# LAND USE CHANGE IN STELLENBOSCH AND ITS ENVIRONS BETWEEN 1994 AND 2004

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## Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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## Abstract

Land use change in urban environments has created an urgent need for updated maps, both for cities and metropolitan areas in South Africa. In Stellenbosch in particular, there is concern that the rural-urban fringe is threatened by urban development. Stellenbosch Square, Bosman's Crossing, new residential construction in Welgevonden and the planned Paradyskloof golf estate on the slopes of Stellenbosch Mountain indicate that the degree of land use change is unprecedented. These changes in the urban environment foster the need to examine land use transformation in Stellenbosch and the surrounding area. A land use database for 2004 was generated and compared with the existing 1994 dataset. The 2004 land use dataset was developed by mapping the 2001 digital orthophoto imagery and updated through extensive field observations. The land use Kappa Index of Agreement (KIA) was calculated in IDRISI's GIS analysis cross-tabulation module which permitted the comparison of two-date grids of 100 X 100m resolution.

This research found that urban growth through residential and commercial development threatens farmland and the natural environment that lie in the rural-urban fringe. The land use areas for agriculture, urban development, commerce, informal settlements and open land category shows that changes took place from 1994 and 2004. Notable land use changes during the period 1994 to 2004 were found in annual agriculture, rural institutional, rural industry, recreation, forestry and open land/veld that decreased by 32.5 per cent, 6 per cent, 34.3 per cent, 25.4 per cent, 16.2 per cent and 6.4 per cent, respectively. In contrast, perennial agriculture, industrial agriculture, formal urban development, informal settlements, rural commerce and hotels and extraction increased by 14.2 per cent, 191.3 per cent, 7.8 per cent, 566.7 per cent, 140 per cent and 100.80 per cent, respectively. Practically speaking, the areas of rural institutional and rural industry were stable within these two dates although the computation of area shows that changes took place in these categories. At the same time, the recreational areas actually increased from 1994 to 2004.

The urban area and informal settlements developed rapidly during the decade at the expense of the natural environment and agricultural areas. This study determined that the proposed future urban growth sites will be located in the sensitive natural environments. The overall KIA of land use change in Stellenbosch and its environs is 0.74 indicating that the two date's images are not completely different although land use changes took place from 1994 to 2004. This study has updated the land use database developed in the past and gives a good indication of land use dynamics. Hopefully, this research will aid future urban land use planning and decision-making with regard to sustainable land resource management and also contribute to the field of global environmental change.

**Keywords:** Land use, land use change, urban-fringe, Kappa.

## Opsomming

Grondgebruikverandering in stedelike omgewings het 'n dringende behoefte aan opgedateerde grondgebruik-kaarte van stede sowel as metropolitaanse gebiede in Suid-Afrika laat ontstaan. Veral in Stellenbosch is daar kommer dat die landelike-stedelike oorgangsgebied deur stedelike ontwikkeling bedreig word. Stellenbosch Square, Bosman's Crossing, nuwe residensiële uitbreidings in Welgevonden en die beplande Paradyskloof-gholflandgoed teen die hange van Stellenboschberg dui op 'n ongeëwenaarde mate van grondgebruikverandering. Hierdie veranderinge in die stedelike omgewing noodsaak die ondersoek van grondgebruiktransformasie in Stellenbosch en omstreke. 'n Grondgebruikdatabasis vir 2004 is opgestel en met die bestaande 1994-datastel vergelyk. Die 2004-grondgebruikdatastel is ontwikkel deur gebruikmaking van die kartering van die digitale ortofotobeeld van 2001 en by wyse van uitvoerige veldwaarnemings bygewerk. Die Kappa Indeks van Ooreenkoms (KIO) ten opsigte van grondgebruik is in IDRISI se GIS-analise kruistabelleringsmodule bereken, wat die vergelyking van twee-datum-ruitnette van 100 x 100m-resolusie moontlik gemaak het.

Hierdie navorsing het bevind dat stedelikegroei as gevolg van residensiële en kommersiële ontwikkeling 'n bedreiging vir plaasgrond en die natuurlike omgewing wat in die landelike-stedelike oorgangsgebied lê, inhou. Die grondgebruikgebiede vir landbou, stedelike ontwikkeling, handel, informele nedersettings en die opegrondkategorie toon daarop dat daar tussen 1994 en 2004 veranderinge plaasgevind het. Beduidende grondgebruikveranderinge in die tydperk 1994 tot 2004 is waargeneem ten opsigte van standhoudende landbou, landelike-institusionele ontwikkeling, ontspanning, bosbou, en oop grond/veld wat met 32.5 persent, 6 persent, 34.3 persent, 25.4 persent, 16.2 persent en 6.4 persent onderskeidelik afgeneem het. Daarteenoor het landbou van meerjarige gewasse, industriële landbou, formele stedelike ontwikkeling, informele nedersettings, landelike handel, hotelle en die ekstraksiebedryf met 14.2 persent, 191.3 persent, 7.8 persent, 566.7 persent, 140 persent en 100.80 persent onderskeidelik toegeneem. Vir alle doeleindes was die gebiede van landelik-institusionele ontwikkeling en landelike nywerhede tussen hierdie twee datums stabiel alhoewel die gebiedsbepaling aantoon dat daar veranderinge in hierdie kategorieë plaasgevind het. Terselfdertyd het die oppervlakte vir ontspanningsgebiede in werklikheid van 1994 na 2004 toegeneem.

Die stedelike gebied en informele nedersettings het gedurende die dekade vinnig ontwikkel ten koste van die natuurlike omgewing en landbougebiede. Tydens hierdie studie is vasgestel dat die voorgestelde toekomstige stedelike groeigebiede in die sensitiewe natuurlike omgewings geleë sal wees. Die oorhoofse KIO van grondgebruikverandering in Stellenbosch en omgewing, soos rekenaarmatig bereken, is 'n bevredigende 0.74, met 'n beduidende verskil tussen 1994 en 2004. Hierdie studie het die grondgebruikdatabasis wat in die verlede opgestel is, bygewerk en gee 'n goeie

aanduiding van die grondgebruikdinamika. Hopelik sal hierdie navorsing van nut wees tydens toekomstige beplanning van en besluitneming oor stedelike grondgebruik met betrekking tot volhoubare grondhulpbronbestuur en ook 'n bydrae lewer op die gebied van globale omgewingsverandering.

**Sleutelwoorde:** Grondgebruik, grondgebruikverandering, landelike-stedelike oorgangsgebied, Kappa indels

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# CHAPTER 1: LAND USE CHANGE IN STELLENBOSCH AND ITS ENVIRONS

## 1.1 Land use change as a research problem

The current understanding of land use and land cover change in the Stellenbosch area is inadequate due to the anecdotal or very limited nature of the past research. The Council for Scientific and Industrial Research (2000) stated that accurate, up-to-date information on land cover/land use and state of the environment are significant components for environmental planning and management. In Stellenbosch, there is concern that the urban fringe is deteriorating due to urban impacts through residential, industrial and commercial developments (Van der Merwe 2004, pers comm). Zietsman (2001) stated that the current pattern and form of residential development in Stellenbosch exerts great pressure on the urban edge and the agricultural and natural resources which lie beyond. "The towns… such as Stellenbosch and Franschhoek are rapidly expanding on these level fertile areas" (Zietsman 2001: 1). There are many examples of land use change in Stellenbosch, Cape Town and worldwide, but a few will suffice to illustrate the range of issues at stake.

Stellenbosch Square, a new shopping complex, was constructed in 2004 along the R44 road between Stellenbosch to Somerset West. Stellenbosch Square is located about four kilometers from Stellenbosch on R44 directly opposite the De Zalze golf estate. Eikestadnuus (2004g) states that the complex consists of over 50 shops which include a combination of up-market boutique clothing and accessory stores, home accessory and food retailers such as Pick 'n Pay. In addition, open and undercover parking which accommodates 662 cars is available. A second example is the Bosman's Crossing development opened during February 2005 which includes new residential flats, automotive and panel-beating facilities representing land use changes in the commerce category. Botmanskop Mountain Resort, which is pending, is expected to consist of a hotel, restaurant, conference and educational/environmental centre and other resort components. The endorsement of this resort is faced with a number of unanswered questions regarding bioregional planning (Eikestadnuus 2004d). Eikestadnuus (2004d) further states that the resort is to be developed against the slopes of the Botmanskop above the 240 m contour line which falls within the area zoned for nature conservation.

In addition to the uncertainties and discussions over the construction of the Botmanskop Mountain Resort (Eikestadnuus 2004d), the Paradyskloof golf estate on the slopes of the Stellenboschberg is also causing intense debate (Cape Argus 1999). The Paradyskloof golf estate proposal includes a hotel and 547 houses on a 277 hectare site on the slopes of the Stellenboschberg has run into deep controversy, undiminished by a public inquiry and a recommendation that the project should go ahead

(Eikestadnuus 2004b). In the township Kayamandi, a sporting complex is being constructed, which will include a football field, tennis-court, netball field and other sport activities (Eikestadnuus 2004a). The major concern about these developments relates to their imputed impacts on the natural environment. Opponents have raised concerns about the nature conservation, the development of the golf course and the development's threat to the urban-fringe around the town. The economic boost that these projects can generate for the area, including the creation of job opportunities, source of revenue and so on, is significant. The construction of golf estates has also come under fierce criticisms that there is little concern for the natural environment and the opinions of the local residents and that golf courses uses greater volumes of water.

Intrusions by urban activities outside Cape Town's rural-urban fringe have been a continuous challenge to the appropriate management of that city's natural resources (Die Burger 2002). The concern is that Cape Town is expanding beyond of its boundaries and encroaching on the natural and agricultural environments. This is similar to what is happening around Stellenbosch. The rural areas in and around Stellenbosch municipal area are under threat from various developments. These activities include:

- urban sprawl that has changed the rural landscapes;
- the loss of fertile farmland and disturbance of natural ecosystems;
- unplanned rural subdivision and settlement density which denigrates the cultural, scenic and aesthetic characteristics; and
- the invasion of urban practices into the rural environment giving rise to a vague distinction between town and its environs.

Several studies provide striking examples of conflict over the use of land internationally. Owens & Cowell (2002), report on a major company in Berkshire, England, that wished to build its headquarters in a controversial natural area. Concerns ranged from the occurrence of congestion and pollution and the claim that the development would make a mockery of government planning guidelines seeking to reduce motor-car dependency. In Scotland development interests proposed a funicular cable-way in the UK's most important mountain plateau (Owens & Cowell 2002). This development was considered to carry the booming number of tourists into the Cairngorms. Environmentalists feared the impact of more tourists in a remote, exotic and ecologically vulnerable landscape. In the USA, urban sprawl is transforming forests, agricultural land, and wetlands into built-up environments beyond the boundaries of urban areas (the urban fringe) at a shocking and increasing rate (Gillham 2002, as quoted by Robinson, Newell & Marzluff 2005). Matlack (1993); Zuiderna *et al.*

(1996); McDonnell *et al.* (1997) and McKinney (2002), as quoted by Robinson, Newell & Marzluff 2005) declare that it is urban sprawl that impinges on water availability, wildlife, habitat availability and overall habitat integrity. Urban sprawl, for example, is implicated in 51 per cent of all wetland degradation in the USA (US Fish & Wildlife Service 2000, as quoted by Robinson, Newell & Marzluff 2005). Sprawl not only consumes natural environments but also disintegrates, denigrates, and alienates residual natural areas (Marzluff & Restani 1999 and Marzluff 2001, as quoted by Robinson, Newell & Marzluff 2005). The sprawling landscape is often dominated by non-indigenous plant species. Consequently, natural vegetation in and adjacent to sprawl development is susceptible to invasion by non-native vegetation and may rapidly become subjugated by such species (Zuidema *et al.* 1996; Cadenasso & Pickett 2001 and Marzluff 2001, as quoted by Robinson, Newell & Marzluff 2005). Urban sprawl has been the major cause of the loss of agricultural land in the Netherlands largely as a result of construction of industrial and commercial facilities in urban fringe areas, as well as urbanites' desire for more living space (Valk 2002, as quoted by Robinson, Newell & Marzluff 2005). In Russia residential and recreational use of land around Moscow, mainly due to the creation of second summer homes known as "dachas" and cottages, is leading to a decrease of commercial viable farmland (Ioffe & Nefedova 2001 and Ioffe & Nefedova 1998, as quoted by Robinson, Newell & Marzluff 2005).

Land is needed for all human activities and it is the source of natural resources needed for this conduct. Human use of land resources gives rise to land use which differs according to the purposes it serves. These purposes may be food production, recreation, urban development, residential development, extraction, conservation of the natural environment and so on. Briassoulis (2000) stated that land use is being created under the influence of two broad sets of forces, that is, human needs and environmental features and processes. However, it is because of these uses of land where "[l]ay and scientific interest …[in land use change] has a long history as there have been no instances in which people used land and its resources without causing any harm to the environment" (Briassoulis 2000: 1). The rate and extent of human alterations of the earth's surface are unprecedented. Singh & Asgher (2005: 592) declared "[u]nderstanding the land use changes and forces which compels man to bring these changes is crucial in understanding, modelling, predicting and managing the local, regional as well as global land use patterns". It is feared that these processes could result in settlement patterns which are environmentally unsustainable and have adverse impacts on the surrounding countryside (e.g. Antrop 2000 and Swenson & Franklin 2000, as quoted by Pauleit, Ennos & Golding 2005).

Urban development and urbanization are the most pressing problems that trigger land use changes in most developing and developed countries. In the developing world, urbanization has been growing at an exponential rate and subsequently there is a proportionate change in land use. The proportion of total world population living in urban areas was only 17 per cent in 1950, it reached 25 per cent in 1970 and by 2000 and it rose to 41 per cent (Singh & Asgher 2005). Between 2000 and 2025, urban population in developing countries will double (Hall & Pfeiffer 2000, as quoted by Singh & Asgher 2005). Singh & Asgher (2005) contended that the urban population increased rapidly in developing country cities and that the built-up area in developing countries increased by 118 per cent between 1980 and 2000. The more populous the city becomes the more resources are needed (Hardoy, Mitlin & Satterthwaite 1992, as quoted by Singh & Asgher 2005). Thus a growing population of an urban area implies a greater demand for residential, commercial, industrial, public facilities and other physical services.

Stellenbosch Municipality (2003) has maintained that land consumption in the town of Stellenbosch (2002-2006) is 61 hectares annually. This trend is unsustainable, given that the consumption involves irreplaceable agricultural land and natural resources. Land use change in Stellenbosch is alarming and will continue if measures are not taken to curb or counteract the trend. James (2001) found that agricultural and forestry development and the erection of buildings and other structures on mountain slopes is a significant problem in the Boland region. Internationally, Dolman, Verhagen & Rovers (2003) have argued that there is a clarion call for spatially explicit assessments of the dynamics of the land use systems. Presently an understanding of changes in land use, identification of the driving forces behind them, and the implications of change within the context of sustainable development are inadequate (Semwal *et al.* 2004).

This research addresses a critical need to provide a better quantitative understanding of how Stellenbosch and its hinterland is changing. The study aims at generating a two-dates GIS database, which describes the spatial distribution of land uses and allows for the quantification and spatial characterization of these changes. The public participation advertisements of the Environmental Impact Assessment (EIA) proposals that are conducted for the expansion and rezoning of suburbs and farms also give an indication of the magnitude of land use dynamics in Stellenbosch and its environs. Two recently proposed housing schemes serve as examples to illustrate the pressure being exerted on agricultural land in the Stellenbosch land beyond the urban environment. Dennis Moss Partnership (Architects and Urban and Regional Planners) proposed the extension of the Kayamandi township in Stellenbosch. This urban expansion is planned to encroach by about 30 hectares into the area adjoining and to the southwest of Kayamandi. The development is planned to include 2000 erven for residential, educational, and institutional business purposes, and will include streets and public open spaces (Eikestadnuus 2004h). Eikestadnuus (2004f) reported another request for the development of a housing scheme consisting of a maximum of 280 components on the farm Amalinda 82, Stellenbosch, situated to the north of the Welgevonden residential complex; the size of the development site being 7.7 ha. Indeed, the use of land in Stellenbosch and its environs will continue to change both presently and in the future.

Undoubtedly, there is a need to examine the use of land in Stellenbosch and its hinterland. Land cover and land use represent the people-environment reciprocity and their alteration both temporally and spatially. Randolph (2004) contended that the considerable attention given to urban development is appropriate for three reasons, and because it is where most people live. First, the rural-urban fringe is the habitat to important ecological, cultural and agricultural resources. Second, the use of rural land for agriculture, forestry and mineral extraction has considerable environmental impacts. Third, rural areas are increasingly attractive as people become tired of the congestion and lifestyle of the city. Improved information and understanding about the state of the land surface and the rates and patterns of land use change are needed to help scientists and decision-makers in land use planning, land management and natural resource conservation.

The 'sprawl' of informal settlements and urban development along transport corridors is causing serious concern in highly-industrialized countries. The concern is that these processes lead to settlement patterns which are environmentally unfriendly and have adverse impacts on the surrounding rural area (Antrop 2000 and Swenson & Franklin 2000, as quoted by Pauleit, Ennos & Golding 2005). Therefore, dramatic strategies have to be designed to ensure that the developing countries do not follow suit. There is a need for less-developed countries to avoid the same trap, and instead learn from the experiences of the highly-industrialised countries. The next section explains this study's overarching aim of detecting land use change and the specific objectives to be pursued to achieve the aim.

