SPATIAL TECHNOLOGY AS A TOOL TO ANALYSE AND COMBAT CRIME

By

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I declare that

SPATIAL TECHNOLOGY AS A TOOL TO ANALYSE AND COMBAT CRIME is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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Corné Eloff Date

KEYWORDS

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Ecological theory
Electromagnetic energy
Geographical Information Systems
High density residential
House Burglaries
Hyperspectral
Informal Settlements
Land use classification
Light detection and ranging (LiDAR)
Low density residential
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Mapping
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Orbital science
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EXECUTIVE SUMMARY

This study explores the utilisation of spatial technologies as a tool to analyse and combat crime. The study deals specifically with remote sensing and its potential for being integrated with geographical information systems (GIS). The integrated spatial approach resulted in the understanding of land use class behaviour over time and its relationship to specific crime incidents per police precinct area.

The incorporation of spatial technologies to test criminological theories in practice, such as the ecological theories of criminology, provides the science with strategic value. It proves the value of combining multi-disciplinary scientific fields to create a more advanced platform to understand land use behaviour and its relationship to crime.

Crime in South Africa is a serious concern and it impacts negatively on so many lives. The fear of crime, the loss of life, the socio-economic impact of crime, etc. create the impression that the battle against crime has been lost. The limited knowledge base within the law enforcement agencies, limited logistical resources and low retention rate of critical staff all contribute to making the reduction of crime more difficult to achieve.

A practical procedure of using remote sensing technology integrated with geographical information systems (GIS), overlaid with geo-coded crime data to provide a spatial technological basis to analyse and combat crime, is illustrated by a practical study of the Tshwane municipality area. The methodology applied in this study required multi-skilled resources incorporating GIS and the understanding of crime to integrate the diverse scientific fields into a consolidated process that can contribute to the combating of crime in general.

The existence of informal settlement areas in South Africa stresses the socio-economic problems that need to be addressed as there is a clear correlation of land use data with serious crime incidents in these areas. The fact that no formal cadastre exists for these areas, combined with a great diversity in densification and growth of the periphery, makes analysis very difficult without remote sensing imagery. Revisits over time to assess changes in these areas in order to adapt policing strategies will create an improved information layer for responding to crime. Final computerised maps generated from remote sensing and GIS layers are not the only information that can be used to prevent and combat crime. An important recipe for ultimately successfully managing and controlling crime in South Africa is to strategically combine training of the law enforcement agencies in the use of spatial information with police science.

The researcher concludes with the hope that this study will contribute to the improved utilisation of spatial technology to analyse and combat crime in South Africa. The ultimate vision is the expansion of the science of criminology by adding an advanced spatial technology module to its curriculum.

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Crime in South Africa is a serious concern and impacts negatively on so many lives. The fear of crime, the loss of life, the socio-economic impact of crime, etc. all creates the impression that the battle against crime has been lost. The limited knowledge base within the law enforcement agencies, limited logistical resources and low retention rate of critical staff all contribute to the difficulty of reducing crime.

This study introduces remote sensing technology integrated with geographical information systems (GIS) that are overlaid with geo-coded crime data to provide a spatial technological basis to analyse and combat crime in an improved scientific way. The methodology applied in this study requires a multi-skilled resource consisting of remote sensing, GIS and the understanding of crime to allow the diverse scientific fields to be integrated into a consolidated process that can contribute to the combating of crime in general.

This study is based on a solid platform of knowledge of the core criminological theories and how to apply the theory in practice through the integration of spatial technologies for visual illustration. Criminology is the scientific approach of the study of criminal behaviour (Siegel 2003:4). Criminology explains the etiology (origin), extent and nature of crime in society. In the researcher's view, natural science, with the stress on geomatics, combined with criminological principles to explain the relationship between human behaviour (land use) and criminal behaviour, will provide a significant contribution to the science of criminology. Ecological theories of crime in particular have contributed to this study and are highlighted in the practical exercise described in Chapter 4.

For the practical application in this study, the Tshwane municipality boundary was selected as it has an urban characteristic and fits the concentric zones described by Shaw and McKay in the ecological theory of criminology (Siegel 2003:184).

In summary this study emphasises criminological theories, specifically their ecological dynamics. The basic scientific principles of remote sensing and temporal analysis using a combination of multi-sensors and geographical information systems (GIS) are explained. The relevance of spatial technology to the analysis and combating of crime is proved. Recommendations to integrate this technology within the law enforcement agencies conclude the study.

1.2 DEFINITIONS

1.2.1 Criminology

Criminology is the scientific study of criminal behaviour and explains the etiology (origin), extent and nature of crime in society. It is essentially an interdisciplinary science, incorporating mostly sociology, but also criminal justice, political science, psychology, economics and the natural sciences (Siegel 2003:4).

1.2.2 Criminological theories

Theoretical criminology is a sub-field of general criminology, which describes crime and its occurrence, and posits explanations for criminal behaviour (Schmalleger 1999:19).

1.2.3 Crime

Crime is an intentional act in violation of criminal law committed without defence or excuse, and is penalised by the state as a felony or misdemeanour (Brown, Esbensen & Geis 1998:18).

1.2.4 Criminologist

A criminologist is one whose professional training, occupational role and pecuniary reward are primarily concentrated on a scientific approach to, and study and analysis of, the phenomenon of crime and criminal behaviour (Howitt 2002:8).

1.2.5 Murder

The unlawful killing of one human being by another with malice aforethought constitutes murder (Brown *et al.* 1998:425).

1.2.6 Burglary

Burglary is generally defined as a crime against a dwelling. A burglar is a person who breaks and enters the dwelling house of another with the intent to commit a felony therein (Brown *et al.* 1998:473).

1.2.7 Robbery

Robbery is the felonious taking of money or goods of value with intent to steal from the person of another, or in his presence, against his will, violence or putting in fear (Brown *et al.* 1998:37).

1.2.8 Rape

The definition of rape has expanded in scope from just a violent crime against a female to a violent crime that includes homosexual rape, sexual assault of females upon males, and forced sexual activity other than penile-vaginal intercourse (Brown *et al.* 1998:440).

1.2.9 Electromagnetic energy

Electromagnetic energy is a dynamic form of energy that is caused by oscillation or acceleration of an electrical charge (Avery & Berlin 1992:5).

1.2.10 Electromagnetic radiation

Electromagnetic radiation (EMR) is electromagnetic energy in transit that can be detected only when it interacts with matter. It travels in a straight path at the speed of light across empty space and only slightly slower in the atmosphere (Avery & Berlin 1992:5).

1.2.11 Remote sensing

Remote sensing is defined as the technique of obtaining information about objects through the analysis of data collection by special instruments that are not in physical contact with the objects of investigation. As such, remote sensing can be regarded as reconnaissance from a distance (Avery & Berlin 1992:1).

1.2.12 Spatial Technology

The technologies related to study, analysis, processing, modelling, simulation, visualisation and capturing of spatial features are called the spatial technologies (for example, GIS, GPS, Satellite Imagery, RADAR imagery, Aerial Photography, etc) (Chetty 1991:34).

1.2.13 Crime analysis

Effective crime analysis employs data mining, crime mapping, statistics, research methods, desktop publishing, charting, presentation skills, critical thinking, and a solid understanding of criminal behaviour. In this sense, a crime analyst serves as a combination of an information systems specialist, a statistician, a researcher, a criminologist, a journalist, and a planner for a law enforcement agency (Osborne, Deborah & Wernicke 2003:12).

1.2.14 Crime combating

Combat, or fighting, is purposeful violent conflict between two or more persons or organizations, often intended to establish dominance over the opposition. Combat violence can be unilateral, whereas fighting implies at least a defensive reaction. Crime combating is therefore the fighting of crime by law enforcement agencies as a defensive reaction against criminal behaviour (Osborne *et al*. 2003:34).

1.3 STATEMENT OF THE PROBLEM

The utilisation of spatial technologies by South African law enforcement agencies is very limited. There is a lack of details of the training of police officials and case studies that include science and relate to remote sensing and GIS. It is believed that the basic elements of the natural sciences can contribute to the knowledge base of crime analysts and crime investigators. The understanding of the environmental profile of a police precinct can also assist the station commissioner to implement improved policing strategies to curb crime in the area.

The current information systems of the SAPS (South African Police Service) lack remote sensing information layers and historical information layers with regard to the ever-changing land use class portfolios within each police precinct. The different socio-economic classes and population density changes have a direct impact on the crime portfolio within an area. Station commissioners require a policing strategy which is distinctive for his/her own police precinct as opposed to a generic policing strategy.

The literature reviewed during this study applies primarily to case studies based in the United States and Europe. There is a lack of material on remote sensing technology and GIS used to analyse crime in South Africa. The availability of remote sensing data, geo-coded crime data and advanced GIS information layers in South Africa offers a new opportunity in the science of criminology to adopt these technologies in future empirical and qualitative studies.

The problem statement is a scientific approach based on 12 years' personal experience of dealing with crime intelligence, remote sensing and GIS. This study is ground breaking work and the start of a new body of literature that will help capacity building in law enforcement agencies in South Africa in particular.

1.4 RESEARCH AIMS AND OBJECTIVES

The primary research aim is to determine whether remote sensing technology can contribute to the science of criminology as a spatial tool to better analyse and understand crime within a specific area.

The objectives of this study are to:

- Introduce the basic science of remote sensing.
- Integrate spatial technology into specific criminological theories.
- Apply remote sensing, GIS and crime data into a practical case study to illustrate the integration potential of these technologies.
- Illustrate the relationship between specific land use classes, their behaviour over a remote sensing time series and certain serious crime types, e.g. murder, vehicle hijacking, house burglaries and rape.
- Contribute to the science of criminology by introducing new spatial technologies that can contribute to the reduction of crime.

1.5 METHODOLOGY

1.5.1 Selection of study area

The selection of the study area required the following specific criteria to be fulfilled (see sections 1.6, 4.2, 4.3 and 4.5):

- Diverse socio-economic classes (heterogeneous).

- Availability of a well represented remote sensing time series in the medium and very-high resolution categories.
- Validated geo-coded crime data in a time series must be available over the whole study area.
- The area must consist of high levels of different types of serious crime.
- The selected area must consist of a number of police precinct areas
- The study area must fit a formal geographic boundary such as a municipality boundary.
- Availability of macro and micro land use classification layers are essential and need to be mapped if not available.

The above-mentioned criteria correspond with the Tshwane municipality area that was selected for this study. It has a heterogeneous socio-economic profile, efficient remote sensing time series are available, high number of crime incidents exist and classification data over this area is accurate (see sections 1.6.1.1 and 4.2).

1.5.2 Spatial analysis techniques

The methodology used to apply spatial analysis techniques to understand the relationship between specific land use behaviour and crime types can be divided in three categories. These categories provide the understanding necessary to appreciate the significance of spatial technology in controlling crime with perhaps the ultimate objective of preventing crime. These categories are described below.

1.5.2.1 GIS project management

- Step 1: Identification of objectives
- Step 2: Project database creation
- Step 3: Data analysis and modelling
- Step 4: Presentation of results

1.5.2.2 Macro analysis

This study uses the post-classification technique, which was identified as the most suitable for detecting land cover change (Weismiller, Kristof, Scholz, Anuta & Momin 1977:1533). In the post-classification technique, multi-temporal images are independently classified (Jensen 1981:130, Jensen & Toll 1982:630, Singh 1989:995, Jensen 1996:316, Yuan & Elvidge 1998:170). The classified images are then combined to create a new change image classification, which indicates the changes that have occurred. However, it should be noted that the iterative nature of image classification and post-classification techniques allow further refinement in order to produce more reliable change detection results. Construction of the change detection model consists of the following steps:

- data collection
- pre-processing of remotely sensed data
- image classification using appropriate logic
- change detection using GIS algorithms
- post-classification assessment and distribution of results.

1.5.2.3 Micro analysis

Up-to-date high-resolution digital ortho-rectified aerial photography (1:3 000) and satellite imagery (SPOT 5) were used as the primary reference datasets to collect point layers from the imagery.

Detailed updates (e.g. new house counts) were generated primarily from aerial photography. SPOT 5 imagery was used if suitable photographs were not available. It has been demonstrated that house counts can be updated from SPOT 5 imagery if used in conjunction with erf cadastre boundary data (Sevenhuysen 2004:6). Individual data points for each building structure in formal residential areas (including formal township areas) were utilised in the analysis. The urban growth data layer was derived from two (or more) residential dwelling point counts, and provides a quantitative indication of the number of new dwellings that have been built in a specific area within a certain time period.

Growth information is provided for both formal residential areas (including formal townships) and townhouse/cluster complexes (Sevenhuysen 2004:13). Growth rates are expressed as changes in the number of actual dwelling structures, and can be aggregated to either suburb boundaries or enumerator area (EA) (1996) boundaries.

The micro analysis for this specific study of the Tshwane municipality area was based on police precinct areas to illustrate an accurate land use class growth for comparison between 2003 and 2004 which was ultimately derived from aerial photographs and/or Quickbird 60 cm resolution satellite imagery.

1.5.2.4 Statistical analysis and thematic maps

The detailed statistical and area coverage results calculated in hectares are given per police precinct boundary. They were used to generate the spatial statistical maps in ArcGIS 9.1 software to illustrate the dominance of a specific land use class within a specific police precinct. The different dominances of specific land use classes per police precinct provide valuable information to the criminologist for understanding the geo-profile of human activity in each police precinct area. The workflow procedure that was followed is illustrated in Diagram 1.1.

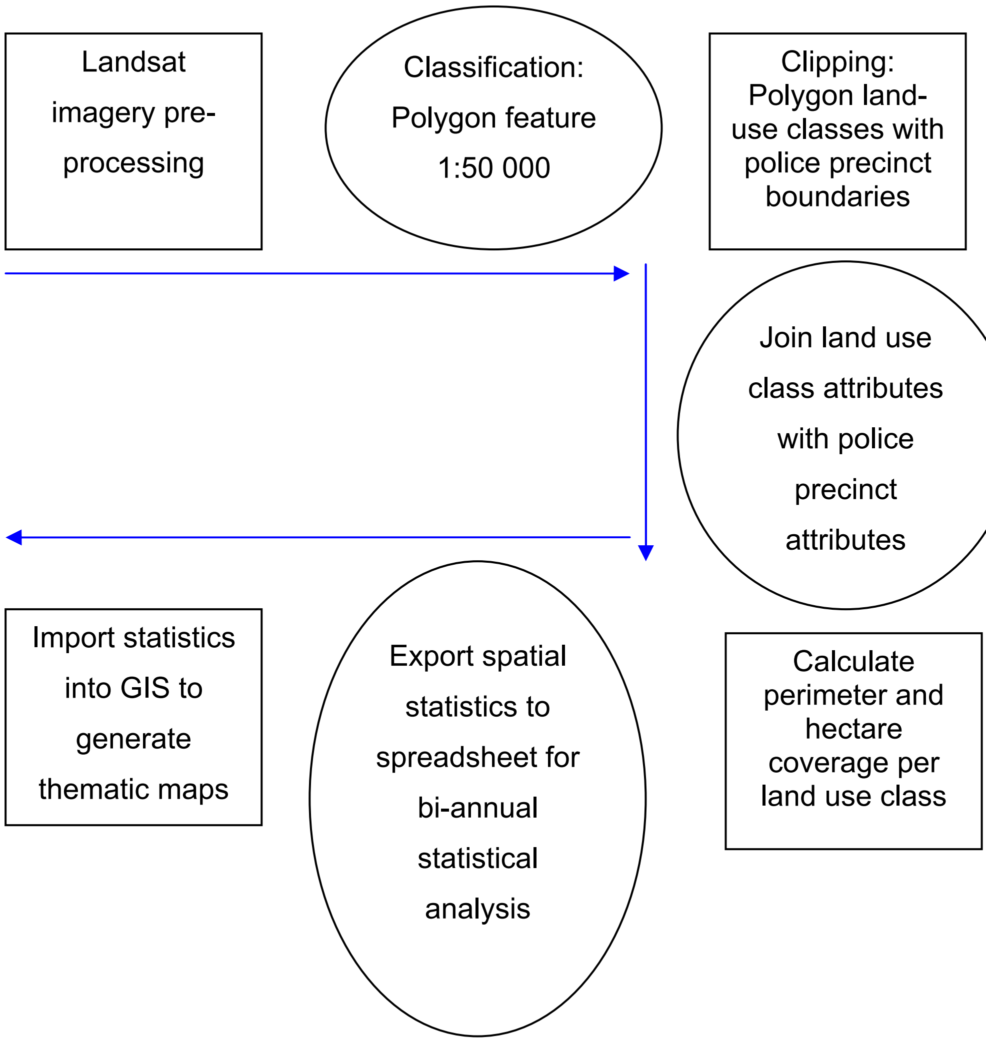


Diagram 1.1: Workflow process to generate thematic maps based on macro analysis

1.6 RESEARCH RESULTS

1.6.1 Macro results

1.6.1.1 Commercial land use class

The concentration of commercial shopping areas dominated the central areas of the Tshwane municipality area (see section 4.5.2.1). These areas do in fact have a high incidence of crime which includes various serious offences. This land use class showed very small changes over the 8-year analysis, which therefore illustrates that no large increase in shopping malls occurred. The spatial illustration of the commercial areas and their relationship with specific crime types can assist the police to reduce crime in these areas through Crime Prevention Through Environmental Design (CPTED) techniques and an improvement in security surveillance in hot spot areas.

1.6.1.2 Industrial land use class

The highest concentration of industrial activities was recorded in the central and western areas of Tshwane (see section 4.5.2.2). The growth pattern from 1994 to 2002 illustrates high industrial growth in the southern part of Tshwane. The results of industrial growth are employment opportunities and the socio-economic impact on the surrounding environment. The spatial analysis highlighted that crime incidents recorded over the industrial dominated area of Pretoria West were moderate to low, yet high crime incidents were evident in Pretoria Central. The industrial land use class is spatially a very small coverage compared to the total Tshwane area. It is important to analyse this class in relationship to the other land use classes in the area.

1.6.1.3 Informal land use class

The growth of informal settlements in South Africa is a known phenomenon and which is also evident in the Tshwane municipality area. The highest concentration of informal areas was found in the northern areas of Tshwane (see section 4.5.2.3). The highest growth in informal settlement areas was recorded in Mamelodi and Atteridgeville. High growth was recorded in the Akasia and Hammanskraal police precinct area. The peripheral growth of informal settlement areas is a serious concern despite the high density of the population in most of these areas. There is concern about high unemployment, lack of basic municipal services such as water, electricity and sanitation facilities. Socio-economic conditions in these areas differ from those in the low-density and high-density residential classes. There is a correlation of the high number of crime incidents in the informal land use class areas. As there are no formal addresses in these areas, geo-coding from the national address directory database is impossible. Very-high-resolution satellite imagery can assist with crime mapping in these areas, otherwise it must be done by the physical collection of ground control points using handheld global positioning systems to record the coordinate readings.

1.6.1.4 Residential high-density class

The greatest concentration of high-density residential classes is evident in the south-eastern part of Tshwane (see section 4.5.2.4). The highest growth of high-density residential areas from 1994 to 2002 was in the Akasia, Silverton and Garsfontein areas. The densification of residential areas in the Tshwane area highlights a great increase in population in this area over the past eight years, which has created an ideal situation for offenders to commit crimes. The concern is that this rapid increase in population in a very small area without any growth of police logistic capabilities to balance out crime could result in anarchy.

Spatial analysis of the high-density areas and their growth, along with the correlation of these areas with specific crime types, will assist the law enforcement agencies to reduce and prevent crime.

1.6.1.5 Residential low-density class

The highest concentration of low-density residential classes is evident in the central part of Tshwane. The percentage coverage of low-density residential areas is primarily located in Pretoria North, Hercules, Sinoville and Wierdabrug (see section 4.5.2.5). No-low density residential growth was recorded. A decrease in this class was evident and in some areas such as Lyttelton as much as -21% was recorded. The reverse effect, namely the decrease of low-density classes into rapidly increasing high-density land use classes is an indicator of the overall densification of the Tshwane area.

1.6.2 Micro results

1.6.2.1 Consolidated micro analysis

Micro analysis showed high growth concentrations in the eastern and western areas of Tshwane. The Mamelodi, Pretoria-West and Atteridgeville police precincts had the highest overall growth from 2003 to 2004. The highest counts of land use activities were recorded in the Mamelodi, Rietgat, Wierdabrug, Temba, Atteridgeville, Akasia, Mabopane, Garsfontein, Soshanguve and Lyttelton areas. Extreme growth was evident in the Mamelodi police precinct, within which more than 10 782 new informal units were counted (see section 4.6.1).

1.6.2.2 Informal settlements

The eastern and western part of Tshwane showed the highest concentration of informal settlement growth. The highest concentration of this land use class was recorded in Rietgat, Temba, Mamelodi, Akasia and Mabopane - these were the top five police precinct areas (see section 4.6.4). The highest count of new informal dwellings was in the Mamelodi area (10 782), Akasia (2 195) and Soshanguve (2 170). Informal settlement growth was very large in specific police precinct areas as also revealed by the macro analysis results.

1.6.2.3 High-density houses

The western and southern parts of Tshwane had the highest concentration of high-density house growth. Pretoria West and Atteridgeville were the highest followed by Wierdabrug and Lyttelton police precincts (see section 4.6.2). The highest concentrations of this land use class were recorded in Mamelodi, Wierdabrug, Atteridgeville, Garsfontein and Lyttelton, which were the top five police precinct areas. New houses recorded in the Pretoria West and Atteridgeville areas exceeded 3 000 units, which therefore signified extreme growth and property development activities.

1.6.2.4 Low-density houses

The northern and southern parts of Tshwane showed the highest concentration of low-density house growth (see section 4.6.3). Lyttelton and Erasmia were the highest in the southern area, followed by the Akasia, Sinoville, Pretoria North and Hammanskraal police precincts in the north. The highest concentration of this land use class was recorded in Pretoria North, Hercules, Akasia, Wierdabrug and Hammanskraal, which were the top five police precinct areas. The highest count of new houses recorded was in the Lyttelton area (25). The overall conclusion is that according to the number count, low-density house growth is very low in the Tshwane area compared to high-density house growth.

1.6.3 Crime analysis

The crime analysis was based on data from 28 police precinct areas. The crime incidents were calculated from the geo-coded crime statistics with geodetic spatial reference, and represent the 46 priority crime categories as defined in the codes of the SAPS Daily Statistics for Serious Crime (DSSC). The geo-coded data used in this study were for the 2002 to 2004 calendar years. The geo-coded crime statistics from the SAPS that are derived from the Crime Administration System (CAS) was for 2002. The data before 2002 have not been validated spatially and were limited to the address directories available. The geo-coded crime statistics that were authorised for this study went up to the first quarter of 2005. The researcher used the annual data to ensure that it would be comparable within the same time frames, which resulted in a micro analysis from 2002 to 2004. The serious crime types that were selected for more detailed analysis were murder, vehicle hijacking, house burglaries and rape. The reasons for selecting these particular crime types are given in section 4.7.1.

1.6.3.1 Murder

The crime of murder has a high spatial correlation with a specific land use class, in this case informal settlement areas as discussed in sections 1.6.1.3

and 1.6.2.2. An interesting phenomenon is the decrease in murder in Mamelodi and Atteridgeville despite the high population growth. Thus a negative correlation is evident between informal land use class growth and murder in specific areas. Loate consists of 77% informal settlement coverage with less than 50% growth since 1994. This area also experienced a decrease in murder from 53 to 38 incidents. The opposite is true for Temba, which had a murder incident growth from 62 to 78 and then a decrease to 70 in 2004 with only a small land use class growth from 1994.

1.6.3.2 House burglaries

The south-eastern part of Tshwane is primarily covered by the high-density residential land use type as described in sections 1.6.1.4 and 1.6.2.3. A high correlation was found between the high-density residential land use class and house burglaries. The areas that had experienced high-density residential growth since 1994 are the dominant areas affected by burglaries. Areas such as Temba had a growth in house burglaries as did Mamelodi. The western part of Tshwane, such as the Hercules and Pretoria West areas, showed a growth in house burglaries although this was not as dominant as in the south-east. The overall pattern of house burglaries was not effectively displaced or prevented from 2002 to 2004. The pattern of the highest occurrence of house burglaries in the Tshwane area remains the same year after year.

1.6.3.3 Car hijackings

The geo-coded crime statistics showed that there was an increase of 15.7% in car hijackings from 2002 to 2003. A smaller increase from 2002 to 2004, 1.4%, was recorded. This crime type dominates the southern, central and north-western areas of Tshwane. The southern part of Tshwane is primarily covered by the high-density residential, industrial and to a lesser extent low-density residential land use classes. The central area of Tshwane is primarily high-density residential and commercial land use classes (see sections 1.6.1.1 and 1.6.1.4). The north-western part of Tshwane is dominated by informal settlement areas (see sections 1.6.1.3 and 1.6.2.2).

There is therefore a high correlation between high-density residential land use class, informal settlement areas and car hijackings. The areas that showed high-density residential and informal settlement growth since 1994 are also the dominant areas affected by car hijackings. The pattern of car hijackings also showed very little change or displacement from 2002 until 2004.

1.6.3.4 Rape

The geo-coded statistics used for this analysis showed an increase of 0.24% in rape incidents from 2002 to 2003. A higher increase from 2002 to 2004, namely 0.8%, was recorded. This crime type dominates the central and north-western areas of Tshwane. The central area of Tshwane consists primarily of high-density residential and commercial land use classes discussed in sections 1.6.1.4 and 1.6.1.1 respectively. The north-western part of Tshwane is dominated by informal settlement areas as given in sections 1.6.1.3 and 1.6.2.2. Mamelodi, which has the highest number of rape incidents, is situated to the east of Tshwane, and is dominated by informal settlements and high-density residential classes. There is a high correlation of rape between high-density residential land use class and informal settlement areas. The areas that have shown high-density residential and informal settlement growth since 1994 also correspond to the dominant areas affected by rape incidents. The pattern of rape incidents showed very little change or displacement from 2002 until 2004.

1.7 THESIS OUTLINE

The thesis outline is as follows:

In Chapter 2, *The role of criminological theory to assess the spatial distribution of crime*, core criminological theories and how to apply theory in practice through the incorporation of spatial technologies for visual illustration is discussed. This is the foundation of this study.

In Chapter 3, *Remote sensing and future related technologies*, basic spatial technology is explained, with the emphasis on remote sensing science. The natural science underlying remote sensing and its applications are briefly discussed. The applications that can be created from multi-sensors at different ground resolutions cover a wide range of scientific areas such as agriculture, forestry, urban planning, change detection, land use/land cover mapping, safety and security planning, etc. The discussion also includes electromagnetic energy, the electromagnetic spectrum, image characteristics, remote sensing systems, orbits, earth observation satellites and future satellite systems and instrumentation.

Chapter 4, *Temporal spatial analysis of the Tshwane municipality area to determine the relationship between land use growth and crime*, discusses practical analysis utilising remote sensing imagery and vector data layers coupled with relevant auxiliary data to determine whether there is a relationship between land use growth and specific crime types.

Chapter 5, *Conclusion and recommendations*, explores the relevance of spatial technology to criminology and makes recommendations to integrate the technology specifically within law enforcement agency activities to better understand crime patterns and to optimise crime reduction efforts.

1.8 CONCLUSION

High crime incidents in a small spatial area was evident in the Sunnyside and Pretoria Central police precinct areas. Mamelodi, Brooklyn, Eersterust and Pretoria Moot were the second highest category for crime density. The crime pattern from 2002 to 2004 indicates very few changes except for an increase in the Akasia, Wonderboompoort and Eersterust areas. The highest number of incidents every year was recorded in the Pretoria Central, Sunnyside, Brooklyn and Mamelodi areas. The fact that the spatial distribution and density patterns of crime did not change rapidly over the three-year analysis period is cause for concern about the effectiveness of policing methods in these areas. The constant spatial pattern of crime could be due to a lack of knowledge or insight into the actual crime patterns and the correct policing strategy to reduce and prevent a specific crime type, which differs from police precinct to police precinct area. This will be illustrated in the following chapters of the thesis.

CHAPTER 2: THE ROLE OF CRIMINOLOGICAL THEORY IN ASSESSING THE SPATIAL DISTRIBUTION OF CRIME

2.1 INTRODUCTION

Knowledge of the core criminological theories and how to apply them in practice through the incorporation of spatial technologies for visual illustration is the foundation of this study. This chapter focuses on the theoretical aspects of criminology, and the following chapter includes the spatial analysis component of this study.

Criminology as defined by Siegel (2003:4) is the scientific approach to the study of criminal behaviour. Criminology explains the etiology (origin), extent, and nature of crime in society. It is essentially an interdisciplinary science, consisting mostly of sociology, but also criminal justice, political science, psychology, economics and the natural sciences. In the researcher's view the natural sciences, with the stress on geomatics, can be combined with criminological principles to explain the relationship between human behaviour (land use) and criminal behaviour.

Factors that contribute to crime were grouped into five categories of risk factors according to Dr Alice Maree (in Hough & du Plessis 2003:173) that were determined during various foreign studies. These risk factors are family/home factors, community factors, school factors, extra-family relationships and personality factors. Overall research findings support the conclusion that no single cause or risk factor accounts for offending and that no single pathway leads to a life of crime. Nine associations have been identified by various analysts as contributing to crime, regardless of their field of expertise. These associations are population demographics, uncontrolled urbanisation, economic strain and deprivation, substance abuse, education level, past experience of criminal activities, cultural activities and crime opportunities (Hough & du Plessis 2003:175-181).

The assessment of criminogenic risk with the aim of developing crime reduction strategies led criminologists to develop many different theories to explain crime. These can be broadly divided into individual-centred theories and milieu-centred theories. whereas milieu-centred theories highlight social phenomena in the individual's personal environment, individual-centred theories see crime as the result of faults in the individual which are mostly attributed to biological and psychological irregularities which the individual cannot control. But crime is not fully explained by any one theory. Consequently, a variety of approaches are integrated to supplement each other so that a more comprehensive understanding of criminal behaviour can be attained and effective prevention and intervention programmes developed (Hough & du Plessis 2003:185).

Theoretical criminology, a sub-field of general criminology, rather than simply describing crime and its occurrence, posits explanations for criminal behaviour (Schmalleger 1999:19). The term "theory" is derived from the Greek "theoros", to observe and reflect upon the meaning of an event. Without incisive theories, a field or discipline becomes a hopeless catalogue of random and seemingly unrelated facts. However, theories are not laws or facts, although this is something that is forgotten by those who become convinced of the correctness of a particular theory which they come to espouse (Hagan 1990:120).

According to Schmalleger (1999:19), a theory is described as a series of interrelated propositions that attempt to describe, explain, predict and ultimately to control some class of events. A theory gains explanatory power from inherent logical consistency and is "tested" by how well it describes and predicts reality.

An integrated theory is an explanatory perspective that merges concepts drawn from different sources (Schmalleger 1999:19). Williams and McShane (1999:269) emphasise the importance of the integration of criminological theories. As long as people see each theory as separate and distinct, there will be little progress in criminology. This chapter explains some of the historical criminological theories and how they evolved into contemporary theories to understand their proper context. Future criminological theories are highlighted and integrated theories are discussed as an important principle of this study. This chapter concludes by aligning specific theories to the applied research of this study which utilises spatial technology to determine the behaviour of humans over time and its associations with certain criminogenic factors.

2.2 MAJOR THEORETICAL APPROACHES IN CRIMINOLOGY

In Siegel (2003:654) a synopsis of basic criminological theories is given which categorises the major historical theories that formed the foundation of criminology. The theories are summarised in table 2.1.

