	53803003	Grantham Park	KWAZULU-NATAL	uMhlathuze
	Richem	53803009	53803009	Richem	KWAZULU-NATAL	uMhlathuze
	Kildare	53803005	53803005	Kildare	KWAZULU-NATAL	uMhlathuze

Ward no	Sub_place name				Province	Municipality
10	Kwashodlisa	53807002	53807002	Kwashodlisa	KWAZULU-NATAL	uMhlathuze
	Ongoye	53807005	53807005	Ongoye	KWAZULU-NATAL	uMhlathuze
11	Msasandla	53807004	53807004	Msasandla	KWAZULU-NATAL	uMhlathuze
12	Ndleleni	53802011	53802011	Ndleleni	KWAZULU-NATAL	uMhlathuze
	Madlanghala	53802008	53802008	Madlanghala	KWAZULU-NATAL	uMhlathuze
13	Bhiliya	53802002	53802002	Bhiliya	KWAZULU-NATAL	uMhlathuze
	Gubhethuka	53802006	53802006	Gubhethuka	KWAZULU-NATAL	uMhlathuze
	Empembeni	53802004	53802004	Empembeni	KWAZULU-NATAL	uMhlathuze
	Mabuyeni	53802007	53802007	Mabuyeni	KWAZULU-NATAL	uMhlathuze
	Amadaka	53802001	53802001	Amadaka	KWAZULU-NATAL	uMhlathuze
	NONE	53814000	53814000	NONE	KWAZULU-NATAL	uMhlathuze
14	Gobandlovu	53802005	53802005	Gobandlovu	KWAZULU-NATAL	uMhlathuze
	Gobandlovu	53808001	53808001	Gobandlovu	KWAZULU-NATAL	uMhlathuze
	Uzimgwenya	53808007	53808007	Uzimgwenya	KWAZULU-NATAL	uMhlathuze
15	Ncombo	53802009	53802009	Ncombo	KWAZULU-NATAL	uMhlathuze
	Ndindima	53802010	53802010	Ndindima	KWAZULU-NATAL	uMhlathuze
	Nkhubosa 1& 2	53802013	53802013	Nkhubosa 1& 2	KWAZULU-NATAL	uMhlathuze
	Ngwenhyeni	53802012	53802012	Ngwenhyeni	KWAZULU-NATAL	uMhlathuze
16	Dube	53802003	53802003	Dube	KWAZULU-NATAL	uMhlathuze
17	Esikhawini H	53804001	53804001	Esikhawini H	KWAZULU-NATAL	uMhlathuze
18	Nyembe	53808003	53808003	Nyembe	KWAZULU-NATAL	uMhlathuze
	Port Dunford	53808005	53808005	Port Dunford	KWAZULU-NATAL	uMhlathuze
	Port dunford	53808004	53808004	Port dunford	KWAZULU-NATAL	uMhlathuze
	Mahunu	53808002	53808002	Mahunu	KWAZULU-NATAL	uMhlathuze
19	Mtunzini NU	53813002	53813002	Mtunzini NU	KWAZULU-NATAL	uMhlathuze
20	Esikhawini J	53804002	53804002	Esikhawini J	KWAZULU-NATAL	uMhlathuze
21	Uzimgwenya	53802014	53802014	Uzimgwenya	KWAZULU-NATAL	uMhlathuze
22	Sikhalasenkosi	53808006	53808006	Sikhalasenkosi	KWAZULU-NATAL	uMhlathuze
23	Panorama	53803008	53803008	Panorama	KWAZULU-NATAL	uMhlathuze
24	Movamhlone	53816004	53816004	Movamhlone	KWAZULU-NATAL	uMhlathuze

	Matshana	53816003	53816003	Matshana	KWAZULU-NATAL	uMhlathuze
25	Sgisi	53816009	53816009	Sgisi	KWAZULU-NATAL	uMhlathuze
	Mtengu	53816005	53816005	Mtengu	KWAZULU-NATAL	uMhlathuze
	Dondolo	53816001	53816001	Dondolo	KWAZULU-NATAL	uMhlathuze
26	Lower Umfolozi NU	53813001	53813001	Lower Umfolozi NU	KWAZULU-NATAL	uMhlathuze
	Noordsig	53803007	53803007	Noordsig	KWAZULU-NATAL	uMhlathuze
	Empangeni Central	53803001	53803001	Empangeni Central	KWAZULU-NATAL	uMhlathuze
	Inyala Park	53803004	53803004	Inyala Park	KWAZULU-NATAL	uMhlathuze
	Fair View	53803002	53803002	Fair View	KWAZULU-NATAL	uMhlathuze
	Zidedele Village	53803010	53803010	Zidedele Village	KWAZULU-NATAL	uMhlathuze
	Felixton	53810008	53810008	Felixton	KWAZULU-NATAL	uMhlathuze
27	Ngwelezane	53816007	53816007	Ngwelezane	KWAZULU-NATAL	uMhlathuze
28	Kuleka	53803006	53803006	Kuleka	KWAZULU-NATAL	uMhlathuze
29	Eniwe	53816002	53816002	Eniwe	KWAZULU-NATAL	uMhlathuze
	Ndabayakhe	53816006	53816006	Ndabayakhe	KWAZULU-NATAL	uMhlathuze
	Nqutshini	53816008	53816008	Nqutshini	KWAZULU-NATAL	uMhlathuze
30	Mangeze	53807003	53807003	Mangeze	KWAZULU-NATAL	uMhlathuze
	Khandisa	53807001	53807001	Khandisa	KWAZULU-NATAL	uMhlathuze
	NONE	53815000	53815000	NONE	KWAZULU-NATAL	uMhlathuze