## 1.2 Land use change detection: aim and objectives

This study aims to detect the rate, extent, pattern and type of land use changes in Stellenbosch and its environs by comparing land use at two different dates, namely 1994 and 2004. In so doing the use of land in Stellenbosch and its environs could be studied retrospectively over a period of ten years. Change detection is a process of identifying the differences in the state of an object or phenomenon by observing it at different dates. This study aims to update the land use database for Stellenbosch revised by Kunneke (1995) and Van der Merwe (1997) in a ten-year interval (1994-2004). The two research explorations by Kunneke (1995) and Van der Merwe (1997) form the baseline studies for land use change in Stellenbosch.

This investigation will contribute towards developing strategies aimed at effectively managing urban growth by encouraging urban planners to use land more effectively within the urban edge. There is a necessity to manage the future growth of Stellenbosch in an appropriate, effective and sustainable way that is sensitive to the distinctive character and location features that make Stellenbosch unique. The research will contribute towards the prevention of development towards natural areas, avoiding unsuitable development within agricultural areas, and conserving the scenic beauty of the urban and rural landscapes. The research will give urban planners an indication of land use changes and hopefully, the results will contribute to future land use planning and decision-making in Stellenbosch.

The proper indication of land use change in Stellenbosch and the surrounding rural areas should identify unplanned urban sprawl and help to protect the natural resources and the unique attributes of Stellenbosch. The major element in properly managing our natural resources is inventorying what currently exists to provide baseline information for rational decision-making. There has been an urgent need for land use management policies based on accurate and reliable understanding of present land use conditions to guarantee prospective sustainable growth (Hefny 1983; Biswas 1993, as quoted by Yin *et al.* 2005). The more explicit research objectives are two-fold:

- To provide knowledge and understanding of which land use types have changed and where those land use dynamics are located spatially; and
- To compute the rate, extent and pattern of land use change in Stellenbosch and its environs.

### 1.3 Stellenbosch as area of study

Stellenbosch, situated in the Eerste River valley of the Cape Winelands region, is one of the most beautiful locations of the Southwestern Cape (Figure 1.1). Stellenbosch is situated to the east of Cape Town and Bellville and southwest of Paarl. Figure 1.2 shows the boundary of the area studied by Kunneke (1995) as well as the study area demarcated for this research. Figure 1.3 shows the present study area at a larger scale. The demarcation incorporates the town of Stellenbosch, Technopark, Jamestown, Lynedoch, Vlottenburg and Devon Valley, as well as all farms in between. It also includes Cloetesville, Koelenhof, and partially Elsenburg and the farms sandwiched in between. Towards the east it extends beyond Delaire to near Kylemore.

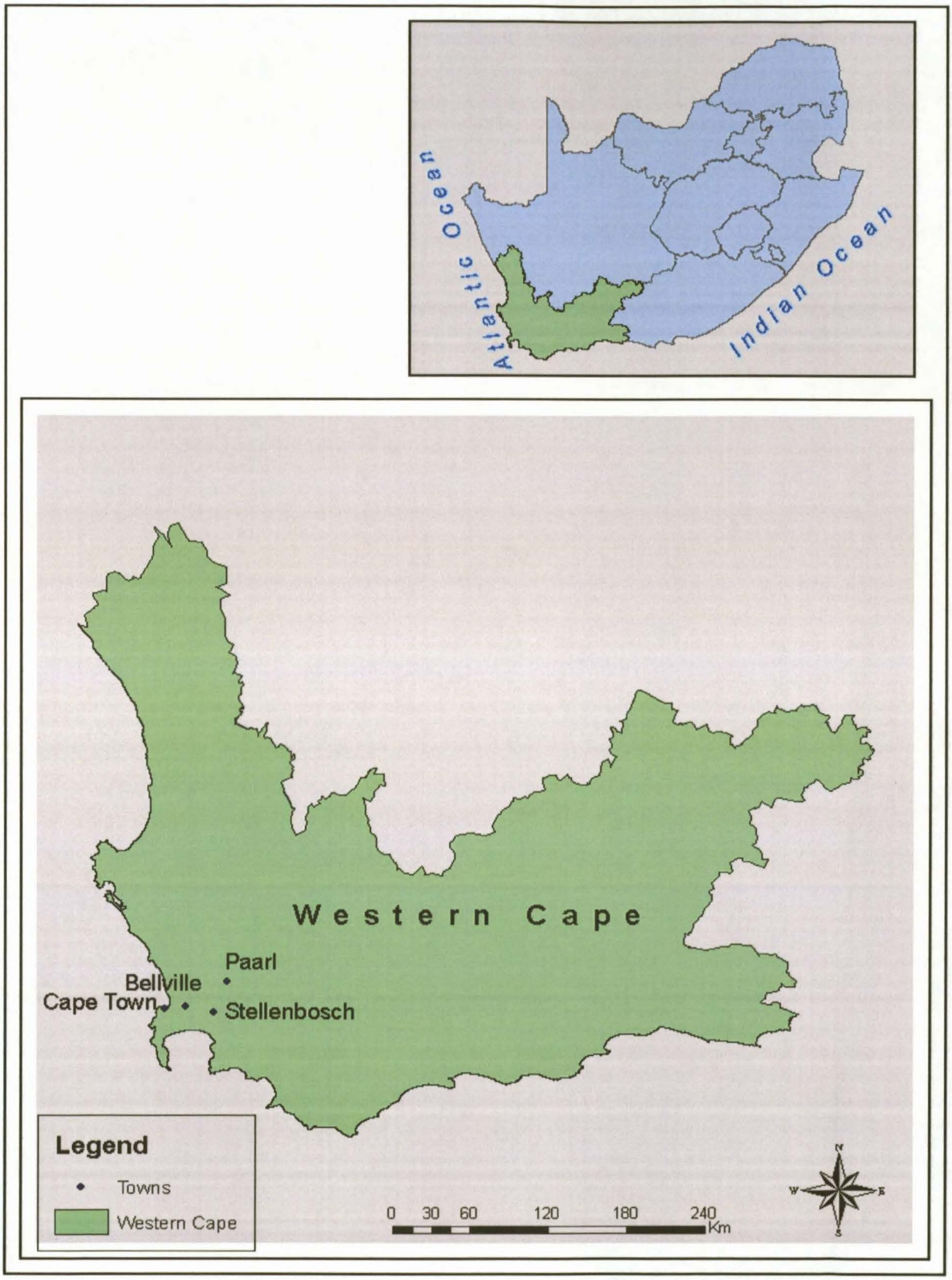


Figure 1.1: Stellenbosch in the Southwestern Cape

The fertile Eerste River valley with its tributary streams is a region blessed with relatively vast areas of moderately level land with undulating low-lying hills suitable for agricultural purposes. These fertile gently sloping areas are mostly covered by vineyards, but stone fruit orchards, olive groves and vegetable gardens are also found. Stellenbosch and its environs is sprawling or encroaching into this high monetary valuable land. Most of the fertile valleys in the area run in a northwesterly direction, consequently the area is characterised by sunny, warm north-easterly facing and cooler south-westerly facing slopes. Subsequently, this provides a diverse micro-climatic environment, which is of value to the wine-producing industry as it generates conditions conducive to viticulture that also triggers wine tourism development. The Mediterranean climate of the region implies hot, sunny and dry summers with cool and wet winters. Annual "[r]ainfall figures range from 500 mm on the low-lying areas to above 3000 mm in the high mountains providing an abundance of runoff" (Zietsman 2001: 1).

In delimiting the study area, practical factors such as data availability, costs and money, were taken into consideration. In this study it was not possible to investigate land use change in the exact area that was previously examined by Kunneke (1995) due to the following practical considerations. Firstly, there was no adequate data to detect land use change in the area of study investigated by Kunneke (1995). Essentially, to detect change at least two databases representing different times are needed. Given the existing 1994 database, there was a need for, at least, a more recent database. A long search for the latest data produced the digital aerial orthophoto images provided by the Stellenbosch local authority but, unfortunately, these orthophotos did not cover the whole area studied by Kunneke (1995). Secondly, the study area was chosen due to its easy accessibility to the researcher. The digital orthophoto images from the local municipality of Stellenbosch captured in 2001 needed to be updated for developments that occurred between 2001 and 2004. In addition, time and financial constraints imposed by a large study area would have been prohibitive given the need to collect data in the field. Thirdly, during the reviewing of the study literature, it was established that most of the changes are located in the area demarcated as the study area for this research and the areas omitted from the previous study were deemed to be insignificant to detecting land use change. In essence, there are no considerable changes omitted from this study as a result of not using the identical study area of Kunneke (1995). Even though there is a dissimilarity in the two study areas, the overarching aim of this study was not to compare the two studies, but rather to examine change of land use between 1994 and 2004.

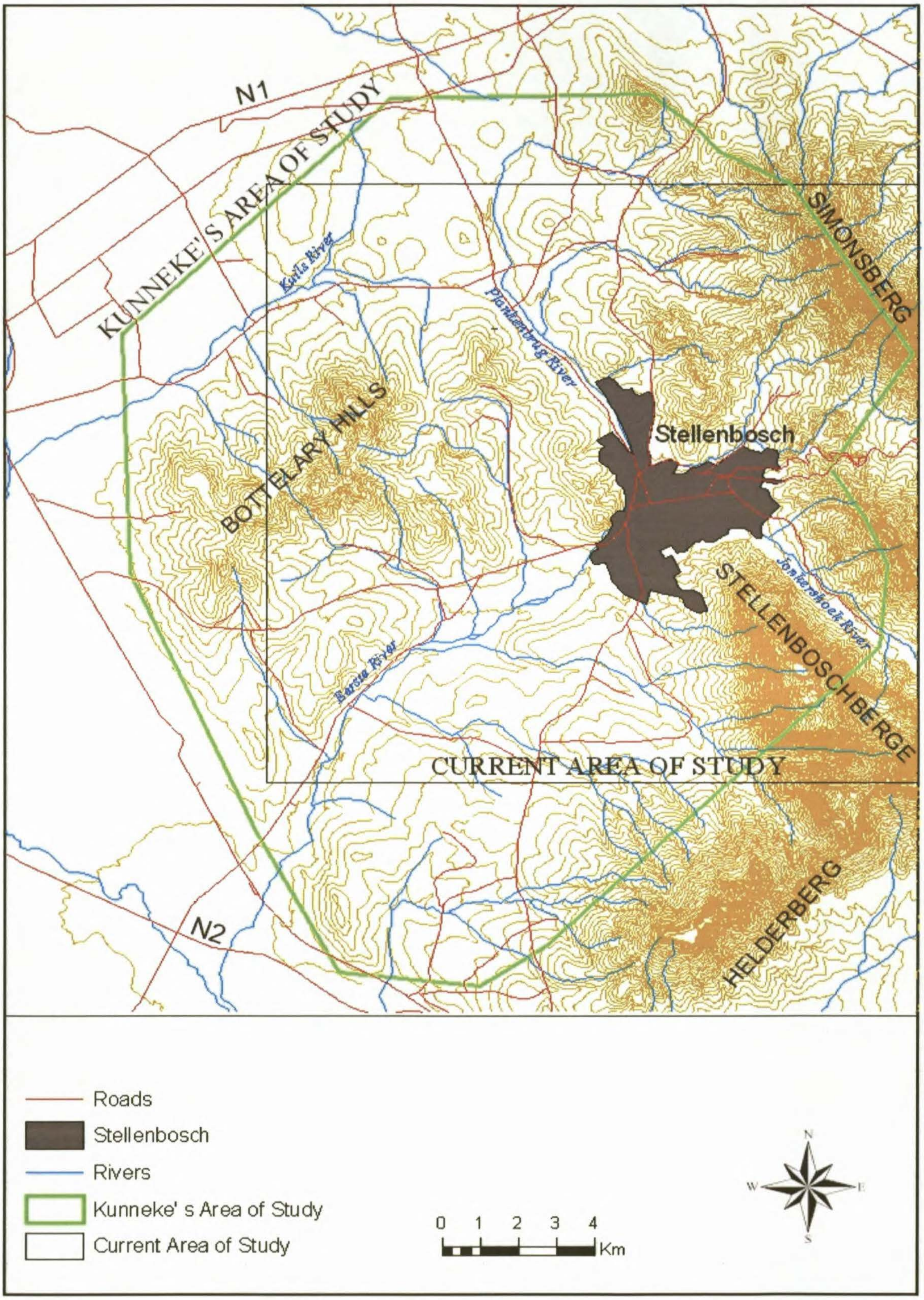


Figure 1.2: Boundary of the present study area and that of Kunneke (1995)

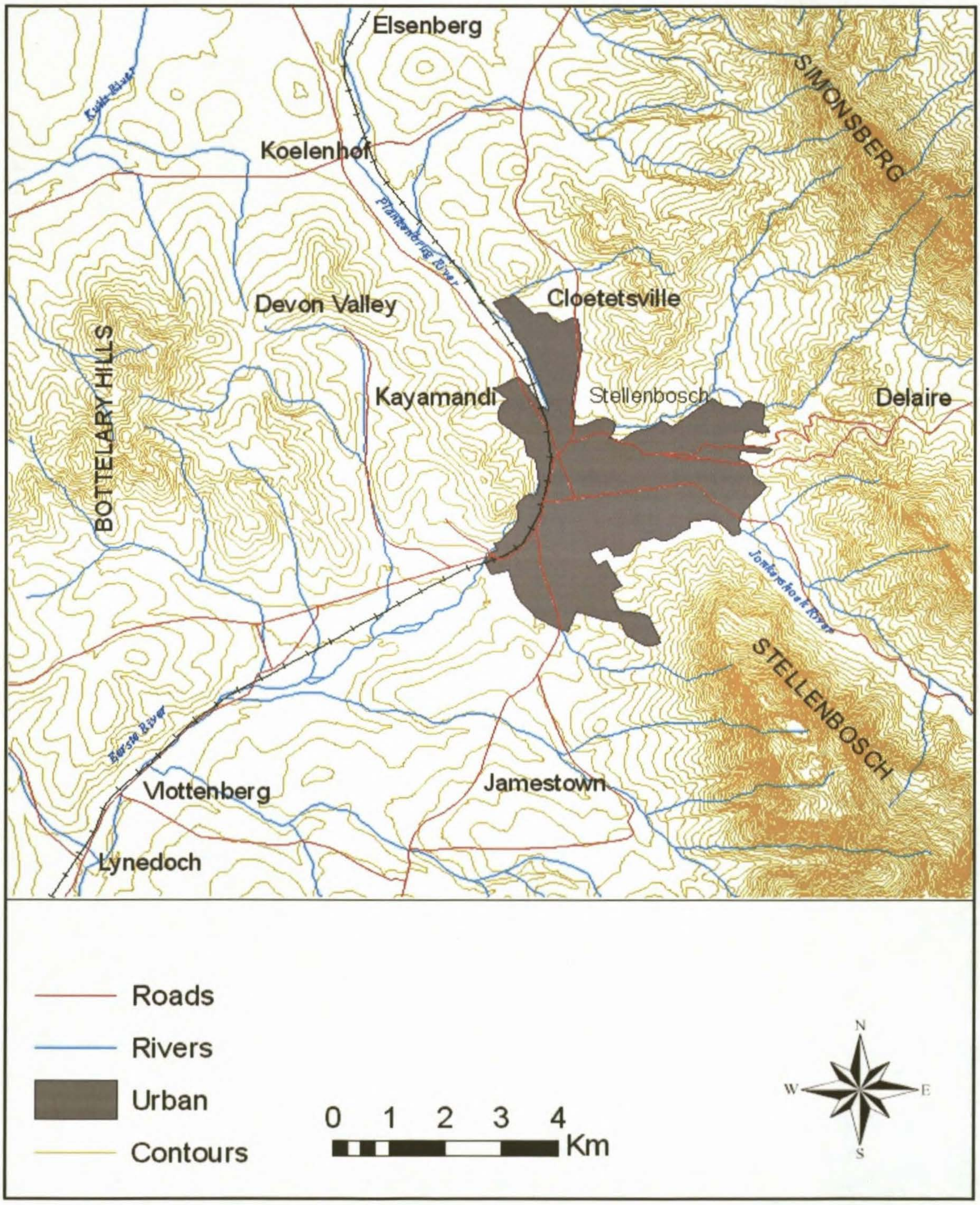


Figure 1.3: The study area: Stellenbosch and its environs

## 1.4 The research framework

Figure 1.4 provides a chapter guide to the report. Chapter 1 gives a background of land use change both locally, regionally and internationally. It discusses the issues that triggered the undertaking of this study. The relevant literature is reviewed, the aim and objectives in terms of urban land use analysis and decision-making are set out. Lastly, the study area is briefly described in terms of its geographical location and climatological conditions.

In Chapter 2, the scientific merit of land use change detection is discussed, the practical and theoretical value of the research in Stellenbosch is affirmed, and the relevant theories, definitions and concepts are introduced. The causes of land use conversion and the consequent negative impacts of these activities in Stellenbosch are discussed. The chapter concludes with an introduction to remote sensing and GIS research methodologies and analysis procedures for land use data collection.