Table 2.1: Synopsis of criminological theories

Theory	Origin	Founders	Core ideas	Modern outgrowths
Classical	About 1764	Cesare Beccaria, Jeremy Bentham	People choose to commit crime after weighing the benefits and costs of their actions. Crime can be deterred by certain, severe and swift punishment.	RationalChoice theory, Routine Activities theory, General Deterrence theory, Specific Deterrence, Incapacitation.
Marxist/ Conflict	About 1848	Karl Marx, Willem Bonger, Ralf Dahrendorf, George Vold	Crime is a function of class struggle. The capitalist system's emphasis on competition and wealth produces an economic and social environment in which crime is inevitable.	Conflict theory, Radical theory, Radical Feminist theory, Left Realism, Peacemaking, Power-Control theory, Post-modern theory, Reintegrative Shaming, Restorative Justice

Theory	Origin	Founders	Core ideas	Modern outgrowths
Positivist	About 1810	Franz Joseph Gall, Johann Spurzheim, J. K. Lavater, Cesare Lombroso, Enrico Ferri, Raffaele Garofalo, Earnest Hooton, Charles Goring	Some people have biological and mental traits that make them crime prone. These traits are inherited and are present at birth. Mental and physical degeneracies are the cause of crime.	Biosocial and Psychological theory, Cognitive theory, Behavioural theory, Evolutionary theory, Arousal theory, Life Course theory, Latent Trait theory.
Sociological	About 1897	Emile Durkheim, Robert Ezra Park, Ernest Burgess, Clifford Shaw, Walter Reckless, Frederic Thrasher	A person's place in the social structure determines his or her behaviour. Disorganised urban areas are the breeding ground of crime. A lack of legitimate opportunities produces criminal subcultures. Socialisation within the family, the school and the peer group controls behaviour.	Strain theory, Cultural Deviance theory, Social Learning theory, Social Control theory, Social Reaction theory, Labelling

Source: Siegel 2003: 654

2.2.1 Demonological theory

Demonological or supernatural explanations of criminality dominated thinking from early history well into the 18th century and still have modern remnants. In a system of knowledge in which theological explanations of reality were predominant, the criminal was viewed as a sinner who was possessed by demons or damned by otherworldly forces. Mankind was viewed as at the mercy of the supernatural: Fates, ghosts, furies, and/or spirits. In Siegel (2003:4) superstition and fear of satanic possession dominated thinking during the Middle Ages (1200 – 1600). The prescribed method for dealing with the possessed was burning at the stake, a practice that survived into the 17th century.

Early cranial surgery, or **trephination**, was apparently intended to release evil spirits thought to be residing within the heads of offenders. Such surgical interventions were undoubtedly crude and probably involved fermented anaesthesia along with flint cutting implements. To the uncritical observer the theory of spirit possession as a cause of deviance, and cranial surgery as a treatment technique, might have appeared to be supported by the "evidence" of low rates of future crime (Schmalleger 1999:151).

Scientific criminology generally scoffs at claims of supernatural influences in crime commission (Schmalleger 1999:108). However, in the researcher's view the demonic era is based on thoughts and beliefs applicable to the milieu to which humankind was exposed. Religious institutions ruled the regulatory environment and behaviour of man. The influence of the demonological theory on contemporary theories can also be seen in the global multi-tribes/multi-cultures which are distinguished by their own unique beliefs and traditions. Tribes or cultures create their own rules and legislation to create their own controlled and disciplined environment. To put this into perspective the discussion that follows summarises the black South African tribes and a modernised classification of tribes based on a modernised methodology.

South Africa is a unique multi-cultural nation: its population of about 44.6 million is spread across nine provinces and speaks 11 different official languages. Each group has its own ethnic and cultural heritage (De La Harpe & Derwent 2001:4). The tribes in South Africa have their own cultural believes and traditions. The KhoiSan were already well established at the Cape when Dutch sailors first landed on its shores. They had had a marked impact on the black people with whom they had come into contact. The major tribes that settled in South Africa are descended from four major groups that are again divided into nine distinctive ethnic groups. The **Sotho** group comprises the North Sotho, the South Sotho and the Tswana people, while the **Nguni** group consists of the Zulu, Xhosa, Swazi and Ndebele people. The **Shangaan-Tsonga** group are traditionally found in the Gazankulu and Mpumalanga regions and the **Venda** people largely live in Limpopo Province (De La Harpe & Derwent 2001:4).

Although all these groups spoke Bantu languages, each had an identity of its own, with particular customs and traditions (De La Harpe & Derwent 2001:4). Each tribe dominated specific geographical areas. Table 2.2 gives the South African tribe matrix.

Table 2.2: South African tribe matrix

Tribe	Ethnic group	Sub-Group	Location
Sotho	Northern	Pedi Lovedu	Heterogenic
	Southern		Lesotho
	Western		Botswana
Nguni	Ndebele	Ndzundza	Highveld areas, northeast of Pretoria
		Manala	Heterogenic
	Zulu		KwaZulu-Natal
	Xhosa		Eastern Cape
	Swazi		Swaziland
Shangaan-Tsonga	Tsonga Shangaan		Gazankulu Mpumalanga
Venda			Northern Province

Source: De La Harpe & Derwent 2001:5

Although each of these groups has their own traditional home area, the black population of South Africa has spread throughout the country's towns and cities, and across its rural landscape. In many of the rural areas, customs and rituals are still nurtured according to conventions established by the ancestors. Due to the onslaught of modernism and Western culture, many traditions are being eroded by demands of an increasingly industrialised and cosmopolitan society (De La Harpe & Derwent 2001:6).

The aim of the SA Tribes research study in 2002 (Burgess 2002) was to help companies understand how South Africans were changing and the commercial implications of the changes. Over time it became apparent that SA Tribes could contribute to a wider and more important conversation taking place in South Africa, a conversation perhaps best introduced through an analogy (Burgess 2002:2). Thinking of people as having complex social identities offers theoretical, conceptual and practical advantages over thinking of them as members of racial identity groups. Conceptually, social identity is isomorphic to the human condition in South Africa. It allows one to conceive of the varied influences and complexity of changing individual characteristics, social interaction and the complexity of changing individual characteristics, social interaction patterns and associations, diverse environmental influences and varied living circumstances (Burgess 2002:6).

SA Tribes designed an identity influence model to create four major tribe classes within a democratic modernised South Africa as we know it today. The resulting model reflected the following tribe classes (Burgess 2002:48):

- **Rural Survivalists:** (42.7%) are the largest group, comprising four tribes. They live a traditional agrarian lifestyle in deep rural areas. They have the lowest level of human development and the least access to the formal sector.
- **Emerging Consumers:** (37.0%) include five tribes. They have running water, electricity and flushing toilets and are beginning to add some luxuries – radios, TVs, fridge/freezers are among the likely choices.
- **Urban Middle Class:** (12.5%) is not a middle class comparable to that of industrialised Western countries. They have many amenities associated with middle-level human development, such as electricity, running water, common household appliances and motor vehicles.
- **Urban Elite:** (7.8%) includes three tribes and is the smallest and most advantaged group. Sophisticated, exposed to global culture and development, digitally connected and active.

The relevance of the more commercial classification of social identity in South Africa creates new social cohesion, social stratification and geographical spread of specific types of classes for analysis. The indigenous beliefs and strong tribal traditions of the 1800s and the 1900s are busy eroding with the onslaught of modernism. De La Harpe & Derwent (2001:6) clearly state, “Many beautiful and ancient customs and practices, once integral to traditional African culture, survive only as tourist attractions. Unless all the people of southern Africa honour the spirits of their ancestors and nurture their age-old conventions and wisdom, in time, they could be lost forever”.

The “tribal” change in South Africa influences the thoughts of traditional criminological schools and therefore continuous adoption of contemporary theory to explain and understand crime in its modernised landscape is essential. The demonological theory was the first to analyse criminal behaviour and the activities that surround it to manage this abnormal behaviour. These preventative actions were influenced by the social cultural/ class in control, as it is still the case today.

2.2.2 Classical theory

The Enlightenment, also known as the Age of Reason, was a highly significant social movement which occurred during the 18th century. The Enlightenment built upon ideas such as empiricism, rationality, free will, humanism and natural law (Schmalleger 1999:154). Although criticised from a post-modern point of view it must also be borne in mind that the Enlightenment fuelled the fires of social change, leading eventually to the French and American revolutions and providing many of the intellectual underpinnings of the U.S. Constitution (Schmalleger 1999:154).

Within criminology the Enlightenment led to the development of the classical school of criminological thought. Crime and deviance, which had been previously explained by reference to mythological influences and spiritual shortcomings, took their place in Enlightenment thinking alongside other forms of human activity as products of the exercise of free will. Once man was seen as self-determining, crime came to be explained as a particularly individualised form of evil, or moral wrong-doing fed by personal choice (Schmalleger 1999:158).

The Italian *Cesare Beccaria* (1738 – 1794), along with British philosopher Jeremy Bentham (1748 – 1832), is seen as the principle advocate of the classical school of criminological theory. Beccaria stated his famous theorem as follows (Siegel 2003:5):

"In order for punishment not to be in every instance, an act of violence of one or many against a private citizen, it must be essentially public, prompt, necessary, the least possible in the given circumstances, proportionate to the crimes, and dictated by the law."

Jeremy Bentham wrote in his *Introduction to the Principles of Morals and Legislation (1789)* that “nature has placed mankind under the governance of two sovereign masters, pain and pleasure.” To reduce crime the pain commission must outweigh the pleasure to be derived from criminal activity. This approach of Bentham has been termed **hedonistic calculus** or **utilitarianism,** that behaviour holds value to any individual undertaking it according to the amount of pleasure or pain that it can be expected to produce for that person (Schmalleger 1999:160).

Points of the classical school of theory highlighted by Williams & McShane (1999:22) can be summarised as the influence of environmental and social infrastructure that implies certain social relationships to protect society against criminal behaviour:

- People exist in a world with free will and make their own rational choices, although they have a natural tendency toward self-interest and pleasure.
- People have certain natural rights, among them life, liberty and ownership of property.

- Governments are created by the citizens of a state to protect these rights and they exist as a social contract between those who govern and those who are governed.
- Citizens give up only the portion of their natural rights that is necessary for the state to regulate society for the benefit of all and to protect society against the natural self-interest of individuals.
- To ensure civil rights, legislators enact law that both defines the procedures by which transgression will be handled and specifies the exact behaviours that make up those transgressions. This law specifies the process for determining guilt and the punishment to be meted out to those found guilty.
- Crime consists of a transgression against the social contract, therefore crime is a moral offence against society.
- Punishment is justified only to preserve the social contract. Therefore the purpose of punishment is to prevent transgressions by deterring socially harmful behaviour. Only that amount of punishment necessary to offset the gains of harmful behaviour is justified.
- All people are equal in their rights and should be treated equally before the law.

The significance of the classical school of thought is that they are still embedded in today's criminal justice system. The deterrence of criminal behaviour by moving towards a more conservative and punitive mode, has embraced the concept of deterrence and clamoured for harsher sentences (Williams & McShane 1999:23).

The deterrence of certain crimes in South Africa such as drunk driving with mobile courts to process the offences quicker spatially serves as an example to effect a change in dominated human criminal behaviour. In the history of South Africa administration of the criminal procedure law there have been statutory provisions that deprived the courts of their discretion in sentencing. The following examples illustrate this (Hiemstra 1997:644):

- The compulsory imposition of corporal punishment in certain circumstances (1952).
- Imprisonment for the prevention of crime and correctional training as compulsory punishment when the accused's criminal record (previous convictions) complied with certain requirements (1959).
- Various compulsory sentences under Act 41 of 1971 for drug-related offences.

Sections 51 to 54 of the Criminal Procedure Law Amendment Act 105 of 1997 make provision for compulsory minimum sentences of life imprisonment for certain serious crimes (e.g. murder, robbery and rape), except if "compelling and substantial" circumstances are found which justify a lesser sentence (Hiemstra 1997:644). These provisions became effective on 1 May 1998. The Van den Heever Commission found that the rationale for compulsory minimum sentences could be traced back to a clear call from the community for heavier sentences and for offenders to serve a more realistic portion of imprisonment.

Criminologists have also given a good deal of popularity to the concept of rational offenders. The rational choice theories suggest a connection between opportunities for offending, the environmental conditions at the time, and the readiness of the offender to commit the offence (Williams & McShane 1999:24).

The classical school provided a basis on which much of current policy and conceptual activity is based. The contemporary theories created from the foundations of the classical school serve as principles that can be aligned with this study. The rational choice or routine activity theories highlight the environment in which an offender operates. This was emphasised by the early Enlightenment thinking, the free will of man and its movement (Schmalleger 1999:154). The spatial analysis of a specific area enables the researcher to classify high and low-risk areas based on their surroundings, activities, road networks, environmental conditions, etc. Thus although the classical school focused more on the personalised and juridical side of criminology, its contemporary form can be used to analyse and explain criminogenic risk factors spatially (Hough & du Plessis 2003:185).

2.2.3 Neoclassical theory

The neoclassical criminology is a more contemporary version of classical criminology which emphasises deterrence and retribution with reduced emphasis on rehabilitation. Two neoclassical criminology schools exist today (Schmalleger 1999:163). The *first* neoclassical school continues to build up ideas inherent in the notion of a social contract and places emphasis on individual rights and due process. The *second* takes the form of three ideas (Schmalleger 1999:163):

- criminal behaviour is the result of free choice
- criminal behaviour is rewarding and crime holds a number of attractions, from sensuality to monetary gain to fame
- criminal punishment is necessary for deterrence.

In its modern guise this second type of classical thinking has taken the form of a **just deserts model** of criminal sentencing, with a society-wide emphasis on both deterrence and retribution as the twin goals of criminal punishment. The just deserts model is defined as the notion that criminal offenders deserve the punishment they receive at the hands of the law and that punishment should be appropriate to the type and severity of crime committed (Schmalleger 1999:163).

The neoclassical theory as a refined theory from the classical school puts more emphasis on punishment and the use of recidivism to measure the success of a specific punishment. The defining of specific deterrence and general deterrence and the applicability of capital punishment is not the focal point of this study. In the researcher's view this theory is more aligned with the juridical process than with environmental criminology principles. However, spatial analysis can assist with the analysis of the criminal event and the environment in which it occurred. The selection of a specific punishment to ensure a deterrent effect is beyond the scope of this study.

The neoclassical theory focuses more on punishment and does not address the effect of crime displacement or diffusion. Types of displacement have been identified (Paulsen & Robinson 2004:160):

- displacement of crime from one place to another (geographical displacement)
- where crimes move from one time to another (temporal displacement)
- displacement of crime from one target to another (target displacement)
- where one method of committing a crime is replaced by another (tactical displacement)
- displacement of one crime to another (crime type displacement).

Criminal diffusion refers to the spreading of crime from one place to another. This type of diffusion can be divided into contagious diffusion and hierarchical diffusion. The first depends on direct contact and occurs between adjoining areas such as neighbouring cities or countries, whereas hierarchical diffusion spreads broadly through commonly shared influences and does not require direct contact (Paulsen & Robinson 2004:163).

An offender can change his or her behaviour by adopting a specific displacement technique. If punishment of a specific crime type is too harsh in a specific juridical area or country he can move to another area or commit another type of crime. Mapping and spatial analysis of the diffusion or displacement of crime enables analysts better to learn how and where crime occurs. These methods enable better prevention of criminal victimisation based on the understanding of the spatial dynamics of crime.

2.2.4 Marxist / Conflict theory

In his *Communist Manifesto* and other writings, Karl Marx described the oppressive labour conditions prevalent during the rise of industrial capitalism

(Siegel 2003:9). Marx saw the main limitation of modern society in the alienation (or distancing of modern man from his real nature and products of his labour) of man under capitalistic economics. Alienation means that man is unable to recognise his true state and build the required conditions for real social progress. Marx declared that capitalism values men primarily through their differing abilities to produce commodities. The industrial age was known for the conflict between two economic classes of society, the proletariat (the working class) and the dominant bourgeoisie (Williams & McShane 1999:169).

The rich and diverse productive activity of mankind (mode of production) is reduced to a process of producing commodities for exchange. Any social relationship man has with the items he produces is lost - while the worker puts his labour value into a product, this labour value is ignored and the only value which is considered of importance is the quantity of money for which the commodity produced can be exchanged (Williams & McShane 1999:169).

The productive features of human life are further dehumanised when this exchange value is thought of as something which inheres in the commodity itself, rather than relating to the activity of the worker. Man's basic productive activity is thereby obscured by the process of exchange, and the productive role and capacity of the individual is not recognised. Instead, an abstract thing, Capital, is seen as the primary productive entity. Capital is seen as producing a surplus value, and buying labour power is merely a lesser unit in the means of production (Morrison 1995:45).

Marxist criminologists have assumed that class struggle affects crime on three fronts (Siegel 2003:16):

- Law itself is a tool of the ruling class.
- All crime (in capitalist nations) is the product of a class struggle producing individualism and competition.
- Relationships to the mode of production is an explanation for crime.

The major concepts in radical explanations of crime from the Marxist criminologists are based on five concepts (Morrison 1995:55):

- social class and stratification
- political economy
- family disorganisation
- economic conditions
- surplus value as the capitalist exploitation of the difference between the cost of production and the value of the product.

The main criticism of the Marxist and radical theories was their simplicity, therefore a new theory emerged in the 1980s translating radical ideas into realistic social policy, which is similar to the grounded labelling theory called *Left Realism*. The basic notion deviates from the Marxist view that all crime is a product of the capitalist system. Realists also recognise the presence of crime in socialist countries and regard crime as a real problem for all (Siegel 2003:22).

According to Williams and McShane *(*1999:174) the major points of the theory are:

- Conflict is a fact of life, society is most appropriately characterised by conflict.
- Resources, both physical and social, are scarce and therefore in demand. It is the attempt to control these resources that generates the major portion of conflict in society.
- Control of resources creates power, and the power is used to maintain and expand the resource base of one group at the expense of others.
- Once a group achieves dominance over others, it seeks to use available societal mechanisms for its benefit to ensure it remains dominant.
- Law is a societal mechanism that provides the group in power with strong means of control over other, less powerful groups.

- Laws are formulated so that they express the values and interests of the dominant group, and restrict behaviour common to less powerful groups.
- The application and enforcement of law leads to a focus on the behaviour of less powerful groups, thus disproportionately "criminalising" the members of those groups.
- In Marxists versions of conflict theory, the conditions generated under the capitalist political economy are the primary cause of political and economic actions that generate crime.

In the researcher's view the Marxist/Radical or Left Realism theories as a cluster of shared concepts can be applied in this study through the visual classification of different social classes spatially over time. South Africa, with its diverse society and governance policies that changed from an apartheid regulatory environment to a democratic society, has created formal and informal socio-economic classes. The use of remote sensing imagery to display the establishment, growth as well as displacement of a specific spatial class such as an informal settlement area over a specific time period forms part of this study. This enables the researcher to determine the effect of certain legislation on certain land use classes and its relationship to crime (see sections 5.3.2 and 5.3.3).

2.2.5 Positivist theory

While the Classical reformers sought to modernise and civilise the system within which they lived, the Positivists reached out to order and explain the world around them. Those who studied criminals from a positivist perspective commonly used scientific research techniques. Much of the system of analysis that constitutes sociological positivism today was developed by Auguste Comte, a 19th century French philosopher and social scientist who is credited with being the farther of sociology. His approach to the study of social phenomena included an insistence on testable hypotheses, the use of comparative methods, the careful classification of societies, a systematic approach to the study of social history and the study of abnormality as a means to understand normality (Williams & McShane 1999:35).

In applying Comte's approach, criminological positivists emphasise a consensus world view, a focus upon the criminal actor rather than the criminal act, a deterministic model (usually biological or psychological in nature), a strong faith in the scientific expert, and a belief in rehabilitation of "sick" offenders rather than punishment of "rational" actors. Stressing a scientific rather than philosophical orientation, there are three elements to the positivistic approach (Hagan 1990:136):

- Application of the scientific method
- The discovery and diagnosis of pathology (sickness)
- Treatment (therapy or corrections).

The major categories of positivism are biological and psychological theories. The works of Charles Darwin in the mid-19th century had a profound impact upon theory in the social sciences as well as on criminology. Concepts such as evolution, natural selection, survival of the fittest and human genetic connections to a savage past captured the imaginations of theorists in the young social sciences, including criminology (Schmalleger 1999:195).

Biological positivism is usually traced back to the Italian thinkers, Cesar Lombroso, Raffaele Garofalo and Enrico Ferri. Lombrosian theory can be summed up by a few simple statements. First, Lombroso believed that serious offenders – those who engaged in repeated assault or theft-related activities – had inherited criminal traits. These "born criminals" inherited physical problems that impelled them into a life of crime. This view helped stimulate interest in a criminal anthropology. Second, Lombroso held the view that born criminals suffer from *atavistic anomalies* – physically, they are throwbacks to more primitive times when people were savages (Williams & McShane 1999:37).

Today, those criminologists who suggest that crime has some biological basis also believe that environmental conditions influence human behaviour. Hence, the term biosocial theory has been coined to reflect the assumed link between physical and mental traits, the social environment and behaviour (Siegel 2003:7).

The types of biological theories are illustrated by way of a summary in table 2.3 to put the theory in perspective (Schmalleger 1999:194):

Table 2.3: Theory in perspective: Types of biological theories

Biological Theories: Adhere to the principle that the basic determinants of human behaviour, including criminality, are constitutionally or physiologically based and inherited.			
Early positivism: These biological approaches build upon evolutionary principles and were the first to apply scientific techniques to the study of crime and criminals. Early positivistic theories saw criminals as throwbacks to earlier evolutionary epochs.	**Constitutional theories:** Such biological theories explain criminality by reference to offenders' body types, inheritance, genetics, and/or external observable physical characteristics.	**Body chemistry:** Such biological theories utilise chemical influences, including hormones, food additives, allergies, vitamins, and other chemical substances to explain criminal behaviour.	**Sociobiology:** A theoretical perspective developed by Edward O. Wilson to include "the systematic study of the biological basis of all social behaviour", which is "a branch of evolutionary biology and particularly of modern population biology.
Period: 1880s – 1930	**Period:** Modern 1960s – Present Classical 1930s – 1940s	**Period:** 1940s – present	**Period:** 1975 – present
Theorists: F. J. Gall, J. G. Spurzheim, C. Lombroso, C. Garing	**Theorists:** E. Kretschmer, W. H. Sheldon, R. Dugdale, A. H. Estabrook, H.	**Theorists:** Various	**Theorists:** Edward O. Wilson

and E. Hooton	H. Goddard		
Concepts: Phrenology, atavism, born criminals, criminaloids	**Concepts:** Somatotyping - mesomorph, ectomorph, endomorph, XYY supermale, twin studies	**Concepts:** Hypoglycaemia, vitamins, food allergies, serotonin, PMS, MAOA	**Concepts:** Altruism, tribalism, survival of the gene pool

Source: Schmalleger 1999:194

The critique of early biological positivism is summarised as follows (Schmalleger 1999:218):

- Few biological studies adequately conceptualise criminality for the reason that several studies have defined criminality on the basis of a single arrest.
- Twin studies, in particular, have sometimes failed to properly establish whether a pair of twins is monozygotic (MZ) or dizygotic (DZ). This is because some MZ twins are not identical in appearance and only a few twin studies have depended on biological testing rather than on a simple evaluation of appearances.
- Problems of estimating the degree of criminality among sample populations are rife in biological studies of criminality. Interview data are open to interpretation and existing statistical data on the past criminality of offenders are not always properly appreciated.
- Methodological problems abound in many studies which attempt to evaluate the role of genetics in crime.
- Results obtained outside the United States may not apply in this country. Twin studies conducted in Sweden and Denmark provide an example of this potential lack of generalisability.

The Positivists undoubtedly contributed a great deal to criminological science. In the researcher's view the scientific procedures and analysis also contributed to other sciences such as sociology and psychology. From a scientific point of view, it opened historical methodologies used in the natural sciences to explain human criminal behaviour .The biological nature of the research and philosophies has, however, little value for this study, which uses spatial technology to analyse and combat crime except for the interaction with social and environmental factors. Today, those criminologists who suggest that crime has some biological basis also believe that environmental conditions influence human behaviour. The term biosocial theory has been coined to reflect the assumed link between physical and mental traits, the social environment and behaviour (Siegel 2003:7).

2.2.6 Sociological theories

The early classical, biological and psychological traditions in criminological theory were similar in their relatively conservative view of society as well as in their search for the cause of crime in either lack of fear of deterrence, defective individual genetics, or the psyche. The individual criminal was the unit of analysis. The foundations of sociological criminology can be traced to the works of pioneering sociologists L. A. J. Quetelet (1796 – 1874) and Emile Durkheim (1858 – 1917). Quetelet investigated the use of data and statistics in criminological research. Durkheim, considered one of the founders of sociology, defined crime as a normal and necessary social event (Siegel 2003:7).

Quetelet and André-Michel Guerry began what was known as the **cartographic school of criminology**. This approach made use of social statistics that were being developed in Europe in the early 19th century. Statistical data provided important demographic information on the population, including density, gender, religious, affiliations and wealth (Siegel 2003:8).

The difference in demographic profiles per area can be explained by the results of social stratification. Inequalities exist in all types of human society. Even in the simplest cultures, where variations in wealth or property are virtually non-existent, there are inequalities between individuals, men and women, the young and old. To describe inequalities, sociologists speak of *social stratification*. Stratification can be defined as structured inequalities between different groupings of people. The four major types of stratification can be distinguished by slavery, caste, estate and class. The first three depend on legally or religiously sanctioned inequalities, and class is associated with more modern stratification as it is known today (Giddens 1998:240). The most influential theories of stratification are those developed by Karl Marx and Max Weber (Giddens 1998: 244). They clearly distinguish between the worker class and capitalists.

Durkheim's vision of social positivism explains crime as part of human nature because it has existed during periods of both poverty and prosperity. Crime is normal because it is virtually impossible to imagine a society in which criminal behaviour is totally absent. Durkheim believed that the inevitability of crime was linked to the differences (heterogeneity) within society. Since people are so different from one another and employ such a variety of methods and forms of behaviour to meet their needs, it is not surprising that some will resort to criminality. In Durkheim's book, *The Division of Labor in Society,* he described the consequences of the shift from a small, rural society, which he labelled "mechanical", to the more modern "organic" society with a large urban population, division of labour and personal isolation. From this shift flowed **anomie**, or norm and role confusion, a powerful sociological concept that helps describe the chaos and disarray accompanying the loss of traditional values in modern society (Siegel 2003:8).

The thinking of the Enlightenment built upon ideas such as empiricism, rationality, free will, humanism and natural law. Although it can be criticised from a post-modern point of view, it must also be borne in mind that the Enlightenment fuelled the fires of social change. (Schmalleger 1999:154). The Enlightenment led to the development of the classical school of criminological thought. The main point highlighted by Williams and McShane (1999:22) regarding the classical school of thought is the influence of environmental and social infrastructure, which implies certain social relationships to protect society against criminal behaviour. In the earlier discussion of the classical theory of criminology, it was noted that the development of social classes and new demographic profiles can now be linked to the concept of anomie and the social disorganisation theories.

Table 2.4 summarises the major theoretical approaches in sociological criminology. These theories are divided into Social Structure Theories and Social Process Theories (Siegel 2003:205 & 241).

Table 2.4: Sociological theories: Social structure theories and social process theories

Theoretical School	**Major Premise**	**Strengths**
	Social Structure Theories	
Social Disorganisation Theory		
Shaw and McKay concentric zone theory	Crime is a product of transitional neighbourhoods that manifest social disorganisation and value conflict.	Identifies why crime rates are highest in slum areas. Points out the factors that produce crime. Suggests programmes to help reduce crime.
Social ecology theory	The conflicts and problems of urban social life and communities, including fear, unemployment, deterioration and siege mentality, influence crime rates.	Accounts for urban crime rates and trends.
Strain Theory		
Anomie theory	People who adopt the goals of society but lack the means to attain them seek alternatives, such as crime.	Points out how competition for success creates conflict and crime. Suggests that social conditions and not personality can account for crime. Can explain middle- and upper-class crime.
General strain theory	Strain has a variety of sources. Strain causes crime in the absence of adequate coping mechanisms.	Identifies the complexities of strain in modern society. Expands on anomie theory. Shows the influence of social events on behaviour over the course of life.
Institutional anomie theory	Material goals pervade all aspects of American life.	Explains why crime rates are so high in American

Theoretical School	Major Premise	Strengths
		culture.
Relative deprivation theory	Crime occurs when the wealthy and poor live close to one another.	Explains high crime rates in deteriorated inner-city areas located near more affluent neighbourhoods.
Cultural Deviance Theory		
Sellin's culture conflict theory	Obedience to the norms of their lower-class culture puts people in conflict with the norms of the dominant culture.	Identifies the aspects of lower-class life that produce street crime. Adds to Shaw and McKay's analysis. Creates the concept of culture conflict.
Miller's focal concern theory	Citizens who obey the street rules of lower-class life (focal concerns) find themselves in conflict with the dominant culture.	Identifies the core values of lower-class culture and shows their association to crime.
Cohen's theory of delinquent gangs	Status frustration of lower-class boys, created by their failure to achieve middle-class success, causes them to join gangs.	Shows how the conditions of lower-class life produce crime. Explains violence and destructive acts. Identifies conflict of lower class with middle class.
Cloward and Ohlin's theory of opportunity	Blockage of conventional opportunities causes lower-class youths to join criminal, conflict, or retreatist gangs.	Shows that even illegal opportunities are structured in society. Indicates why people become involved in a particular type of criminal activity. Presents a way of preventing crime.
Social Process Theories		
Social Learning Theories		
Differential association theory	People learn to commit crime from exposure to antisocial definitions.	Explains onset of criminality. Explains the presence of crime in all elements of social structure. Explains why some people in high-crime

Theoretical School	Major Premise	Strengths
		areas refrain from criminality. Can apply to adults and juveniles.
Differential reinforcement theory	Criminal behaviour depends on the person's experiences with rewards for conventional behaviours and punishment for deviant ones. Being rewarded for deviance leads to crime.	Adds psychological learning theory principles to differential association. Links sociological and psychological principles.
Neutralisation theory	Youth learn ways of neutralising moral restrains and periodically drift in and out of criminal behaviour patterns.	Explains why many delinquents do not become adult criminals. Explains why youthful law violators can participate in conventional behaviour.
Social Control Theories		
Containment theory	Society produces pushes and pulls toward crime. In some people, they are counteracted by internal and external containments, such as a good self-concept and group cohesiveness.	Brings together psychological and sociological principles. Can explain why some people are able to resist the strongest social pressure to commit crime.
Hirschi's social bond theory	A person's bond with society prevents him or her from violating social rules. If the bond weakens, the person is free to commit crime.	Explains the onset of crime, can apply to both middle and lower-class crime. Explains its theoretical constructs adequately so they can be measured. Has been empirically tested.
Social Reaction Theory		
Labelling theory	People enter into law-violating careers when they are labelled for their acts and organise their personalities around the labels.	Explains the role of society in creating deviance. Explains why some juvenile offenders do not become adult criminals. Develops concepts of criminal careers.

Source: Siegel 2003: 205 & 241

The social disorganisation theory as part of the *social structure theory* cluster is the crux of the present study. However, it must not be seen in isolation but must also be integrated with other contemporary theories of criminology. The concept of the social disorganisation theory, including its sub-theories such as the concentric zone theory, the ecological or the Chicago school theory, is fundamental to this chapter as it relates directly to spatial technology's contribution to the analysis and combating of crime. The strain theory in general is discussed and its relation to social disorganisation. The cultural deviance theory and the rest of the social process theories are be discussed in further detail as they relate more to the sociological aspect of crime.

In Siegel (2003:214) *social process theories* hold that criminality is a function of individual socialisation. These theories draw attention to the interactions people have with various organisations, institutions and processes of society such as education, employment, family life and peer relationships.

The relationship between crime and social stratification concepts as discussed earlier from a sociological perspective need to be highlighted. Any satisfactory account of the nature of crime must be sociological, for what crime is depends on the social institutions of society. One of the most important emphasis of sociological thinking about crime is on the interconnections between conformity and deviance in different social contexts. Modern societies contain many different subcultures, and behaviour that conforms to the norms of one particular subculture may be regarded as deviant outside it (Giddens 1998:176).

2.2.7 Social structure theories

Many criminologists view the disadvantaged economic class position as the primary cause of crime. This view is referred to as **social structure theory**. As a group, social structure theories suggest that social and economic forces operating in deteriorated lower-class areas push many of their residents into criminal behaviour patterns. These theories consider the existence of teenage gangs, high crime rates and social disorder in slum areas as major social problems (Siegel 2003:180).

The three branches of social structure theory are well described in Siegel (2003:182):

Table 2.5: The three branches of social structure theory

Social disorganisation theory focuses on conditions in the environment: ▪ Deteriorated neighbourhoods ▪ Inadequate social control ▪ Law-violating gangs and groups ▪ Conflicting social values		
	Cultural deviance theory combines the other two: ▪ Development of subcultures as a result of disorganisation and stress ▪ Subculture values in opposition to conventional values	**CRIME**
Strain theory focuses on conflict between goals and means: ▪ Unequal distribution of wealth and power ▪ Frustration ▪ Alternative methods of achievement		

Source: Siegel 2003:182

2.2.7.1 Strain theory

The term "anomie" is generally referred to a disregard for law. Anomie as used by Emile Durkheim and Robert K. Merton involves a moral malaise, a lack of clear-cut norms with which to guide human conduct (normlessness) (Giddens 1998:177). The work of Merton has been used by contemporary integrated criminological theories as an important basis of thought. These contemporary theories are discussed at the end of this chapter.