Source: Modified from Statistics South Africa (2001)

Appendix B Child headed-household

Municipality	No. of households headed by Children			Number of households			% of households headed by children		
	1996	2001	2011	1996	2001	2011	1996	2001	2011
KZN262: UPhongolo	172	429	475	15 967	24 814	28 772	1,1	1,7	1,7
KZN263: Abaqulusi	348	435	530	27 046	35 914	43 299	1,3	1,2	1,2
KZN265: Nongoma	226	399	589	26 146	31 581	34 341	0,9	1,3	1,7
KZN266: Ulundi	229	403	460	24 684	33 776	35 198	0,9	1,2	1,3
DC27: Umkhanyakude	**739**	**1 268**	**2 032**	**72 714**	**101 563**	**128 195**	**1,0**	**1,2**	**1,6**
KZN271: Umhlabuyalingana	193	374	466	19 464	26 324	33 857	1,0	1,4	1,4
KZN272: Jozini	195	454	692	22 100	33 589	38 849	0,9	1,4	1,8
KZN273: The Big 5 False Bay	45	113	116	3 835	6 214	7 998	1,2	1,8	1,5
KZN274: Hlabisa	91	171	181	8 595	10 611	12 586	1,1	1,6	1,4
KZN275: Mtubatuba	215	187	576	18 721	24 826	34 905	1,1	0,8	1,7
DC28: Uthungulu	**972**	**1 401**	**2 100**	**122 025**	**171 480**	**202 976**	**0,8**	**0,8**	**1,0**
KZN281: Mfolozi	86	141	326	14 043	19 143	25 584	0,6	0,7	1,3
KZN282: uMhlathuze	171	407	581	10 100	67 127	86 609	1,7	0,6	0,7
KZN283: Ntambanana	108	102	161	38 200	12 441	12 826	0,3	0,8	1,3
KZN284: uMlalazi	290	434	540	34 775	38 446	45 062	0,8	1,1	1,2
KZN285: Mthonjaneni	61	157	125	5 404	10 108	10 433	1,1	1,6	1,2
KZN286: Nkandla	256	404	367	19 503	24 216	22 463	1,3	1,7	1,6
DC29: iLembe	**853**	**1 164**	**1 348**	**109 229**	**120 390**	**157 692**	**0,8**	**1,0**	**0,9**
KZN291: Mandeni	127	305	355	23 555	28 657	38 235	0,5	1,1	0,9
KZN292: KwaDukuza	219	279	331	39 417	44 117	70 284	0,6	0,6	0,5
KZN293: Ndwedwe	240	285	386	25 117	25 467	29 200	1,0	1,1	1,3
KZN294: Maphumulo	267	294	276	21 139	22 149	19 973	1,3	1,3	1,4
DC43: Sisonke	**1 381**	**1 817**	**1 525**	**75 718**	**102 349**	**112 282**	**1,8**	**1,8**	**1,4**
KZN431: Ingwe	275	340	299	17 309	21 332	23 073	1,6	1,6	1,3
KZN432: Kwa Sani	38	60	37	3 061	3 723	3 673	1,2	1,6	1,0
KZN433: Greater Kokstad	63	223	126	8 717	19 625	19 140	0,7	1,1	0,7
KZN434: Ubuhlebezwe	220	328	280	15 129	21 421	23 487	1,5	1,5	1,2
KZN435: Umzimkhulu	785	901	785	31 501	36 246	42 909	2,5	2,5	1,8
ETH: Ethekwini	**3 197**	**3 365**	**4 781**	**646 345**	**786 746**	**956 713**	**0,5**	**0,4**	**0,5**
KwaZulu-Natal	**14 418**	**17 597**	**21 839**	**1 689 995**	**2 117 274**	**2 539 429**	**0,9**	**0,8**	**0,9**

Source: Statistics South Africa (2012)

Appendix C Proposed residential areas and land ownership in uMhlathuze Municipality

EXPANSION AREA	LOCATION	LAND OWNERS HIP	PROJECT TYPE	BULK INFRASTRUCTURE AVAILABILITY
Expansion Area A	ESikhaleni-Vulindlela Corridor	State	Mixed Residential	Yes
Expansion Area B	Felixton	Private	Mixed Residential	No
Expansion Area D	Empangeni	Private	High Residential	No
Expansion Area E	Empangeni	Private	Mixed Residential	No
Expansion Area F	Richards Bay-Birdswood-Mandlazini & Veldenvlei	State	Mixed Residential	No
Expansion Area G	Nseleli Interchange	Private	Mixed Residential	No
Expansion Area H	Empangeni (Water-stone)	Private	Mixed Residential	Yes

Source: uMhlathuze Municipality (2012)