The descriptive discussion of data collection approaches and procedures forms the theme of Chapter 3. It explains the research methods followed, namely remote sensing and GIS procedures and reports on the field surveys that were conducted.

Chapter 4 embarks on the classification of land uses in Stellenbosch and its environs, and applies the Kappa Index of Agreement to analyse land use change between 1994 and 2004.

Chapter 5 renders a synopsis of the study results. An assessment of the research findings and their pragmatic merit is given. The contributions that the study results make to this field of study, the applicability of the methodology followed as well as the pitfalls are discussed. The chapter concludes with an evaluation of the change detection results and suggests further research applications.

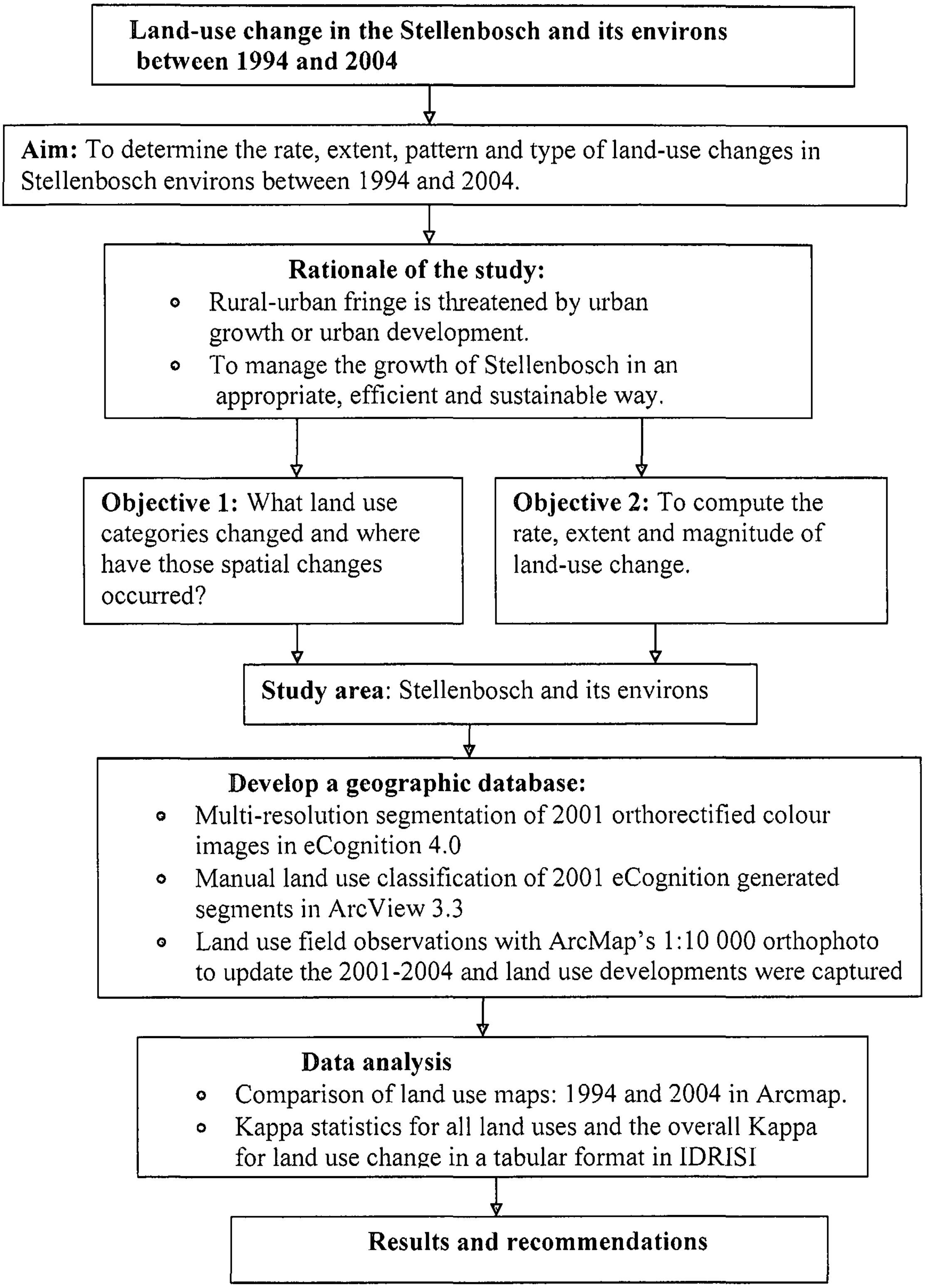


Figure 1.4: Research framework for land use change detection

# CHAPTER 2: LAND USE CHANGE: CONCEPTS, CAUSES, IMPACTS AND METHODOLOGIES

## 2.1 Significance of land use and land cover change

It is important to reflect on the significance of land use change and its importance in geography as a discipline. Global environmental change is one of the many problems that face humanity at present. Land use change is important to a variety of issues fundamental to the study of global environmental change (Mas *et al.* 2004). In fact, land use change reflects the people-environment relationship and how people alter the surface of the earth. Changes in land use or land cover have contributed to increased carbon dioxide content of the atmosphere, greater water demands, considerably changed biogeochemical cycles on earth, and caused dramatic losses of biodiversity around the globe (Dolman, Verhagen & Rovers 2003).

The spatial patterns of land use and land cover also influence the effectiveness of public services, the welfare of human beings and the sense of a community in an area. These public services includes provision of infrastructure and utilities, movement of goods and communications, protection of rural lands and sensitive natural environments, and the support of agriculture and rural activities (Geoghegan *et al.*1997, Neuman 2000 and Pretty *et al.* 2001, as quoted by Croissant 2004). Therefore, policy- and decision-makers need improved tools to help them face the challenges of global environmental change and land use planning. A need exists to evaluate the extent, pattern and type of land use and land cover changes, and predict future land development (Weng 2002). Dolman, Verhagen & Rovers (2003) point out that besides the need to understand the land use system and its complexity, there is concomitant need for spatially explicit assessments of the dynamics of land use systems. The worldwide emphasis on sustainable development underlines these pressing needs.

Our present understanding of changes in land use, the causative driving forces and the implications of change within the context of sustainable development is inadequate (Semwal *et al.* 2004). Zhang *et al.* (2004) have stated that the landscape pattern and change is essential for the monitoring and evaluation of the environmental consequences of urbanization. Therefore, sensible uses of resources require comprehensive planning of community activities because uncoordinated land development can result in undesirable environmental, social, and economic consequences (Campbell 2002). Turner *et al.* (2001) maintain that land-change science forms a central component in the interdisciplinary subfields of global environmental change, and environment and development. The Intergovernmental Panel on Climate Change (IPCC) maintained that land uses are inadequately detected and there is need to detail the magnitude of land use change (Watson 2000). Land use data is vital for important decisions made at the various government levels (Campbell 2002). At the state level, state laws should address issues pertaining to the allocation of land. At the national level, land use information is significant for policy formulation, with regard to economic, demographic, and environmental matters.

South African cities are experiencing an influx of people, migrating from rural areas to urban areas, in search of work and better quality of life. The planners and policy makers lack precise, timely and cost-effective land cover and land use data that is necessary to make decisions with regard to land resource management (Ferreira, Sevenhuysen & Treurnich 1999). The literature shows that, as long as there is demand for space and natural resources, there will be changes in land use management. The historical trend shows considerable and progressive conversion of natural areas into agricultural, urban, or industrial development. Land use patterns, in fact, reflect the interaction of man and environment. Scientifically, the importance of land use research is evidenced in the land use theories developed by Von Thunen, Lösch, Marsh and others working in the disciplines of regional science, economics and geography (Briassoulis 2000 and Campbell 2002).

Stoorvogel, Antle & Crissman (2004) maintained that land use is highly dynamic due to ever-increasing population pressures, highly dynamic world markets, changing biophysical environment through land degradation, rapid technological advancements, and changes in the political arena through, for example, the introduction of a structural adjustment programme. The recognition of the impacts of urban sprawl has prompted policy makers worldwide to establish various regulations and incentives to diminish its effects. These include regulatory controls on the pattern and compactness of development, establishing urban edges, prohibiting new residential development in agricultural environments, creating greenbelts, restricting the numbers of new residential consents granted, land conservation schemes, and tariff incentives (Porter 1997; Razin 1998; Tjallingii 2000 and Gillham 2002, as quoted by Robinson, Newell & Marzluff 2005).

### 2.1.1 Definitions

#### 2.1.1.1 Land

Several definitions of land have developed over time. Land is internationally defined as a delineable area of the earth's terrestrial surface, encompassing all features of the biosphere immediately above or below this surface, including those of the near-surface climate, soils and terrain forms, surface hydrology (including shallow lakes, rivers, marshes and swamps), near-surface sedimentary layers and associated groundwater reserve, floristic and faunistic populations, human settlement patterns, and the physical results of past and present human activity (Watson 2000). Briassoulis (2000), on the other hand, defined land as the stage on which all human activity is being conducted and the source of the materials needed for this conduct and the use of land as a resource gives rise to land use. Hurni (2000) defined land as natural resources, such as soils, water, and living organisms, which are available in a pre-defined spatial unit (land units). Dolman, Verhagen & Rovers (2003) describe land in terms of its functional roles, namely that man utilizes land to produce food, graze livestock, or for shelter.

#### 2.1.1.2 Land use and land cover

The literature reflects that definitions of land use and land cover are often misleading and caution must be taken to distinguish between the two. Numerous definitions of land use have been identified and there has also been confusion between land use and land cover (Andrew & Wessman 1997 and Watson 2000). Often, land use is misconceived as being synonymous with land cover. Campbell (2002: 554) defined land use "...as the use of land by humans, usually with emphasis on the functional role of land in economic activities". "Land use involves both the manner in which the biophysical aspects of the land are manipulated and the intent underlying that manipulation— the purpose for which the land is used" (Turner 1995: 20, as quoted by Briassoulis 2000: 5). Land use means the employment of land, and its resources by humans or the activities undertaken on the earth's surface. Land use entails consideration of the purpose and the actuality of how a certain land surface is altered or used by humans (Grimm *et al.* 2000, as quoted by Croissant 2004). The IPCC (Watson 2000) perceived land use, as the total arrangement, activities, and inputs undertaken in a certain land cover type (a set of human actions). Similarly, land use implies human decision-making with regard to how land will be managed and what kinds of practices will occur on the land (Swihart & Moore 2004).

In contrast, land cover refers to features that manifest on the surface of an area of land. Land cover designates the vegetation, either natural or man-made, on the earth's surface at a specific time of observation (Campbell 2002). Land cover is concrete and lacks the economic function, Turner (1995: 20, as quoted by Briassoulis 2000: 6) defines, "land cover as "...the biophysical state of the earth's surface and immediate subsurface". Land cover denotes the biophysical character of the land surface (Mertens *et al.* 2000), or stated differently it is the observed physical and natural cover of the earth's land, as vegetation or man-made features (Watson 2000). Similarly, Meyer & Turner (1994, as quoted by Briassoulis 2000: 7) stated that "[b]y land cover is meant the physical, chemical, or biological categorization of the terrestrial surface, e.g. grassland, forest, or concrete, whereas land use refers to the human purposes that are associated with that cover, e.g. raising cattle, recreation, or urban living".

**2.1.1.3 Land use change and land cover change**

At a very simple level, land use change and land cover change mean (quantitative) changes in the areal size (increases or decreases) of a given type of land use or land cover, respectively (Briassoulis 2000). There are two generic types of land cover changes: land cover conversion and land cover modification. Land cover conversion entails a shift in the relative proportions of land cover classes within a given area, such as urban expansion into formerly agricultural land, or clear cutting of forests for conversion into croplands or pastures. Land cover modification involves a shift within a particular land cover class, such as tree-thinning on forested land (Andrew & Wessman 1997 and Briassoulis 2000). According to Skole (1994: 438, as quoted by Briassoulis 2000), land cover modification could involve transformation in productivity, biomass and so on.

Similarly, land use change may entail either transformation from one type of use to another, that is, changes in the combination and pattern of land uses in an area or modification of one certain category of land use. Modification of a particular land use may encompass conversions in the intensity of this use, including alterations of its characteristics such as changes from low-income to high-income residential areas. Briassoulis (2000) argues that land cover changes are the consequences of natural processes such as climatic variations, volcanic eruptions and changes in river watercourses or the sea level (Briassoulis 2000). In specific terms, Meyer & Turner (1994, as quoted by Briassoulis 2000: 8) advocate that "[l]and use (both deliberately and inadvertently) alters land cover in three ways: *converting* the land cover, or changing it to a qualitatively different state; *modifying* it, or quantitatively changing its condition without full conversion; and *maintaining* it in condition against natural agents of change".

In terms of agricultural land use, the qualitative classification of land use changes includes intensification, extensification, marginalization and abandonment (Briassoulis 2000). Intensification is the term used to describe increased agricultural output using a high amount of inputs per hectare and is the opposite of extensification. Extensification is the term used to characterize the pattern of agricultural growth which involves using a low number of inputs per hectare. Marginalization involves the course of an entity (e.g. person, social group, organization) or activity (e.g. agriculture) becoming marginal— moving within the margins— of the larger context it exists and operates. A marginalized entity or activity looses its importance within this broader system, it is not accounted for, underrepresented and under-served (Briassoulis 2000).

Briassoulis (2000) further states that the rationale behind the emphasis on the relationship between land use and land cover change is that the environmental impacts of land use change and their role to global change are ameliorated, to a larger extent, by land cover changes. Therefore, their analysis requires the examination of the ways in which land use relates to land cover change at various levels of spatial and temporal detail. In addition, the specification of the spatial and temporal levels of detail is of paramount importance for the analysis of both changes.

## 2.2 The driving forces and impacts of land cover and land use change

According to Briassoulis (2000) the analysis of land use change revolves around two questions: What causes land use change and what are the (environmental and socio-economic) impacts of land use change? Mannion (2000) premised that the causes of land cover and land use change may be natural and anthropogenic (that is, socio-economic). There is a need to address the causes of land use change and land cover change, particularly in Stellenbosch and its environs. The driving forces of land use change are discussed as follows:

### 2.2.1 Open access to markets

The political emancipation of South Africa in 1994 opened opportunities for trade. The new democratic dispensation unlocked opportunities for the country to world markets. That is reflected in a number of activities that have triggered to influence land use change, in the Western Cape region in general, and the Stellenbosch area in particular. To Demhardt (2003: 117) "The apartheid South Africa's haute-gout [unfair policies] and associated sanctions hampered both the wine export and the influx of overseas tourists during the first half of the 1990s". The final round of the free trade agreement between South Africa and the European Union in 2000 prompted a guarantee for the restructuring of domestic and overseas marketing, especially of the wine promotion.

#### 2.2.1.1 Perennial crops

Wine production has developed to be the fourth largest South African tourism attraction and the national prime rural attraction to overseas visitors being more prominent than the national nature reserves and game sanctuaries (Demhardt 2003). The greater Stellenbosch region is a world-class tourist destination. Stellenbosch Municipality (2003) sees the challenge as managing the future growth of Stellenbosch in an appropriate, effective and sustainable way that is aware of the distinctive character and locational aspects that have made Stellenbosch unique. Demhardt (2003) maintains that more than 90 per cent of the vineyards and the associated wine industry are concentrated in the Western Cape which constitutes only one tenth of South Africa's land area.

#### 2.2.1.2 Annual crops

Van der Merwe (2004, pers comm) has pointed out that the production of fresh vegetables and strawberries is one of the important driving factors of land use change in the Boland. As population growth increases there is a need to increase crop production to meet the food needs of the population. One of the strategies that has been used to improve agricultural production is the intensification of agriculture. Agricultural intensification is defined as higher levels of input and increased production (in quantity or value) of cultivated or reared products per unit area and time. Intensification has resulted in a doubling of the world's food production from 1961 to 1996 with only a ten per cent increase in cultivated land globally (Tilman 1999, as quoted by Lambin *et al.* 2001).

Agricultural intensification is stated to be triggered by three factors. First, land scarcity is linked to population growth. Second, markets influence significant land use intensification of commercial agriculture through investment in certain crops and livestock. Lastly, intervention is linked to significant agricultural intensification due to incentives through state-, donor-, or NGO-sponsored projects proposed to promote development in a region usually through commercial agriculture for national and international markets that increase revenue for the participants and the state. Agricultural growth is reported as the main agent of environmental change and impacts on the surface of the earth (Heyns 2000).

#### 2.2.1.3 Tourism

Tourism is one of the most promising economic sectors of the Stellenbosch region. Stellenbosch is the second oldest town in South Africa. It was founded by Simon van der Stel in 1679 and is renowned for its Cape Dutch style buildings, university, rugby, wines, orchards and vineyards (Newbould 2003). Guest houses, bed-and-breakfast establishments, and hotels on wine farms also have contributed to the transformation of the surroundings in the Stellenbosch region. The Spier wine estate is a notable example. Surveys of both domestic and overseas visitors indicate that the wine routes of the Southwestern Cape are the most visited tourist attractions in South Africa (Demhardt 2003). The famous Stellenbosch Wine Routes includes the most internationally known estates and cellars (Demhardt 2003).