Anomie may occur as a pervasive condition in society due to a failure of individuals to internalise the norms of society due to a failure of individuals to adjust to changing norms, or even conflict within the norms themselves. Social trends in modern urban-industrial societies result in changing norms, confusion, and lessened social control over the individual. Individualism increases and new lifestyles emerge, perhaps yielding even greater freedom but also increasing the possibility of deviant behaviour. The close ties of the individual to the family, village and tradition, although confining to the individual, maintained social control. In modern societies constraints upon the individual have weakened. On a theme which would influence many later criminological theories, Durkheim viewed anomie in modern societies as being produced by individual aspirations and ambitions and the search for new pleasures and sensations which are beyond achievement even in times of prosperity (Williams & McShane 1999:93).

The strain theory presents five ways of adapting to strain caused by restricted access to socially approved goals and means. If the emphasis on goals and means is maintained even in the face of a realisation that the means are restricted, an individual will remain conforming. Most people adapt, Merton maintains, and if they did not, the very existence of society would be threatened. The remaining four modes, however, are a departure from this all-endorsing adaptation and are thus the "real" deviant modes of adaptation. These modes are innovation, ritualism, retreatism and rebellion (Giddens 1998:177).

In short, Merton's anomie theory in Williams & McShane (1999:98) explains how social structure contributes to the creation of deviance on all levels, although the primary focus of the theory is on the lower class. Because of the societally induced disjunction between cultural aspirations and the approved methods of attaining those aspirations, the lower class is most likely to exhibit deviant, non-approved adaptive behaviour (Williams & McShane 1999:98).

According to anomie theory, social inequality leads to perceptions of anomie. To resolve the goals-means conflict and relieve their sense of strain, some people innovate by stealing or extorting money, others retreat into drugs and alcohol, others rebel by joining revolutionary groups and still others become involved in ritualistic behaviour by joining religious cult. Merton's view of anomie has been one of the most enduring and influential sociological theories of criminality (Siegel 2003:194).

In the researcher's view, the strain theory is a further development of the basic arguments from the Marxist theories. The existence of different classes formed by capitalist structures results in the goals and means not being available to everyone through conventional ways. The strain theory applies more to the sociological explanation of crime. The spatial technology applied in this study has a limited relationship with this theory, although certain social classes can be mapped and rated in terms of income and residential type, etc.

2.2.7.2 Social disorganisation theory

Social disorganisation theory focuses on the conditions in the urban environment that affect crime rates. A disorganised area is one in which institutions of social control, such as the family, commercial establishments and schools have broken down and can no longer carry out their expected or stated functions. Indicators of social disorganisation include high unemployment and school drop-out rates, deteriorated housing, low income levels and large numbers of single-parent households. Residents in these areas experience conflict and despair, and as a result antisocial behaviour flourishes (Siegel 2003:182).

Social disorganisation operates "through the processes of value and norm conflicts, cultural change and cultural vacuums, and the weakening of primary relationships. Characteristics of the community, including *urbanisation, residential mobility, racial or ethnic heterogeneity, socioeconomic status (SES), family disruption or single-parent households,* and others, inhibit a community's ability to impose social controls over people in the community. The criminogenic influence of social disorganisation operates through processes such as reduced friendship networks, less involvement in community organisations, and less supervision of young people. Specifically, the theories of *strain, differential opportunity, social control and social learning* can all be traced back to social disorganisation research. The social disorganisation theory can be seen as the foundation for several other theories in contemporary criminology" (Paulsen & Robinson 2004:64).

The concept of social integration is a prominent theme in social disorganisation theory. Accordingly, community crime rates are a function of a community's ability to establish formal and informal connections among members so as to realise common values and work toward solving or preventing social problems (Barnett & Mencken 2002:374). The major structural or community-level concepts that impede this process are residential stability or mobility, economic hardship (low SES), and racial/ ethnic heterogeneity (Bursik 1999:85). These structural conditions affect crime indirectly through their effects on community social organisation such as the formation of local friendship networks, the ability to control local teenage populations and levels of civic engagement (Barnett & Mencken 2002:374).

In the researcher's view, social disorganisation creates an environment in which unfair conditions compete with scarce commodities. Unhealthy, uncontrolled conditions and subculture dominance create the ideal grounds for being aligned with the criteria for anomie, with crime as the ultimate outcome. Spatial technology can classify land use and geo-coded crime for pattern recognition with very high resolution imagery to evaluate and monitor certain conditions on the ground. This is an area in which remote sensing or ortho-photos can play an important role in combating and analysing crime combined with geographical information system (GIS) modelling, especially to show up spatially the core elements of social disorganisation. In Siegel (2003:183) the core elements of the social disorganisation theory are poverty, social disorganisation, breakdown of social control, criminal areas, cultural transmission and criminal careers.

a) Shaw and McKay's concentric zones theory

Scholars at the University of Chicago created what has been variously called the “Chicago School of Human Ecology” and the “Chicago School of Criminology” in the early 20th century (Paulsen & Robinson 2004:57). This theory, and the school of thought from which it emerged, came about largely as a result of environmental and social conditions that materialised at the turn of the 20th century in Chicago, including extensive foreign immigration, high rates of juvenile delinquency, and other social problems in the city. *Social disorganisation* was used to explain why these conditions materialised and survived. Robert Park (in Paulsen & Robinson 2004:58) started in the early 1900s to investigate the social conditions in the city of Chicago. From the field of plant ecology, he borrowed two concepts which helped him form what he called the *theory of human ecology*. The field of human ecology encompasses the field of the ecology of crime, but in turn it is encompassed by more general fields of ecology (Paulsen & Robinson 2004:58).

The *first* concept borrowed by Robert Park was from Eugenius Warming. Warming posited that plant communities were made up of individual organisms, each having its own characteristics (Paulsen & Robinson 2004:59). These characteristics in combination resembled the original organism. Thus, each plant community was analogous to a distinct organism. Park (in Paulsen & Robinson 2004:59) saw the city in a similar way – as a super-organism. He noted that many areas existed where different types of people lived. Like the natural areas of plants, each area of the city had an organic unity of its own. Divisions in the city existed, including racial and ethnic divisions, income and occupational divisions, industrial and business divisions and physical divisions separated by architectural and natural structures (Paulsen & Robinson 2004:59).

The *second* concept revolved around how the balance of nature in an area changed. The primary mechanisms identified by Parker were *invasion, domination* and *succession*. He viewed communities as functionally specialised areas within an industrial economy. The patterning of communities was determined by competition, and change was determined by invasion and social succession. Later ecological studies focused on ecological spatial patterns of cities such as Burgess's (1925) *concentric circles*, Hoyt's (1943) *sectors*, and Shaw and McKay's (1929, 1942) work on *delinquency areas* (Paulsen & Robinson 2004:60). In the researcher's view such a division of classes within a city boundary is also related to the early Marxist theories and the difference in behaviour based on social classes.

Clifford Shaw utilised Park's theories as a foundation for studying juvenile delinquency in Chicago (Paulsen & Robinson 2004:60). Shaw believed that juvenile delinquency resulted from the juvenile's *detachment from conventional groups*. This would lead to *social control theories*, popularised by scholars such as Travis Hirschi and Michael Gottfredson, which attribute delinquency, criminality and other forms of antisocial behaviour to a weak bond to society and a low degree of self-control (Siegel 2003:180).

Shaw and Mckay (in Paulsen & Robinson 2004:61) mapped the residences of juveniles identified by the police or courts as delinquent over several decades. The maps produced pinpointed the residences of juveniles who had become involved with the criminal justice system. Other maps showed percentages of the juvenile population who were involved in the criminal justice system. Through zone maps, a general tendency emerged for delinquency to be concentrated towards city's centre. These findings, along with case studies of individual delinquents, led to the theory of *social disorganisation* (Paulsen & Robinson 2004:61).

The concentric zones concept. Shaw and McKay (in Siegel 2003:184) identified the areas in Chicago that had excessive crime rates. Using a model of analysis pioneered by Ernest Burgess (in Siegel 2003:184), they noted that distinct ecological areas had developed in the city, comprising a serious of five concentric circles, or zones, and that there were stable and significant differences in interzone crime rates (see Figure 2.1). The areas of the heaviest concentration of crime appeared to be the transitional inner-city zones, where large numbers of foreign-borne citizens had recently settled. The zones furthest from the city's centre had correspondingly lower crime rates. Shaw and McKay's (in Siegel 2003:184) statistical analysis confirmed their theoretical suspicions. Even though crime rates changed, they found that the highest rates were always in Zones 1 and II (central city and transitional area). The areas with the highest crime rates retained their high rates even when their ethnic composition changed (Siegel 2003:184).

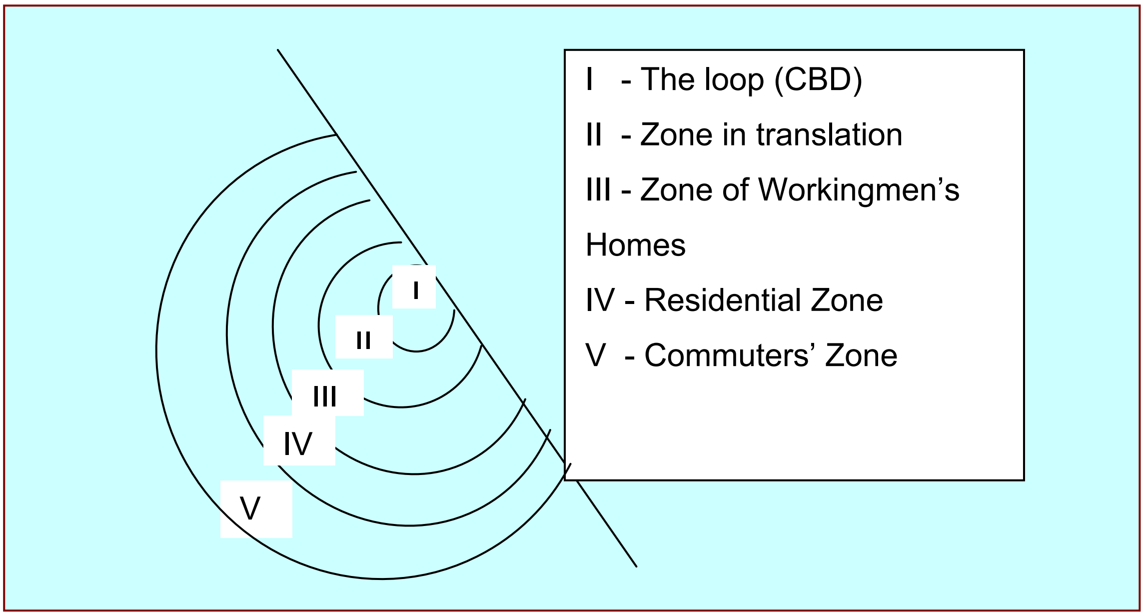


Figure 2.1: Chicago's concentric zones

(Paulsen & Robinson 2004:58)

In the researcher's view the concentric zone theory forms the basis for the use of spatial technology to draw buffers around defined boundaries as per categorised zone areas. The interpretation capability of very high resolution imagery can create additional information layers to define the inner behaviour of the specific zones. Medium-resolution remote sensing imagery over a defined historical period can indicate the expansion behaviour of the city area. Although not all cities have the same urban features, remote sensing imagery and GIS modelling can provide the analyst with enough information to understand which concentric zones can be applied to a specific city. The cities' inner features that relate to an ideal environment for criminal behaviour such as the elements of social disorganisation described above can be mapped and statistically rated in terms of risk. The objective of utilising this type of technology will assist in explaining the growth pattern and social stratification classes within a specific geographical area. This information could then eventually be used to address the prevention of criminal behaviour with a more scientific approach.

b) Ecological theories of crime

In the 1970s, when Oscar Newman and C. Ray Jeffery published their respective books, *Defensible Space* and *Crime Prevention Through Environmental Design (CPTED),* it marked a significant turning point in thinking regarding the etiology of criminal behaviour (Paulsen & Robinson 2004:80). Ecological theory can be traced back to the Chicago School of Human Ecology (Paulsen & Robinson 2004:81). The Chicago theorists actually used primitive maps – pin maps and zone maps, for example – to illustrate where rates of street crimes and delinquency were highest in the city. The development of modern crime mapping can be directly attributed to the work of more modern ecological theorists, including those who have worked in the areas of defensible space, crime prevention, routine activity theory and crime pattern theory (Paulsen & Robinson 2004:81).

i) Defensible space

Defensible space is a term used to describe a residential environment designed to allow and even encourages residents themselves to supervise and be seen by outsiders as responsible for their neighbourhoods. Oscar

Newman's (in Paulsen & Robinson 2004:81) notion of environmental design is based on the development of coordinated design standards – for architecture, land use, street layout and street lighting – which improves security. Its goal is to create environments which reduce the opportunities for crime while encouraging people to use public space in ways that contribute to their safety and enhance their sense of community.

Newman's (in Paulsen & Robinson 2004:81) notion of environmental design is more complex than simply redesigning space. It also redesigns residential environments so that residents use the areas and become willing to defend their territory. Defensible space design strengthens two basic kinds of social behaviour, namely *territorial* and *natural surveillance*. The goal of the defensible space approach is to release the latent sense of territoriality and community among inhabitants so as to allow these traits to be translated into inhabitants' assumption of responsibility for preserving a safe and well-maintained living environment. This theory attempted to reduce both crime and fear of crime in a specific type of environment (public housing) by means of reducing opportunity for crime and fostering positive social interaction among legitimate users (Paulsen & Robinson 2004:81).

ii) Crime Prevention Through Environmental Design (CPTED)

CPTED is aimed at identifying conditions of the physical and social environment that provide opportunities for or precipitate criminal acts, and the alteration of those conditions so that no crime occurs. Since it is aimed at preventing occurrences of criminality, CPTED is conceptually distinct and significantly different from the reactive (and largely failing) strategies employed by the police, courts and correctional facilities (Paulsen & Robinson 2004:86).

The notion of CPTED came to the forefront of criminological thought with C. R. Jeffery's *Crime Prevention Through Environmental Design (CPTED)* in 1971, a work written simultaneously and therefore without influence from Oscar Newman's *Defensible Space* in 1972 (Paulsen & Robinson 2004:86).

Rooted deeply in the psychological learning theory of B. F. Skinner, Jeffery's CPTED approach emphasised the role of the physical environment in the development of pleasurable and painful experiences for the offender that would have the capacity to alter behavioural outcomes. Jeffery's original CPTED model was a stimulus-response (S-R) model positing that the organism learned from punishments and reinforcements in the environment. The major idea here was that by removing the reinforcements for crime, it would not occur. This was the early argument for crime prevention which rejected the more popular crime control goals of revenge, just deserts, or retribution and deterrence, as well as punitive crime control strategies employed by the criminal justice system (Paulsen & Robinson 2004:87).

Jeffery's theoretical work on CPTED was based on a biological rather than a social ecological model, meaning that Jeffery's model of human behaviour contained both a concrete physical environment and a concrete physical organism (Paulsen & Robinson 2004:90). This CPTED model does not focus on abstract sociological concepts such as social disorganisation and social learning that tend to minimise the concrete physical environment in favour of the abstract social environment. Jeffery's shift from a stimulus-response model of human behaviour to an integrated systems approach was motivated by research into the role of the brain in human learning conducted by researchers outside the field of criminology in the early 1970s. Jeffery's CPTED model evolved into a general crime prevention model. It includes both the external environment of the place and the internal environment of the offender (Paulsen & Robinson 2004:90).

As the CPTED model evolved over time and more studies were conducted, it can now be described as the specific management, design or manipulation of the immediate environment in which crimes occur in a systematic and permanent way (Paulsen & Robinson 2004:91). While CPTED generally involves changing the environment to reduce the opportunity for crime, it is aimed at other outcomes, including reducing fear of crime, increasing the aesthetic quality of an environment and increasing the quality of life for law-abiding citizens, especially by reducing the propensity of the physical environment to support criminal behaviour. In conclusion, CPTED that only applies to the external physical environment is limited, and to be more effective it should be applied to both external and internal environments, or to the environments of the place and the offender respectively (Paulsen & Robinson 2004:92).

iii) Situational crime prevention

Situational crime prevention is aimed at eliminating opportunities for crime. It includes opportunity-reducing measures that are directed at highly specific forms of crime that involve the management, design and manipulation of the immediate environment in as systematic and permanent way as possible so as to increase the effort and risks of crime and reduce the rewards as perceived by a wide range of offenders (Paulsen & Robinson 2004:97).

The situational crime prevention model originated from lessons learned from research on correctional treatments by the British Government's Home Office Research Unit that demonstrated the potential for designing out misbehaviour by manipulating situational factors in the immediate environment of institutions (Paulsen & Robinson 2004:98). This research, combined with the "the action research model" in which researchers and practitioners work together to analyse and define problems, identify and implement possible solutions and evaluate results, led to the development of the theory underlying situational crime prevention, as well as the standard methodology it uses. R. V. Clarke (in Paulsen & Robinson 2004:98) contributed largely to the situational crime prevention theory and to some of the approaches available. The four major categories of situational crime prevention are increasing the difficulty of crime, increasing the risks of crime, reducing the rewards of crime and removing excuses for crime.

iv) Routine activity theory

A resurgence and rediscovery of interest in the ecological and social disorganisation theories of crime has been rekindled by formulations such as

Cohen and Felson's (1979) (in Paulsen & Robinson 2004:102) “routine activities approach” to crime causation. This approach says that “the volume of criminal offences will be related to the nature of normal everyday patterns of interactions; there is a symbiotic relationship between legal and illegal activities”. In essence, this theory specifies three concrete elements of crime: a likely offender, a suitable target, and the absence of a capable guardian against crime. It considers how everyday life assembles these three elements in space and time. It shows that a proliferation of lightweight durable goods and a dispersion of activities away from family and household could account quite well for the crime wave in the U.S. in the 1960s and the 1970s without fancier explanations. Indeed, modern society invites high crime rates by offering a multitude of illegal opportunities (Paulsen & Robinson 2004:102).

The term routine activities means any recurrent and prevalent activities which provide for basic population and individual needs, whatever their biological or cultural origins, including formalised work, leisure, social interaction and learning which occur at home, in jobs away from home and in other activities away from home. Felson and Clarke (in Paulsen & Robinson 2004:102) use the acronym VIVA to clarify the four elements that influence a target’s risk of being victimised by crime. They are *value, inertia, visibility* and *access*. Routine activity also points to factors unique to lifestyles or potential offenders and victims as these are affected by larger social processes (Paulsen & Robinson 2004:102).

In a large number of countries in Africa rural poverty has induced urban migration despite the lack of economic growth in their settlements. For many years a common pattern was assumed to characterise the bulk of migration throughout the Third World – most migrants were adult males, the vanguard of a family shift, who sought work in a series of step-like moves up the urban hierarchy at an increasing distance from their point of origin (Hough & du Plessis 2003:176). The first steps are to migrate to a nearby small town, learn some skills and establish an income, then move to a larger settlement with a greater range of opportunities. Apart from the criminological significance of densely populated urban areas, uncontrolled urbanisation places an unmanageable strain on available resources and creates conditions even more conducive to crime. Urban poverty is growing rapidly and in some countries the proportion of poverty in cities is greater than in some rural areas. Large informal settlements around major cities in developing countries, sustaining themselves through criminal economies, are also particularly detrimental to effective policing and crime control (Hough & du Plessis 2003:177).

The importance of victims' lifestyles is also indicated by the lifestyle/exposure theory, which was developed by Hindelang, Gottfredson and Garofalo (Hough & du Plessis 2003:185). This model of criminal events links victimisation risks to the daily activities of specific individuals, especially potential victims. *Lifestyles* are patterned, regular, recurrent, prevalent or "routine activities" (Paulsen & Robinson 2004:104). Lifestyles consist of the activities that people engage in on a daily basis, including both *obligatory activities* and *discretionary activities*. Because lifestyles vary, victimisation is not evenly distributed across space and time. Specifically, lifestyles influence a person's exposure to places and times with differing risks of victimisation and frequency of associations with potential offenders (Paulsen & Robinson 2004:103). Both lifestyle/exposure and routine activity theories can be considered as subsets of a more general *opportunity model* and can be interpreted with the *rational choice theory* (Hough & du Plessis 2003:190).

v) Crime pattern theory

Crime pattern theory is focused on the criminal event, which is an opportune cross-product of law, offender motivation and target characteristics arrayed on an environmental backcloth at a particular point in space-time. It is therefore an attempt to address and correct what P. J. Brantingham and P. L. Brantingham (in Paulsen & Robinson 2004:107) call the primary weakness in most criminological theory, which is a tendency to equate criminality with crime even when criminality is but one of the elements contributing to a criminal event (Paulsen & Robinson 2004:107).

Crime pattern theory is a combination of the complementary work of many parts of an alternative movement in criminology which focuses on the criminal event itself, or on patterns of crime and criminal behaviour including (Paulsen & Robinson 2004:107):

- rational choice theory
- routine activity theory
- environmental criminology
- strategic analysis
- Lifestyle/ exposure theory
- CPTED
- situational crime prevention
- hot spot analysis
- opportunity theories.

Brantingham and Brantingham (in Paulsen & Robinson 2004:108) developed crime pattern theory in order to describe the process whereby a criminal event occurs. Essentially it starts with a person acting or behaving in some manner. With the presence of some event, the desire or willingness to engage in crime is triggered. This triggering event leads to an offender search, which can be minimal or broader depending on such factors as how well the offender knows the area. This search, depending on the availability of suitable targets, may result in the criminal event. The three main concepts of crime pattern theory are nodes, paths and edges (Paulsen & Robinson 2004:108). Nodes refer to where people travel to and from (e.g. home, work, store, etc.). Paths are the main areas of travel between these nodes (e.g. the streets and sidewalks on which people travel to and from home and work). Finally, edges are the boundaries of the area where people engage in their activities (e.g. neighbourhoods and cities where people spend their time).

The activity routines of people help shape their activity space and form so that people develop an awareness space. Search patterns of potential offenders help determine target selection by offenders. Target selection depends on mental templates used to shape searches for targets or victims and to predefine the characteristics of a suitable place for finding targets (Paulsen & Robinson 2004:109).

Crime mapping software is potentially very useful for illustrating the key concepts of crime pattern theory. It is possible to map key nodes of activity and the path of would-be offenders as they travel to and from these locations within the edges of their activity spaces. High-resolution satellite imagery can assist as a backdrop of the actual environment (awareness space) to interpret the accessibility of routes and key nodes within a specific area and its relationship with specific criminal events plotted as a crime layer onto the imagery.

vi) Crime prevention through planning and design – South African perspective

As indicated, certain types of crime can be addressed by altering the environment in which they occur. Changes to the physical environment aim to make it more risky and difficult to commit a crime. The environment can be planned, designed and managed in such a way that it requires more effort by potential offenders to carry out their criminal activities. Crime prevention through planning and design aims to reduce the causes of, and opportunities for, criminal events and to address the fear of crime by applying sound planning, design and management principles to the built environment (Kruger, Landman & Liebermann 2001:7).

Within the South African context, this incorporates the following (Kruger *et al*. 2001:7):

- **Planning –** physical urban planning approaches used at a strategic level, including the promotion of mixed land use, the reduction of vacant land, etc.
- **Design –** the detailed design of the different urban elements, such as the movement system and the roads, the public open space system and individual buildings on their separate sites.

- **Management –** the management of the entire urban system and the different elements and precincts that make up the urban area. This includes infrastructure maintenance, the enforcement of by-laws, etc.

Changes made to the built environment to reduce crime often elicit a response from offenders. People change their behaviour, crime shifts its locale, or the type of crime changes. Environmental design can therefore not always be totally preventive, and for this reason crime prevention measures require constant review to ensure their continued effectiveness (Kruger *et al*. 2001:7).

Most of those responsible for the planning, design and management of the physical environment are not familiar with analysing crime patterns. However, in order for environmental design to be effective, some understanding of the crime situation in South Africa is required. Two features of crime in South Africa have important implications for interventions in the built environment. These are that crime levels are high and that crime affects different people in different parts of the city differently (Kruger *et al*. 2001:13). The latter assumptions are discussed in chapters 3 and 4 as part of the empirical study.

Many of the planning and design crime prevention measures have been developed over many years for use in other, mainly developed, countries. Their adaptation to the South African situation requires a particular understanding of local urban characteristics and dynamics, and their implementation similarly requires an acknowledgement of our previous planning policies and how this has affected the form and structure of the South African city. Much has been written on the subject of the apartheid city. It is acknowledged that these cities, which still bear testimony to our history, are the primary settings in which crime takes place. The following spatial characteristics need to be challenged and comprehensively addressed (Kruger *et al*. 2001:14):

- The spatial dislocation of the poor, which results in long and costly commuting patterns.

- The separation of communities and the vacant land used in the past to divide people.
- The stigma attached to living in certain parts of the city.
- The wide disparities in living levels evident in the depressed quality of life and degraded built environment experienced by many in the apartheid city.
- The effective exclusion of many residents from the amenities and economic opportunities offered by the city.
- The rigid mono-functional zoning of land which leaves some areas deserted at night and others deserted during the day, and reduces residential areas to virtual dormitories.

It remains the function of urban design and planning practitioners to address these issues as part of their responsibility and to play their roles effectively in order to reduce crime and make cities safer places (Kruger *et al*. 2001:15). A process was developed to assist in approaching local crime problems systematically as opposed to an *ad hoc* response. This process can contribute towards reducing specific types of crime in particular locations, it can be incorporated proactively into the design of new developments or the upgrading of existing areas, or it can form part of an integrated community safety plan. This process can be described as follows (Kruger *et al*. 2001:19):

- Activity 1 = Identify the crime problem
    - Crime pattern and trends
    - Crime hot spots
- Activity 2 = Assess the physical environment
    - Macro level
    - Micro level
- Activity 3 = Assess the social and institutional environment
    - Social characteristics
    - Existing crime prevention initiatives
    - Local authority capacity
- Activity 4 = Synthesise and analyse the information

    - Macro level – crime patterns and the spatial configuration of the area
    - Micro level – hot spots and neighbourhood characteristics
- Activity 5 = Develop an appropriate response
    - Macro level – crime patterns and spatial configuration of the area
    - Micro level – hot spots and neighbourhood characteristics

In the researcher's view the environment can play a significant role in influencing perceptions of safety. Certain environments can impart a feeling of safety, while others can induce fear, even in areas where levels of crime are not high. In this regard, planning and design measures can be utilised very successfully to enhance feelings of safety in areas where people feel vulnerable. Spatial technology within the "CPTED" concept in the South African context can be used to create information layers of great importance for activities 1 to 5 as part of the process of crime prevention through planning and design. These concepts are discussed in Chapter 3 of this study.

2.3 THE INTEGRATION OF CRIMINOLOGICAL THEORY

The events and influences that will affect current theoretical direction are difficult to see because of their close proximity to us. A few influences, however, should have a bearing on the ways theorists think. The social influences are political and economic conservatism. The intellectual influences include a new discipline specialising in criminal justice and an emphasis on quantification (Williams & McShane1999:269).

The integration of theory is an ever-important concept in the new way in which criminological theory is formed. Criminology needs to take stock of the theories it has already developed. The same variables have been used time and again to explain crime and delinquency, yet each time the claim was that a new theory was being developed, although not necessarily by the authors themselves. It may even be that we have enough theories and just need to determine exactly what they explain and the context in which they work best. It makes sense to begin to determine exactly how and where existing theories fit together. Macro theories obviously do not compete with micro theories. Structural theories may be compatible with and explain the society in which social process theories operate. Thus a good starting point might be to integrate some of these theories (Williams & McShane 1999:274).

Advocates of theory integration suggest that initial attempts at blending the propositions of different perspectives should begin at the level characteristic of those theories (Schmalleger 1999:579). In other words, theoretical approaches concerned with analysing crime at the individual level (micro level) might be integrated at the same time that sociological, political and economical explanations (macro level) are woven together. Other criminologists have developed rudimentary meta-theories or theories about theories and the theorising process, which they suggest may help to meld existing theories.

Williams & McShane (1999:283) give the *critical-incident meta-theory* as one version of chaos-based post-modern theories. Rather than proposing a theory of behaviour, it proposes a way to view and structure reality, thus a way to "understand" the existing evidence on crime and criminals. The meta-theory basically say that, because reality is highly complex, so are the concepts of crime and criminality. Behaviour is a product of the interplay of genetics, neurochemistry, physical environment, psychological tendencies and social environment. These factors come together in an individual's background, with new events either adding to or subtracting from the accumulating pile of factors. At some time, a critical point is reached and the individual reacts to relieve stress with some behaviour (Williams & McShane 1999:283). The fundamental thoughts of the strain theory can also be integrated. An individual who experiences anomie within a social stratification structure uses criminal methods as an acceptable behaviour to survive or to "fit in" with a specific class.

Some metatheoreticians, however, have expressed the concern that we may be integrating theories without first properly examining their worth and that, as a consequence, we may be left with highly elaborate integrated theories that are worthless (Schmalleger 1999:579). In the researcher's view the theoretical integration process is still in its early stages and will take a while longer to show any practical promise for criminology. However, the concept cannot be ignored and is part of the future criminology roadmap.

Based on evidence produced by environmental design and victimisation research, some criminologists began to conceive of criminals as rational individuals who make their own behavioural choices from a patchwork of opportunity. Others, informed by advances in feminist thought, used age-old evidence on male/female crime to create gender-based explanations of socialisation, power and lifestyle differentials as they affect criminality (Williams & McShane 1999:286). Still others, tired of the orderly way in which mainstream theories relegated deviance to objective existence, insisted that crime is best understood as a subjective experience, a seduction into evil (Williams & McShane 1999:286). Even the concept of crime itself has been questioned, and terrorism became a topic worthy of treatment by two such prominent theorists as Jack Gibbs and Austin Turk (Williams & McShane 1999:286).

Future criminology is defined in Schmalleger (1999:556) as the study of likely futures as they relate to crime and its control. L. E. Wells (in Schmalleger 1999:561) makes a number of specific predictions about the future of criminological theorising. Some of these predictions are:

- more eclectic than past theories, and less tied to a single theoretical tradition or discipline
- more comparative and less confined to a single society or single dominant group within the society
- predominantly *individualistic* rather than collective, and *voluntaristic* rather than deterministic
- more applied and pragmatic in orientation

- more orientated towards explaining white-collar crime
- reflect a renewed appreciation for the biological foundations of human behaviour and will assign more theoretical substance to biological and medical factors.

Schmalleger (1999:562-576) and Williams and McShane (1999:236-239) list the following major new criminological theories:

- Post-modern criminology – a brand of criminology that developed following World War II which builds on the tenets inherent in post-modern social thought.
- Deconstructionist theories – emerging approaches which attempt to debunk existing criminological perspectives and which work towards replacing them with concepts more applicable to the post-modern era.
- Rational choice theory – a perspective which hold that criminality is the result of conscious choice, and which predicts that individuals choose to commit crime when the benefits outweigh the costs of disobeying the law.
- Routine activity theory – a brand of rational choice theory which suggests that lifestyles contribute significantly to both the volume and type of crime found in any society.
- Lifestyle theory – patterned activities, or lifestyles, of individuals lead to differential victimisation rates. These lifestyles are characterised by daily functions involving both work and leisure activities.
- Situational crime prevention – a social policy approach that looks to develop greater understanding of crime and more effective crime prevention strategies through concern with the physical, organisational and social environments that make crime possible.
- Feminist theory – a developing intellectual approach which emphasises gender issues in the subject matter of criminology.
- Power-control theory – a perspective which holds that the distribution of crime and delinquency within society is to some degree founded upon the consequences which power relationships within the wider society

hold for domestic settings, and for the everyday relationships between men, woman and children within the context of family life.

- Peacemaking criminology – a perspective which holds that crime-control agencies and the citizens they serve should work together to alleviate social problems and human suffering and thus reduce crime.
- Realist criminology – an emerging perspective that insists on a pragmatic assessment of crime and its associated problems.

Schmalleger's (1999:585) view is that post-modern criminology, combined with the traditional approaches of the past, appear to offer the best hope of coping with crime and developing a truly just society in the 21st century (Schmalleger 1999:585). Integrated individual theoretical models developed by Terrance Miethe and Robert Meier in their heuristic model, and James Wilson and Richard Herrnstein in their attempted integration of social learning with biological traits, serve as examples (Williams & McShane 1999:274 and 278).

Finally, some researchers attempted to find new ways to reconstruct the old versions of criminological theories, and work on deterrence became more sophisticated (Williams & McShane 1999:286). If the analysis in Williams & McShane (1999: 287) is correct, then contemporary criminology is now coming along nicely. As indicated in this chapter, theorists are considering new evidence on criminality while at the same time reconceptualising and reassessing old evidence. The direction the new theories will take is still not clear. Nonetheless, the field appears to be on the verge of a paradigm revolution as energetic and far-reaching as that which precipitated the labelling movement of the early 1960s (Williams & McShane 1999:287).

In the researcher's view, apart from the integration of theories to explain and forecast criminal behaviour, an essential concept is also the combination of various sciences such as social science with natural science to broaden the science of criminology even further. The way in which theories are integrated is also of interest. Williams & McShane (1999:274) believe that it is possible to put theories together in a sequential, straight-line fashion, referred to as an **end-to-end model**. In this model, a structural, macro-level theory would precede a middle-level theory (bridging theory), and a micro-level theory might conclude the process. Another approach is to borrow concepts from several theories without regard to either the assumptions or the general thrust of the theories. These concepts are then put together in a new fashion. This approach is called a **fully-integrated model** (Williams & McShane 1999:274). The creation of such a model is, however not an objective of this study but to illustrate the significance reciprocity of criminological theory and the science of remote sensing (see section 5.3).

2.4 THE USEFULNESS OF CRIMINOLOGICAL THEORY

Although the word "theory" most likely suggests something that is "just theoretical" and "not practical", the truth is that theory is very useful in the real world. Theory is aimed at explaining things we have observed. Theory thus allows us to make sense of what we experience and things in the world in general. As for criminological theories, they attempt to explain why criminality occurs, based on the many observations of criminal behaviour over the years. Theory allows us to understand why criminal behaviour occurs, and where and when it is most likely to occur. Ultimately, we can use the findings from tests of theories to prevent criminal behaviour or lessen the likelihood that it will occur (Paulsen & Robinson 2004:6).

Spatial analysis techniques, such as crime mapping software, can aid tremendously in these efforts. The main advantage that these techniques offer over non-spatial techniques is that they allow visual depiction of observations by place and time. This has tremendous significance because being able to "see" facts is crucial to understanding them. It is also advantageous because social facts can be mapped along with individual criminal events or crime rates in order to assess relationships between these facts and crime (Paulsen & Robinson 2004:6).

In the researcher's view spatial technology as an analytical and a visual interpretation tool can be applied within the social structural theories and contemporary theories where the focus is not only on the individual criminal but also on the environment in which he or she operates. The availability of high-technology software and improved computer processing capability, mathematical computation and algorithms for statistical analysis of large datasets and the combination of multi-layers in GIS, can provide more and more information about the phenomenon of crime. Crime patterns, displacement of crime and the detection of changed behaviour of land use classes over time to understand the characteristic of a city or a specific environment with the assistance of high or medium-resolution satellite imagery are discussed in the next chapter of this study.

2.5 CONCLUSION

This study shows the interoperable nature of the two concepts: the criminological theories as a method to explain and analyse crime, and spatial technology such as remote sensing and geographical information systems (GIS) to visually map the events of crime and their displacement. This interoperability ultimately assists in the prediction and prevention of crime. In the spatial analysis of crime, a multi-dimensional criminological theory approach is recommended to achieve the ultimate goal: the prediction and prevention of crime. For example, the social structural theories, contemporary theories, the strain theory and Marxists concepts of class differences within a capitalist society can be applied in the explanation of certain spatial characteristics. By integrating these theories with spatial information, a criminologist can verify or improve on certain theoretical concepts and apply them to forecasting and crime prevention models.

Crime statistics as used by the fathers of the ecological school of criminology such as Quetelet and Guerry and the spatial plotting of criminal events indicate the distribution of crime and crime clusters. It is therefore important for this study to have a basic knowledge of the core criminological theories and how to apply them in practice using visual interpretable software to incorporate socio-economic and environmental attributes such as specific land use and land cover classes and their behaviour over time. This concept is discussed and illustrated in Chapter 3.

CHAPTER 3: REMOTE SENSING AND FUTURE RELATED TECHNOLOGIES

3.1 INTRODUCTION

The objective is to provide the reader with a basic knowledge of spatial technology with the emphasis on remote sensing. The science behind remote sensing and its applications is briefly discussed.

The applications that can be created from multi-sensors at different ground resolution cover a wide range of areas such as agriculture, forestry, urban planning, change detection, land use/land cover mapping, safety and security planning, etc. The discussion also includes electromagnetic energy, electromagnetic spectrum, image characteristics, remote sensing systems, orbits, earth observation satellites and future satellite systems and instrumentation.

The essence of this chapter is to explain remote sensing technology at a level where the reader can realise its benefit in the analysis and monitoring of crime and the environment. Criminological theories were discussed in the previous chapter to explain criminological thinking on crime and the philosophy behind it. Spatial information, which provides visual interpretable and classification analysis capabilities, can be used for the mapping of crime patterns and urban zones to assist with crime prevention planning (e.g. concepts like CPTED). This is but one example of how spatial results can be explained by criminological theories such as the social structural theory cluster.

Remote sensing is defined as the technique of obtaining information about objects through the analysis of data collection by special instruments that are not in physical contact with the objects of investigation. As such, remote sensing can be regarded as reconnaissance from a distance (Avery & Berlin 1992:1). Remote sensing thus differs from *in situ sensing*, where the instruments are immersed in, or physically touch, the objects of measurement. A common example of an *in situ* measurement instrument is the soil thermometer. The detection and recording instruments for this special technology are known collectively as remote sensors and include photographic cameras, mechanical scanners, and radar systems. Remote sensors are carried on aircraft and Earth-orbiting spacecraft (Avery & Berlin 1992:1).

3.2 ELECTROMAGNETIC ENERGY

The energy measured in remote sensing is electromagnetic radiation. Electromagnetic energy is a dynamic form of energy that is caused by the oscillation or acceleration of an electrical charge. This is associated with atomic nuclei during fusion reactions, with electrons as they drop from high to lower-energy orbits in an atom or molecule, and with the random movement of atoms and molecules. All natural and synthetic substances above zero continuously produce and emit a range of electromagnetic energy in proportion to their temperatures. Absolute zero is expressed as 0 K on the Kelvin or absolute scale, which is -273.16 °C on the Celsius scale. There is a wide range of natural and artificial electromagnetic energy in the universe. Visible light is familiar to all of us because it is a discernable by our eyes, but other important types include invisible gamma ray, X-ray, ultraviolet, infrared, microwave and radio energy (see Figure 3.1) (Avery & Berlin 1992:5).

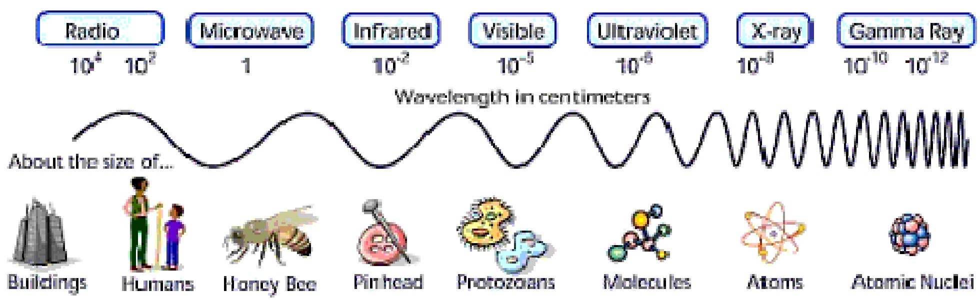


Figure 3.1: Major regions of the electromagnetic spectrum with wavelength scales

(Avery & Berlin 1992:5)

Practically all the natural electromagnetic energy injected into the **Earth system** (i.e. the atmosphere and the Earth's surface) is produced by the sun. It provides the original energy for all forms of terrestrial life and for the natural processes that are operative in the atmosphere, water bodies and upper layers of the solid Earth (Avery & Berlin 1992:3).

Electromagnetic energy also refers to all energy that moves with the velocity of light in a harmonic wave pattern. A harmonic pattern consists of waves that occur at equal intervals in time. The wave concept explains how electromagnetic energy propagates (moves), but this energy can only be detected as it interacts with the matter. In this interaction, electromagnetic energy behaves as though it consists of many individual bodies called *photons* that have such particle-like properties as energy and momentum. When light bends (refracts) as it propagates through media of different optical densities, it is behaving like waves.

Electromagnetic waves can be described in terms of their velocity, wavelength and frequency. This velocity is commonly referred to as the speed of light, which is one form of electromagnetic energy (Avery & Berlin 1992:4). For electromagnetic waves moving through a vacuum, c = 299, 793 km/s, or for practical purposes c = 3 x 108. The wavelength (λ) of electromagnetic waves is the distance from any point on one cycle or wave to the same position on the next cycle or wave. The micrometre (μm) is a convenient unit for designating wavelength of both visible and infrared (IR) radiation. Unlike velocity and wavelength, which change as electromagnetic energy is propagated through media of different densities, frequency remains constant and is therefore a more fundamental property. Velocity (c), wavelength (λ) and frequency (v) are related by (Avery & Berlin 1992:4):

$$C = \lambda v$$

Electromagnetic energy that encounters matter, whether solid, liquid or gas, is called *incident* radiation. Interactions with matter can change the following properties of the incident radiation: intensity, direction, wavelength, polarisation and phase. The science of remote sensing detects and records these changes. During interactions between electromagnetic radiation and matter, mass and energy are conserved according to basic physical principles. They are the following (Floyd 1987: 3):

- Transmitted, that is, passed through the substance. Transmission through media of different densities, such as from air into water, causes a change in the velocity of electromagnetic radiation. The ratio of two velocities is called the *index of refraction (n)* and is expressed as

$$n = \frac{Ca}{Cs}$$

  where Ca is the velocity in a vacuum and Cs is the velocity in the substance.
- Absorbed, giving up its energy largely to heating the matter.
- Emitted by the substance, usually at longer wavelengths, as a function of its structure and temperature.
- Scattered, that is, deflected in all directions. Surfaces with dimensions of *relief*, or roughness, comparable to the wavelengths of the incident energy produce scattering.
- Reflected, that is, returned from the surface of a material with the angle of reflection equal and opposite to the angle of incidence. Reflection is caused by surfaces that are smooth relative to the wavelength of incident energy. Polarisation, or direction of vibration, of the reflected waves may differ from that of the incident waves.

Emission, scattering and reflection are called *surface phenomena* because these interactions are determined primarily by properties of the surface, such as colour and roughness. Transmission and absorption are called *volume phenomena* because these interactions are determined by internal characteristics of matter, such as density and conductivity. The particular combination of surface and volume interactions with any particular material depends both on the wavelength of the electromagnetic radiation and the specific properties of that material. These interactions between matter and energy are recorded on remote sensing images, from which one may interpret the characteristics of the matter (Floyd 1987: 3).

3.3 ELECTROMAGNETIC SPECTRUM

Energy is defined as the capacity to work. In the course of work being done, the resulting energy must be transferred from one body to another or from one location to another location. Such energy transfers can be accomplished by one of three methods, namely conduction, convection and radiation. Radiation is the only method by which solar energy can cross millions of kilometres of free or empty space and reach the earth, and is the method of energy transfer with which remote sensing is concerned. The term radiation is commonly used today to describe both the process of energy propagation and the energy that flows in this manner (i.e. electromagnetic radiation) (Avery & Berlin 1992:4).

Electromagnetic radiation (EMR) is electromagnetic energy in transit that can be detected only when it interacts with matter. It travels in a straight path at the speed of light across empty space and only slightly slower in the atmosphere. Modern physics views EMR as having a dual nature, enabling it to be independently described as a wave or a particle. Remote sensing is concerned with the measurement of EMR returned by the earth's natural and cultural features that first receive energy from the sun or an artificial source such as a radar transmitter. Because different objects return different types and amounts of EMR, the objective in remote sensing is to detect these differences with the appropriate instruments. This, in turn, makes it possible for us to identify and assess a broad range of surface features and their conditions (Avery & Berlin 1992:5).

The entire range of EMR comprises the electromagnetic spectrum. The entire spectrum represents a continuum, consisting of the ordered arrangement of EMR according to wavelength, frequency, or photon energy. For the sun, the electromagnetic spectrum stretches from biologically lethal gamma rays to passive radio waves. A spectral band is composed of some defined group or bundle of continuous spectral lines, where a line represents a single wavelength or frequency. Wavelength is measured in angstroms where (Å) equals 10^{-10} m , or nanometres (nm) where one nm equals 10^{-9} m, or micrometres (µm) where one µm equals 10^{-6} m. The entire frequency range can be expressed in cycles per second, or hertz (Hz). In this unit of measure, EMR frequencies vary from more than 10^{20} Hz for gamma rays to less than 10^{-25} Hz for radio waves. It has become common practice in remote sensing to specify lower frequency ranges in megahertz (MHz) where 1 MHz is equal to 10^{8} Hz, and higher frequency ranges in gigahertz (GHz), where 1 GHz is equal to 10^{9} Hz (Avery & Berlin 1992:5).

Given in order of increasing wavelengths, the bands of the electromagnetic spectrum that are used in remote sensing are *ultraviolet (UV), visible, infrared (IR)* and *microwave*. Traditionally, the most commonly used region of the electromagnetic spectrum in remote sensing has been the visible band or the visible spectrum. Its wavelength is from 0.4 to 0.7 µm, which are the limits established by the sensitivity of the human eye (Avery & Berlin 1992:5).

3.4 IMAGE CHARACTERISTICS

An image is any pictorial representation, irrespective of the wavelength of the imaging device used to produced it. In remote sensing, the terms photograph and image are carefully used. The term photograph is used exclusively for pictorial representations that are recorded directly onto film by a process known as photography. The word photography is derived from the Greek *phos*, meaning “light”, and *graphia,* meaning “writing”. Image is a more general term referring to all pictorial representations of remote sensing data. Therefore, all photographs are images, but not all images are photographs.

The pictorial products of electro-optical, passive microwave, and sonar systems are likewise referred to as images, not photographs (Avery & Berlin 1992:17).

Images can be described in term of certain fundamental properties regardless of the wavelength at which the image is recorded. These common fundamental properties are scale, brightness, contrast, and resolution. Tone and texture of images are functions of the fundamental properties. These fundamental properties are described as follow (Floyd 1987: 6-10):

- Scale is the ratio of the distance between two points on an image to the corresponding distance on the ground. Thus a scale of 1:50 000 on a topographic map means that one unit on the map represents 50 000 units on the ground. Thus 1 cm on the map equals 50 000 cm on the ground. Image scale is determined by the effective focal length of the remote sensing device, the altitude from which the image is acquired and the magnification factor employed in reproducing the image.
- Brightness and tone: Remote sensing systems detect the intensity of electromagnetic radiation that an object reflects, emits or scatters at particular wavelength bands. Variation in intensity of electromagnetic radiation from terrain is commonly displayed as variations in brightness on images. Brightness is the magnitude of the response produced in the eye by light, it is a subjective sensation that can be determined only approximately. Luminance is a quantitative measure of the intensity of light from a source and is measured with a device called a photometer, or light meter. On images acquired in other wavelength regions, tone is determined by other physical properties of objects. On a thermal IR image, the tone of an object is proportional to the heat radiating from the object. On a radar image the tone of an object is determined by the intensity at which the transmitted beam of radar energy is scattered back to the receiving antenna.

- Contrast ratio (CR) is the ratio between the brightest and darkest parts of the image and is defined as CR = B_{max} / B_{min}, where B_{max} is the maximum brightness of the scene and B_{min} is the minimum brightness.
- Resolution can be defined as the ability to distinguish between two closely spaced objects on an image. It is the minimum distance between two objects at which the images of the objects appear distinct and separate. Objects spaced together more closely than the resolution limit will appear as a single object on the image. Four different types of resolution in digital remote sensing can be described:
    - *Spatial resolution* is the minimum distance between two objects that can be identified by a sensor (Colwell 1983:24). It is also described as the subtlety of the detail characteristics available on the image (Verbyla 1995:13).
    - *Spectral resolution* is the available wavelengths in the remote sensing instrument with regard to the electromagnetic spectrum (Star & Estes 1990: 32);
    - *Radiometric resolution* is the number of distinct levels in which a signal could be distributed (Verbyla 1995:15). The Landsat MSS sensor, for example, has raster values which range from 0 to 63 compared to the higher radiometric resolution of the Landsat TM sensor which range from 0 to 255.
    - *Temporal resolution* refers to the time interval for gathering data (images). This is essential during the monitoring of change over time (various physical and cultural phenomena). Temporal resolution is determined by the number of vertical images available over a specific time, also commonly known as revisit times. An image available over the same area in the case of Landsat TM is every 16^{th} day and for Spot it is every 26^{th} day (Verbyla 1995: 17).

Every natural and synthetic object reflects and emits electromagnetic radiation over a range of wavelength in its own characteristic manner according, in large measure, to its chemical composition and physical state. The distinctive reflectance and emittance properties of these objects and their different conditions are called *spectral signatures*. Within some limited wavelength regions, a particular object or condition will usually exhibit a diagnostic spectral response pattern that differs from that of other objects. Remote sensing depends upon operation in wavelength regions of the spectrum where these detectable differences in reflected and emitted radiation occur. It is only then that the features or their different conditions will show enough variation to allow for individual identifications. The largest difference in radiation intensity between vegetation, soil and water occurs near a wavelength of 1 μm. Therefore, we could best discriminate between the three materials with a remote sensing system that detects reflected infrared radiation (Avery & Berlin 1992:14).

3.5 REMOTE SENSING SYSTEMS

The basic components of an *ideal remote sensing system* can be described in the following six steps (see figure 3.2) (Lillesand & Kiefer 1994:31):

- **Step 1: A uniform energy source**. This source would provide energy over all wavelengths, at a constant, known, high level of output, irrespective of time and place.
- **Step 2: A non-interfering atmosphere**. This would be an atmosphere that would not modify the energy from the source in any manner, whether that energy were on its way to the Earth's surface or coming from it. Again ideally, this would hold irrespective of wavelength, time, place and sensing altitude involved.
- **Step 3: A series of unique energy/matter interactions at the Earth's surface**. These interactions would generate reflected and/or emitted signals that not only are selective with respect to wavelength, but also are known, invariant and unique to each and every earth surface feature type and subtype of interest.

- **Step 4: A supersensor**. This would be a sensor, highly sensitive to all wavelengths, yielding spatially detailed data on the absolute brightness (or radiance) from a scene as a function of wavelength, throughout the spectrum. This supersensor would be simple and reliable, require virtually no power or space, and be accurate and economical to operate.
- **Step 5: A real-time data-handling system**. In this system, the instant the radiance versus wavelength response over a terrain element was generated, it would be processed into an interpretable format and recognised as being unique to the particular terrain element from which it came. This processing would be performed nearly instantaneously (in "real time"), providing timely information. Because of the consistent nature of the energy/matter interactions, there would be no need for reference data in the analysis procedure. The derived data would provide insight into the physical – chemical – biological state of each feature of interest.
- **Step 6: Multiple data users**. These people would have knowledge of great depth, both of their respective disciplines and of remote sensing data acquisition and analysis techniques. The same set of "data" would become various forms of "information" for different users, because of their wealth of knowledge about the particular earth resources being sensed. This information would be available to them faster, at less expense, and over larger areas than information collected in any other manner. With this information, the various users would make profound, wise decisions about how best to manage the Earth resources under scrutiny, and these management decisions would be implemented to everyone's delight.

Unfortunately, an ideal remote sensing system as described above does not exist. Real remote sensing systems fall far short of the ideal at virtually every point in the sequence outlined. Therefore South Africa, through the CSIR's Satellite Applications Centre, must focus on promoting all the factors to achieve a near-perfect remote sensing system for the nation and the southern African region.

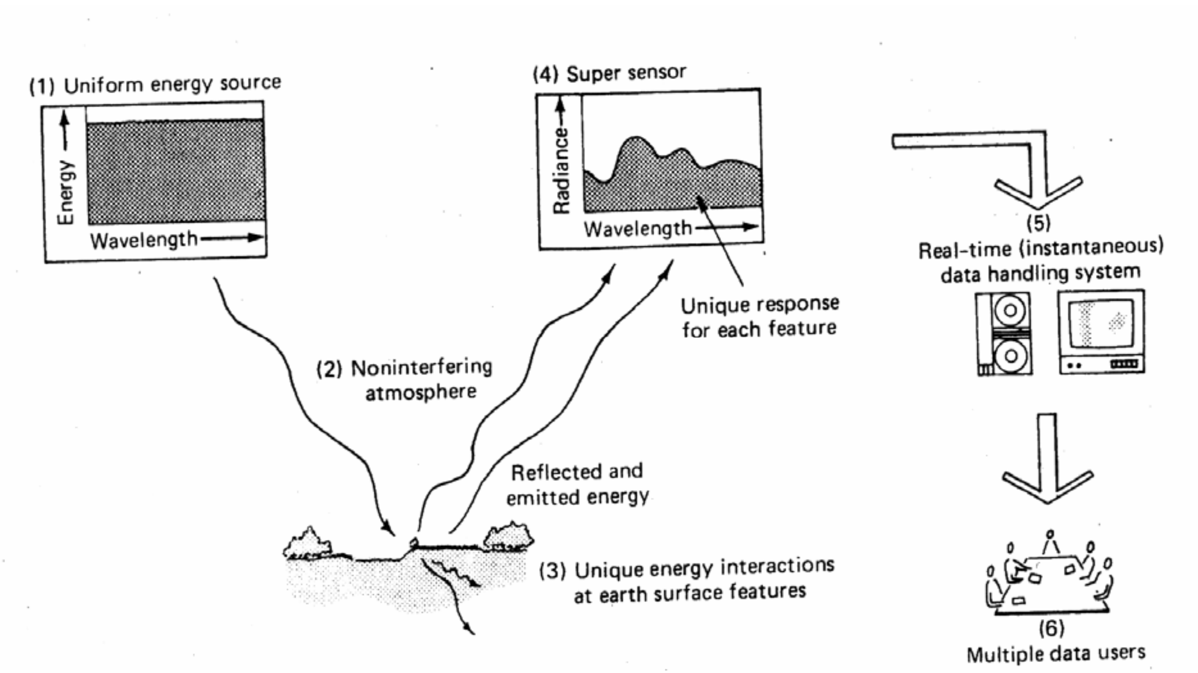


Figure 3.2: Components of an ideal remote sensing system

(Lillesand & Kiefer 1994:33)

3.5.1 Characteristics of real remote sensing systems

The basic shortcomings common to all real remote sensing systems will be considered in order to better understand their general operation and utility. These shortcomings, compared to the ideal remote sensing system, are as follows (Lillesand & Kiefer 1994:32-34):

- **The energy source**. All passive remote sensing systems rely on energy that is either reflected and/or emitted from Earth surface features. The spectral distribution of reflected sunlight and self-emitted energy is far from uniform. Solar energy levels obviously vary with respect to time and location, and different Earth surface materials emit energy to varying degrees of efficiency. While we have some control over the nature of sources of energy for active systems, the sources of energy used in all real systems are generally non-uniform with respect to wavelength and their properties vary with time and location. Consequently, the systems need to be calibrated for source characteristics on a mission-by-mission basis, or must deal with relative energy units sensed at any given time and location.

- **The atmosphere**. The atmosphere normally compounds the problems introduced by energy source variation. To some extent, the atmosphere always modifies the strength and spectral distribution of the energy received by a sensor. It restricts “where we can look” spectrally, and its effects vary with wavelength, time and place. The importance of these effects, like source variation effects, is a function of the wavelengths involved, the sensor used, and the sensing application at hand. Elimination of, or compensation for, atmospheric effects via some form of calibration is particularly important in those applications where repetitive observations of the same geographic area are involved.
- **The energy/matter interactions at the earth’s surface**. Remote sensing would be simple if every material reflected and/or emitted energy in a unique, known way. Although spectral response patterns (signatures) play a central role in detecting, identifying and analysing earth surface materials, the spectral world is full of ambiguity. Radically different material types can have great spectral similarity, making differentiation difficult. Furthermore, the general understanding of the energy/matter interaction of earth surface features is at an elementary level for some materials and virtually non-existent for others.
- **The sensor**. It should come as no surprise that an ideal “supersensor” does not exist. No single sensor is sensitive to all wavelengths. All real sensors have fixed limits of *spectral sensitivity*. They also have a limit to how small an object on the Earth’s surface can be and still be “seen” by a sensor as separate from its surroundings. This limit, called the *spatial resolution* of a sensor, is an indication of how well a sensor can record spatial detail.
- **The data-handling system**. The capability of current remote sensors to generate data far exceeds the current capacity to handle these data. This is generally true whether we consider “manual” image

interpretation or computer-assisted analyses. Processing sensor data into an interpretable format can be – and often is – an effort entailing considerable thought, instrumentation, time, experience and reference data. While much data can be handled by computers, human intervention in data processing is and will continue to be essential to the productive application of remote sensing data.

- **The multiple data users**. Central to the successful application of any remote sensing system are the people using remotely sensed data from that system. The "data" generated by remote sensing procedures become "information" only if and when someone understands their generation, knows how to interpret them, and knows how best to use them. A thorough understanding of the problem is paramount to the productive application of any remote sensing methodology. Also, no single combination of data acquisition and analysis procedures will satisfy the needs of all data users. Remote sensing with its constant improvement in spatial resolution has become an essential tool in many operational programmes involving resource management, engineering, environmental monitoring and exploration.

3.5.2 Satellite scanning systems

The eye is a familiar example of a remote sensing system. The inorganic remote sensing systems described here belong to two major categories: framing systems and scanning systems (Floyd 1987:14-18).

- **Framing systems:** They instantaneously acquire an image of an area, or frame, of the terrain. Cameras and vidicons are common examples of such systems. The human eye can also be considered a framing system. A camera employs a lens to form an image of the scene at the focal plane, which is the plane at which the image is sharply defined. A shutter opens at selected intervals to allow light to enter the camera, where the image is recorded on photographic film. A vidicon is a type of television camera that records the image on a photosensitive electronically charged surface. Film is sensitive only to portions of the UV, visible and reflected IR regions (0.3 to 0.9 μm).

- **Scanning systems:** These employ a single detector with a narrow field of view which sweeps across the terrain to produce an image. When photons of electromagnetic energy radiated or reflected from the terrain encounter the detector, an electrical signal is produced that varies in proportion to the number of photons. The electrical signal is amplified, recorded on magnetic tape, and played back later to produce an image. All scanning systems sweep the detector's field of view across the terrain in a series of parallel scan lines. There are four common scanning modes: cross-track scanning, circular scanning, along-track scanning and side scanning, which are shown diagrammatically in figure 3.3.

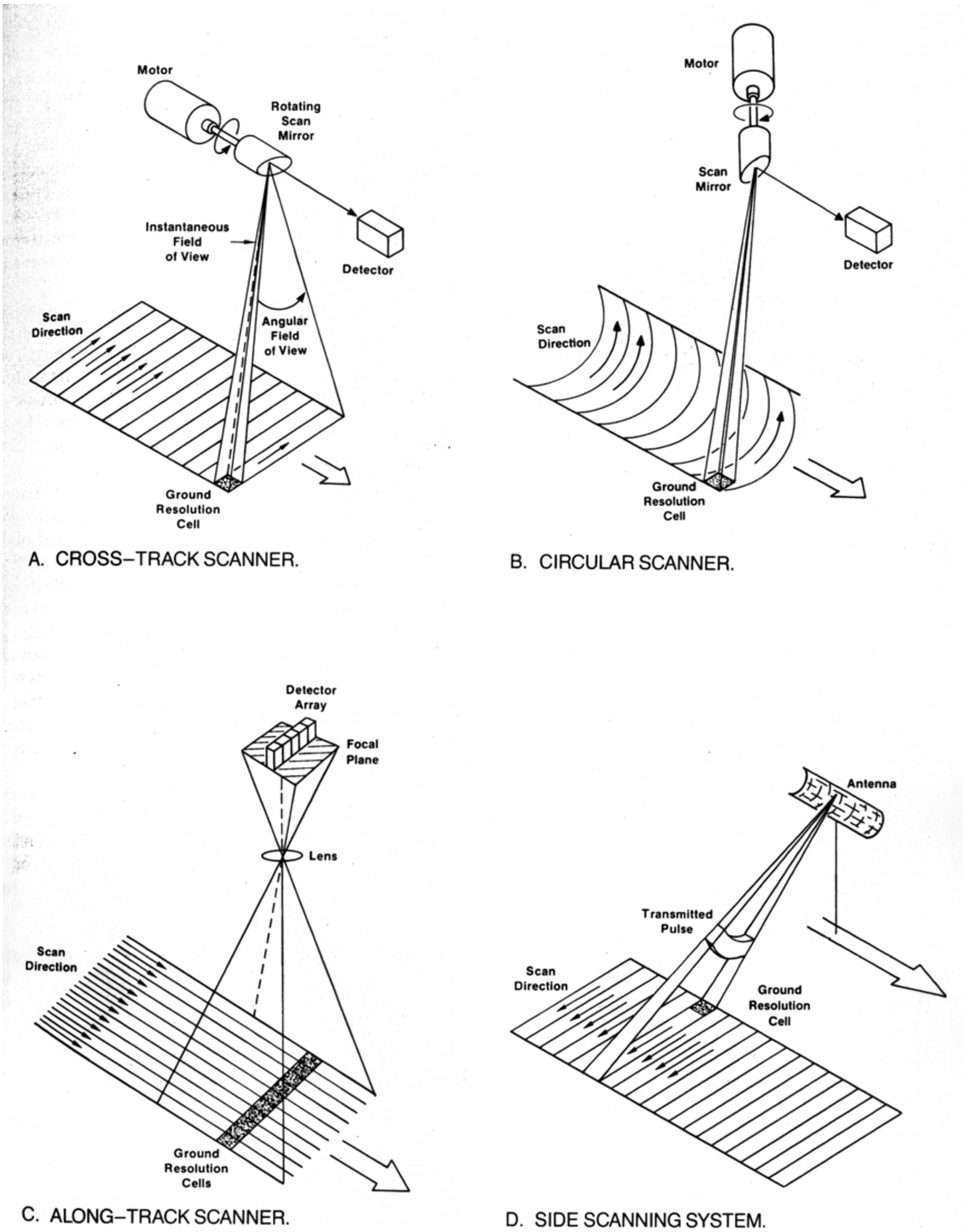


Figure 3.3: Scanning systems for acquiring remote sensing images

(Floyd 1987:15)

- **Multispectral systems:** The framing and scanning systems described above record a single image that represents a single spectral band. For many remote sensing applications, it is essential to record a scene with *multispectral images* acquired at different spectral bands. Today virtually all multispectral image data are acquired by scanner systems. Cross-track scanners employ a spectrometer to disperse the incoming energy into a spectrum. Detectors are positioned to record specific wavelength bands of energy. The Landsat thematic mapper is a cross-track multispectral scanner that records seven bands of data: three visible bands, three reflected IR bands and one thermal IR band. Along-track multispectral scanners employ multiple arrays of linear detectors with each array recording a separate band of energy. Because of the extended dwell time, the detector bandwidth may be narrow and still produce an adequate signal. The SPOT satellite system uses a multispectral along-track scanner (Floyd 1987:17).

3.6 ORBITAL SCIENCE

The orbit of bodies in space is governed by the well-established laws of celestial mechanics and the laws of planetary motion, which were set forth by Johannes Kepler in the 17^{th} century (Chetty 1991:17). When a spacecraft is released at a particular altitude at a particular velocity in a particular direction then the spacecraft stays at that altitude travelling at the same velocity if the centripetal and centrifugal forces are balanced. Otherwise, it may be slowed down by air drag to a lower altitude, and in that process the spacecraft attains a higher velocity which results in a balance of the two forces and attains a new orbit. The velocity increase is equivalent to the loss in altitude, which is given by $V^2 = 2 \times g \times h$, where V is the velocity, g is the acceleration due to gravity and *h* is the orbital altitude. A satellite gains 1% in speed at the expense of a 2% loss in altitude, measured from the centre of the Earth. At the same time, the distance to be travelled by the satellite is also reduced, so that a 2% loss in altitude decreases the orbital path length by 2% and the orbital time by 3% (Chetty 1991:18).