### 2.2.2 Residential growth

Lambin *et al.* (2001) contends that urbanization as a land cover in the form of built-up areas occupies only two per cent of the earth's surface. According to Van der Merwe (2004, pers comm) there is concern that the rural-urban fringe is diminishing due to residential growth and urban growth into the surrounding natural environment. The concern revolves around the encroachment of urban development into the agricultural areas of the fertile valleys of Stellenbosch. Urban or residential growth has been identified as a threat to other land uses such as forest or agriculture (Nagendra, Munroe & Southworth 2004).

Whilst urban growth is perceived as essential for a sustainable economy, urban sprawl causes various problems. These problems include consumption of precious rural land resources at the urban fringe, landscape alteration, environmental pollution and transportation congestion. Urban sprawl and traffic congestion are two of the challenges confronting the Stellenbosch municipality (Stellenbosch Municipality 2003). Land use change and land cover change are the consequences of several interrelated processes and these processes operate over a variety of scales, both temporal and spatial (Dolman, Verhagen & Rovers 2003). Among the number of factors that contribute to changes in land use or land cover, suffice it to say that human activities play the most prominent role through population and residential growth.

### 2.2.3 Other driving factors

Van der Merwe (2004, pers comm) maintains that the land use change in the Western Cape is triggered by factors other than those discussed above. These include deforestation, introduction of alien species around the river valleys and transportation infrastructure. In 2004 and early 2005, many fire incidents occurred in the densely built-up, deprived and populated informal settlements in Kayamandi (Eikestadnuus 2004c and Eikestadnuus 2004e). These fire incidents left people with no homes and caused loss of life. These fire events also contributed to land use alterations. Due to those serious fire problems, the local government has been forced to relocate some of the people to locations that were previously unoccupied. These areas include agricultural and natural environments. These decisions led to the expansion of the already dynamic Kayamandi township.

Turner, Moss and Skole (1993, as quoted by Mertens *et al.* 2000) classified the driving forces of land use change into four groups: (i) variables that affect demand (e.g. population), (ii) variables that determine the intensity of land use (technology) and (iii) variables that reflect access to resources (political economy). Kates & Haarmann (1992, as quoted by Mertens *et al.* 2000) also identified four major driving forces in the alleged poverty-environmental degradation structure and made the distinction between exogenous-driven forces, that is, natural hazards and commercialization, and endogenous-driven forces, that is, population growth and existing poverty. Driving forces are a complex set of actions and underlying principles that give rise to proximate causes, that is, the near-final or final human activities that directly affect the environment (Turner *et al.* 1990, as quoted by Mertens *et al.* 2000).

## 2.3 Environmental and socio-economic impacts of land use change

The use of land results in substantial impacts on the natural and human environment. Changes in land use patterns influence both human phenomena and natural systems (Randolph 2004 and Swihart & Moore 2004). Darkoh (2003) pointed out that rapid accelerating change in the landscape is associated with a wide variety of issues, including declining biodiversity, global climate change and food security, and land degradation as it applies to soils, vegetation and water. There is a need to ascertain how land use changes have transformed the carbon budget, trace gas fluxes, nutrient cycling, and sustainability of ecosystems at local, regional and global scales (Parton *et. al* 2004). Randolph (2004) surmised that in sprawling development, everyone is driving towards areas that were previously inaccessible. Land development consumes agricultural land, green open spaces, and natural ecosystems at a rapid rate by subdivisions for housing and shopping centres.

Other potential ecological impacts include changes in the extent and deterioration of habitat, changes in habitat quality and alteration of the hydrological cycle (IPCC 2000). The dynamics of land cover and land use have significant implications for natural resources through their impacts on greenhouse gas fluxes and the impact of greenhouse gas emissions, soil and water quality, biodiversity, and global climate systems (Houghton *et al.* 1991, as quoted by De Koning *et al.* 1999). Environmental modification has largely resulted in deforestation, biodiversity loss and global warming (Fearnside 2001, as quoted by Mas *et al. 2004*) and reduction of environmental services (Klooster and Masera 2000 and Lambin *et al*. 2001, as quoted by Mas *et al.2004*). In the same vein, "[t]he alterations caused by land use and land cover change have major implications for sustainable development and contribute to processes such as the greenhouse effect, loss of biodiversity and negative changes in regional hydrology and biogeochemical cycles" (Mas *et al.* 2004: 1).

The possible social and economic impacts of land use changes include changes in the costs of providing local services, changes in the products from forest and agricultural lands, changes in traffic congestion, and changes in the aesthetic character of the community (Barbier 2000). Land degradation has resulted in severe expansion of desertification in the semiarid region of China (Zhao *et al.* 2005). Parts *et al.* (2004) indicated how anthropogenic land use change causes myriad infectious disease outbreaks, emergency incidents and modifies the spread of endemic diseases. According to Barbier (2000), land use in Africa has been characterized by extensive land degradation and alteration and these two processes are clearly related (Barbier 2000). Overgrazing and other agricultural practices are the primary influences of land degradation across Africa (WRI 1992, as quoted by Barbier 2000).

### 2.4 Research approaches in land use studies

Over the years researchers have used different approaches to detect land usage according to the dictates of their scientific disciplines and traditions. But recently there has been an increasing collaboration between social scientists and remote sensing experts to improve our understanding of the biophysical forces and human actions that shape land use/land cover changes (Mertens *et al.* 2000). Social scientists study land use from a human-environment perspective using qualitative approaches while natural scientists, geographers and ecologists have focused on land cover and land use using spatially explicit remote sensing and GIS.

Mertens *et al.* (2000) contended that remote sensing data provide measures of the spatial and temporal context of social phenomena and their effects (e.g. environmental consequences and proximate causes of land use changes), and a link across levels of analysis (e.g. to address regional-level questions from local-scale studies). In contrast, for social scientists behaviour is the central topic of study (Dolman, Verhagen & Rovers 2003). In addition, "[s]ocial science provides a better understanding of the driving forces that give rise to proximate causes of land use/land cover change" (Mertens *et al.* 2000: 985). This understanding of driving factors and processes provides in-depth and detailed interpretations of the pattern of land cover change derived from remotely sensed imagery (Mertens *et al.* 2000).

Sussman, Green & Sussman (1994, as quoted by Mertens *et al.* 2000) have investigated how satellite imagery and social science methods can contribute to an understanding of the reasons for deforestation in Madagascar, and highlighted the need for thorough research on current patterns of land use and existing resources to develop an integrated long-term conservation-orientated plan. Guyer and Lambin (1993, as quoted by Mertens *et al.* 2000) combined household and remote sensing data to evaluate the extent of intensification of farming systems in Nigeria and the relative role of two major drivers of land-use change, that is, population pressure and urban market expansion.

### 2.4.1 Remote sensing and GIS in land use change research

The use of aerial photographs and satellite imagery to determine the rate, extent and pattern of land use change is universal in land use research. Graham & Koh (2002) define digital aerial photography as a non-contact, non-destructive method of data capture and information extraction for objects located on the earth's surface. Eastman, McKendry & Fulk (1995) maintain that there is change and time series analysis: change being the examining of the phenomena between two dates, and time-series analysis constituting an analysis of multiple comparisons. According to Nagendra, Munroe & Southworth (2004) land cover data is frequently derived from satellite images which provide a single photograph of land cover at one point in time. In the satellite image the unit of observation is the pixel (from 10 to 80 m for medium resolution sensors) which is not directly linked to any social science unit of observation, for example, individuals, households or villages (Mertens *et al.* 2000). The remote sensing and GIS research approaches are discussed below in terms of the work done outside South Africa and work completed in South Africa, particularly in the Western Cape.

Yin *et al.* (2005) used Landsat TM and ETM+ images to detect urban growth in Cairo, between 1986 and 1999. In this study the researcher also integrated fieldwork and high spatial resolution imagery — IRS, IKONOS and CORONA— to aid in examining urban sprawl. Similarly, Gautam *et al.* (2003) used a Landsat Multi Spectral Scanner satellite image (hereafter MSS image) of 1976, a Landsat Thematic Mapper satellite image of 1989 (hereafter TM image) and an Indian Remote Sensing satellite image for 2000 (IRS-1C, LISS-III; hereafter IRS image) to collect data. Eight black-and-white aerial photographs of 1:50 000 scale for 1978 and 1992, were used for "ground-truth" information necessary for classification and precise estimation of classified MSS and TM images, respectively.

Weng (2002) illustrated the success of the integration of remote sensing, GIS and stochastic modelling in analyses of land use change in China. Land use and land cover change trends for 1989, 1994, and 1997 were detected by using Landsat Thematic Mapper data (December 13, 1989, January 25, 1994, and August 29, 1997), which have a 30m ground coverage (except for the thermal IR band (band 6), which has a 120m resolution. The reference data were collected through fieldwork or from existing land use and land cover maps that had been verified in the field. Large-scale aerial photos were also used as reference data in precision assessment when necessary. Imbernon (1999) applied the following data to map the changes: a panchromatic spot image of August 1995, a set of 1985 aerial photos at 1:12 500 scale and a set of 1958 aerial photos at 1: 50 000 scale. The spot image was georectified using 1: 50 000 topographic maps. The photos were georectified using the spot image as reference.

The spot image and aerial photos were then photo-interpreted before land uses were mapped according to a simplified classification scheme.

In contrast, the South African National Land Cover (NLC) project in 2000 integrated pre-annotation field orientation, land cover mapping at 1:250 000 scale LANDSAT TM SpaceMaps, digitisation of annotated land cover, and field verification and validation of data to give the latest information on land cover for South Africa, Lesotho and Swaziland. The NLC (2000) forms the backbone of this research of land use change detection in that its methodology is more or less similar to that followed in this study's collection of data and analysis procedures. Kunneke (1995) developed the 1994 land use database by manually digitizing the land uses on a 1:50 000 scale topographical map. In a similar manner, she conducted field observations to update urban developments which were not mapped on the 1:50 000 map between 1992 and 1994. However, the aim of her study was to examine waste generation by wine production in Stellenbosch and its environs. This involved waste from the chemicals used during wine-making process, waste from fermentation and washwater from the tanks and filtration.

Tesfamariam (2000) quantified the extent of wetland loss in a highland region of the Western Cape between 1948 and 1999. He identified and determined the relative contributions by different land use types to the loss of the wetlands. The methodology adopted was an analysis of aerial photographs and satellite imagery using GIS, and the incorporation of orthophotos and topographic maps. The aerial photos and the satellite imagery provided land use information and the orthophotos and topographic maps were used to help in finding the locations of Ground Control Points (GCPs) for the georectification of aerial photographs.

Kazapua (2003) investigated time-series analysis of rural land use change in a highland watershed, namely, the Koue Bokkeveld. A sequence of aerial photographs was digitized to produce land use maps. His study focused on land use change between 1948 and 1998. The maps were overlaid using panchromatic satellite imagery as a reference that was taken in 1998. The study incorporated the 1:250 000 topographical maps, a panchromatic satellite image and aerial photographs. The aerial photos and the satellite image made available land use information while the topographical map was used to aid in recognizing features or landmarks. Three years earlier, Heyns (2000) had determined the impact that human activities and agriculture had on the same study area, namely the Central Koue Bokkeveld. This study integrated aerial photographs, orthophotos, topographical maps and satellite imagery in order to achieve its aim. Aerial photographs were adopted to identify the land use categories. The computer-scanned satellite image was used to digitize the land use types. The orthophotos and topographical maps were used to determine the actual coordinates. These real-world coordinates were used in the georeferencing process. Points like road crossings, individual trees, solitary rocks and farmsteads were used to compute the real-world coordinates.

Richards (1999) looked carefully at the transformation of wetlands along a central highland watershed in the Western Cape. This study applied aerial photos as the basis for the interpretation and evaluation of change. The photos were used to identify the wetlands through tone and texture produced by the variable reflectance of different vegetation categories, water and soil. This method was also applied to identify different land use types. Agriculture and the construction of dams were found to be the prominent factors that contributed to the loss of wetlands. In Richards' (1999) investigation some ground-truthing was conducted to help in the evaluation of photos, to collect information from certain wetland sites, to communicate with the local farmers in the area and to substantiate the results. The fieldwork involved driving through the valleys, taking photographs and observing and recording any changes that had occurred between 1997 and 1999. The ground-truthing verified whether or not the natural wetlands still existed or had changed into some other form, whether the dams undergone any conversions and how the agriculture had adapted the landscape.

### 2.4.2 Digitizing

The computer recording or digitizing of features is a common practice in land use change detection research. Land use types are commonly mapped using GIS. There are generally two types of methods used to capture geographical information from secondary sources, namely manual digitizing and automatic scanning (Zietsman 2001). Digitizing involves the electronic recording of features, points, polygons and lines, from data sources such as sheets, aerial photographs or satellite imagery.

### 2.4.3 Field observations

Field observations are required for accurate ground control and as a means of resolving uncertainties in the interpretation process (Campbell 2002). Campbell further states that field observations should be obtained on three occasions during the preparation of the land use maps. Firstly, this is done before the interpretation process of the images starts, during the organizing of the classification system and as a way of familiarizing the interpreter with the area and its major land uses. Secondly, before the interpreter finishes the image overlay process, observations are done to confirm uncertainties and to validate consistency of the interpretation. Thirdly, when the preliminary draft of the map overlay is completed, the observations are used to detect and resolve any problems before the final copy of the map is produced. The interpreter should ensure adequate observation of all land use types in each zone of the study area.

Schloms (2004, pers comm) recommends that it will be good to observe land use changes, for instance, from 2001 to 2004. Richards (1999) conducted fieldwork to verify transformation between two dates, 1948/9 and 1997, and argued that field observations provided an opportunity to take photographs and document observed characteristics. Behrens, Baksh & Mothes (1994, as quoted by Mertens *et al.* 2000) illustrated that they gained great insight into the processes that led to tropical deforestation and transformations in landscape complexity by contrasting land cover disturbances, as measured by remote sensing, and land use changes in Venezuela. Mertens *et al.* (2000) attempted to relate population changes, derived from field surveys, to land-use/land-cover change data in Thailand.

## 2.5 Traditional pixel-based approaches versus object-orientated remote sensing

Definiens Imaging (2004) claims that there is a strong need for automated technologies, because state-of-the-art image analysis procedures, basically pixel-based, are still limited, and traditional approaches are far from being capable of extracting objects of interest. Advantages of object-orientated analysis are semantic statistic and texture computation, an increased uncorrelated feature space using shape (e.g. length, number of edges) and topological characteristics (neighbour, super-object, etc.), and the relationship between real-world objects and image objects (Benz *et al.* 2004). The concept behind eCognition is that key meaningful information essential to interpret an image is not represented in a single pixel, but in significant image objects and their mutual relationship (Baatz *et al.* 2001, as quoted by Tadesse, Coleman & Tsegaye 2003). In this land use research study, eCognition was identified as the best approach for extracting image objects, land use features or objects of interest that were to be extracted from the preceding segmentation step. This approach is more convenient than the traditional pixel-based classification approach.

Southworth, Munroe & Nagendra (2004) maintained that the use of remotely sensed data for land cover change analyses does have some inherent problems that can affect interpretation of land cover change. Southworth, Munroe & Nagendra (2004) further states that these shortcomings include discrete class creation, no within-class variability, the pure pixel assumption, and spatial analysis. Discrete class creation can result in simple pixels being set into different land cover classes and can be a major source of classification error. No within-class variability may cause research to omit significant changes in the landscape. The pure pixel assumption is merely appropriate when land cover classes are discrete and mutually exclusive. But the mixed pixels are largely prominent in land cover classifications and therefore, may induce a problem. A spatial analysis which implies the need to incorporate both spatial and spectral information is a necessity.

Many studies have made use of the object-orientated approach to land use change. In this research, the object-orientated procedure will be used merely to create the vector polygons that will be exported for manual classification in ArcView GIS. Walter (2004) classified remote sensing data using the supervised maximum likelihood classification into different land use categories. The training areas were derived from an already existing GIS database to avoid the laborious task of manual acquisition. Walter (2004) provided an example for a per-field classification approach, which first classifies the image into dissimilar land use types. The fields are subdivided into different classes, depending on the classification product, using thresholds. Remote sensing imagery is a significant source to generate and update GIS databases for land use and land cover change detection. Tadesse, Coleman & Tsegaye (2003) compared traditional classification approaches and the object-orientated method. Their first task of analysis was to generate similar image objects or segments on the basis of spectral and contextual information using five parameters, namely scale, colour, shape, smoothness and compactness. The segmentation resulted in a hierarchical network of image objects, each connected to its vertical and horizontal neighbour.

Grenzdorffer (2005) examined the spatial extent of urban developments that involve land use changes using different remote sensing sensors and image analysis techniques. The change detection in 1989 and 1995 at a scale of 1:50 000 were based on the merged Landsat and SPOT satellite images. The change detection research was successful even though the scale of 1:50 000 is suitable for generic purposes and for a detailed study data of high spatial resolution is required. In this land use change detection research in Stellenbosch, the digitally corrected orthophotos with a high resolution images will be mapped to determine the new urban developments over a ten-year period.