3.6.1 Injection into orbit

What is essential for injection into orbit is the specific velocity required for attaining a specific orbit at a given altitude. When injecting a payload into orbit, the standard and most economical procedure is first to establish a low altitude parking orbit (usually circular) and then to change into a second orbit, which intersects the desired final orbit. Thus from the circular orbit, the satellite is first injected into the perigee of a highly eccentric ellipse. When it reaches apogee, it is at the desired altitude for the circular orbit. However, its velocity is still not enough to hold it in a circular orbit. The additional velocity is imparted by firing the apogee kick motor. This approach requires a multi-restart capability to perform two burns, one at perigee and the other at apogee. The original eccentric orbit is called a transfer orbit or Hohmann ellipse and is defined as that ellipse which is simultaneously tangential to two circular orbits (Chetty 1991:20).

3.6.1.1 Orbital elements

Five parameters, called orbital elements, are needed to specify the size, shape and orientation of an elliptical orbit. A sixth orbital element defines the angular position of the satellite in its orbit. The size and shape of the orbit are defined by the *semi-major axis a* and *eccentricity e*. The point P where the satellite comes closest to the earth's centre C is called *perigee,* and the *perigee* distance CP is $a(1 - e)$. At the other end of the major axis is the apogee A, where the satellite is furthest from the earth, and CA = $a(1 + e)$. Thus the semi-major axis *a* can be regarded as the mean distance of the satellite from earth's centre, in the sense that it is the average of the perigee and apogee distances (see figure 3.4) (King-Hele 1987:3).

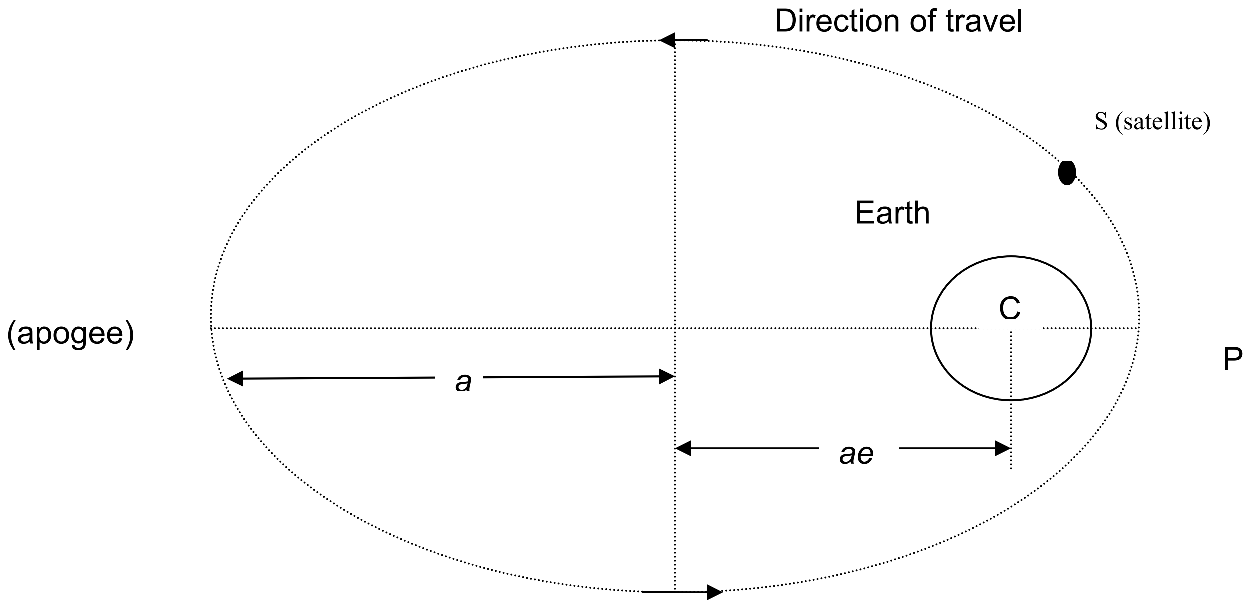


Figure 3.4: Semi-major axis *a* and eccentricity *e* of an elliptic satellite orbit about the Earth

(King-Hele 1987:4)

3.6.1.2 Earth observation orbit types

If a satellite is placed in orbit about 41 000 km from earth's centre and its is motion parallel to that of the earth's rotation, its velocity matches that of earth and it remains above a fixed point on the surface. This orbit is known as a *geostationary satellite orbit*. Such a satellite orbit can monitor almost an entire hemisphere all the time, and can transmit directly to any point on that hemisphere. This is of particular use for climatic observations, but the distance means that pixel resolution is very coarse: 1 km x 1 km to 4 x 4 km pixel resolution on average (Drury 1990:45).

A sharper view of the planet requires a lower orbit and narrower field of view. To obtain full global coverage, the orbit must pass close to the poles and successive orbits must move progressively around the earth, so that ultimately the fields viewed by the instruments overlap completely. The other important consideration in passive remote sensing is that the orbits should cross all parts of the earth when they are illuminated by the sun at the same time of day. This is so that results can be compared from one area to another. This orbit is known as a *sun-synchronous polar orbit*. Such orbits are limited to an altitude height of between 450 km and 950 km, and must incline relative to the equator to ensure correct timing and eventual global coverage. When an active remote sensing method is used, such as radar, matching orbits to the same time of the day is not important. Moreover, both the ascending (northward) and descending (southward) orbits can be used (Drury 1990:46).

3.7 EARTH OBSERVATION SATELLITES

3.7.1 Earth observation satellite history

After the first scientific satellites had been placed in orbit by the Soviet Union and the United States, the next step was to think about the practical applications of the technology that had been developed. The lead was taken by the United States with a family of satellites known as TIROS, which orbited the earth from 1 April 1960. Nine TIROS satellites were launched between 1960 and 1965. Each satellite carried a pair of miniature television cameras and approximately half of the missions included a scanning infrared radiometer and an earth radiation budget instrument which monitored the amount of radiation received and re-radiated by the earth.

The ESSA satellites were launched between 1966 and 1969. They were fitted with larger television cameras (2 - 54 cm), significantly increasing the quality of the cloud cover pictures over those obtained from earlier TIROS cameras (1 -27 cm). The second decade of meteorological satellites was ushered in by the successful orbiting of ITOS-1 on 23 January 1970. After being placed in orbit, it was redesignated as NOAA-1 for the series to follow. NOAA-17 was placed in orbit in 2002, providing continuous daily images of earth. The third-generation operational polar orbiting environmental satellite system, designated Tiros-N, was put into operational service in 1978 with the expectation that eight spacecraft would provide a global observational service from 1978 to 1985 (Gatland & Clarke 1981:86).

The five geo-stationary satellites of the international network included three SMS/GOES satellites supplied by the USA, one Meteosat satellite built by Europe and one Japanese GMS satellite. This network was part of the Global Atmospheric Research Program (GARP) during 1978 and 1979. The satellites operated in the visible and infrared parts of the spectrum, producing pictures of the Earth's cloud cover by day and night. With the supplied data, meteorologists were able to identify, track and monitor severe storms, snow cover, sea surface and atmospheric temperatures, hurricanes and typhoons (Gatland & Clarke 1981:105).

3.7.2 The first remote sensing sensors

The value of satellites for monitoring agriculture, forests and other natural resources was first discovered some years after the space age had begun. The first hint came in 1960 when TIROS (NOAA) weather satellites showed map-like outlines of the world beneath the clouds. The multi-spectral sensors used in observation satellites work on the same principles as those in weather satellites. The features of the earth's surface can generally be identified by the energy it emits or reflects from the sun. The spectral signature for vegetation is different from that of rock, soil or water. These differences are registered by sensing equipment aboard the satellite and can be interpreted in different (false) colours defining these variations within the region surveyed (Gatland & Clarke 1981:106).

The first satellites dedicated to detailed attention to this science were the Landsat series developed by General Electric for the US National Aeronautics and Space Administration (NASA). The early Landsat satellites travel in north-south circular orbits at an altitude of about 917 km and their coverage of land and oceans shifts westwards as the earth rotates beneath them. The orbit was such that a single satellite could report on nearly every area of the world every 18 days. Images were digitised and transmitted to dish antennae at receiving stations on the earth's surface, where it was stored on magnetic tape for conversion to photographic prints in colour and black and white (Gatland & Clarke 1981:110).

Landsat D, the fourth in the series, was designed to survey the earth from an altitude of more than 640 km using improved sensing equipment, a multi-spectral scanner (MSS) and thematic mapper (TM), capable of discriminating features as small as 0.2 acres – as compared to 1.2 acres – enabling users to extract much more detailed and timely information. Applications that were developed over the years using this satellite imagery are cartography, agriculture, rangelands, forestry, oceanography, ice reconnaissance, oil pollution, air pollution, mineral detection, meteorology, wild life, fossil fuels, fishing, coastal geography, storm warning, earthquake detection, water resources and coastal erosion. Other countries developed their own earth observation satellites such as France in 1978 with their SPOT series, as well as India in 1979 with their IRS series (Gatland & Clarke 1981:113).

3.7.3 Earth resource satellites in operation

The role of the Committee on Earth Observation Satellites (CEOS), as the body with responsibility for co-ordination of earth sensing satellite programmes to ensure that future space-based observing systems and earth-based observing systems is suitably harmonised to address the most critical requirements. This body falls under the European Space Agency (ESA) and provides important information on all current and future earth observation programmes. Some of this information is discussed in the following paragraphs (Liebig 2005:1).

3.7.3.1 Current earth observation satellite missions

It is estimated that more than 150 different earth observation satellite missions will be operating in the next 15 years. Many of these comprise series of missions planned to provide the continuity which is essential for many observations and applications. The principal satellite series are enumerated below as described by the Committee on Earth Observation Satellites (CEOS) in their 2005 edition on satellite missions (Liebig 2005:10-15).

Geostationary meteorological satellites

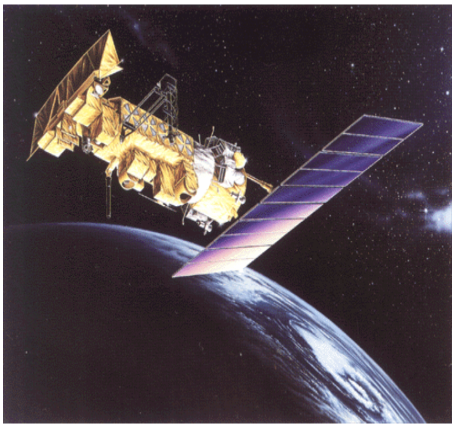
There is a world-wide network of operational geostationary meteorological satellites which provide visible and infrared images of the earth's surface and atmosphere. Countries/regions with current geostationary operational meteorological satellites are the USA (GOES series), Europe (METEOSAT series), Japan (GMS series), India (INSAT series), China (FY series) and Russia (GOMS).

DMSP series

This is the long-term meteorological programme of the US Department of Defense (DoD) whose objective is to collect and disseminate worldwide atmospheric, oceanographic, solar-geophysical, and cloud cover data on a daily basis.

NOAA polar orbiters

The current series of operational polar orbiting meteorological satellites is provided by NOAA. Two satellites are maintained in polar orbit at any one time, one in a 'morning' orbit and one in an 'afternoon' orbit. The series provides a wide range of data of interest, including sea surface temperature, cloud cover, data for land studies, temperature and humidity profiles and ozone concentrations.



NOAA satellite

METEOR series

Roshydromet maintains two or three satellites in orbit at any time mainly for operational meteorological purposes. Other applications include experimental measurement of ozone and earth radiation budget.

ERS & Envisat series:

ERS-1 was launched by ESA in July 1991, ERS-2 in April 1995, and Envisat in March 2002. This series concentrates on global and regional environmental issues, using active microwave techniques that enable a range of measurements to be made of land, sea and ice surfaces regardless of cloud cover and atmospheric conditions. In addition, the ATSR/AATSR instruments on these missions provide images of the surface or cloud top and the GOME instrument on ERS-2 gives measurements of ozone levels. ERS-1 and ERS-2 operated in tandem for around a year in 1995 and 1996, providing data for topographic applications such as differential interferometry. Envisat features a range of new sensors for land surface and atmospheric studies.

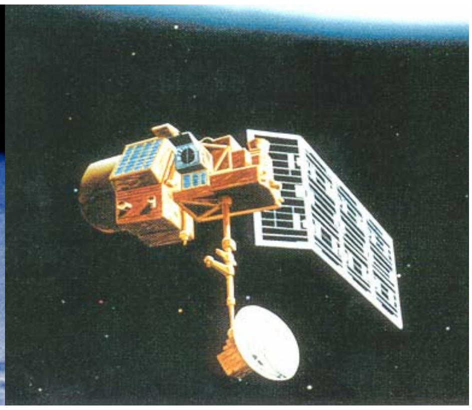
ERS-2 satellite

RADARSAT series

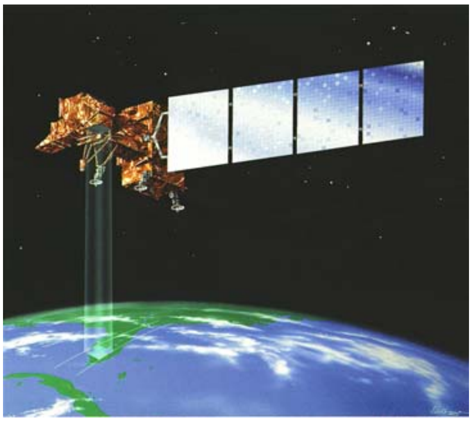
Launched in November of 1995, RADARSAT provides researchers and operational users with a range of SAR data products which are used for marine applications such as ship routing and ice forecasting, as well as for land applications such as resource management and geological mapping. Data continuity will be ensured through the planned launch of RADARSAT-2.

SPOT and Landsat series

The SPOT satellites operated by French, Swedish and Belgian space agencies, and the Landsat satellites operated by USGS provide high-resolution imagery in a range of visible and infrared bands. They are used extensively for high-resolution land studies. Data from these satellites is supplemented by the availability of very high resolution imagery (up to 1 m) from various commercial satellites.



SPOT 5 satellite Landsat 5 satellite



Landsat 7 satellite

IRS series

The Indian IRS satellites provide high-resolution imagery in a range of visible and infrared bands. Their primary objectives are national mapping of various resources. The series was supplemented by IRS-P4 (for ocean colour studies) in May 1999.

CBERS series

This is a joint mission series of China and Brazil, aimed at environmental monitoring and Earth resources. The latest satellite in the series was launched in April 2002.

KOMPSAT series

Korean missions aimed at cartography, land use and planning and ocean and disaster monitoring – starting from December 1999.

TOPEX/POSEIDON and JASON series

These satellites form a joint NASA/CNES precision radar altimetry mission to measure ocean topography and hence the speed and direction of ocean currents.

NASA's EOS missions

These missions carry the latest advanced sensors and each mission is dedicated to the investigation of particular earth system issues – including the Terra and Aqua missions.

LAGEOS series

These missions are designed to measure the earth's crustal motion and gravitational field. The space segment comprises corner cube laser retroreflectors and the ground segment is a global network of transportable laser sites. The design life of the space segment is 10 000 years.

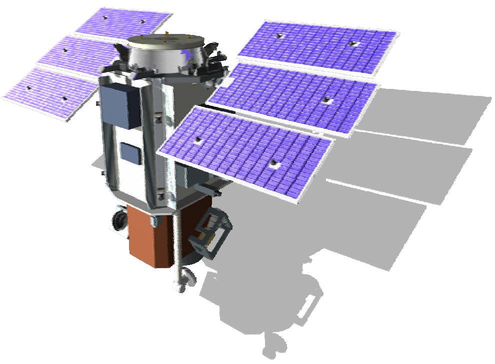
IKONOS

The IKONOS satellite is owned by the United States Space Imaging. Since its launch in September 1999, the IKONOS Earth imaging satellite has provided a reliable stream of image data that has become the standard for commercial high-resolution satellite data products. IKONOS produces 1-metre black-and-white (panchromatic) and 4-metre multispectral (red, blue, green, near infrared) imagery that can be combined in a variety of ways to accommodate a wide range of high-resolution imagery applications.

IKONOS

QUICKBIRD

The QuickBird satellite is owned by the US company DigitalGlobe. It was launched by a Delta IV rocket by Boeing in 2001. It currently leads the high resolution product range in the commercial market. It provides 0.6 m panchromatic and 2.4 m multispectral images with a 16.5 km x 16.5 km swath. The next generation QuickBird will be known as WorldView with a 0.5 m resolution capability with higher ordering and onboard storage capability. The launch of this satellite is scheduled for 2006.



QuickBird

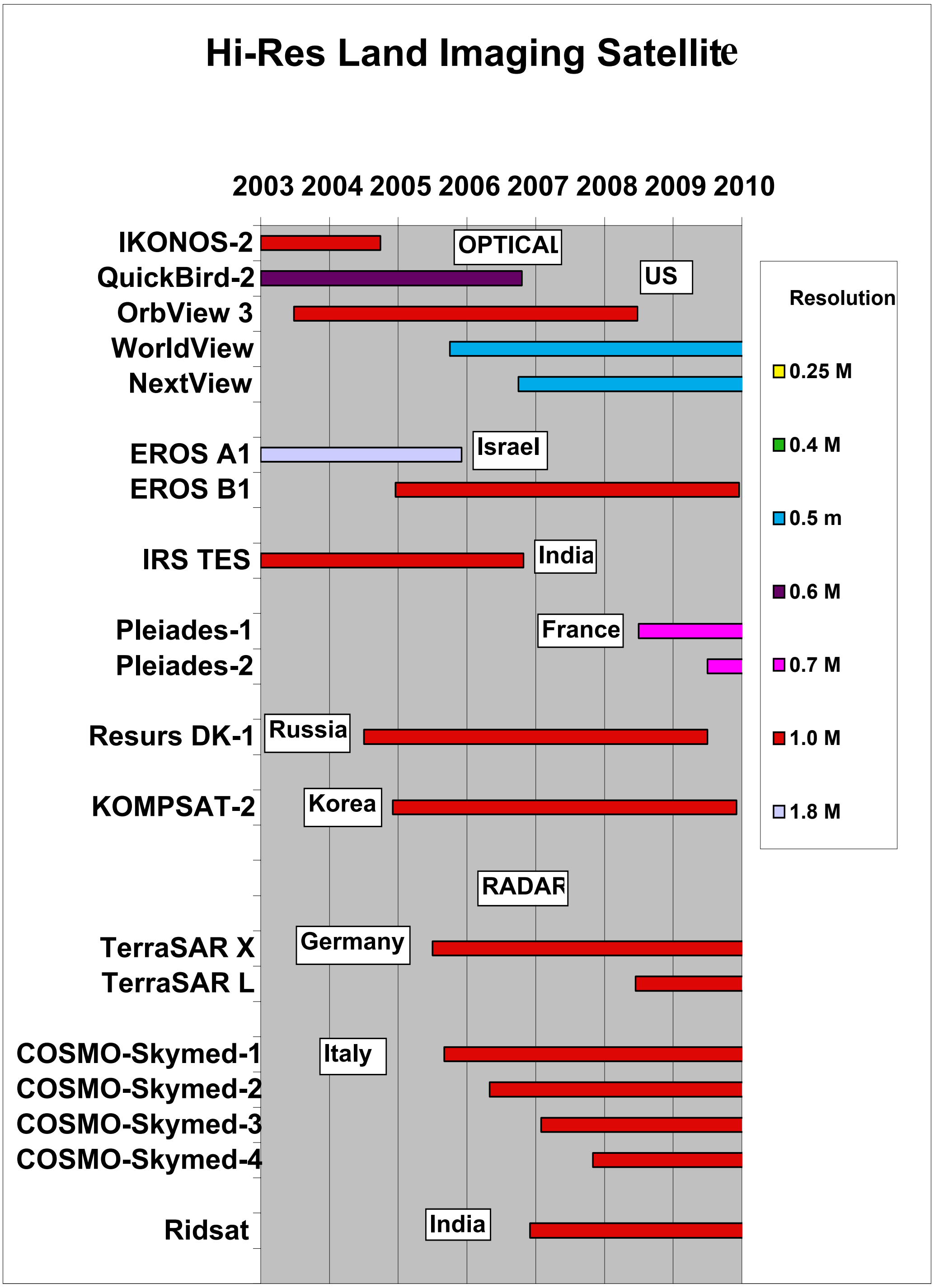


Figure 3.5: Summary of high-resolution satellites: currently available and planned missions

(Liebig 2005:128)

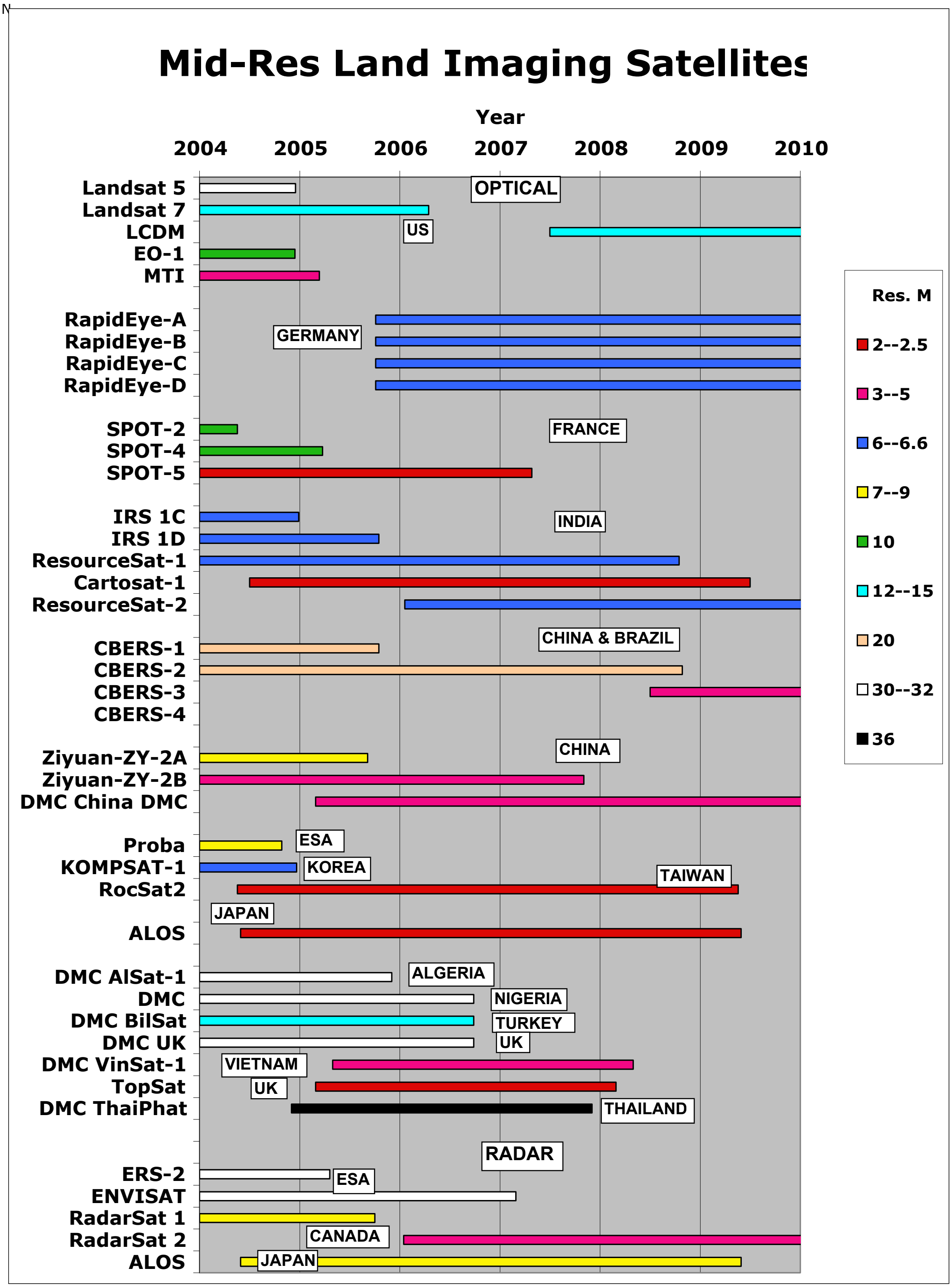


Figure 3.6: Summary of medium/ mid-resolution satellites: currently available and planned missions

(Liebig 2005:128)

3.7.3.2 Future missions

Current plans supplied by CEOS agencies estimate that approximately 150 new satellite missions will be launched for operation between mid-2002 and 2018. The next few years will mark a significant era for satellite earth observations, with half of these new missions to have been launched before the end of 2005.

These new programmes will ensure continuity of key measurements, provide improved resolutions and accuracies, and introduce several exciting new capabilities. Some of the highlights are described below (Liebig 2005:125).

Gravity and magnetic field studies

The GRACE and GOCE missions are dedicated to providing more precise measurements of the geoid, while DEMETER and ESPERIA will study links between electromagnetic fields and earthquake predictability.

Polar ice cap studies

Given the significance of information on changes in the continental ice sheets, two missions dedicated to their study are planned for the coming decade: NASA's ICESat (late 2002) and ESA's Cryosat (2004).

Cloud properties and climate links

By 2006, a multiple satellite constellation will be in place (comprising CloudSat, Aqua, Aura, CALIPSO and PARASOL) and will fly in orbital formation to gather data needed to evaluate and improve the way clouds are represented in global models, and to develop a more complete knowledge of their poorly understood role in climate change and the cloud-climate feedback.

Operational meteorology

The current geostationary programmes will continue operationally. With the launch of the METOP series in 2005, EUMETSAT and NOAA shared responsibility for the provision of polar orbiting meteorological satellites. The NOAA series of satellites will evolve to become NPOESS, featuring more advanced sensors and new capabilities. China will also operate the FY-3 series of polar orbiting satellites from late 2004.

Atmospheric studies

New data on the chemistry and dynamics of the earth's atmosphere will be gathered by missions from many countries, including ADEOS-2 and GCOM-A1 (Japan), EOS Aura (USA), and SCISAT-1 (Canada). ADM-Aeolus (Europe) will provide new information on winds.

Radiation budget

Continuity and new capabilities will be provided by NASA's SORCE (late 2002) and Triana missions (launch TBD), and by operational meteorology missions, such as the MSG and NPOESS series.

Ocean observations

Continuity and improvements in many current measurements are assured with the launch of missions such as Envisat, Aqua and ADEOS-2 in 2002. SMOS is worthy of special note since it will provide new capabilities for measurements of ocean salinity from 2006.

Land surface observations

A range of different sensors are planned for land surface observations, including advanced SAR systems such as ALOS and TerraSAR. From 2005, VCL will provide innovative new data on the vegetation canopy structure. SMOS will measure soil moisture from 2006.

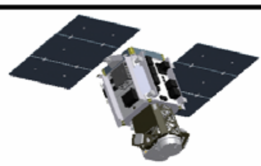
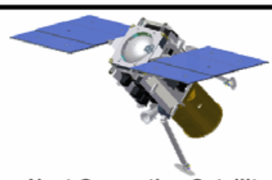
3.8 FUTURE TECHNOLOGIES

The future technologies that will be addressed will include very high resolution satellite constellations notably WorldView (USA) and Pleiades (France). Complementary technologies such as Light Detection and Ranging (LiDAR), hyperspectral sensors and High Altitude Long Endurance Unmanned Aircraft Vehicles (HALE UAVs) will be addressed during this discussion. The last point for discussion is the critical element of Object Orientated Image Analysis (OOIA). The project within this study was done through intensive manual processes to demarcate land use classes. The future trend of advance geo-processing is to automate specific feature extractions from remote sensing that will result in a more feasible and timely way of implementing the methodology operationally within a national perspective.

3.8.1 Very high resolution satellites

The WorldView satellite is scheduled to be launched by 2007 which will be operated and owned by the commercial US company DigitalGlobe. The satellite will have an image capacity of collecting 25-cm resolution imagery from space available to the US government and 50-cm resolution available to the commercial market.

Table 3.1: Specification comparison between the current QuickBird satellite and the next generation WorldView constellation

Parameter	 QuickBird	 Next Generation Satellite(s)
Operational Altitude	450 km	770 km
Weight Class	2000 lbs	5700 lbs
Spectral Characteristics	Pan / 4 MS	Pan / 8 MS
Panchromatic / Multispectral Resolution (nadir)	.60 /2.4 meters	.50 /2.0 meters
Standalone geolocation accuracy (CE90)	23 meters	<10 meters
Avg. revisit at 1m resolution (40° latitude target)	2.5 days	1 day
Swath Width	16.5 km	16 km
Monoscopic Area Capacity	1x	>3.5X
Single-Pass Monoscopic Area Coverage	1 x 10 Scenes (<30° off nadir)	4 x 4 Scenes (<40° off nadir) 1 x 10 Scenes (<40° off nadir)
Single-Pass Stereoscopic Area Coverage	Single Scene (<10° off nadir)	2 x 2 Scenes (<30° off nadir) 1 x 10 Scenes (<30° off nadir)
Primary Attitude Control Mechanism	Reaction Wheels	Control Moment Gyros
Onboard Storage	128 Gbits	1600 Gbits
Wideband Link Rate	320 Mbps	800 Mbps

The WorldView satellite will complement automated geo-processing production systems and will ensure the automation of various products. Land use and land cover, 3D products such as digital terrain models and digital elevation models, image city maps and micro change detection information layers (see figure 3.7). All these applications are critical spatial layers for crime prevention and policing strategies. The level of spatial information and temporal revisit capacity of this technology provides an up-to-date overview of specific hot spot areas to analyse and to apply correct diverse preventative policing strategies associated with accurate geo-coded crime data.

Product	Agriculture	Civil Govt	Forestry	Vis/Sim	Foreign Govt	U.S. Govt
Basic Imagery						
Ortho Imagery						
Stereo Imagery						
DEMs						
Aerial Photography						
SPOT Imagery						
Street Centerlines						
Land Use/Land Cover						
Pervious/Impervious Surfaces						
3D Buildings						
3D Fly-thrus						
Tree Crown						
Fuels Loads						
AgroWatch Grn Vegetation Index						
AgroWatch Scout Aid						
AgroWatch Soil Zone Index						
CIB						
DTED						
Gridded Airfield Graphics (GAG)						
Image City Maps (ICM)						

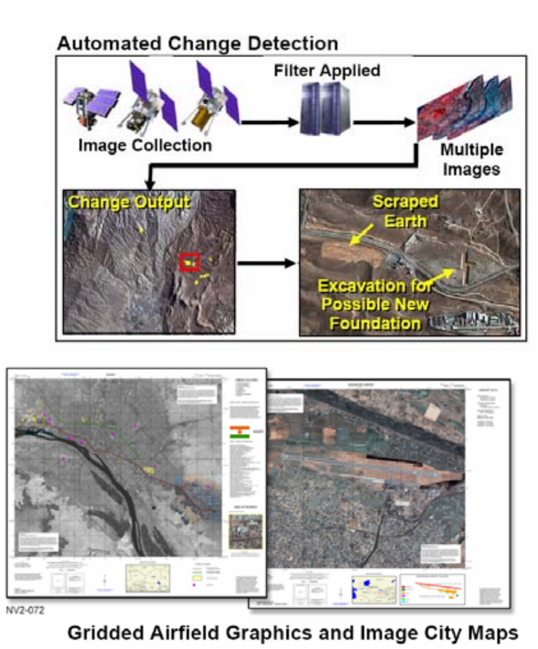
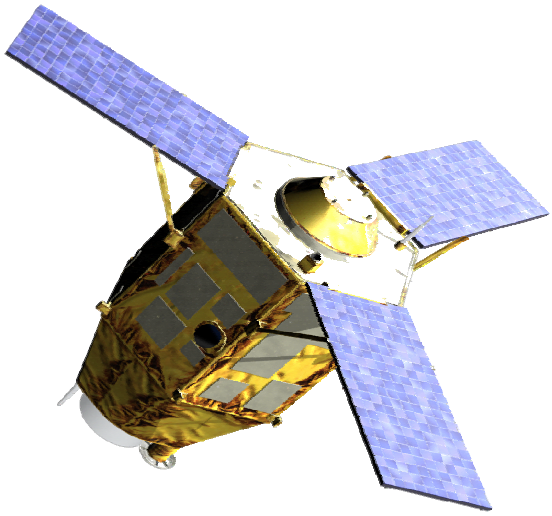


Figure 3.7: Automated applications associated with very high resolution satellites such as WorldView

The French-designed future very high resolution satellite constellation will be called Pleiades and will be launched from 2009 (see figure 3.8). The uniqueness of the satellite will be the large imaging capacity over a specific area. Its agility will provide tri-stereo imaging that can be defined as the collection of three images at different angles over a specific area within one orbit. The result is the automation of an accurate 3D terrain image as illustrated in figure 3.9. The applications from a satellite such as this will relate to security and urban planning and play a phenomenal role. The 3D monitoring of urban development, the demolition of buildings, the erection of new ones, etc. will provide an accurate land use profile over micro areas to integrate concepts such as CPTED as discussed in section 2.2.6.1.2 (b) - **Ecological theories of crime.**



- Panchromatic : 5 TDI units
    - 5 detectors, 6 000 pixels = 30 000 pixels/line
    - Ground Sampling Distance at nadir: 70 cm
    - Sampling time: 103.5 μs
    - GSD with ground processing: 50 cm
- Multispectral : 5 CCD units
    - 5 quadrichrome CCDs, 1 500 pixels ->7 500 pixels/ line
    - Ground Sampling Distance at nadir : 2.8 m
    - B0, B1, B2, B3 (blue, green, red, NIR)

Figure 3.8: Pleiades very high resolution satellite

Figure 3.9: 3D image over Toulouse, France at 50-cm geo-processing resolution

3.8.2 Light Detection and Ranging (LiDAR)

The only company in South Africa that provides highly accurate LiDAR data is Airborne Laser Solution (ALS) situated in Midrand. The ALS system consists of six major components:

1. Aerial survey platform (Aerial Laser Terrain Mapper 3033, Helicopter or Cessna aircraft).
2. Laser System (inertial measurement unit, 33 000 laser pulses per second, operating at an altitude of 180 m to 3 000 m).
3. Global Positioning System (two ground-based dual-frequency GPS receivers and one air-based GPS receiver).
4. Navigation system (GPS-based mission control system (Inertial Navigation System (INS)).
5. Digital Imaging System (Kodak DCS 420 or Hasselblad digital cameras).

6. Video component (One = vertical view and two = forward view at an angle of 20° to 45° below horizontal).

The imaging technique that consists of a combination of highly accurate ground and non-ground points geo-referenced to high-resolution aerial photographs simultaneously is very complex. A brief explanation of how this technology works, its accuracy and applications are given in the following paragraphs.

- LiDAR functioning

A scanning laser unit is mounted in a camera port on the aircraft. As the aircraft flies along a line, the laser unit emits a stream of light pulses (up to 33 000 per second) in a side-to-side motion perpendicular to the aircraft's direction of flight. The time it takes for each pulse to return to the aircraft is recorded along with the angle from nadir at which each pulse was emitted. Airborne GPS data are also recorded at a rate of 1 Hz for the entire session, and an Inertial Measurement Unit (IMU) gives the altitude of the aircraft at a rate of 50 Hz for the entire session. During post-processing, the slant distance between the aircraft and the ground for each returned pulse is calculated as one-half the time it takes for a laser pulse to travel from the aircraft and back, multiplied by the speed of light. Each slant distance is then corrected for atmospheric conditions, and for the roll, pitch and yaw of the aircraft using the IMU data. GPS data are processed separately and imported into the LiDAR solution. Each corrected slant distance is transformed to a ground surface elevation. Additional software is used to generate contours, quality control the DTM, and study certain aspects of the data, such as calibration parameters (Brinkman & O'Neill 2000:24).

- LiDAR accuracy

Flying at lower altitudes provide a smaller laser spot size or footprint, which gives more accurate data. Operating altitudes for LiDAR projects are generally 400 to 1 200 m, although some units have extended capabilities that allow operating altitudes of up to 3 000 m. Horizontal accuracy is 1/2 000th of the flying height. Vertical accuracy is better than 15 cm when the operating altitude is 1 200 m or below, and up to 25 cm when the operating altitude is above 1 200 m to 2 500 m. Thus, when a project is flown at 1 200 m or below, the final DTM will be accurate to 15 cm or better. One primary factor in the final DTM accuracy is the airborne GPS data. If flight layouts are optimised for GPS, then vertical accuracies of 7 to 8 cm can be routine (Brinkman & O'Neill 2000: 28).

- LiDAR applications

With LiDAR, surveying is possible during day or night in dry conditions. LiDAR projects can be flown during any sun angle and during overcast conditions as long as the ceiling is above the aircraft. However, flights during hazy conditions should be minimised, and not in rain or mist. LiDAR allows generation of DTMs in areas with hills, heavy vegetation or shadows. This often eliminates the need for survey crews to return to the field to capture points that could not be compiled photogrammetrically. Points can even be captured with LiDAR where ground access is limited, such as in high-security installations, military firing ranges and training areas, and in installations with large acreage outside a cantonment area. Likewise, it can be used for hydrochannel mapping, shoreline mapping, and for obstruction analysis mapping for airports. LiDAR can also be used for mapping areas with poles and towers and to obtain the elevations of power lines. LIDAR can be integrated with traditional aerial photography, photogrammetry and remote sensing to produce highly accurate and cartographically correct contours (Brinkman & O'Neill 2000:32).

The upcoming soccer World Cup in South Africa in 2010 will greatly benefit from LiDAR technology which can create a very accurate 3D terrain map over all the soccer stadiums and surrounding areas for event planning.

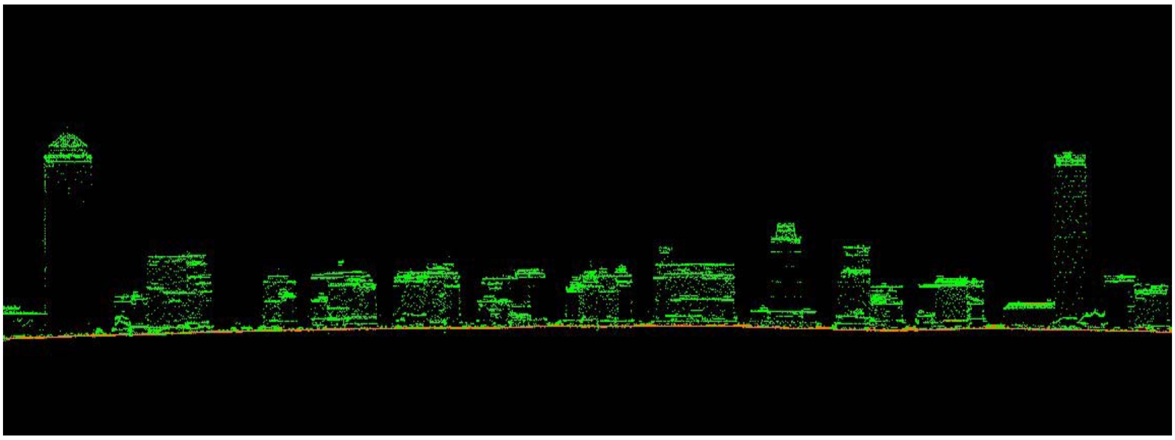


Figure 3.10: Ground (brown) and non-ground (green) points over the Johannesburg CBD area in a side view

Figure 3.11: LiDAR digital surface model over Johannesburg CBD

3.8.3 Hyperspectral imagery

Hyperspectral imagery can be defined as the use of many narrow sections of the electromagnetic spectrum in remote sensing. Multispectral remote sensors such as the Landsat Thematic Mapper and SPOT XS produce images with a few relatively broad wavelength bands. Hyperspectral remote sensors, on the other hand, collect image data simultaneously in dozens or hundreds of narrow, adjacent spectral bands. These measurements make it possible to derive a continuous spectrum for each image cell, as shown in figure 5.6. After adjustments for sensor, atmospheric, and terrain effects are applied, the image spectra can be compared with field or laboratory reflectance spectra in order to recognise and map surface materials such as particular types of vegetation or diagnostic minerals associated with ore deposits. Hyperspectral images contain a wealth of data, but interpreting them requires an understanding of exactly what properties of ground materials we are trying to measure, and how they relate to the measurements actually made by the hyperspectral sensor (Smith 2006:3).

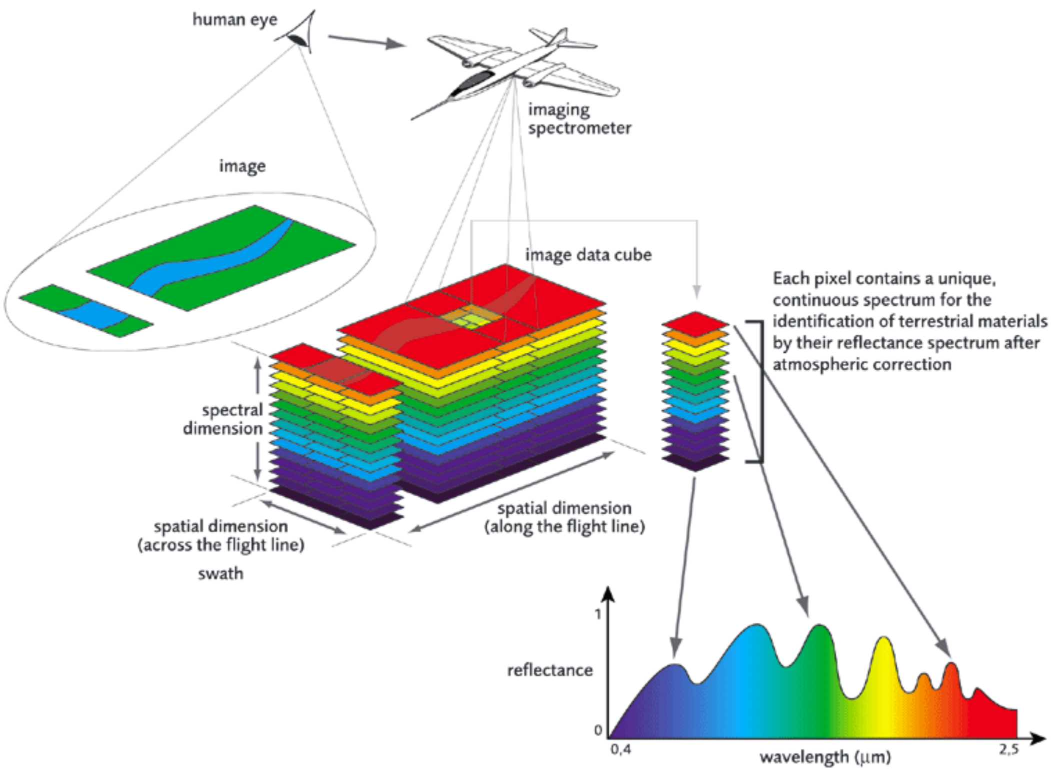


Figure 3.12: Hyperspectral sensors collect image data simultaneously in dozens or hundreds of narrow, adjacent spectral bands

(Smith 2006:3)

3.8.3.1 The imaging spectrometer

Hyperspectral images are produced by instruments called imaging spectrometers. The development of these complex sensors has involved the convergence of two related but distinct technologies: spectroscopy and the remote imaging of earth and planetary surfaces. Spectroscopy is the study of light that is emitted by or reflected from materials and its variation in energy with wavelength. As applied to the field of optical remote sensing, spectroscopy deals with the spectrum of sunlight that is diffusely reflected (scattered) by materials at the earth's surface. Instruments called spectrometers (or spectroradiometers) are used to make ground-based or laboratory measurements of the light reflected from a test material.

An optical dispersing element such as a grating or prism in the spectrometer splits this light into many narrow, adjacent wavelength bands and the energy in each band is measured by a separate detector. By using hundreds or even thousands of detectors, spectrometers can make spectral measurements of bands as narrow as 0.01 µm over a wide wavelength range, typically at least 0.4 to 2.4 µm (visible through mid-infrared wavelength ranges) (see figure 3.13). Remote imagers are designed to focus and measure the light reflected from many adjacent areas on the earth's surface. In many digital imagers, sequential measurements of small areas are made in a consistent geometric pattern as the sensor platform moves and subsequent processing is required to assemble them into an image (Smith 2006:4).

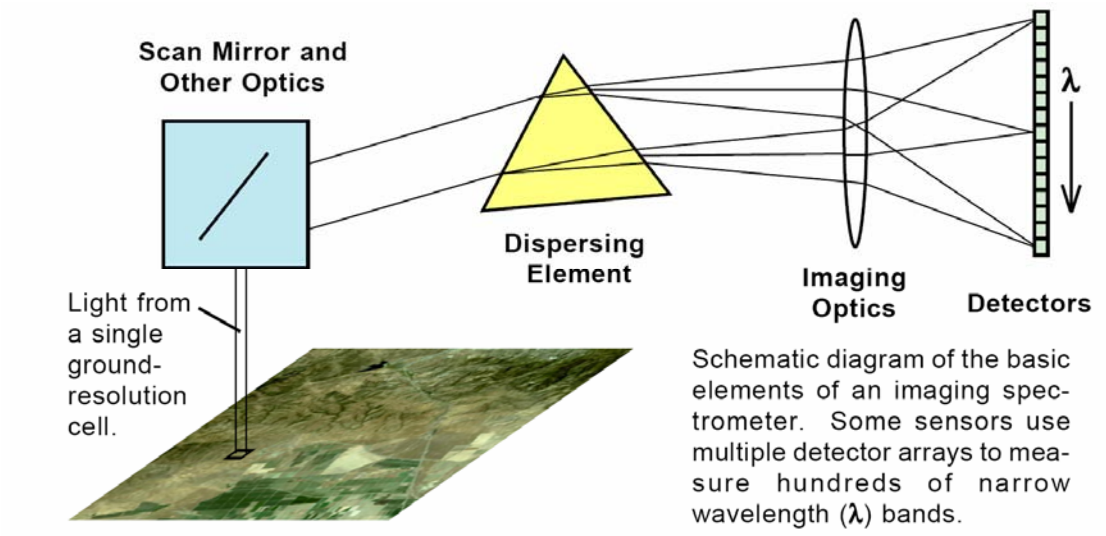


Figure 3.13: Diagram of the basic elements of an imaging spectrometer

(Smith 2006:4)

3.8.3.2 The Airborne Prism Experiment (APEX)

APEX is an airborne (dispersive push broom) imaging spectrometer developed by a Swiss-Belgian consortium on behalf of the European Space Agency (see figure 3.14). It is intended as a simulator and a calibration and validation device for future spaceborne hyperspectral imagers. Furthermore, APEX is an advanced scientific instrument for the European remote sensing community, recording hyperspectral data in approximately 300 bands in the wavelength range between 400 nm and 2 500 nm and at a spatial ground resolution of 2 m to 5 m (Debruyn 2006:2)

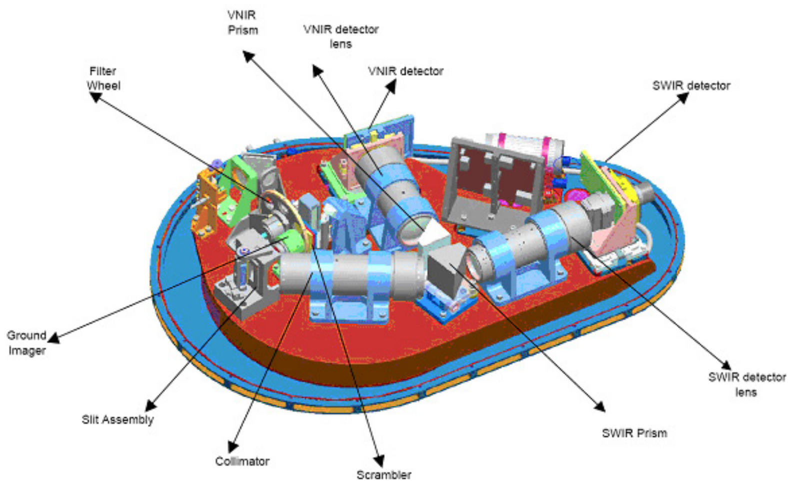


Figure 3.14: APEX instrument

(Debruyn 2006:4)

The relevance of hyperspectral imagery to policing is the detection and monitoring of illicit crops such as cannabis. By mounting an APEX-like instrument onto a future spaceborne satellite such as the envisage Micro Satellite for Multi-Instruments (MSMI) of South Africa in 2009, 15-m hyperspectral resolution images will be generated which will be ideal for illicit crop application (Mostert 2006:12).

3.8.4 High Altitude Long Endurance Unmanned Aircraft Vehicles (HALE UAVs)

The HALE UAV will operate at an altitude of between 18 000 m to 20 000 m using its more than 16 m solar wingspan to generate enough energy for long endurance flights, up to 8 months at a time (see figure 3.15). The stratospheric environment in which the UAV will operate has a temperature of -50 to -70 °C, air pressure that is 5% of that of ground level and wind speeds of lower than 20 m/s (Everaerts 2006:13).

The HALE UAVs will provide the missing link between airborne and spaceborne sensors. Satellites operate in a polar orbit and image in a north to south direction at nadir. The UAV can be fully controlled to circle over specific areas and can image in any direction for high temporal collection of imagery at very high resolution. The speed of such a UAV is 800 km/h and can therefore reach a specific area in good time. The HALE UAV will consist of four critical instruments listed below (Everaerts 2006:16).

1. Multispectral digital camera: 20 cm pixel resolution and positioning over 2 km swat with up to 10 spectral channels (450 – 1 000 nm) (see figure 3.16).
2. Laser scanner: 0.25 pt/m^2 point density (see figure 3.17).
3. Synthetic Aperture RADAR: 2.5 m ground resolution over 4.5 km swath.
4. Thermal infrared digital camera: 2 spectral channels (3 – 5 μm, 8 - 12 μm), 1 – 2 m pixel resolution over 2.4 km swath (see figure 3.18).

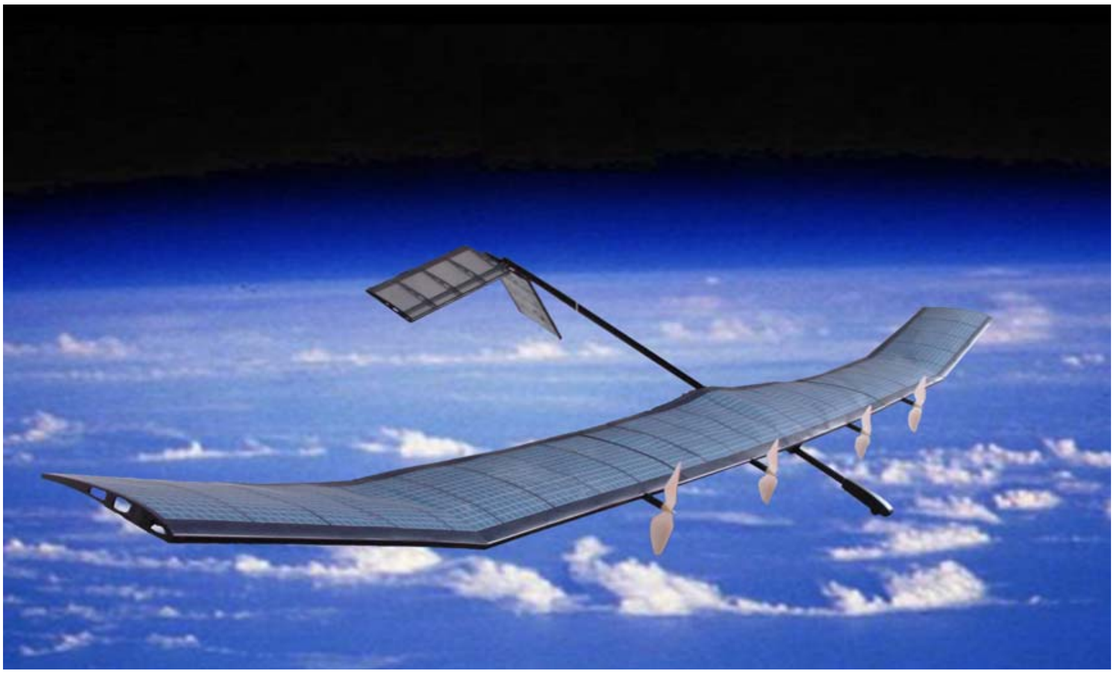


Figure 3.15: HALE UAV

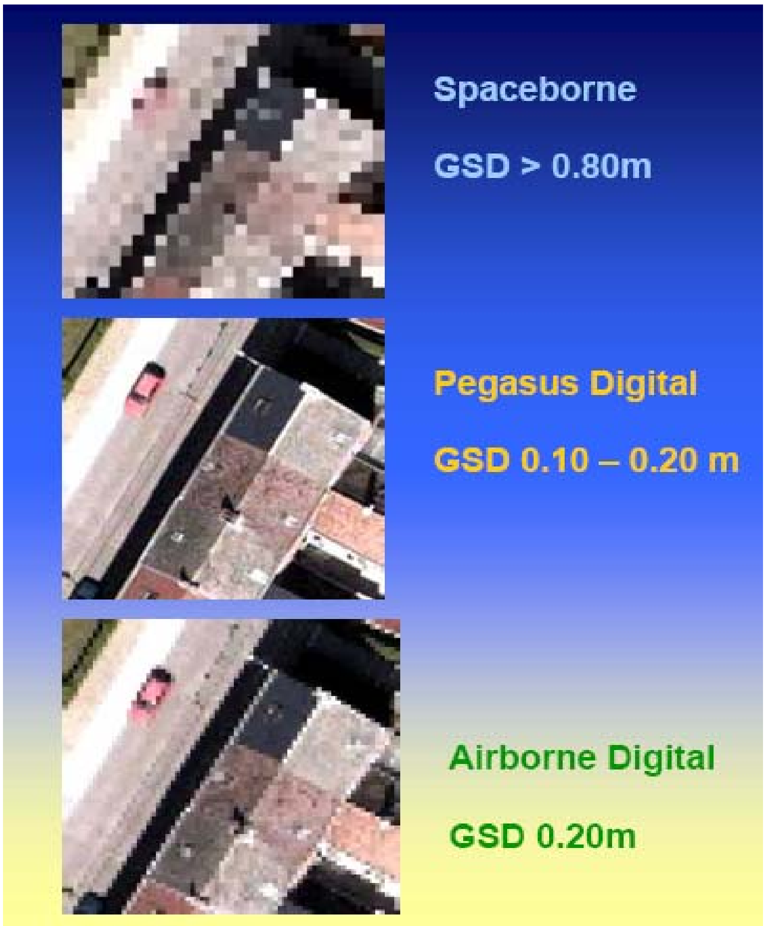


Figure 3.16: Multispectral digital camera

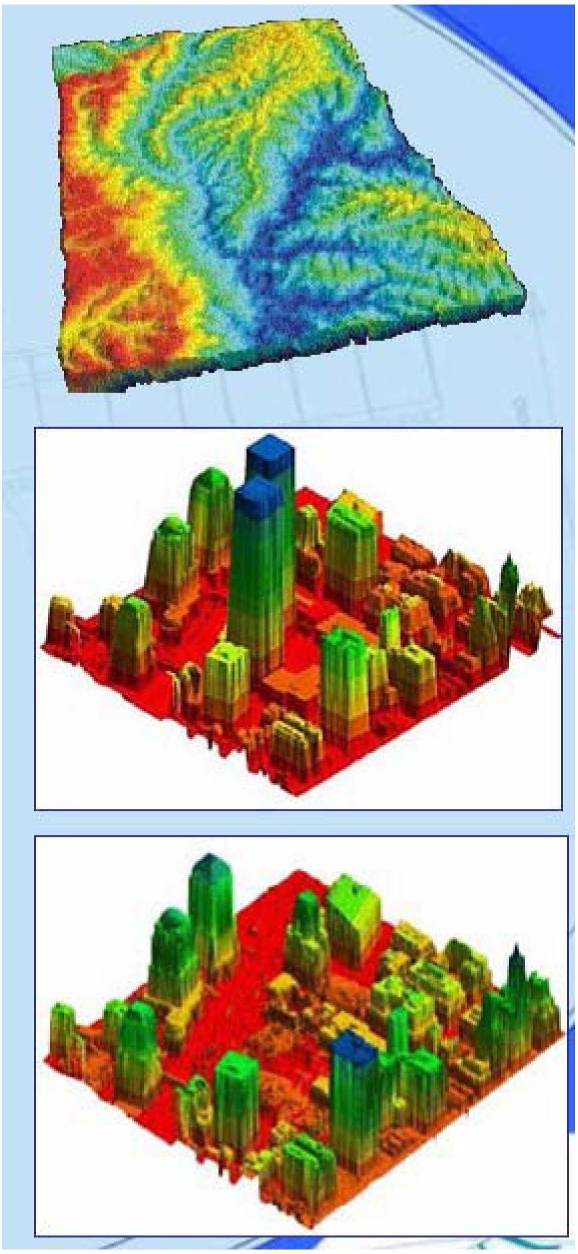


Figure 3.17: LiDAR laser scanner

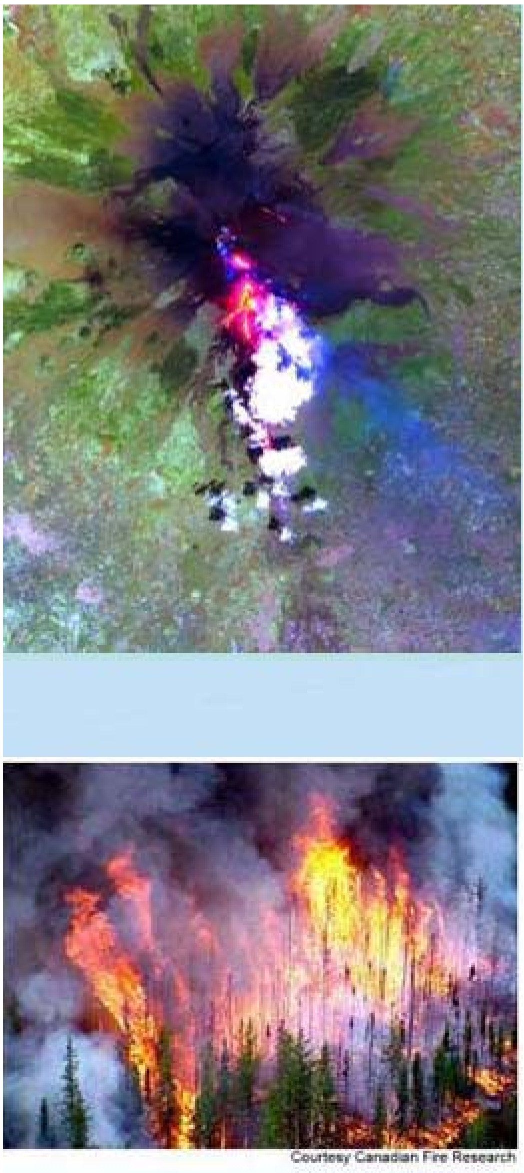


Figure 3.18: Thermal Infrared Digital Camera

The applications relevant to policing are the agility and full operational control of the UAV. It can perform dirty and dangerous work, and therefore image an area that is highly sensitive without arousing any suspicions. The flexibility and the long endurance of the HALE UAV make it a complementary platform for earth observation purposes. Near real-time data processing provides operational ready-to-use products to the end user within a few hours. All-weather, 24 h/day operational capability makes it the ideal technology for border control (Everaerts 2006:35).

3.8.5 Object orientated image analysis

The extraction of thematic information from images is the essence of remote sensing. After remotely sensed imagery has been geo-normalised and radiometrically normalised the thematic information can be extracted from imagery by using quantitative classification techniques, which can subsequently be automated. Conventional classification techniques aim to associate image elements or pixels to thematic classes defined by radiometric properties within each spectral band. This approach is inherently limited, as it does not take account of spatial relationships such as neighbourhood, distance and location of other pixels belonging to the same class, describing texture and fractal dimension (Blaschke & Strobl 2001:12).

This is particularly relevant with images of a high spatial resolution. During the past five years a revolutionary technology appeared on the remote sensing horizon as implemented in the eCognition software. This new approach attempts to identify surfaces and objects within images, and compute contextual information with which these objects can be attributed to classes. The methodology is referred to as Object Oriented Image Analysis and is described in greater detail below, as it is the ideal tool to automate classification and has many applications applicable for land use monitoring (Lück 2002:34).

3.8.5.1 Image segmentation

Image segmentation is a process whereby homogeneous areas or areas with similar textural properties are grouped and delineated by polygons, also referred to as segments. eCognition uses the Fractal Net Evolution Approach (FNEA), also called multi-resolution segmentation, to segment images. This algorithm starts by selecting a single pixel within an image, comparing it with its neighbours, clustering them pair-wise in such a way as to minimise the resulting summed heterogeneity. Clusters are then in turn compared with their neighbours and merged into larger segments or pixel groups until a user-defined homogeneity threshold (scale factor) is reached. This results in segments of varying size with small segments in areas of high texture or pronounced spectral variability or change, and big segments in homogeneous areas. Segmentation can further be constrained by weighting image layers/bands of one or several images differently according to their importance to the subject of enquiry. The homogeneity threshold is composed of criteria such as pixel values (colour) and polygon shape properties. The latter can further be broken down into segment border smoothness and segment compactness. It is up to the user to find the optimal scale factor and homogeneity criterion for the object delineation and feature extraction best suited to the application (Baatz, Benz, Dehghani, Heynen, Höltje, Hofmann, Lingenfelder, Mimler, Sohlbach, Weber & Willhauck 2002:112).

A multitude of features are calculated per newly formed segment, which will later provide the basis for a classification. These variables can be grouped into the following classes (Baatz *et al*. 2002:119):

- Layer values, values computed from pixel values within a segment such as mean, standard deviation (StdDev), ratio between mean and general brightness, ratio of mean values to those of neighbouring brighter and darker segments and relative border to brighter and darker segments.
- Polygon shape features such as area, length, width, border length, length:width ratio, shape index, density, main direction and asymmetry.
- Line features based on sub-objects (SO), such as line SO length, line SO width, line SO curvature/length, line SO: StdDev curvature.
- Position, x-centre, y-centre, x-min, y-min, x-max, y-max.
- Shape properties in relation to super-objects such as relative inner border, relative area and relative radial position.
- Layer value texture based on sub-object, such as mean of SO StdDev and average mean difference to neighbours of SO.
- Form texture based on SO such as area of SO mean and StdDev, density of SO mean and StdDev, asymmetry of SO mean and StdDev, and direction of SO mean and StdDev.

- Hierarchy such as hierarchic level, number of higher and lower levels, number of neighbours and SOs.
- Thematic attributes which are available if thematic layers such as climate, geology, site index class, soil properties or thematic probability layers (e.g. probability of hyperion zone) were imported into the system.

Besides the object features "Class-Related Features", which depend on some form of previous classification, as well as "Terms", can be calculated to aid future classification (Baatz *et al*. 2002:136).

3.8.5.2 Processing steps: From source data to classification product

To fulfil all the requirements of the new land cover data model, a complex processing chain is required. Considering the fact that different land cover classes require different source data and that all data may not be available for the whole area, classes need to be extracted from imagery independent of one another. The image classification is naturally undertaken using eCognition software on an iterative basis working from a fine to a coarse scale in the following steps (Lück 2005:5):

1. After automatic pre-processing of all imagery and ancillary data with the additional generation of metadata, data required for class extraction at a fine scale (high-resolution imagery) are loaded into eCognition together with a reference dataset, allowing the stratification of the country into landscape types or broad land-use classes. These broad classes consist of urban, rural (tribal use), agriculture (field cultivation), forestry and remote (rangeland, deserts and nature reserves).
2. Segmentation is performed with target class optimised parameters at three levels only on landscape types requiring high-resolution imagery for their class extraction (urban).
3. Image classification is performed with pre-defined class hierarchies extracting only classes of interest.

4. After a classification-based segmentation taking Land Cover Classification System (LCCS) hierarchies into account, new segmentations are performed for coarser scales for the same imagery optimised for a new set of classes. Segments previously classified are masked in order to be preserved.
5. After the loaded imagery is exploited for class extraction, classified objects are exported together with their feature values, class hierarchies and measures of classification accuracy.
6. New imagery suitable for coarser classes covering a wider area are loaded together with previous classifications as thematic layers to ensure a seamless composite when all classifications are finally integrated. Steps 2 – 5 are repeated for each set of class scales and image datasets until the coarsest class group has been dealt with.
7. The separate classifications are class specific at this stage and contain voids for non-related classes. All classifications are integrated using a map-join function filling these no data values, using a standard GIS package such as ArcGIS. Remaining holes in the database require manual image interpretation and classification.
8. In the case where land cover updates are required, a previous classification product may be loaded together with coarser satellite imagery and a simple recoding of image objects can be performed by applying a standard rule base.