# CHAPTER 3: RESEARCH METHODOLOGY AND COLLECTION OF SPATIAL DATA

## 3.1 Development of a geographic database

To compute land use change, imagery is required for at least two different dates. This study relied primarily on two-date imagery to assess trends in land use change in Stellenbosch and its environs between 1994 and 2004. However, the datasets were not directly comparable in terms of classification, mapping standards and geographical coverage, making the compilation of a 2004 dataset no easy task. Although change detection is an increasingly common application for remotely sensed information, there is neither a comprehensive theoretical framework nor a universally applicable methodology (Blaschke 2003).

### 3.1.1 Digital land use coverages for 1994

The Centre for Cartographic Analysis at Stellenbosch University provided the land use coverages for 1994 which served as basis to compare land use change over a period of ten years. These data were in the form of ready-to-use classified digital land use Arc/Info coverages for 1994 and were manually digitized and captured from the 1:50 000 maps which were updated through fieldwork between 1992 and 1994. The 2004 land use map, on the other hand, was made using an object-orientated remote sensing approach. In this study many impediments were encountered in obtaining another fairly recent dataset. Even the existing land use map of 1994 needed to be improved to include informal settlements so as to ensure that the two datasets are comparable. The 1994 dataset was created in a study aimed to quantify waste created by wine cellars in Stellenbosch and its environs and not necessarily for change detection, hence it needed to be somewhat updated.

The additional features, i.e. informal settlements, were mapped or updated with the help of aerial photographs obtained from the Stellenbosch Municipality for the years between 1991 and 1994. Direct comparison of the photos and the land use map of 1994 made it possible to demarcate or digitize the locations of informal housing in Kayamandi in 1994. From the aerial photographs, it was feasible to deduce the spatial location of informal settlements and their boundaries in certain locations in Kayamandi although the population density was low when compared with the density observed during field observations. Since the datasets were created by different people, differences are bound to be present due to subjective interpretations of the land uses by the different researchers. Although these factors may affect the correct delineation of boundaries between specific land uses, it is doubtful that they will have a significant effect on the mapped spatial distribution of the various land uses as the difference between the land use types that were distinguished are indisputable.

### 3.1.2 Digital colour orthophoto imagery for 2001

The second dataset was not easy to obtain for the study area. In fact, the Chief Directorate of Surveying and Mapping (CDSM) in Mowbray, which is responsible for the official, definitive, national topographic mapping of South Africa, does have the aerial photographs for 2000 and the orthophoto coverage of 2001, which are the latest available. Presumably, the orthophotos are much better to use being more accurate than the aerial photos which are just pictures, neither geometrically corrected nor geo-referenced to space. Although colour orthophotos are more convenient than the aerial photos, since they are corrected for geometric distortions, the digital orthophotos were not immune from problems. Firstly, the orthophotos were not captured for the entire Stellenbosch region and its environs. For example, the area of Stellenbosch town is represented partially, some sections have no data and orthophoto images do not exist for some areas at all. Secondly, these orthophoto images had geometric errors which could lead to geographical mislocations between orthophotos.

The above-mentioned problems existed for the data provided both by the CDSM and the Centre for Cartographic Analysis. The Centre for Cartographic Analysis also obtained this data from the CDSM, therefore the data from both parties was analogous. In reality, the 2001 orthophoto data did not originate from the CDSM, but the Department of Water Affairs and Forestry collected the data for its own purposes that include mapping the encroachment, pattern and extent of alien species towards the native vegetation and along the river courses in the Western Cape region (Chief Directorate: Surveying and Mapping (CDSM) 2004, pers comm). Therefore, during the capturing of data, the CDSM was interested only in river courses and their catchments areas. The CDSM requested the data from the Department of Water Affairs and Forestry and managed it on behalf of the public. The problems with the orthophoto imagery created the need for alternatives, consequently the Stellenbosch Municipality had the orthophoto coverage for Stellenbosch and its environs. The GIS consultants company, Global Images, which manages remote sensing and GIS data for the Stellenbosch Municipality, provided the digital orthophoto imagery for 2001. The data needed to be pre-processed since it was for the digital unclassified orthophoto images.

### 3.2 Processing of data and images

Processes such as stitching together of the images, projecting the image and subsetting, and segmenting the mosaiced image and later manually classifying the polygons, were executed to make the data ready for processing in various remote sensing and GIS packages.

This data was not without its flaws as it needed to be clipped or cut for its white borders on each orthophoto Joint Photographic Experts Group (JPEG) format. The errors were mainly the white boundaries on the orthophoto sheets and white clouds on the images (See Figure 3.1, even though the white boundaries have already been rectified). The images were clipped through ESRI ArcView GIS 3.3 software's image analysis extension and were displayed in 3 bands (red, green and blue). The spatial resolution of those colour orthophoto images is 1.5m x 1.5m. The twelve orthophotos for the study area needed to be mosaiced for easy manipulation and management. To mosaic the images, Erdas Imagine 8.7 provided the best utility to stitch the images as a single image through its data preparation menu. Mosaicing is the process of joining georeferenced images together to form a larger image or set of images (Erdas Imagine 8.7 On-line Help 2004). The images were merged for processing in eCognition. Figure 3.1 shows the digital orthophoto mosaiced imagery displayed in 3 bands (red, green and blue) and this is the image that will be vectorised to produce the land use cartographic and geographical database of 2004.

This data was projected in order to be used in eCognition Professional, remote sensing object-orientated image analysis software. The data was defined and projected into the transverse Mercator projection, the spheroid and the datum with WGS84, respectively and the central meridian 19. Once more, the mosaiced image was too big for manipulation in eCognition. Just to open the image alone, it took approximately ten minutes and to save the image about 30 minutes. It became obvious that the image was too large to work on and needed to be divided into manageable units. Therefore, the image was separated into four blocks. This involved the subsetting of the image into four units which made the processing easier in eCognition.

Prior to 1st January 1999, the co-ordinate reference system used in South Africa as the basis for most surveying, engineering and geo-referencing projects was the Cape Datum. This Datum was referenced to the Modified Clarke 1880 ellipsoid and had its origin point at Buffelsfontein, near Port Elizabeth. To put it differently, the 1994 data needed to be projected from the Cape Datum to the Hartebeesthoek94 datum. However, using traditional surveying techniques, errors and distortions with


Figure 3.1: Digital orthophoto imagery 2001: Stellenbosch and its environs

the Cape Datum were detectable using modern positioning techniques such as the Global Positioning System (GPS). In addition to these flaws and distortions, the Cape Datum did not have the centre of their reference ellipsoids concurrent with the centre of the Earth, thus making them useless for some applications. Since the 1st January 1999, the official co-ordinate system for South Africa has been based on the World Geodetic System 1984 ellipsoid, commonly known as WGS84, with the co-ordinates of the Hartebeesthoek Radio Astronomy Telescope used as the origin of this system. This new system is known as the Hartebeesthoek94 Datum. In ArcGIS, the 1994 data was converted with Cape datum and Clarke 1880 and projected into the Hartebeesthoek94 datum and the World Geodetic System of 1984 as the ellipsoid. This projection was done so that the two datasets could overlay accurately.

## 3.3 Creation of vector information to bridge remote sensing and GIS

The traditional pixel-based classification algorithm was considered ineffective to classify the image. The digital colour orthophoto imagery that needed to be classified had three bands (red, green and blue). Therefore, with 12 land use types to be classified, the primitive pixel-based approach was considered to be unsuited to the task at hand. Besides, there is an increasing interest in recent technologies of information extraction because the traditional approach is far from being effective for extracting image objects. The pixel-based classification was incompatible and thus an eCognition' object-orientated method was followed. eCognition follows an object-orientated procedure towards image analysis. One of the features of eCognition is that the important semantic information necessary to interpret an image is represented as a collection of objects as opposed to the traditional pixel-based approaches. eCognition extracts image objects which are based in the previous segmentation process.

### 3.3.1 Multi-resolution segmentation and classification

Benz *et al.* (2004) describe image segmentation as the creation of image objects which involves the subdivision of an image into separate regions. Image segmentation is a process that searches for homogenous regions in an image and multi-resolution segmentation is a bottom-up region merging technique (Darwish, Leukert & Reinhardt 2003). Image segmentation starts by considering each pixel as a separate object and ultimately pairs of image objects are merged to form bigger segments. Multi-resolution segmentation is a patented procedure used to extract objects from an image. It allows the segmentation of an image into a network of image objects at any predetermined resolution. In eCognition segmentation is a semi-automated process where the user can define specific parameters such as scale, colour, shape, smoothness and compactness that influence the size and shape of resulting image segments (Herold *et al.* 2002). This process extracts meaningful image objects (such as built-up areas, vegetation, agricultural areas) based on their spectral and textural features. eCognition offers a whole set of meaningful information, amongst others, shape, texture and tone, which can be used during the classification process (Definiens Imaging 2004).

The 2001 digital orthophoto imagery was segmented in eCognition. Since the aim of this research is to investigate land use change but not to develop a remote sensing methodology to classify an image, eCognition was merely used to segment the image or to extract the objects of interest to investigate land use change. The segmentation was performed using the following parameters: scale 200, shape 0.409, compactness 0.6 and smoothness 0.4. These parameters control size, shape, smoothness and spectral variation of each object. Unfortunately, this approach caused problems in the segmentation process as the individual land use sometimes combined with adjacent segments, for instance, urban development and informal settlements. The above problem was corrected in ArcGIS 'arcedit' module. After segmentation, vectorization functionality allowed the production of polygons and skeletons of image objects (Benz *et al.* 2004).

Figure 3.2 shows the multi-resolution image segmentation results from the mosaiced image that was subdivided into segments. These results indicate meaningless segments which need to be classified in order to have any spatial significance for this research. These eCognition's segments were manually classified in ArcView by using non-spatial attributes. For practical reasons, these polygons, with their size and shape information, were exported into ArcView GIS 3.3. Consequently ArcView provided the best means for the manual classification of hundreds of polygons. The software was more user-friendly compared to eCognition and the classification was performed easily given ArcView's capability to compare features on the view and the table of attributes.

The goal of classification was to provide a comprehensive and accurate land use product that forms the basis for analysing the rate, extent and pattern of land use change. In reality, the land use features were classified by creating a new field in the attributes that were exported with the segmentation results. The column header was named 'code' of which the 12 land use types were represented with codes. Through the opened table of attributes and the use of the 'zoom to selected feature button', the records were assigned values under the field 'code'. Some features were difficult to identify on the image, but the literature review and the researcher's general knowledge confirmed that some features were not on the imagery, hence field observations were considered necessary to update urban developments that had taken place between 2001 and 2004.

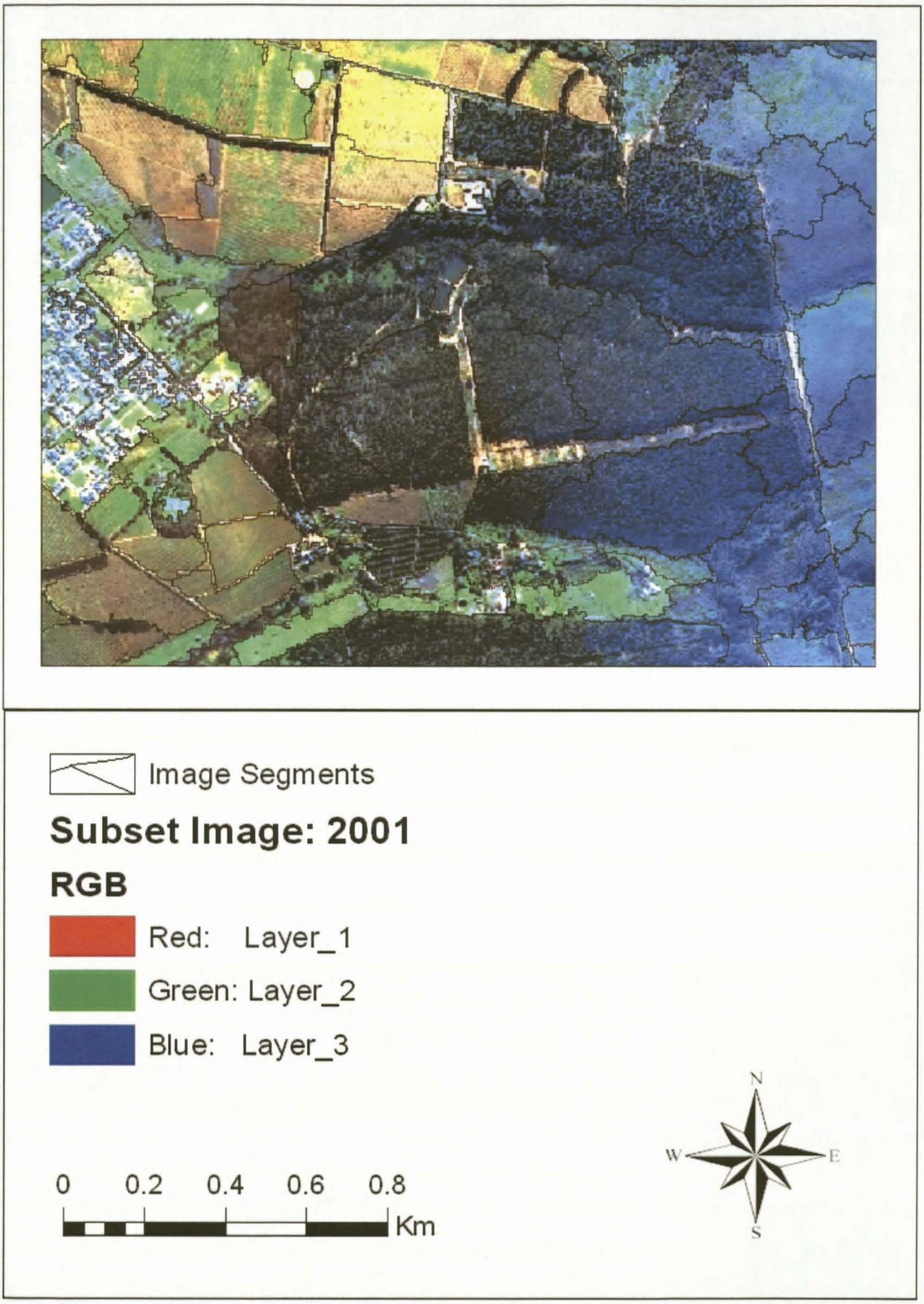


Figure 3.2: Multi-resolution segmentation product

### 3.3.2 Generation of 1: 10 000 land use maps for field observations

To do the field work, it was considered necessary to have 1:10 000 land use maps from the classified 2001 dataset for orientation purposes. The 1:10 000 scale maps assisted to exactly identify the absolute locations of phenomena in the field. These maps were overlays of Arcmap's classified land use data for 2001 with the orthophoto coverage of 2001. The objective was to make the maps transparent enough to observe land use features on the map while the key to the features enabled the identification of different land use features. Since in Arcmap there is a possibility to display the data in an effective manner, the programme was used to create land use maps which were overlain with their original orthophotos to view both the image and eCognition segments overlayed. ArcView GIS software also provides this utility but it is not useful enough to display the geographical data effectively. Figure 3.3 demonstrates an overlaid example of a land use orthophoto map that were employed to conduct field observations. The land use maps were taken into the field to orientate the researcher in the area of study and to update developments not occurring prior to 2001.

### 3.3.3 Land use field observations

Field verification was used to validate the final land use data and to provide an opportunity to observe, note and plot the land use changes on the maps. Although the field validation was also used to familiarise the interpreter with the area of study, the field observations were conducted to identify the land use changes that occurred between 2001 and 2004. This involved travelling through the road network, almost across each individual orthophoto, during which time reference notes and photographs were taken. The field surveys were performed using a bicycle for transportation, and it was the most interesting and rewarding part of the study after sitting in front of the computer for a couple of months processing the data. The new developments were manually plotted on the previously prepared land use maps and were later digitized on screen in ArcGIS 'arcedit' module. In addition to the plotting of recent developments, field notes were taken about the novel complexes and land use dynamics, and digital photographs were taken as evidence of the field observations and also to enhance and clarify the results. In conjunction with field notes, binoculars were used in situations where some locations were inaccessible due to privacy, unavailability of roads and remoteness as in mountainous areas. The land use verification methods were considered to balance scientific rigour and economical feasibility with practical limitations of cost and time.

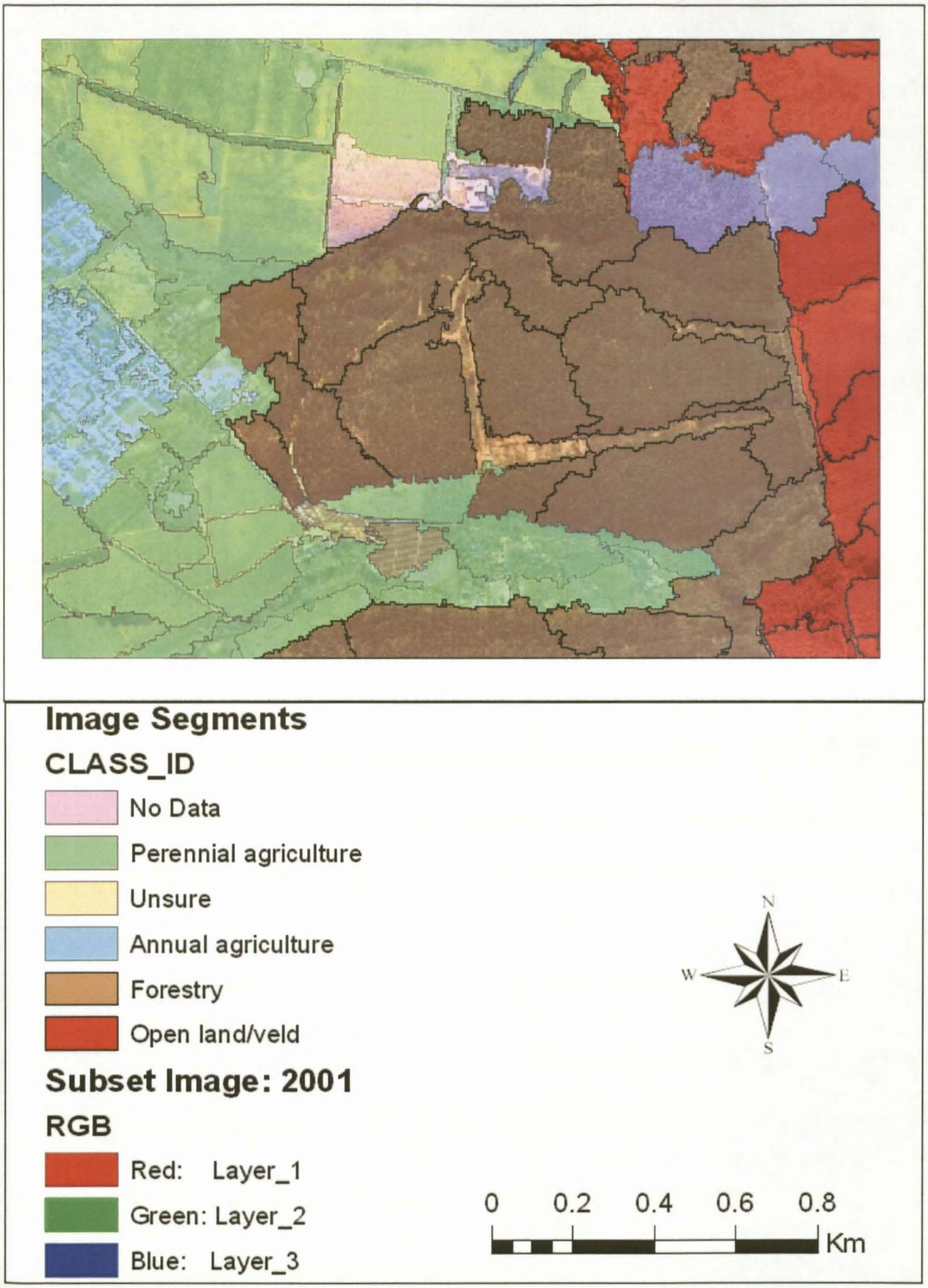


Figure 3.3: Generalised land use orthophoto maps 2001: Stellenbosch and its environs

The field observations made it possible to update those land uses that were not classified during the manual classification. Specifically, these objects from the previous segmentation step were extracted not separately from each other, but as one segment. Walter (2004: 236) states that "[t]he main reason that the approach (object-orientated remote sensing) classifies objects into a wrong class is that in practice, the appearance of objects can be very inhomogeneous". If, for example, an urban object contains large areas of urban areas but only few pixels that represent settlements, it will be classified as urban development and not as settlements. Field inspections, therefore, enhanced the classification process through the identification of misclassification of urban areas and the informal sector.

All the land use changes observed in the fieldwork were digitized and captured in the ArcGIS 8.7 Arcedit module which is more effective in terms of accuracy for editing and digitizing compared to ArcView. In the Arcedit environment, the land use coverages were displayed and the polygons were edited by digitizing individual features identified in the field observations as accurately as possible and corrected with the command 'clean' and 'build'. The command 'clean' was used to generate coverage with correct polygon or arc-node topology, and also to correct geometric errors and assemble arcs into polygons and create and update feature attribute information with the 'build' command. In addition, all the polygons that had more than one label were shown with the 'labelerrors command' and were corrected for their errors. Thereafter the coverage was digitized for the updates, and was corrected with the 'build' and 'clean' commands before it was considered accurate and reliable for land use calculations using the Kappa method.

Chapter 4 describes the land use categories and gives examples. The data analysis procedure is discussed.

# CHAPTER 4: DESCRIPTION OF LAND USE CLASSIFICATION TYPES AND DATA ANALYSIS

## 4.1 Land use classification

The land use classification system for Stellenbosch was devised in 1994. This system was produced by Van der Merwe (2004, pers comm) in contributing to the land use database of Stellenbosch and later revised by Kunneke (1995). Details of the scheme are provided in Table 4.1.

Table 4.1: Kunneke's revised land use types: 1994

| Land use categories and identification numbers | | Land use descriptions |
|---|---|---|
| Perennial agriculture | 1 | Orchards and vineyards such as wine grapes, olives, peaches, pears and apples |
| Annual agriculture | 2 | Vegetable production, cereals and grazing land |
| Industrial agriculture | 3 | Two-fold: (a) Livestock agriculture i.e. piggery, chicken farm<br>(b) Nursery and greenhouse production i.e. strawberry tunnels |
| Formal urban development | 4 | Formal built-up areas and housing development |
| Informal settlement | 5 | Informal sector or shacks or roughly built cabins |
| Rural institutional | 6 | Stellenbosch airfield, Elsenburg College, Infrutec (fruit research) |
| Rural commerce and hotels | 7 | Malls, office blocks, hotels |
| Rural industry | 8 | Rural industries such as the Koelenhof industrial area, Distell |
| Mining | 9 | Gravel and clay mining in Koelenhof |
| Recreation | 10 | Sports fields and golf estates |
| Forestry | 11 | Forested areas/plantations |
| Open land | 12 | Natural areas/open land/veld |

Source: Kunneke (1995)

This is a comprehensive and easily applicable system that accommodates different types of land uses common in the study area. The land use classification system by Kunneke (1995) was slightly modified and refined to accommodate the different activities currently taking place in Stellenbosch and its environs. It must be emphasized that the 1994 scheme did not have any errors *per se,* but it was fine-tuned to demarcate the land use classes that were not classified in the land use scheme of 1994.

The Stellenbosch land use classification system was, to some extent, revamped for certain land use classes. No serious shift or amendment of land use types *per se* was made but the land use description was made more meaningful. These land use categories need to be satisfactorily elucidated and some examples are given. The altered land use types are: industrial agriculture was split into livestock agriculture, and nursery and greenhouse production and in the commerce category, hotels were included. Full descriptions of the land use categories are provided below.

### 4.1.1 Perennial, annual and industrial agriculture

Perennial agriculture simply incorporates orchards and vineyards that are preponderant in the study area i.e. wine grapes, olives, peaches, pears and apples. Annual agriculture comprises fresh vegetable production, cereals and grazing land that consist of areas that were ploughed in the past. Industrial agriculture encompasses livestock production which includes cattle farming, chicken farming and pig farming in Koelenhof, nurseries and greenhouse production such as plant nurseries in Lynedoch, and greenhouses and tunnels of strawberries along the R44 road to Somerset West (or south-west in the study area in Figure 1.2).

### 4.1.2 Formal urban development and informal settlements

Formal urban development covers the built-up areas and formal housing developments. Urban land refers to the areas where there is a permanent concentration of people, buildings and other man-made structures and activities. Urban development represents areas in which people reside on a permanent or near-permanent basis. Examples of formal urban development are, inter alia, the town of Stellenbosch, Cloetesville, and Uniepark. Infomal settlements are found in Kayamandi, Cloetesville, Idas Valley and Jamestown. Informal settlements include smallholdings frequently located on the urban fringe i.e. the informal sector housing, shacks or roughly built cabins.

### 4.1.3 Rural institution, rural commerce and hotels, rural industry and extraction

Rural institutional areas include places such as Stellenbosch airfield, Elsenberg College and Infrutec (fruit research). Rural commerce and hotels involve shopping complexes, retail outlets, business offices and hotels. Existing examples of rural commercial activities and hotels are Stellenbosch Square and Protea hotel. These are non-residential areas used primarily for the conduct of retail businesses and services, typically located in the central business district (CBD). Rural industry includes sites where the manufacturing and processing of products and commodities is conducted such as Distell, TechnoPark and the Koelenhof industrial area on the outskirts of the town. Extraction/mining refers to gravel and clay mining in Koelenhof. This involves areas in which mining operations are done and includes both open-cast mines and quarries.

#### 4.1.4 Recreation, forestry and open land

Recreation involves sports complexes and golf-courses such as the Coetzenburg sports complex is a notable example. Golf-courses include the Stellenbosch golf club, De Zalze and Devon Valley golf estates. Forestry comprises the forested areas and plantations as on the slopes of Stellenboschberg, Simonsberg and Jonkershoekberge. Open land and open veld encompass natural areas where vegetation exists and includes Stellenbosch Mountains and Bottelary Hills.

### 4.2 Data analysis

The analysis of data was executed both in ArcGIS's ArcView 3.3 and ArcGIS Arcmap to generate land use maps and IDRISI Kilimanjaro to compute the land use change Kappa Index of Agreement (KIA) statistics. The KIA was developed by Cohen (1960a), as quoted by Lorup (2005) in the field of psychology and psychiatric analysis, but was subsequently adopted by the remote sensing community as a measure of classification accuracy and also used as a tool to indicate the extent of land use change. The KIA is an important index that the cross-classification of two images generates. Such cross-classification mainly compares two images of different dates, commonly applied in land use change detection taken on the same area of land. The objective of the KIA is to evaluate whether areas fall into the same class on the two dates or whether a transformation to a new class has occurred. To calculate the KIA it is necessary for the land use databases to be converted into gridded format for raster manipulation and processing in IDRISI— the raster-based software.

The 1994 and 2004 vector data were rasterised or converted into a grid format in ArcView 3.3 GIS software before they were imported into IDRISI as raster grid layers. From the theme manual in ESRI's ArcView 3.3 GIS software, the land use polygons were converted into a grid with a cell size of 100m x 100m resolution. To export the data source, under the file menu, these 100m x 100m resolution raster grids for both dates were exported as simple raster ASCII files so that they can be opened easily in any software. The ASCII raster file format is a simple format that can be used to transfer raster information between different applications. In IDRISI, these simple ASCII raster files were imported with the arcraster option under the file menu via ESRI formats. In the ArcInfo raster exchange format window, the ArcInfo raster ASCII files were transformed with the output file checked in order to convert the output file from real into integer values. These ASCII files were imported to calculate the KIA in IDRISI.

The KIA measures the relationship between the two input images and aids in evaluating the output image. Its values vary from -1 to +1 after adjustment for change agreement. If the two input images are in perfect agreement (no change has occurred), KIA equals 1. If the two images are totally different, KIA takes the value of -1. If the conversion between the two images happened by chance, then KIA equals 0. To calculate the KIA statistics for each category, in IDRISI software under the GIS analysis menu to cross-tab via change/time series, the 1994 and the 2004 grids were both cross-classified to generate the cross-tabulation matrix with KIA statistics for each land use class. The overall KIA for the change of all the land use categories was also generated. The results of this cross-tabulation are given later after the presentation of the two-date spatial database maps.

Chapter 5 presents the results in detail and discusses the main findings of this research. Firstly, the land use spatial database between the two dates and examples will be identified that were captured during field observation. Secondly, the overall land use change areas in Stellenbosch and its environs will be calculated, analysed and interpreted.

# CHAPTER 5: LAND USE CHANGE RESULTS, CONCLUSIONS AND FUTURE STUDIES

This chapter reports on the spatial land use databases for the two dates of the study period. Maps display spatial features of land use for the two dates and the changed and unchanged areas. The results are also expressed and elucidated using tables generated during the cross-tabulation and photographs taken during the field observations to study land use dynamics.

## 5.1 The maps of two-date spatial database of land uses

The overarching aim of this research was to develop the land use database by mapping the location of the land use categories for the two dates and show their spatial distribution. Figures 5.1 and 5.2 show the location of land use types in 1994 and 2004 respectively. Land use maps of Stellenbosch and its environment reveal that land use changes took place over the ten-year period. Figures 5.1 and 5.2 show an increase in the extent of Stellenbosch and its environs's urban area. Most notable are the north or northeast and south or southwest expansion of the town of Stellenbosch onto the surrounding natural areas and the valuable agricultural land. Figure 5.3 shows the extent of the town of Stellenbosch urban area in 1994 and 2004 respectively. Moving away from the urban area into the rural urban area in Stellenbosch and its environs, the visual comparison indicates that some land use changes took place between 1994 and 2004.

By visual comparison, agriculture did change, but not significantly. Perennial agriculture changed into annual agriculture northeast of the town of Stellenbosch. The map analysis also identified pre-urban and commercial places in the slopes of the Stellenboschberge, Jonkershoekberge and the vineyards in Stellenbosch and its environs. While these places are currently not developed yet, they should be noted as future sites of urban growth, forming part of future urban development. It is also important to point out that most of the urban development took place along the road network and further change will continue as long as there is economic development. To make the map analysis more meaningful, areas of urban development on the maps are represented by numbers and this includes places already existing and those perceived to be future sites of urban growth (Table 5.1). This procedure is adopted to avoid cluttering of the names of places on the maps. Numbers 1, 3, 4, 5, 6, 9, 10, 12, 13, 14, 15 and 16 represents existing locations and numbers 2, 7, 8, 11 and 17 are sites for proposed future developments.

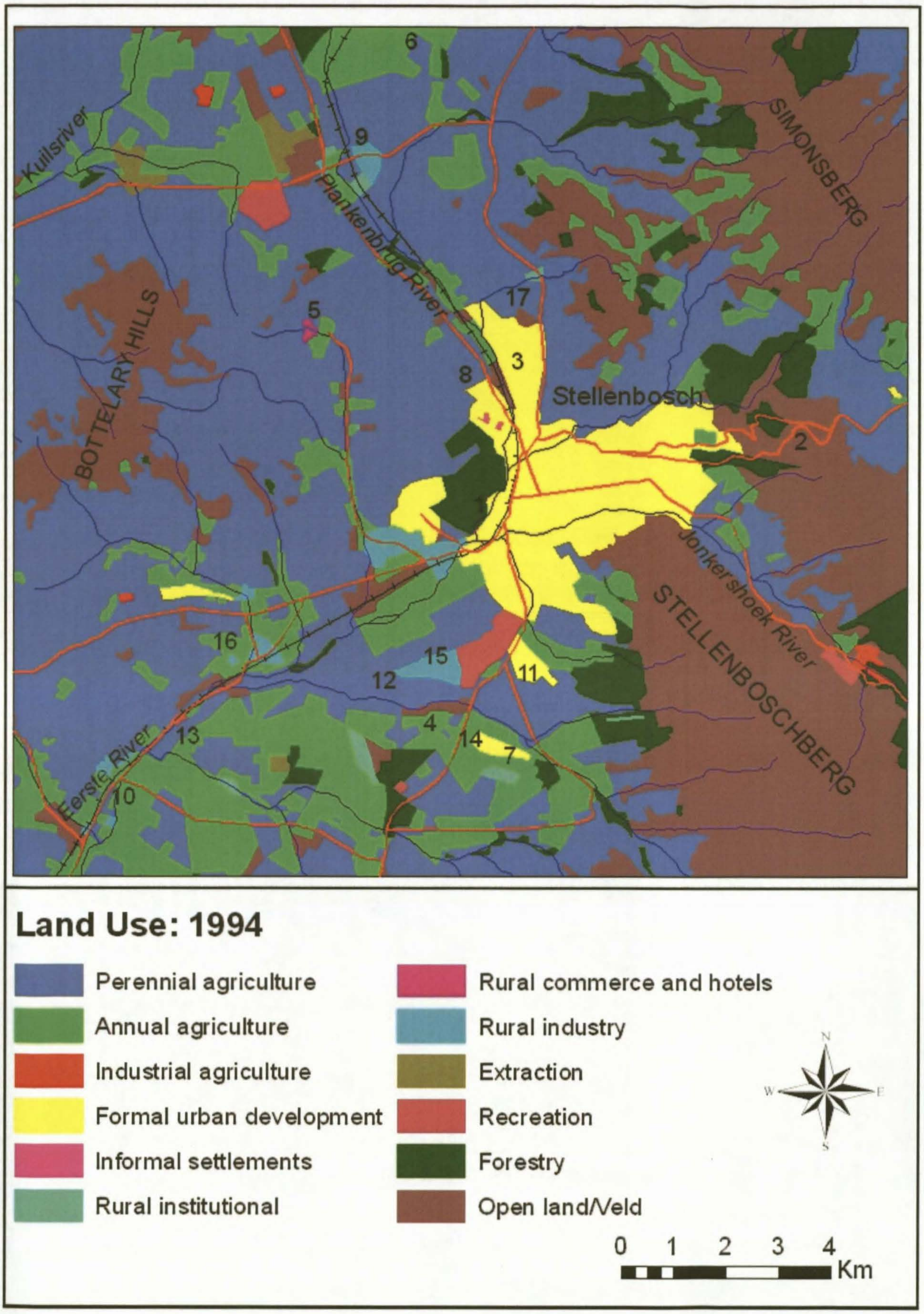


Figure 5.1: Land use in Stellenbosch and its environs: in 1994 according to Kunneke (1995)