Following the classification, all data can be integrated into a geo-database. Classified products are in the form of shape files, exported class hierarchies in simple text files, containing class definitions and fuzzy or hard rules used to classify image objects. Metadata in XML format is available for the base data used for classification. A log file may be translated into an appropriate format to construct XML metadata for the classification product. These files are all ingested into the ORACLE database with the aid of translators to construct a geo-database. From here the ORACLE geo-database can be converted to tiles of personal geo-databases (see figure 3.19).

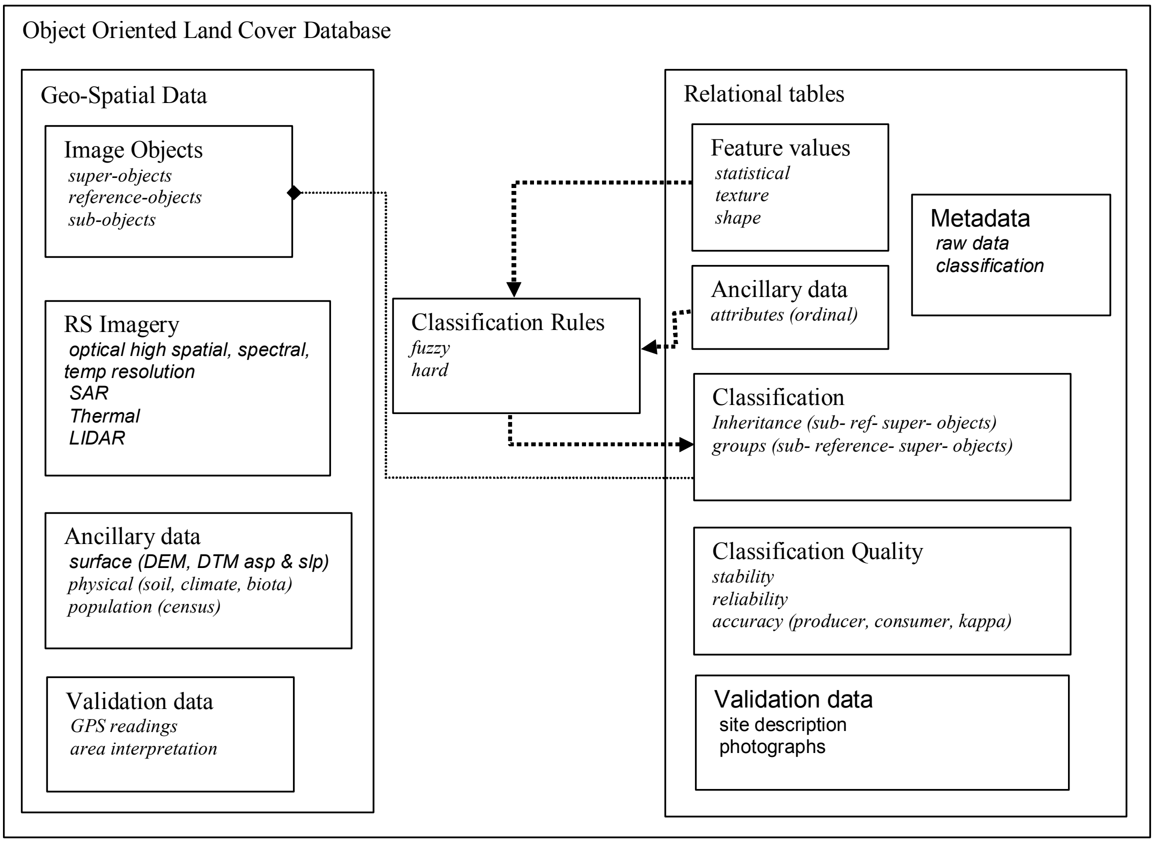


Figure 3.19: Unified Modelling Language (UML) aggregate context diagram of components in an Object Oriented Land Cover Database

(Lück 2005:5)

3.9 REMOTE SENSING APPLICATIONS

Successful application of remote sensing is premised on the *integration* of multiple, interrelated data sources and analysis procedures. No single combination of sensor and interpretation procedure is appropriate to all resource inventorying, and monitoring problems are not amenable to solution by means of remote sensing at all. Among the appropriate applications, a wide variety of data acquisition and analysis approaches exist. Conceptually, however, all designs of successful remote sensing efforts involve, at a minimum (Lillesand & Kiefer 1994:35), the following:

- clear definition of the problem at hand

- evaluation of the potential for addressing the problem with remote sensing techniques
- identification of the remote sensing data acquisition procedures appropriate to the task
- determination of the data interpretation procedures to be employed and the reference data needed
- identification of the criteria by which the quality of information collected can be judged.

The success of many applications of remote sensing is improved considerably by taking a *multiple-view* approach to data collection. This may involve *multistage* sensing wherein data about a site are collected from multi-altitudes. It may involve *multispectral* sensing whereby data are acquired simultaneously in several spectral bands. Or it may entail *multitemporal* sensing, where data about a site are collected on more than one occasion. In the multistage approach, satellite data may be analysed in conjunction with high altitude data, low altitude data, and ground observations (*in situ sensing*). Each successive data source might provide more detailed information over smaller geographic areas. Information extracted at any lower level of observation may then be extrapolated to higher levels of observation. Multitemporal sensing involves sensing the same area at multiple times and using changes occurring with time as discriminates of ground conditions. This approach is frequently taken to monitor land use changes, such as suburban development in urban fringe areas. In fact, regional land use surveys might call for the acquisition of multisensor, multispectral, multistage, multitemporal data to be used for multiple purposes.

The geographic information systems (GIS) environment permits the synthesis, analysis, and communication of virtually unlimited sources and types of biophysical and socioeconomic data, as long as they can be geographically referenced. Remote sensing can be thought of as the “eyes” of such systems providing repeated, synoptic visions of earth sources from an aerial or space vantage point. GIS technology involves nearly as many terms, acronyms and definitions as users. A commonly accepted definition of GIS is “a system of hardware, software, data, people organisations, and institutional arrangements for collecting, storing, analysing and disseminating information about areas of the earth”. In short, GISs are computer-based systems that can deal with virtually any type of information about features that can be referenced by geographical location. These systems are capable of handling both *locational data* and *attribute data* about such features. That is, not only do GISs permit automated mapping or display of the locations of features, but these systems also provide a relational database capability for recording and analysing descriptive characteristics about the features (Lillesand & Kiefer 1994:40).

Remote sensing images, and information extracted from such images, have become primary data sources of modern GISs. Indeed, the boundaries between remote sensing and GIS technology have become blurred and these combined fields will continue to revolutionise how we inventory, monitor and manage natural resources and land use on a day-to-day basis.

Remote sensing is primarily developed and used in the natural sciences rather than the social sciences. Remote sensing applications are used in agriculture, forestry, geology, hydrology and marine ecology. Applications applicable to this study that will be discussed are (Canada Centre for Remote Sensing, Remote Sensing Tutorial 2000: 174-232):

- Land use/land cover classification.
- Mapping.
- Safety and security with the emphasis on border control.

3.9.1 Land use/land cover mapping

Knowledge of land use and land cover is important for many planning and management activities concerned with the surface of the earth. The term *land cover* relates to the type of feature present on the surface of the earth. Corn fields, lakes, forestry and concrete highways are a few examples of land cover. The term *land use* relates to the human activity or economic function associated with a specific piece of land. As an example, a tract of land on the fringe of an urban area may be used for single-family housing. Depending on the level of mapping detail, its *land use* could be described as urban use, residential use, or single-family residential use. The same tract of land would have a *land cover* consisting of roofs, pavement, grass and trees.

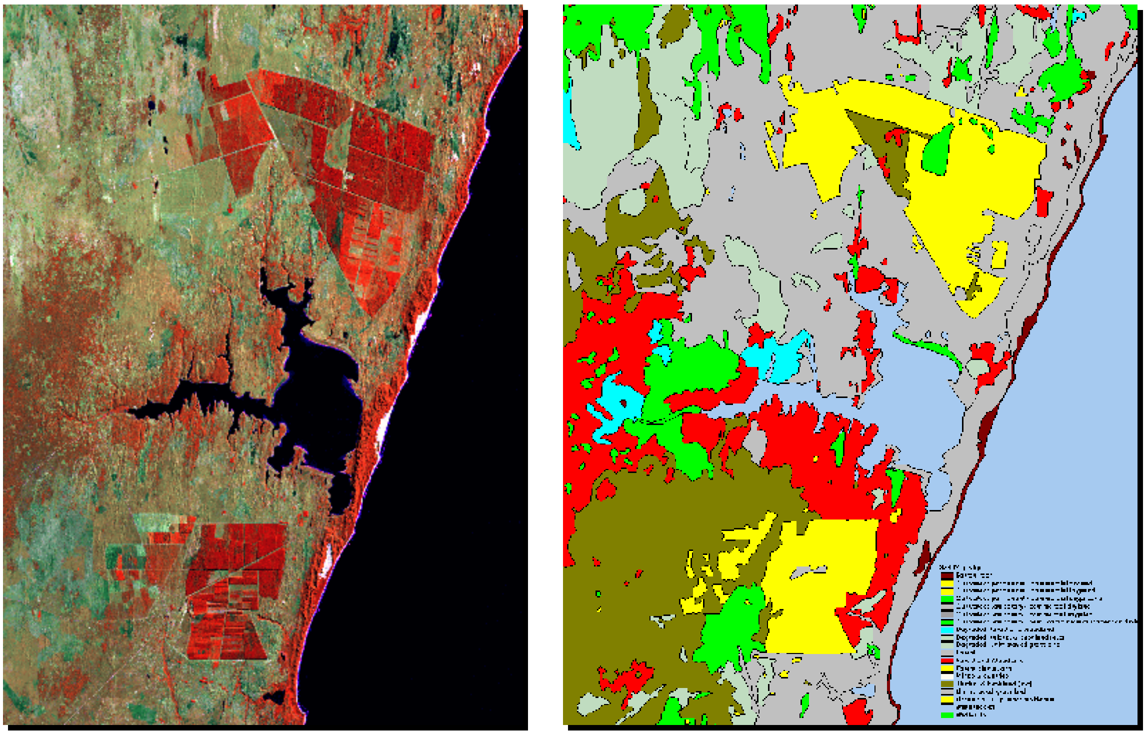


Figure 3.20: SPOT 4 image used to generate a land cover map consisting of various classes in raster polygon format

(CSIR, Satellite Applications Centre)

Identification of land cover establishes the baseline from which monitoring activities (change detection) can be performed, and provides the ground cover information for baseline thematic maps. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify the land use changes from year to year. This knowledge will help develop strategies to balance conservation, conflicting uses and developmental pressures. Issues driving land use studies include the removal or disturbance of productive land, urban encroachment and depletion of forests. It is important to distinguish the difference between land cover and land use, and the information that can be ascertained from each. The properties measured with remote sensing techniques relate to land cover, from which land use can be inferred, particularly with ancillary data or a priori knowledge. Land cover/land use studies are multidisciplinary in nature, and thus the participants involved in such work are numerous and varied, ranging from international wildlife and conservation foundations, to government researchers and forestry companies. In addition to facilitating sustainable management of the land, land cover and land use information may be used for planning, monitoring and evaluation of development, industrial activity or reclamation. Detection of long-term changes in land cover may reveal a response to a shift in local or regional climatic conditions, the basis of terrestrial global monitoring.

Land use applications of remote sensing include the following:

- natural resource management
- wildlife habitat protection
- baseline mapping for GIS input
- urban expansion/encroachment
- routing and logistics planning for seismic/exploration/resource extraction activities
- damage delineation (tornadoes, flooding, volcanic, seismic, fire)
- legal boundaries for tax and property evaluation
- target detection – identification of landing strips, roads, clearings, bridges, land/water interface.

3.9.2 Mapping

Mapping constitutes an integral component of the process of managing land resources, and mapped information is the common product of analysis of remotely sensed data. Natural features and manufactured infrastructures, such as transportation networks, urban areas, and administrative boundaries can be presented spatially with respect to referenced co-ordinate systems, which may then be combined with thematic information. Baseline, thematic, and topographic maps are essential for planning, evaluating and monitoring, for military or civilian reconnaissance, or land use management, particularly if digitally integrated into a geographic information system as an information base. Integrating elevation information is crucial to many applications and is often the key to the potential success of present-day mapping programmes.

Traditionally, this information was obtained through surveying and photogrammetric techniques, which have been costly and time consuming, particularly for periodic revision of outdated information. Recent advances in computer technology (speed, data handling and storage capability) and a growing demand for digital databases and computer-based mapping production capabilities have encouraged the use of remotely sensed information as a data source for cartographic applications. There is a growing demand for the utilisation of remote sensing data in map production, since the following benefits may be provided: stereo coverage, frequent revisits, timely delivery, wide area coverage, low labour intensity, virtually global coverage, and storage in digital format to facilitate subsequent updating and compatibility with current GIS technology. End users of base maps and mapping products include resource companies (forestry, mining), support and service industries (engineering), utility and infrastructure development agencies (pipelines, telecommunications, transportation, power), government mapping agencies, and the military. This diversification from traditionally military users to commercial applications has resulted in a greater demand for a wider range of mapping products, with the emphasis on the benefits of improved information content and scale, and accuracy versus data costs. Developing countries are currently initiating mapping programmes to cover large unsurveyed areas to increase their topographic and planimetric knowledge base. The derived information will be used to support territorial sovereignty issues, assess and monitor resource potential and exploitation, and encourage economic opportunity. Radar data will be relied on in tropical areas for remote sensing mapping solutions.

Mapping applications of remote sensing include the following:

- planimetry
- digital elevation models (DEMs)
- baseline thematic mapping/topographic mapping.

3.10 REMOTE SENSING APPLICATIONS FOR SAFETY AND SECURITY

In the researcher's view the integration potential between remote sensing and GIS will enable the creation of a visual interpretable geographical platform to detect environmental change and geographical profiling based on human behaviour. The availability of high-resolution imagery (< 1 m ground sample distribution) with high temporal revisit potential creates the ideal technology for updating maps and continuously monitoring and evaluating a specific area. The displacement and diffusion of crime patterns in relation to land use classes and the changes associated with it enables the crime analyst to understand the correlation between specific crimes, their environment and human behaviour as per defined land use class. A remote sensing image is a snapshot in time over a specific area on the earth’s surface. The satellite image can also serve as a reliable source for *prima facie* evidence in court as used in the Merriespruit slimes dam disaster in 1995.

Image data usually consists of satellite images of a place or area that has been geo-referenced so that it fits with other spatial data with a similar projection. Adding images to a GIS viewer can greatly enhance a user’s understanding of the physical area that is being analysed. In addition, adding image data is an excellent method for improving the attractiveness and comprehension of map data for a map’s final audience. As an example of a robbery cluster analysis, added image data make the map more easily understandable and also provides some other visual clues as to why crime is occurring in that location (Paulsen & Robinson 2004:252).

Crime in South Africa affects all citizens. The economic impact of crime, loss of property and human life create an immense need for utilising the best combination of technology to assist protection forces to combat and understand criminal behaviour better. Understaffing, lack of skills and lack of finances to properly fund protection services are a few of the factors that influence effective combating of crime.

The researcher identified the following application areas in which remote sensing science is being used in safety and security applications globally:

- Border control monitoring and trail feature extractions (see section 3.10.1 below as an example)
- Map updating - terrain maps and topographical maps.
- Multi-spectral and hyper-spectral instrumentation to identify specific narcotic plant species such as cannabis.
- Creation of 3-D terrain models and fly-through applications for tactical operational planning.
- Detailed land use classification for urban profiling.
- Image backdrop to enhance visual interpretation of crime data.
- Crime forecasting based on new land use behaviour and growth.
- Geographical profiling.
- Mapping of vector layers such as roads, railways, buildings, etc. from high-resolution imagery as additional spatial information.

3.10.1 Border control as a safety and security application example

The mandate of the SAPS to protect the national borders of South Africa serves as a good example of how multi-sensor technologies and platforms can be integrated into an operational system.

The utilisation of multi-sensors, i.e. spaceborne sensors such as the SPOT constellation, QuickBird and Ikonos, combined with technology such as HALE UAVs will provide the ultimate border trail mapping monitoring system using multispectral imagery. The SPOT constellation provides spatial resolution from 20 m to 2.5 m covering a specific hot spot area of at least 60 km x 60 km once every two to three days - that is, bearing in mind the constraint of cloud. In practical terms an area can be imaged once a week as a snapshot in time. This provides a good monitoring basemap to digitise change relevant to the spectral and spatial resolution available (see figure 3.21).

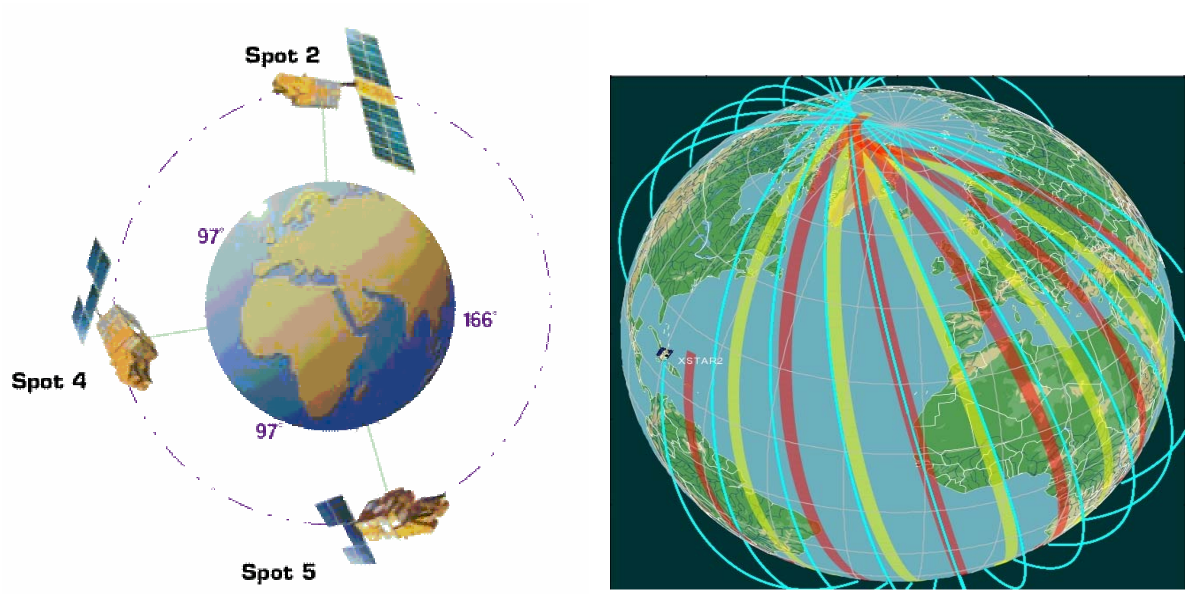


Figure 3.21: SPOT constellation orbit path

The identification of vegetation that has changed to small trails crossing the national border of over 3 000 km in length requires high temporal imagery. In order to collect enough imagery, a HALE UAV with imaging capacity from west to east or east to west, combined with high-resolution polar Earth observation satellites will secure enough imagery for frequent change detection. The combination of multi-resolution imagery into a mosaic requires image processing techniques such as image fusion and very accurate ortho-rectification processing. The combination of various image tiles along the border allows feature extraction techniques as discussed in section 3.8.5. The tiles required to cover South Africa's northern border using the SPOT constellation would consist of more than 60 cells (see figure 3.22).

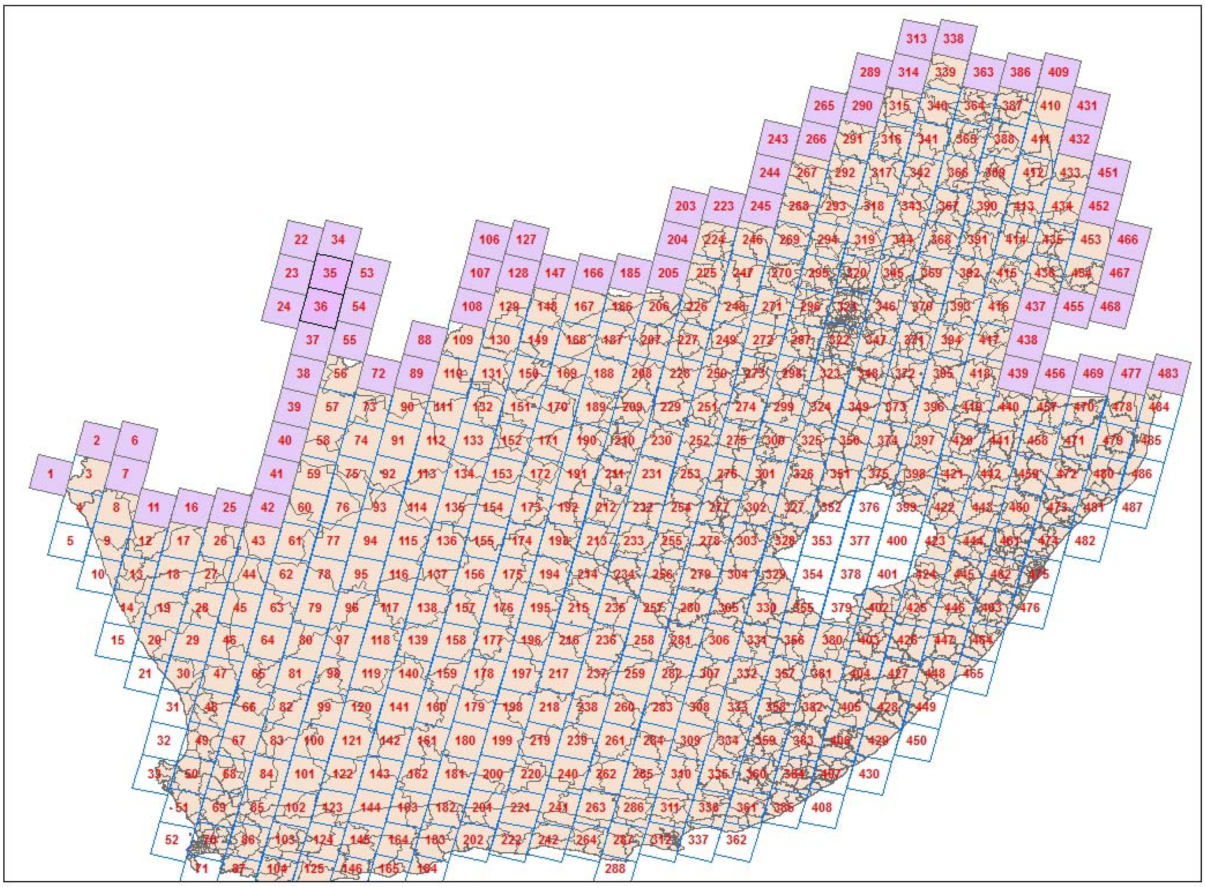


Figure 3.22: SPOT grid cells illustrating national border coverage

The collection of imagery and the processing of it into a seamless mosaic is the first step in preparing the dataset for feature delineation and change detection. The processing of such a mosaic can be done within a few days after all the images have been ortho-rectified. The tie points (TPs) are generated automatically and operators only have to assess the root mean square (RMS) errors and delete those that appear incongruent between new imagery and the original base layer. With the seamless mosaic generated, the next step is to extract trails from the imagery. The object-orientated software utilised for this is eCognition as described in section 3.8.5. The software uses a suite of machine-learning algorithms to classify features according to spectral characteristics as well as to spatial context. The operators must select a few sample trails and specify specific variables that represent the spectral bands and spatial representations of the imagery. This process trains the software to recognise targeted feature pixels in the image and classify them (see figure 3.23) (Cao 2003:38).

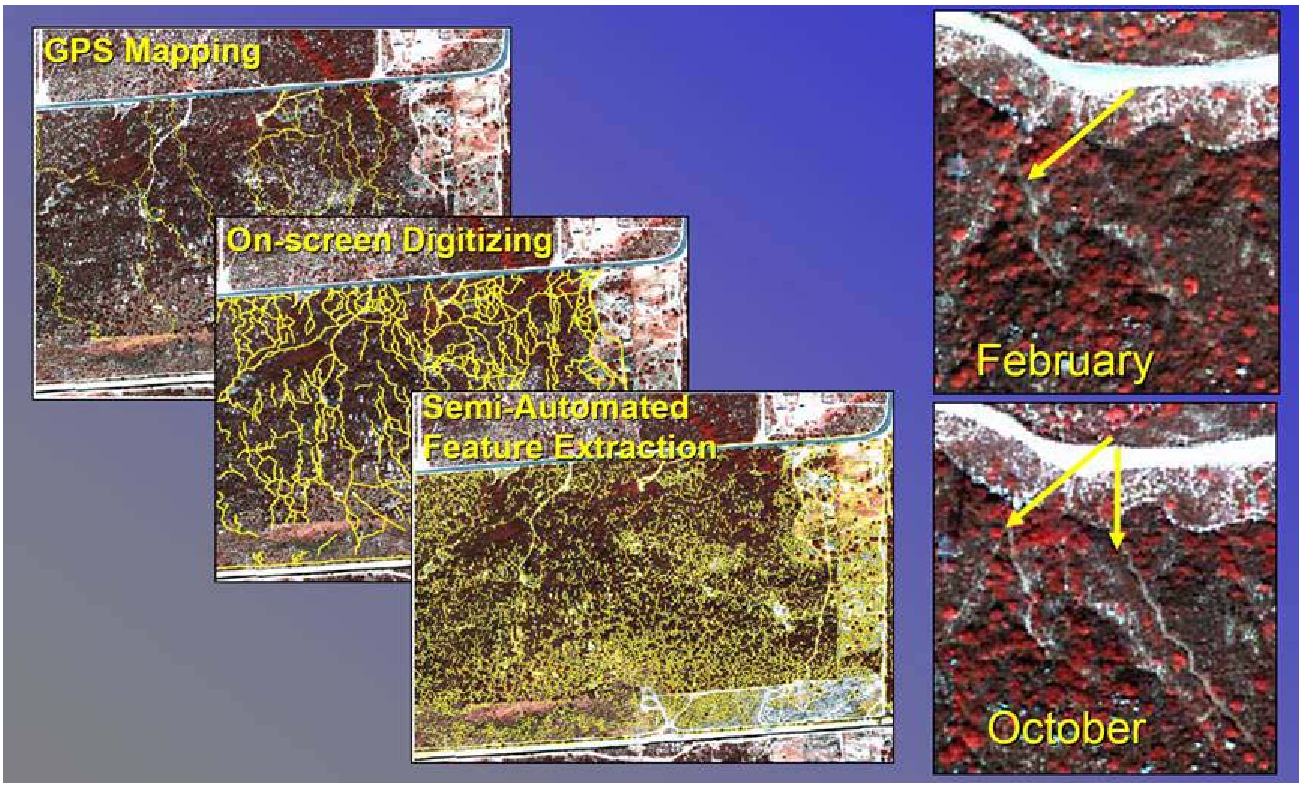


Figure 3.23: Trail feature extraction process

Once trails have been extracted from a specific set of imagery, it will then be possible to explore changes in trails over time. The SAPS will then have a new spatial tool ready to adopt from regular mapping and monitoring of the dynamic trails (Cao 2003:38).

The example of border control was discussed in the general sense. Chapter four of this study deals with more specific methodologies to integrate remote sensing, GIS and crime data to improve crime analysis.

3.11 CONCLUSION

Remote sensing science is a complex and ever-emerging technology. The image improvement in spectral wavelengths and resolution has created an environment which should not be disregarded by any science. The introduction to remote sensing in this chapter sets the scene in the next chapter to illustrate how remote sensing, crime data and GIS information layers can be integrated into a spatial information tool that can help to analyse and prevent crime in a more efficacious way.

The concepts of electromagnetic energy and spectrum were introduced. The image characteristics of remote sensing systems and basic orbital science provided the reader with the necessary background to understand the science on which remote sensing is based.

This chapter introduced new and emerging technologies such as very high resolution satellite sensors, for example WorldView and Pleiades, LiDAR, hyperspectral sensors, HALE UAVs and OOIA techniques. These emerging technologies will provide a complementary spatial capacity in the safety and security arena in the future to continuously improve crime analysis and combating. Border control became the responsibility the SAPS as from 2005, and they are now accountable for the control and prevention of illegal border crossings.

A multi-sensor approach is needed to implement a spatial strategy to monitor specific border areas. The combination of spaceborne and airborne sensors will increase the number of temporal and spatial revisits over identified areas so that an object-orientated image analysis process can be implemented through an artificial intelligence computation called feature extraction. The delineation of border trails and the automation of change detection can provide valuable information for the SAPS to identify illegal cross-border activities.

The next chapter illustrates the application of remote sensing and GIS to analyse the environmental profile within each police precinct in the Tshwane municipality and its correlation with serious crime types.

CHAPTER 4: TEMPORAL SPATIAL ANALYSIS WITHIN THE TSHWANE MUNICIPALITY BOUNDARIES TO DETERMINE THE RELATIONSHIP BETWEEN LAND USE GROWTH AND CRIME

4.1 INTRODUCTION

Up to now this study has focused on the basic science involved in, and applications of, remote sensing and Geographical Information System (GIS) analysis. The discussion also introduced criminological theory, both classical and contemporary, and its relevance to spatial technology. The spatial analysis given later in this chapter relate to the detailed discussion of the sociological theories (section 2.2.6), with specific attention to social structure theories (section 2.2.6.1) which highlight the social disorganisational theories (section 2.2.6.1.2), such as Shaw and McKay's concentric zone theory (Siegel 2003:184) and social ecology theory (Paulsen & Robinson 2004:81).

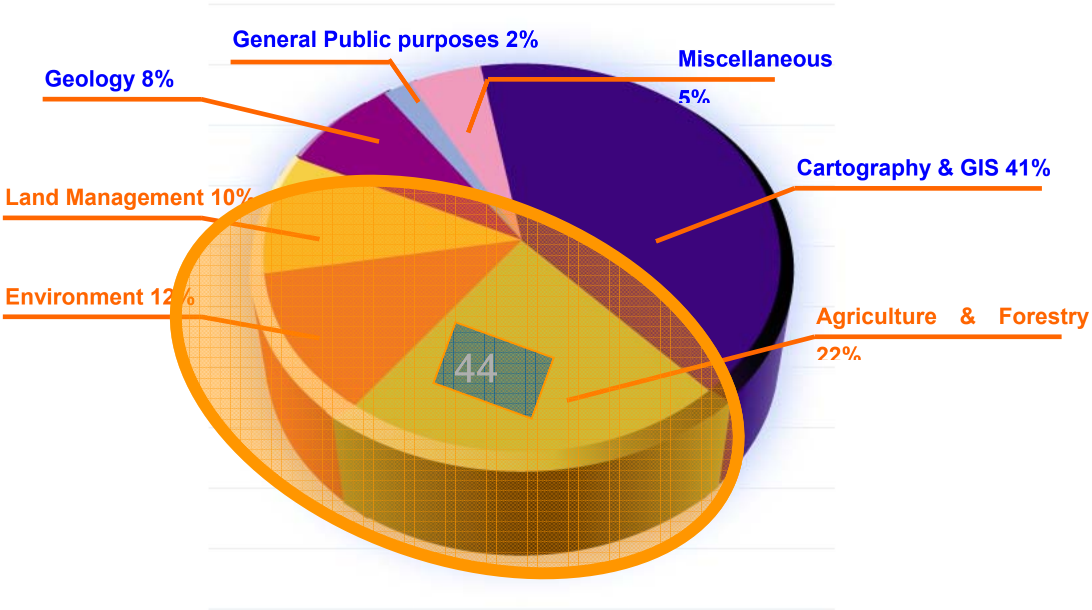
The selected study area, the Tshwane municipality boundary, provides an urbanised characteristic and fits the concentric zones described by Shaw and McKay (Siegel 2003:184). The study area also has a diverse socio-economic nature that incorporates activities described in the social ecological theories (Paulsen & Robinson 2004:81-109), such as defensible space, Crime Prevention Through Environmental Design (CPTED), situational crime prevention, routine activity theory and crime pattern theory. The latter activities differ between each police precinct area in Tshwane as do the crime types that dominate each area.

This chapter introduces a practical analysis utilising remote sensing imagery and vector data layers coupled with relevant auxiliary data to determine whether there is a relationship between land use growth and specific crime types.