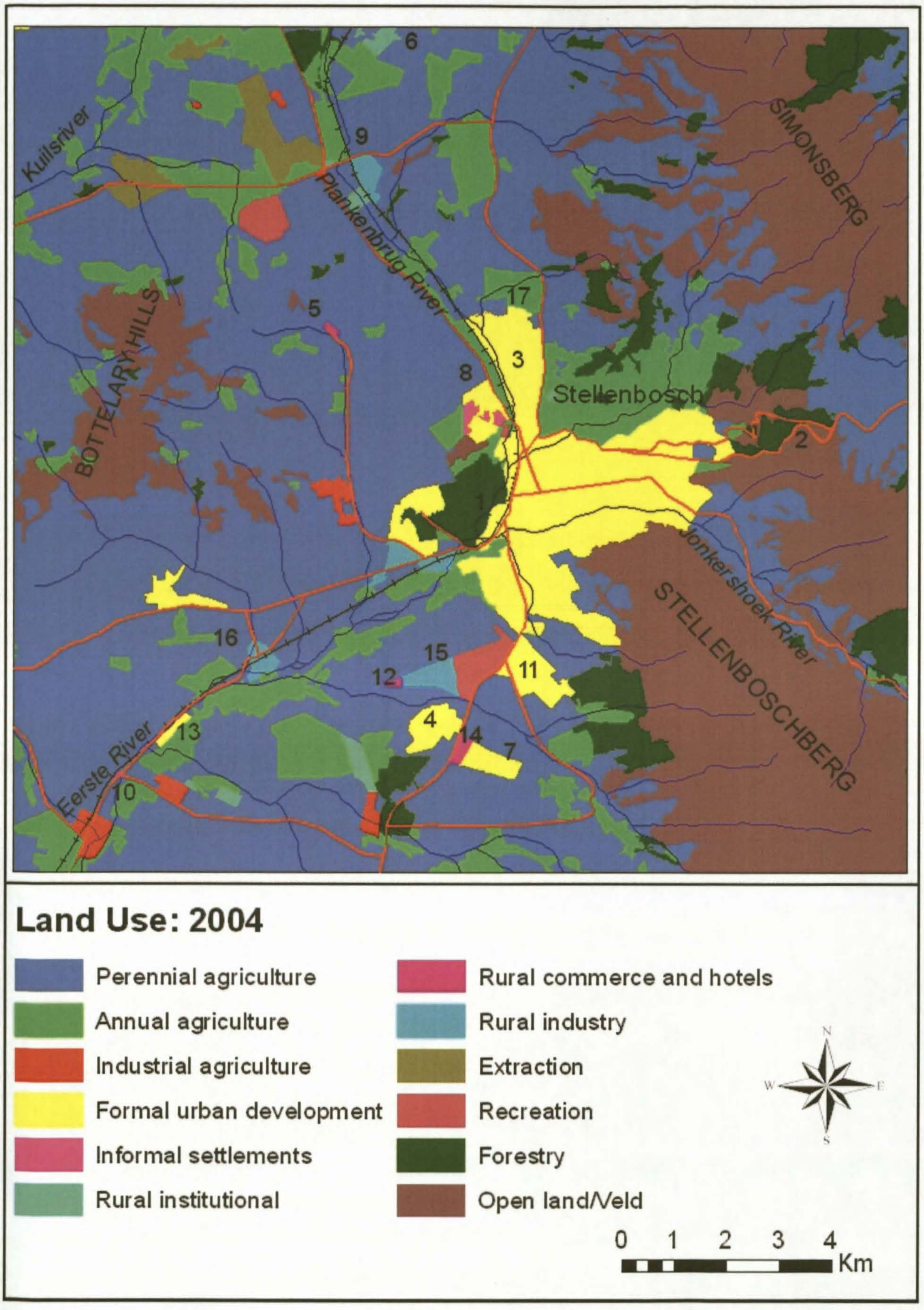


Figure 5.2: Land use in Stellenbosch and its environs in 2004

Table 5.1: Codes for places on the maps

| Code | Features on the map : 2004 | | |
|---|---|---|---|
| 1 | Bosman's Crossing | 10 | Lynedoch |
| 2 | Botmanskop Mountain Resort | 11 | Paradyskloof |
| 3 | Cloetesville | 12 | Protea Hotel |
| 4 | De Zalze Estate | 13 | Spier |
| 5 | Devon Valley | 14 | Stellenbosch Square and Donford Motors |
| 6 | Elsenburg College | 15 | Technopark |
| 7 | Jamestown | 16 | Vlottenburg |
| 8 | Kayamandi | 17 | Welgevonden Estate |
| 9 | Koelenhof | | |

Currently new developments are proposed on locations 7, 8, 11 and 17. While Figures 5.1 and 5.2 provide a picture of change between the two dates, there is a need for a less subjective measure of difference between two maps. Using the raster land use images, qualitative change between 1994 and 2004 will be examined with the cross-tabulation technique and the KIA. The cross-tabulation technique indicates areas where land uses changed and areas where land uses remained unchanged.

## 5.2 Cross-classification of land use categories

The cross-tabulation operation in IDRISI raster-based software via GIS analysis performs two operations: cross-classification and cross-tabulation. Cross-classification entails overlaying two images to produce a new image which shows the combinations of the categories in the original images. A cross-tabulation is produced presenting these groupings with the left-hand categories referring to the map listed as the first date and those on the right referring to the image listed as the second date in the title. In this research the cross-classification images and tables were generated, but it was considered impracticable to include them in the results because the images produced a number of cross-classifications too difficult to understand as there are many land use types involved. The new image produced by cross-classification made no significant contribution because the image had many cross-classifications which were difficult to understand. The new image also generated a legend which showed many cross-classes with little meaning. To make the cross-classifcation image easier to understand, Figure 5.4 shows two images that were generated, one showing where changes took place and the other where land uses have remained the same between the two dates. Visual comparison of Figure 5.4 shows that significant changes did take place in certain areas on both maps.

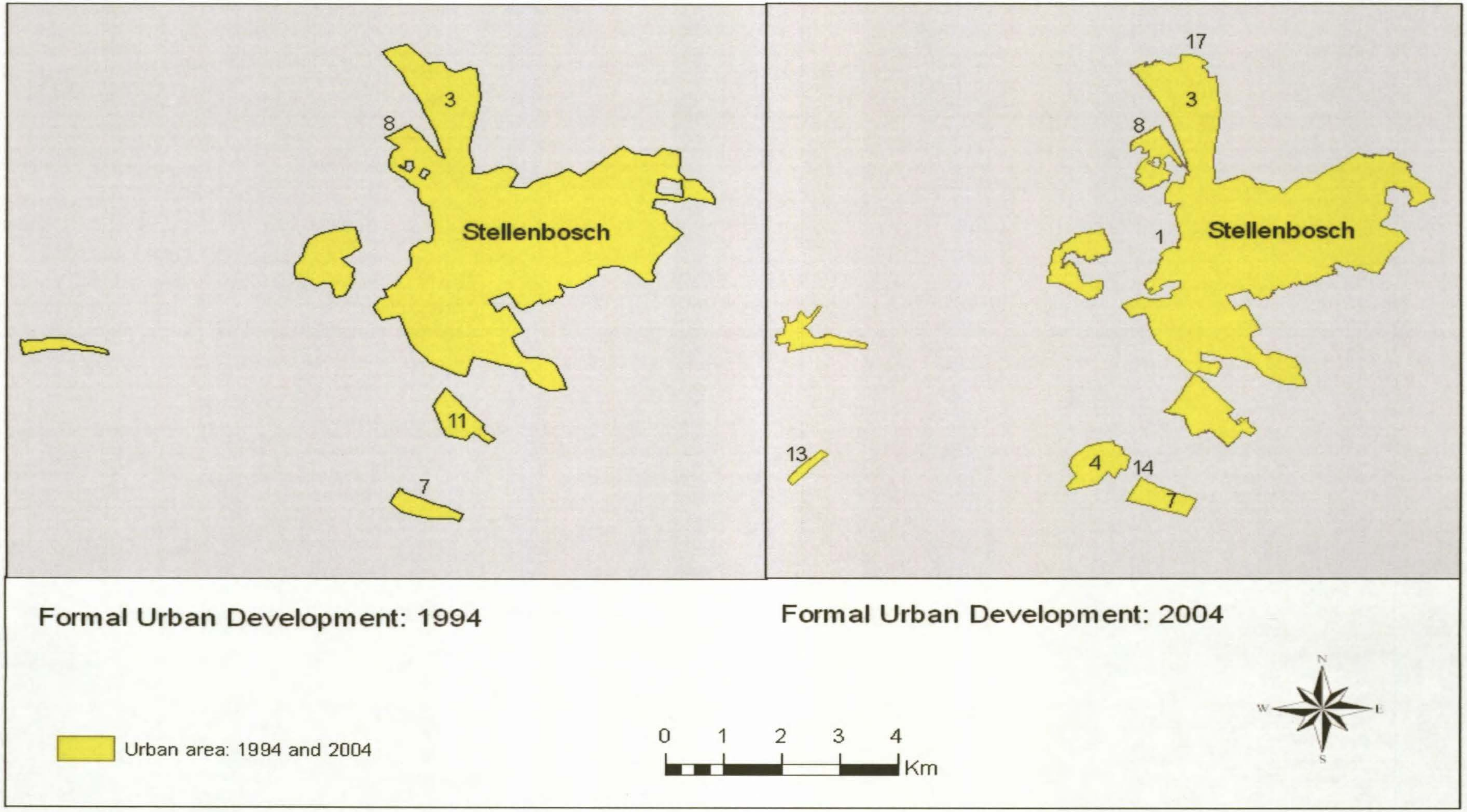


Figure 5.3: Stellenbosch urban areas: 1994 and 2004

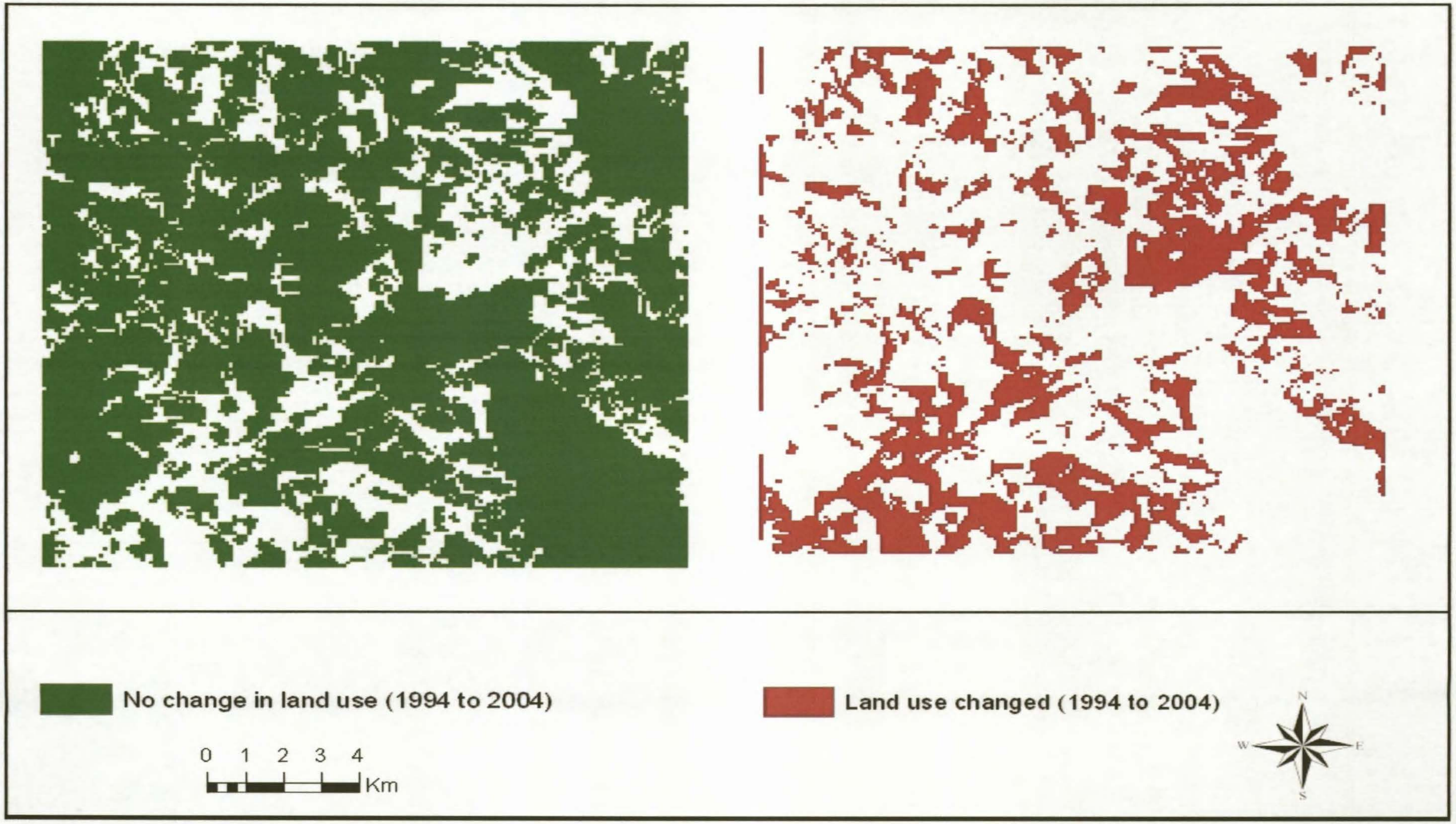


Figure 5.4: Cross-classification image of land use: 1994 and 2004

These changes involve transformation within the agricultural category, which is change from perennial agriculture into annual agriculture. As it has been pointed out earlier, there is also change from perennial agriculture and natural areas into formal urban development and commerce and hotels category. In addition, most of the land use dynamics, as pointed out already, are mostly spatially distributed towards the north and north-east and south or south-west of the Stellenbosch and its environs. Simonsberg, Jonkershoek and Stellenboschberg have remained intact between 1994 and 2004 respectively although future sites of urban growth are foreseen in these open mountainous areas. The land use dynamics will be further discussed in the presentation of land use areas and the overall KIA of change in Stellenbosch and its environs.

### 5.3 Land use computations

As has been discussed earlier, cross-classification is a procedure used to compare two images. Its most common application is land cover/land use change analysis using two-date images taken on the same area of land with the same number of land use categories (Eastman, McKendry & Fulk 1995, Thiam 1998 & Schneider & Pontious 2001). The classification assigns the same unique and distinct identifier to each class on both dates. The cross-classification is carried out by calculating the logical and the possible combinations of classes on the two classified input image datasets. The aim is to assess whether areas fall into the same class on the two dates or whether a change to a new class has occurred. The procedure can be summarized by a cross-tabulation matrix that shows the distribution of image cells between classes. The categories at the first date are displayed on the X axis while the Y axis shows the same categories at the second date. The cells corresponding to stable areas are in the diagonal entries of the matrix.

Off-diagonal entries indicate areas that have changed to new classes. If no change has occurred, all cells for each category would be on the diagonal entries and the off-diagonal entries would have zeros. In the case of change, pixels transform from one category to another. Cross-classification produces a cross correlation image as well as a cross-tabulation table both of which can be used to produce a change image. The output table of cross-tabulation simply counts and sorts category combinations. In other words, cross-tabulation results in a table showing the numbers of cells classified as belonging to the land use categories in each image with cell totals provided.

The cross correlation image shows all possible category combinations. It can be used to produce two types of change images according to the objective of the study. First, in this research, the cross correlation image is used to differentiate overall changed areas and overall non-changed areas.

Second, the objective of the analysis was to identify which classes on the first date (1994) has changed to other classes on the second date (2004) and the area involved. In this study, the change image displays all categories on Date 1 and Date 2 except those that have not changed. The KIA, on the other hand, is an essential index that the cross-classification produces. It measures the relationship between the two input imagery and aids to assess the output representation. Its values range from -1 to +1 after adjustment for chance agreement. If the two input images are in perfect agreement or no change has occurred, KIA equals 1. If the two images are completely different, KIA takes a value of -1. If the change between the two dates occurred by chance, then KIA equals 0. KIA is an index of agreement between the two input images and it also evaluates a per-category agreement by indicating the degree to which a particular land use type agrees between two dates.

A cross tabulation matrix that shows land use area that fall with each land use category on the one time periods was generated. This matrix helped illustrate the area of each land use class as 1 pixel unit equals to 1ha (100m X 100m). Given that errors are likely to occur in any change detection study because of changes in pixel values due to different conditions related to data availability and classification accuracy. In this study the KIA values generated with the cross tabulation matrix made easier to calculate the area of land use categories. In addition, the overall KIA generated with the cross tabulation matrix will indicate if the two images are in agreement with each other. KIA less than 0.70 is negative i.e. it indicates that the two images are not in agreement and are totally different in terms of the area of the land use classes. KIA of 0.70 or more indicates that the two images are in agreement, not really different to each other. KIA's of each land use class were difficult to interpret because the combinations of 144 pairs (12 X 12 land use classes) made unease to determine the land use changes. However, the overall KIA of all the land use classes was much better to interpret if using the KIA criteria developed by Eastman, McKendry & Fulk (1995).

Table 5.2 shows that land use changed over the period from 1994 to 2004 in Stellenbosch and its environs. Table 5.2 in essence illustrates the land use areas rate and extent generated during the cross classification process. In this study as 1 pixel unit is equal to 1 ha, therefore the area of land use classes is easily illustrated. From 1994 to 2004, annual agriculture, rural institutional, rural industry, recreation, forestry and open land/veld decreased by 32.5 per cent, 6 per cent, 34.3 per cent, 25.4 per cent, 16.2 per cent and 6.4 per cent, respectively. In contrast, perennial agriculture, industrial agriculture, formal urban development, informal settlements, rural commerce and hotels and extraction increased by 14.2 per cent, 191.3 per cent, 7.8 per cent, 566.7 per cent, 140 per cent and 100.80 per cent, respectively. Practically speaking, the areas of rural institutional and rural industry were stable within these two dates although the computation of area shows that changes took place in these categories. The recreational areas actually increased between 1994 and 2004. To a large extent, land use change from 1994 to 2004 was characterized by a replacement of agriculture with urban development, rural commerce and hotels and informal settlements. It is clear that instead of agricultural land being converted into economic and residential development, in the near future open land/veld will also be transformed due to urban development.

Table 5.2 Land use: 1994 and 2004

| | | 1994 | 2004 | 1994-2004 | |
|---|---|---|---|---|---|
| **ID** | **Land use categories** | **Area (ha)** | **Area (ha)** | **Change per category (ha)** | **Change per category (%)** |
| **1** | Perennial agriculture | 12740 | 14549 | 1809 | 14.2 |
| **2** | Annual agriculture | 4117 | 2781 | -1336 | -32.5 |
| **3** | Industrial agriculture | 46 | 134 | 88 | 191.3 |
| **4** | Formal urban development | 1658 | 1788 | 130 | 7.8 |
| **5** | Informal settlements | 3 | 20 | 17 | 566.7 |
| **6** | Rural institutional | 83 | 78 | -5 | -6 |
| **7** | Rural commerce and hotels | 10 | 24 | 14 | 140 |
| **8** | Rural industry | 242 | 159 | -83 | -34.3 |
| **9** | Extraction | 124 | 249 | 125 | 100.9 |
| **10** | Recreation | 197 | 147 | -50 | -25.4 |
| **11** | Forestry | 1589 | 1331 | -258 | -16.2 |
| **12** | Open land/veld | 7071 | 6620 | -451 | -6.4 |
| | | **27880** | **27880** | | |

From 1994 to 2004, the reduction of forested areas was mainly due to harvesting (and no replanting of pines) and forest fires. The impact of harvesting and fires mostly accounted for the reduction of forested land in the same manner that economic and residential development changed agricultural land. The mountainous areas have remained relatively stable but they are possible future sites of urban growth given the proposed Paradyskloof golf estate and the Botmanskop mountain resort. It should be worrying because these possible future sites of urban growth are located in sensitive fynbos mountainous areas. In terms of sustainable land resource management, the conversion of uneconomical, non-viable agricultural land into feasible practicable use such as residential development, tourism development, recreation etc. is important. The principles of sustainable land resource management are that development should be environmentally friendly, socially accepted and economically sound. It is therefore important to comprehend those optional developments on non-viable agricultural land or land that was never utilised for agricultural activities and that can provide the best practicable environmental alternative. The principle of sustainable land resource management is development on a sustainable manner which depends on good environmental practices.

The issue of development in the natural open veld is a controversial problem which requires those involved in conservation, forward planning and future development to think carefully about the implications of such developments. For instance, the proposed Paradyskloof golf estate and the Botmanskop mountain resort are totally unacceptable in a beautiful mountains panorama. The proposed land use changes are triggered by the increasing demand for non-agricultural land and demand for urban and residential development. As such rapid urban growth is a very important factor for land use change in Stellenbosch and its environs. The direct result of land use change is the reduction of agricultural land by increasing urban and commercial development. The increasing loss of agricultural land into informal settlements is also another crucial factor for land usage.

Urbanization is very common in the developing countries in that there is a need for residential development to shelter the growing numbers of the population in urban areas. Most often these people do not have the means for formal housing and usually opt for informal housing to meet their need. The situation is no different in Stellenbosch and its environs in that many people do not afford formal residential housing. As such informal settlements are characterised by a high density of small, shelters built from varied materials. They usually lead to the degradation of the local ecosystem that sometimes involves soil erosion, floods and landslides because of unstable areas. They are also characterised by severe social problems such as the unavailability of service infrastructure such as water, sanitation, electricity and the high rate of crime. The area where informal settlements expanded in Stellenbosch and its environs mostly involves agricultural areas around Kayamandi. These informal settlements are quite often, but not always, occupying areas where formal residential development will ultimately take place. In addition, these unplanned settlements threaten ecological systems in the natural areas and open veld. The informal settlements form one of the factors that exerts pressure on the agricultural and natural environment that lie beyond Stellenbosch and its environs. They increased alarmingly (566.7%) from 1994 to 2004 and just as population increases rapidly in urban areas perhaps ten years later from 2004 the current pattern may lead to a severe problem facing the local authority.

In Table 5.2, the area of the land use classes is calculated and differences between the land use classes have also been computed. Table 5.2 examines the perennial category further, the 12740 ha (45.7%) area identified as perennial agriculture in 1994 increased by 1089 ha (14.2%) to 14549 ha (52.2%) in 2004. Annual agriculture covered 4117 ha (14.8%) and 2781 ha (10%) in 1994 and 2004 respectively, and decreased by 1336 ha (32.5%). The area of industrial agriculture increased by 88 ha (191.3 %) comprising 46 ha in 1994 (0.2%) and 134 ha (0.5%) in 2004. Industrial agricultural activities did not really increase from 1994 to 2004 but this land use type has been modified with plant nurseries and strawberry tunnels. The area of formal urban development increased by 130 ha (7.8%) between the two dates, comprising 1658 ha (5.9%) in 1994 and 1788 ha (6.4%) in 2004. The area of informal settlements increased by 17 ha (566.7%) between the two dates comprising 3 ha (0.01%) in 1994 and 17 ha (0.1%) in 2004. The informal sector indeed is developing very quickly even though drastic measures are undertaken to curb this trend.

The rural institutional land use decreased by 5 ha (6%) comprised 83 ha (0.3%) in 1994 and 78 ha (0.3%) in 2004 indicating that no institutions were constructed between the two dates. The rural commerce and hotels land use covered 10 ha (0.03%) in 1994 and increased to 24 ha (0.1%) in 2004 making an increase of 14 ha (140%). As mentioned earlier, this category has been modified and no reliable comparison can be made between the two dates. As stated before rural industry should be considered with caution because no industries recorded have been developed nor demolished between the two dates. The rural industry land use comprised 242 ha (0.9%) in 1994 and 159 ha (0.6%) in 2004. The area of extraction land use increased by 125 ha (100.9%), comprising 124 ha (0.4%) in 1994 and 249 ha (0.9%) in 2004.

The area of recreational activities have increased from 1994 to 2004 even though this category decreased by 50 ha (25.4%) from 197 ha (0.7%) in 1994 to 147 ha (0.5%) in 2004. The logical explanation for the difference in this category involves the land use class definitions used by two different interpreters in 1994 and 2004. The area of forestry land use decreased by 258 ha (16.2%) comprising 1589 ha in 1994 (5.7%) and 1331 ha (4.8%) in 2004. This decrease is attributed to harvesting and forest fires that characterise the Western Cape including Stellenbosch and its environs during the summer period. Open land/veld comprised 7071 ha (25.4 %) in 1994 and 6620 ha (23.7 %) in 2004 making a decrease of 451 ha (6.4%) between 1994 and 2004. Open land/veld did not really decrease between 1994 and 2004 but the limitations and constraints imposed by the mapping scale, the two different cartographical databases. In addition, the land use class definitions developed by two different researches in 1994 and 2004, as mentioned before, explains the differences for the change of this category.

### 5.3.1 Land use Kappa Index of Agreement (KIA) statistics

Table 5.3 demonstrates the KIA statistics of land use categories in 1994 and 2004 respectively. The KIA values in Table 5.3 were generated by the computer and were slightly modified to include column: change 1994 to 2004, to make the results more meaningful. The KIA shows that perennial

Table 5.3: Per category and overall Kappa Index of Agreement statistics

| Land use categories | KIA 1994 | KIA 2004 | Change 1994 to 2004 |
|---|---|---|---|
| Perennial agriculture | 0.30 | 0.34 | + 0.042 |
| Annual agriculture | 0.10 | 0.07 | - 0.031 |
| Industrial agriculture | 0.00 | 0.00 | + 0.002 |
| Formal urban development | 0.04 | 0.04 | + 0.003 |
| Informal settlements | 0.00 | 0.00 | + 0.000 |
| Rural institutional | 0.00 | 0.00 | - 0.000 |
| Rural commerce and hotels | 0.00 | 0.00 | + 0.000 |
| Rural industry | 0.01 | 0.00 | - 0.002 |
| Extraction | 0.00 | 0.01 | + 0.003 |
| Recreation | 0.00 | 0.00 | - 0.001 |
| Forestry | 0.40 | 0.03 | - 0.006 |
| Open land/veld | 0.17 | 0.16 | - 0.011 |
| **Overall KIA 0.7459** | | | |

agriculture increased by 0.042 between the one time period of two dates, comprising 0.30 in 1994 and 0.34 in 2004. Annual agriculture decreased by 0.031 representing 0.10 in 1994 and 0.07 in 2004. Industrial agriculture remained stable from 1994 to 2004 representing 0.00 respectively. This category is not comparable because the 2004 dataset was modified by adding tunnels and greenhouses. Formal urban development increased by 0.003 from 1994 and 2004 although it comprises 0.4 for the two dates respectively. The informal settlements category remained the same in 1994, comprising 0.00 in 1994 and 2004 respectively. Thus informal settlements do not really give a good indication of the growth of informal settlements because they comprised a very small portion in relation to the other land use classes. In a similar vein, rural institutional land use area remained more or less the same from 1994 to 2004, comprising 0.00 in 1994 and 2004 respectively.

The commercial and hotel category changed from 1994 to 2004 despite that it comprises 0.00 for the two dates respectively. The hotels were not part of the commerce land use activities in 1994. The hotels were classified as a component of the recreational category in 1994 hence making it difficult comparatively in 1994 and 2004 databases. In a similar manner, no new industries were developed in Stellenbosch and its environs despite that this land use category decreased by 0.002 comprising 0.01 and 0.00 in 1994 and 2004 respectively. The extraction category increased by 0.003 in Stellenbosch and its environs, comprising 0.00 and 0.01 in 1994 and 2004 comparatively. The growth of urban areas and urbanization increases the demand for bricks and the very process of the establishment of brick kilns and the manufacture of bricks degrades both land and environment and forces the farmers to shift their land from agricultural to non-agricultural uses.

The recreational land use, similarly to rural commerce and hotels category, is not comparable because of omission of hotels in the 2004 dataset. The hotels which were originally classified under the recreational land use were classified under the commerce category in the 2004 dataset. Deforestation took place by 0.006 from 1994 and 2004 and forestry land use comprising 0.40 in 1994 and 0.03 in 2004. Open land/veld also decreased by 0.011 representing 0.17 and 0.16 in 1994 and 2004 respectively. Open land/veld has did not really changed from 1994 to 2004 but sites of future urban development are foreseen in the inaccessible sensitive mountainous fynbos areas. The overall KIA value indicates that land use change took place from 1994 to 2004 despite the fact that the two cartographic databases are not completely in disagreement.

Cohen (1960b)'s interpretation criteria of the KIA is as follows: KIA less than 0.70 indicates that the two images are not in agreement. In other words, the overall KIA statistic generated during the cross classification process of this study is 0.7459. That means the two images are in agreement although the images were not aligned or overlaid perfectly. In other words no serious changes took place from 1994 to 2004 but areas of future urban growth pose a great concern. These pre-urban future sites of urban growth are mostly proposed in sensitive natural environments. The KIA values of each land use category are presented because they support the land use computations of area from 194 to 2004. The cross tabulation matrix assisted to calculate the area of each land use class from the 1994 and 2004 imagery. However, no remote sensing study does not have shortcomings, because the two datasets were developed and classified by different researchers who applied their dissimilar approaches to map land usage from 1994 to 2004.

The cross-classification procedure seems to be a suitable method of undertaking a classification accuracy assessment as well as assess changes that have occurred in the land usage between two dates. The change assessment can be done using either of the outputs of the cross-classification, the cross-classification images and the cross-tabulation table. The cross-classification image is a qualitative output that shows spatial distribution land usage change. In contrast to the cross-classification image, the cross-tabulation table is a quantitative output. It provides the possibility to quantify the changes from the classification matrix which shows how much of a given land usage type has transformed into which class/es. The KIA generated with the table is also a quantitative means of evaluating the land use changes. The KIA can be used whenever the land use classes of two-date images must be evaluated for change. It provides change agreement for the two images as whole and per category change agreements.

The results presented and analysed above shows that some land which is currently under agricultural practices is likely to shift to non-agricultural uses. Rapid growth of urbanization indicates that the pressure on land for non-agricultural practices is increasing. There are major developments that are proposed future sites of urban growth on high mountain slopes in Stellenbosch and its environs. This is exactly what James (2001) found; that the erection of buildings and other structures on mountain slopes is a significant problem in the Boland region. These developments will have serious environmental implications on the agricultural and natural areas which lie outside the urban environment. The golf course developments, for example, are not popular for their high water consumption. The planned Paradyskloof golf course may imply serious environmental problems for the area of study, not least the water resources and natural vegetation. This proposed golf course development can be contradictory to sustainable development with development on environmentally sensitive land, high on the mountain overlooking Stellenbosch and its environs. Similarly, the Botmanskop mountain resort is also proposed in a highly vulnerable area in terms of environmental conservation. This mountain resort will be located in an area where there is sensitive natural vegetation, water resources and land which has a potential for grape production. Given the above discussions it is time to stop unsustainable developments and think very carefully about the developments that will riddle our already threatened environmental heritage.

### 5.4 Evaluation of land use results and future applications

The results obtained in this research succeed in achieving the overarching aim of the study, namely to determine the rate, extent and pattern of land use change in Stellenbosch and its environs. The accuracy, level of generalization and information content of the mapped landscape presented in the study are defined by the limitations and constraints imposed by the mapping scale, the two different geographical databases and the land use class definitions used by two different interpreters, for the datasets. The study's research area differs from the one demarcated for the 1994 baseline study. The cartographic and geographical databases that were used were developed with different research methodologies and the 1994 land use categories were somewhat refined to accommodate the present study. However, the constraints obtained in this study should not be considered as a limitation.

This research ascertained that land use did not change significantly between 1994 and 2004 but land use changes in the categories have been identified in this research. This research was based on the premise that urban areas are dynamic environments, hence there is a need to develop the cartographic and geographic databases to enable city planers to develop policies that take into account the nature of that change. A number of new commercial and urban developments were mapped and those areas include the following: first, residential development in the Welgenvonden Estate, Kayamandi, Technopark et cetera, is encroaching towards the agricultural and natural environment. Secondly, the Stellenbosch Square, Donford garage, Protea hotel and De Zalze estate (geographically scattered residential development) forms one of the interesting developments in and around Stellenbosch. Thirdly, although the informal settlements are destructed, paving the way to formal housing development in Kayamandi, these informal settlements increased rapidly between 1994 and 2004. Fourth, it is time to take a closer look at the developments that are proposed for future urban growth and see if the present changes of land usage in Stellenbosch and its environs are in line with the principles of what I will call sustainable urban growth development.

The process of urban growth and expansion will probably never stop as long as population growth and urbanisation occur. The greater the population of Stellenbosch the more the need will be for resources, which in turn promotes land use transformation. This is why a pressing need exists to detect land use dynamics in and around Stellenbosch to develop ways to conserve the natural environment. There is an increasing need to determine the impacts and extent of change in the rural-urban fringes that lie beyond the urban environment of our towns and cities. In order to develop a sustainable urban environment for Stellenbosch there is a need for regular, accurate and up-to-date information on land use and land cover in and around the town. This regular up-to-date information will enable forward planning for sustainable future urban growth sites in Stellenbosch and its environs.

There is increasing interest by the remote sensing community in advanced technologies. The object-orientated remote sensing approach, as opposed to the pixel-based approach is becoming an important method of examining land use and land cover change by developing and classifying aerial photographs and satellite images. The literature suggests that eCognition, the object-orientated remote sensing method, has capabilities which need to be developed further. Methodological challenges are unfolding in object-based image analysis and standard pixel-based techniques of change detection are no longer satisfactory. The advanced object-orientated remote sensing describes objects in terms of shape, tone, boundary and topological information instead of relying on traditional basic image processing concepts developed in the 1970s, that is per-pixel classification of land use classification.

There is a need of information on the environmental effects of urban growth and such information is necessary for a better understanding of the sustainability of urban environmental practices, both deliberate and unplanned. There is need to ascertain where land cover and land use are changing, what the nature of the change is and over what time scale it is occurring. It is also necessary to establish the causes and consequences of land cover and land use change in relation to climate change. The challenge to develop and implement land use planning that balances competing interests, that is, the conservation of nature and sustainable environmentally friendly economic development, is a vital concern.

[Word count 17 649]

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