4.2 RATIONALE FOR STUDY AREA

The Tshwane area was selected for its geographical location and socio-economical characteristics. The analysis depended on accurate geo-coded crime and the availability of remote sensing data. Sufficient point feature data to indicate growth was also available which strengthened the case for the selection of the Tshwane area. The selected area has a diverse social and economic profile which enabled the researcher to understand the relationship between specific social classes and crime types. The heterogenous nature of the area, and the availability of a temporal remote sensing dataset to complete a macro and micro study, contributed positively to the selection of this area. The area is also recognised as a high crime area with various incidents of serious crimes, as given in section 1.5.1.

The graph below illustrates the use of remote sensing data in specific scientific applications (see graph 4.1). The dominant application of remote sensing is in the agro-environmental area, followed by cartography. It is believed that a study such as this can contribute to the application of remote sensing imagery in the security industry, which will allow crime to be analysed and combated through the understanding of land use behaviour in each police precinct area. It is the researcher's hope that the safety and security domain will become a more dominant user of remote sensing to improve crime reduction strategies in the long term.



Graph 4.1: Remote sensing market analysis

4.3 SELECTED STUDY AREA

The Tshwane municipality covers approximately 2 200 square kilometres and incorporates 28 police precinct areas (see figures 4.1 and 4.2). The environmental and socio-economic profile of each of the 28 police precinct areas within Tshwane are significantly different, as are their identified growth patterns as defined by the relevant land use classes (see section 1.5.1). Each police precinct furthermore exhibits a unique pattern of specific crime types per area which allows for a statistical representative sample for this spatial analysis. Multivariate statistical analysis techniques to determine the relationship between different variables such as crime type, land use class and demographics can be applied over such a diverse area to determine specific spatial patterns of behaviour. The diverse nature of land use classes within Tshwane creates an ideal platform to correlate with the social disorganisation theories of criminology to understand and reduce crime.

The concern during this study was the fact that police precinct boundaries do not mach the official statistical boundaries in accordance with the mandate of

Statistics South Africa. The police precinct areas are not aligned with enumerator areas, sub-place or official municipality boundaries. The result is that a census as auxiliary data can only be used from provincial boundary level onwards or to allocate a percentage of crime to overlapping areas as a percentage. This means that a census does not reflect the true geo-location of the actual crime incidents.

Figure 4.1 underlines the misfit of the police precinct boundaries with the municipality boundary. Figure 4.2 illustrates the subplace boundary and its misalignment with the police precinct boundaries. Figure 4.3 is a magnification of the subplace boundary over the Lyttelton police precinct area. The green circles represent the overlapping areas between the subplace area and the Lyttelton police precinct boundary. The southern part of Lyttelton is not included at all within the official municipality boundary, which represents at least 30% of the police precinct area.

The key problem that was solved during this project was the illustration of land use growth since 1994 using Landsat satellite imagery from which to derive the necessary classes (see figures 4.11 to 4.15). The vector classes were grouped into a personal geo-database to ensure a well-managed file data structure in order to manage all macro and micro layer data so that the geo-coded crime layers could finally be analysed. The results were illustrated by generating thematic maps such as colour-coded maps (see figures 4.16 to 4.28) and statistical circular maps (see figures 4.29 to 4.42).

The deficiencies that were identified need to be rectified through a multi-government approach. The custodians of the relevant spatial data need to consolidate the data layers into one standard to ensure spatial alignment.

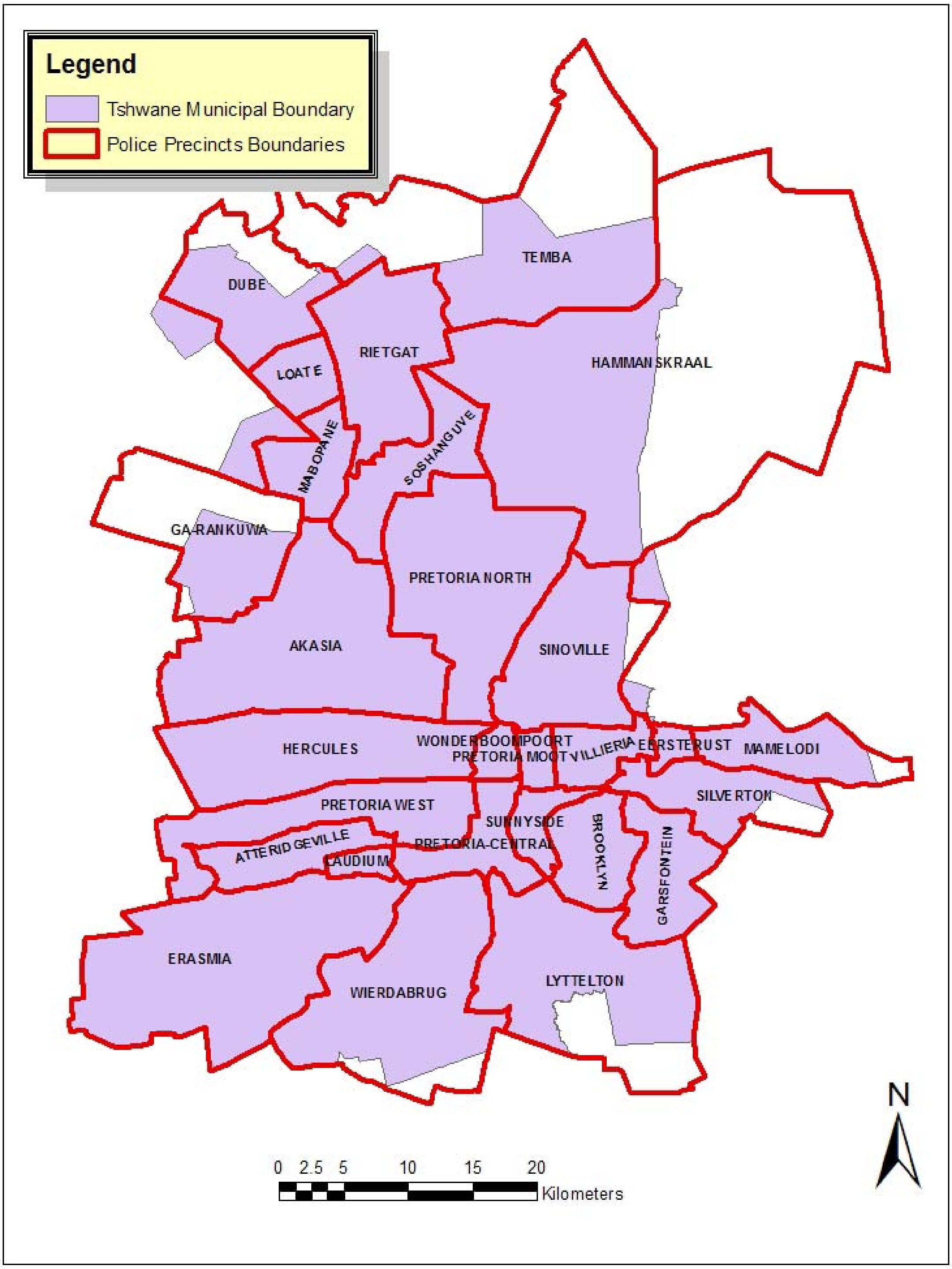


Figure 4.1: **Tshwane municipal boundary and intersecting police precincts**

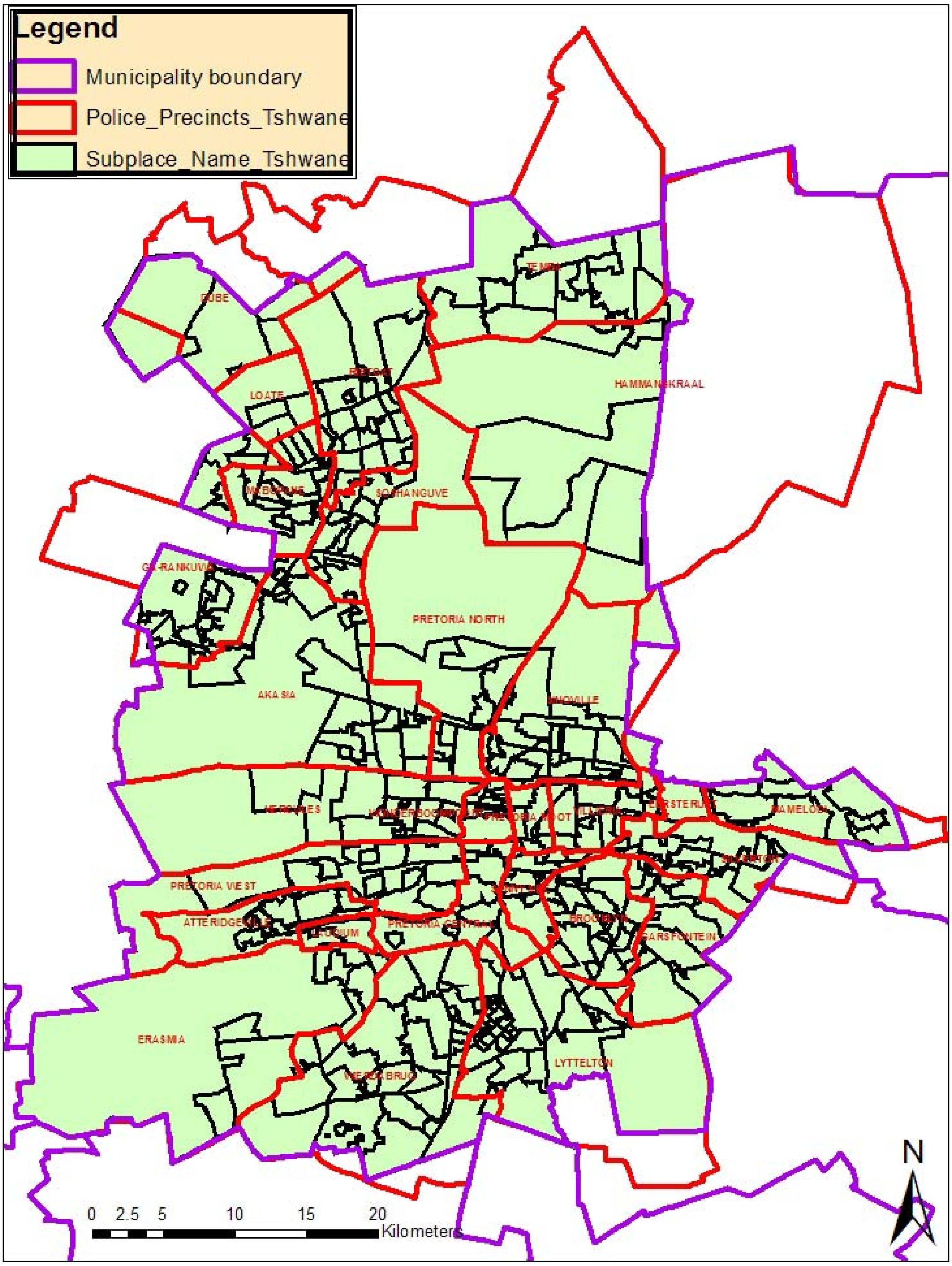


Figure 4.2: Subplace boundaries within Tshwane and intersecting police precincts

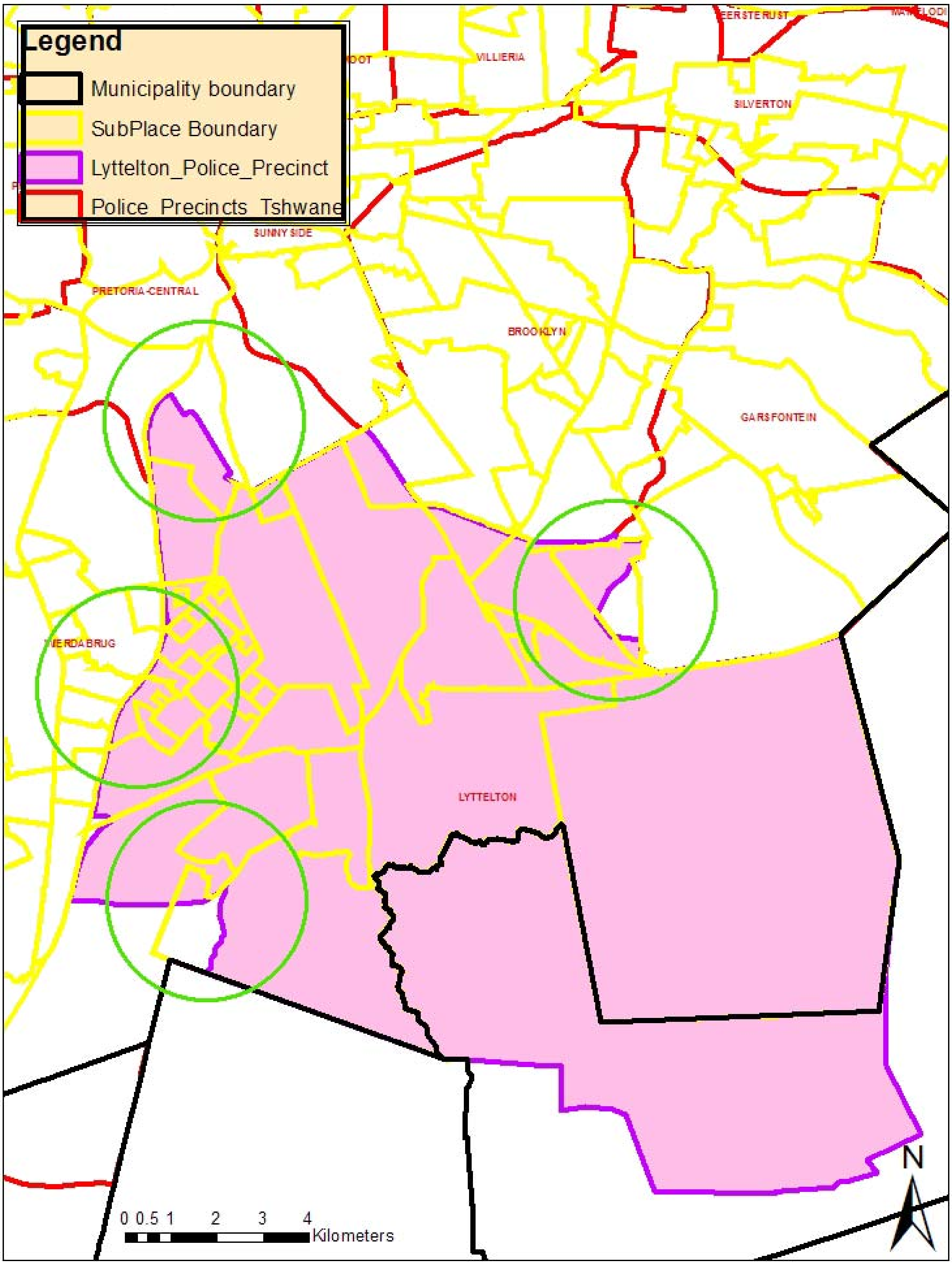


Figure 4.3: **Subplace boundary magnified over Lyttelton police precinct boundary**

4.4 METHODOLOGY FOR SPATIAL ANALYSIS

The methodology used to apply spatial analysis techniques to understand the relationship between specific land use behaviour and crime types can be divided into three categories. These categories allow a proper understanding necessary to appreciate the significance of spatial technology for controlling crime with the ultimate objective of preventing crime. These categories are:

- GIS project management
- Macro analysis
- Micro analysis.

4.4.1 GIS project management

This component includes the identification of project objectives, creation of a project database and the development of GIS functions to enable analytical modelling (Crossier, Booth & Mitchell 2002:69).

- **Step 1: Identification of objectives**

  This component requires due consideration of the following questions:

  - What is the problem to solve? How is it solved now? Are there alternative ways of solving it using a GIS?
  - What are the final products of the project – reports, working maps, presentation-quality maps?
  - Who is the intended audience of these products – the public, technicians, planners, officials?
  - Will the data be used for other purposes? What are the requirements for these?

  The outcome of this component is vital in determining the scope of the project and informs the ultimate implementation methodology.

- **Step 2: Project database creation**

  There are 3 components pertaining to project database creation:

1. *Database design* - includes identification of the required spatial data based on the requirements of the analysis, determination of the required feature attributes, setting of the study area boundary and the selection of the project coordinate system.
2. *Data automation* - involves digitising or converting data from pre-defined systems and formats into relevant and usable formats as well as data verification and correction.
3. *Database management* - involves verification of the coordinate systems and joining of adjacent layers.

Project database creation is a critical and time-consuming part of any GIS project. The completeness and accuracy of the data used in analysis ultimately determines the accuracy of the results.

- **Step 3: Data analysis and modelling**

  Analysing data in a GIS ranges from simple mapping to creating complex spatial models. A model is a representation of reality used to simulate a process, predict an outcome, or analyse a problem. A spatial model involves applying one or more of three categories of GIS function to some spatial data. These functions are:

  1. *Geometric modelling functions* – calculating distance, generating buffers and calculating areas and perimeters.
  2. *Coincidence modelling functions* – overlaying datasets to find places where values coincide.
  3. *Adjacency modelling function* – allocating, pathfinding and redistricting.

- **Step 4: Presentation of results**

  The final result must adequately communicate the findings of the study to the reader. In most cases, the results of a GIS analysis can best be shown on a map. Charts and reports of selected data are alternative ways of presenting the results. The combination of maps, charts and reports can be printed or integrated with other documents as complementary information.

The selected study in this chapter is a practical example to illustrate the application of the GIS project management component.

4.4.2 Macro analysis

Change detection is a technique used in remote sensing to determine the changes in a particular object of study between two or more time periods (Singh 1989:990; Jensen 1996:316; Macleod & Congalton 1998:208). Change detection is an important process for monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution in the area of interest. Masry, Crawley & Hillborn (1975:1145) and Yuan & Elvidge (1998:167) demonstrated that the procedure of detecting land cover or land use change by comparing two or more satellite images acquired at different times, can be used to evaluate the temporal or spectral reflectance differences that have occurred between them (see 3.10.1 as an applied example in this regard).

Advances in change detection studies brought with them the development of procedures to determine the accuracy of different techniques, which has become increasingly important in order to give credibility to results. This study uses the post-classification technique, which was identified as the most suitable for detecting land cover change (Weismiller, Kristof, Scholz, Anuta & Momin 1977:1533). In the post-classification technique, multi-temporal images are independently classified (Jensen 1981:130; Jensen & Toll 1982:630; Singh 1989:995; Jensen 1996:316; Yuan & Elvidge 1998:170). The classified images are then combined to create a new change image classification, which indicates the changes that occurred. However, what is noteworthy is the iterative nature of image classification and post-classification techniques, which allow further refinement in order to produce more reliable change detection results. The change detection model, as per table 4.1 below, follows the sequence of: data collection, pre-processing of remotely sensed data, image classification using appropriate logic, change detection using GIS algorithms, post-classification assessment and distribution of results. The final results of each classified land use map are illustrated as per figures 4.11 to 4.15.

The quality assurance used during this mapping project to demarcate specific land use classes can be summarised as illustrated by figures 4.4 to 4.8. The mapping scale was set to a frame scale of 1: 50 000.

The criminological significance of such a macro analysis, in combination with satellite imagery, geographical information system modelling and geo-coded crime data, is that it is an enhanced platform to analyse crime and to explain its spatial distribution over time. The growth pattern of a specific land use class such as informal settlement areas and its relationship to specific crime types provide new spatial content for the criminologist to analyse. A better understanding of the study area and its behaviour (land use) over time will ultimately contribute to improved strategies to prevent crime and to identify socio-economic problems that contribute to criminal behaviour in general (see section 6.4 and figure 4.24).

Table 4.1: Change detection process for land cover and land use classification

Methodology	RASTER DATA	VECTOR DATA
1. Data Collection	- Raster data: Landsat 5 TM and Landsat 7 ETM+ - Base Maps: derived from SPOT 2 & 4 datasets - Aerial photography acquired from the	- Vector data: Maps and feature shapefiles from the municipalities - Inconsistencies in projection systems and parameters rendered the data unusable.
2. Data preprocessing	Image georectification - Image-to-image co-registration - Nearest neighbour transformation - Geo (Lat/Lon) Projection	
3. Feature Classification	- Unsupervised classification - On-screen feature extraction - Assign classes and descriptions	
4. Post-classification Analysis	- Feature validation: high-resolution aerial photography - Recoding of classes	
5. Change Detection	- Change analysis: 1st image vs. 2nd image - Use Change Matrix: Change 'from' and 'to' classes	- Clean vector layer (.arcinfo) - Build topology (.arcinfo)

4.4.2.1 High-density residential land use class

Figure 4.4: High-density residential area – township with more than 50 dwelling units per hectare

A dwelling/house is any housing unit estimated to have a lifespan of at least 20 years and which is built in accordance with the requirements of the National Building Regulations and Building Standards Act, 1977 (Act No 103 of 1977), i.e. built from conventional materials, mainly bricks and mortar. There are usually also one or more additional structures on a property other that the main building (house) e.g. garage, storeroom, etc.

Figure 4.5: Residential high-density, suburban type low-cost housing

4.4.2.2 Low-density residential land use class

Figure 4.6: Low-density residential area – at most 10 units per hectare

Figure 4.7: Low-density residential area – at most 10 dwelling units per hectare

A small agricultural unit around the urban periphery, that may or may not be intensively farmed (usually horticulture, glasshouse cultivation, pigs, poultry, etc.). The main building is usually in the form of a formal house with one or more additional structures on the property e.g. garage, storeroom, etc. This definition provides a guideline to map small-holdings and low-density residential areas.

4.4.2.3 Informal residential land use class

Figure 4.8: Residential informal - situated near the contrasting formal settlement. Compact structure and undeveloped road structure

Settlements that consist mainly of makeshift structures (shacks) not erected according to approved architectural plans and not of a permanent nature. They are usually made of materials such as corrugated iron, cardboard, etc. with minimal or no basic services. Due to the shortage of formal/conventional houses, a trend has developed whereby homeowners/tenants allow friends, family or tenants to build shacks, similar to those found in squatter settlements, in their backyards.

4.4.3 Micro analysis

The micro analysis component of this project utilised a highly accurate commercial dataset, "the Growth Indicator Product", created by GeoTerraImage Pty (Ltd). This dataset consists of a suite of spatial data layers that quantify urban development in South Africa's metropolitan areas (Sevenhuysen 2004:3). It concentrates on residential areas and includes detailed information on house numbers, location of formal and informal settlements and rates and extent of urban expansion and densification. Detailed information is provided down to individual erf level. The data are suitable for both GIS and non-GIS users (i.e. spreadsheet reporting).

Up-to-date high-resolution digital ortho-rectified aerial photography (1:3 000) and satellite imagery (SPOT 5) were used as the primary reference datasets (see section 3.7.3.1). Aerial photography was used to create the initial base data for each metro and updated annually using either aerial photography or satellite imagery depending on data availability. Detailed updates (e.g. new house counts) were generated primarily from aerial photography. SPOT 5 imagery was utilised if suitable photography was not available. It has been demonstrated that updating of house counts can be derived from SPOT 5 imagery if used in conjunction with erf cadastre boundary data (Sevenhuysen 2004:6).

Individual data points for each building structure in formal residential areas (including formal township areas) were utilised in the analysis and are illustrated in figures 4.9 and 4.10.

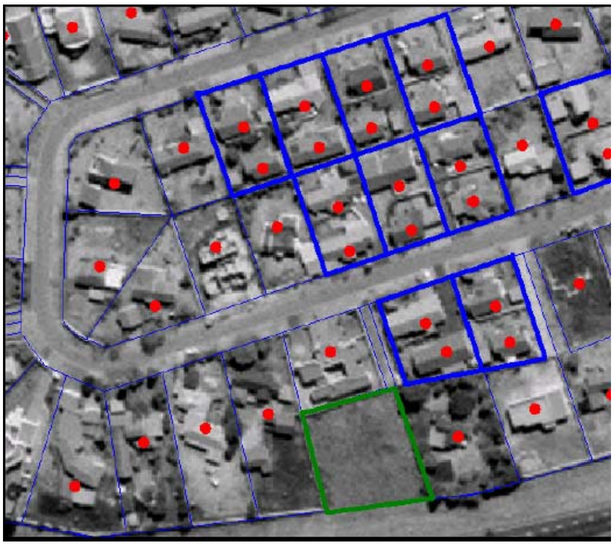


Figure 4.9: Dwelling count using aerial photography 1: 30 000

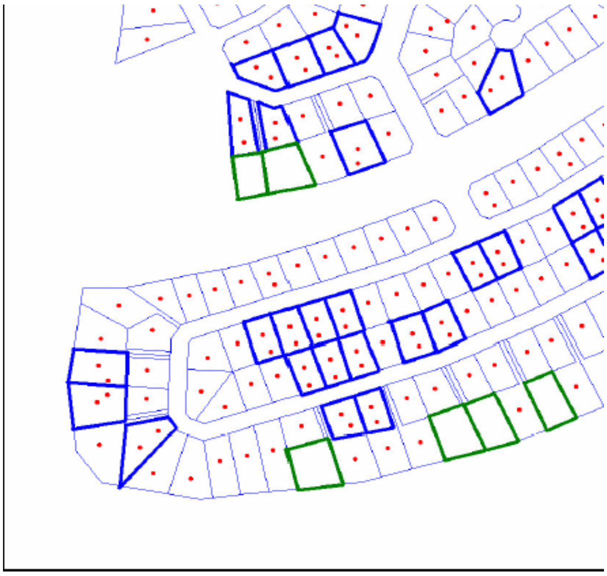


Figure 4.10: Erf cadastre vector layer for quality assessment

Figures 4.9 and 4.10 show examples of dwelling point count data that overlaid on an original aerial photograph and current erf cadastre boundaries respectively. The combination of the point data and cadastre indicates the status of current erf sub-divisions as well as the accuracy of available erf cadastre boundary data.

The urban growth data layer was derived from two (or more) residential dwelling point counts, and provides a quantitative indication of the number of new dwellings that have been built in a specific area within a certain time period.

Growth information is provided for both formal residential areas (including formal townships) and townhouse/cluster complexes (Sevenhuysen 2004:13). Growth rates are expressed as changes in the number of actual dwelling structures. Growth rates can be aggregated to either suburb boundaries or enumerator area (EA) (1996) boundaries.

The micro analysis for this specific study over the Tshwane municipality area was based on police precinct areas to illustrate an accurate land use class growth for comparison between 2003 and 2004 ultimately derived from aerial photographs and/or QuickBird 60 cm resolution satellite imagery.

The criminological significance of such a micro analysis, in combination with high-resolution satellite imagery, geographical information system point data and geo-coded crime data, is that it illustrates spatial distribution of land use classes and crime incidents very accurately. The behaviour of a specific land use class such as an informal settlement area and its relationship with specific crime types using point features data, is the ultimate tool for advanced statistical and spatial analysis techniques such as crime hot spot analysis (Anselin, Cohen, Gorr & Tita 2002:213). Each point represents a geographical latitude and longitude reading with accuracies less than 10 min horizontal distance. This enables geo-profiling techniques be used to understand criminal behaviour in very small grid areas of aerial analysis (Anselin *et al*. 2002:231).

4.5 MACRO ANALYSIS RESULTS

4.5.1 Landsat image classification 1994 to 2002

Image pre-processing followed the methodology described in section 3.2 in order to ensure the integrity of the bi-annual analysis (i.e. image-to-image registration to ensure that growth on the periphery per land use class is accurately updated). The analysis is based on hectare growth per class compared to individual object counts described in the micro analysis methodology. Figures 4.11 to 4.15 below illustrate the high level demarcation output of each defined land use class and the behaviour of the change pattern within each police precinct area.

The legends in figures 4.11 to 4.15 refer to the selected land use classes that were mapped from Landsat satellite imagery from 1994 to 2002. Each category of land use classes were mapped in a two-year interval time series. The description of each class is as follows:

- YR(a)_YR(b)_commercial_shp = The commercial land use class from one time series to another.
- YR(a)_YR(b)_industrial_shp = The industrial land use class from one time series to another.
- YR(a)_YR(b)_informal_shp = The informal settlement land use class from one time series to another.
- YR(a)_YR(b)_residential_hd_shp = The residential high-density land use class from one time series to another.
- YR(a)_YR(b)_residential_ld_shp = The residential low-density land use class from one time series to another.

The intention is for the reader to be able to visually interpret the changes and geographical dominance of a specific land use class within a specific area. For example, from 1996 the residential high-density class has dominated the south-eastern part of Tshwane, and the informal settlement class has dominated the north-western part with large expansion in the western area (Mamelodi).

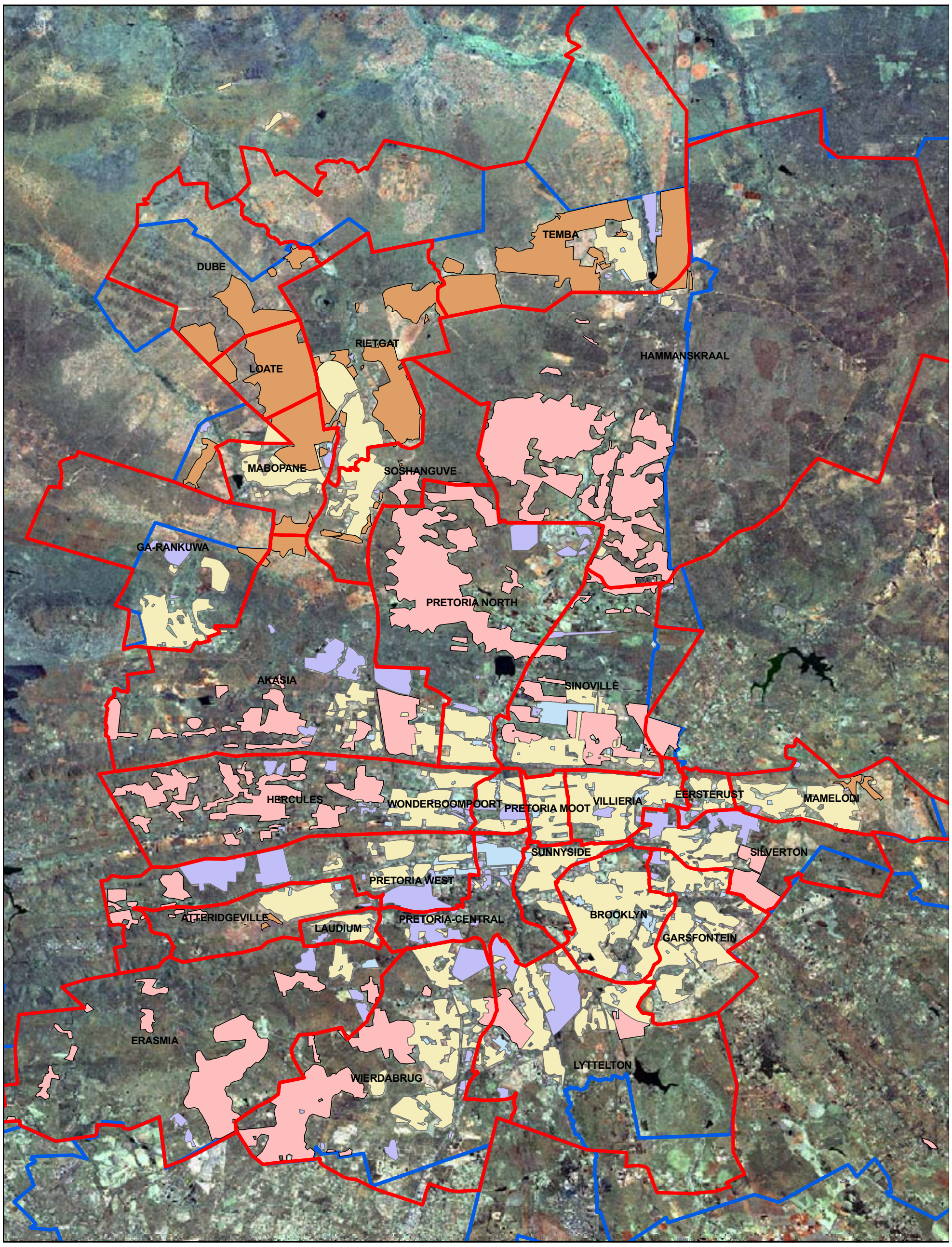
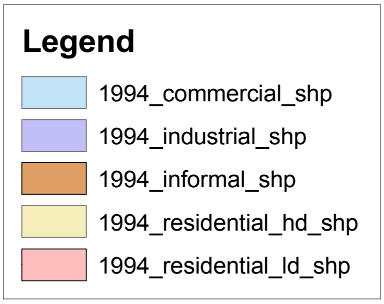


Figure 4.11: Landsat image used to demarcate land use classes for 1994



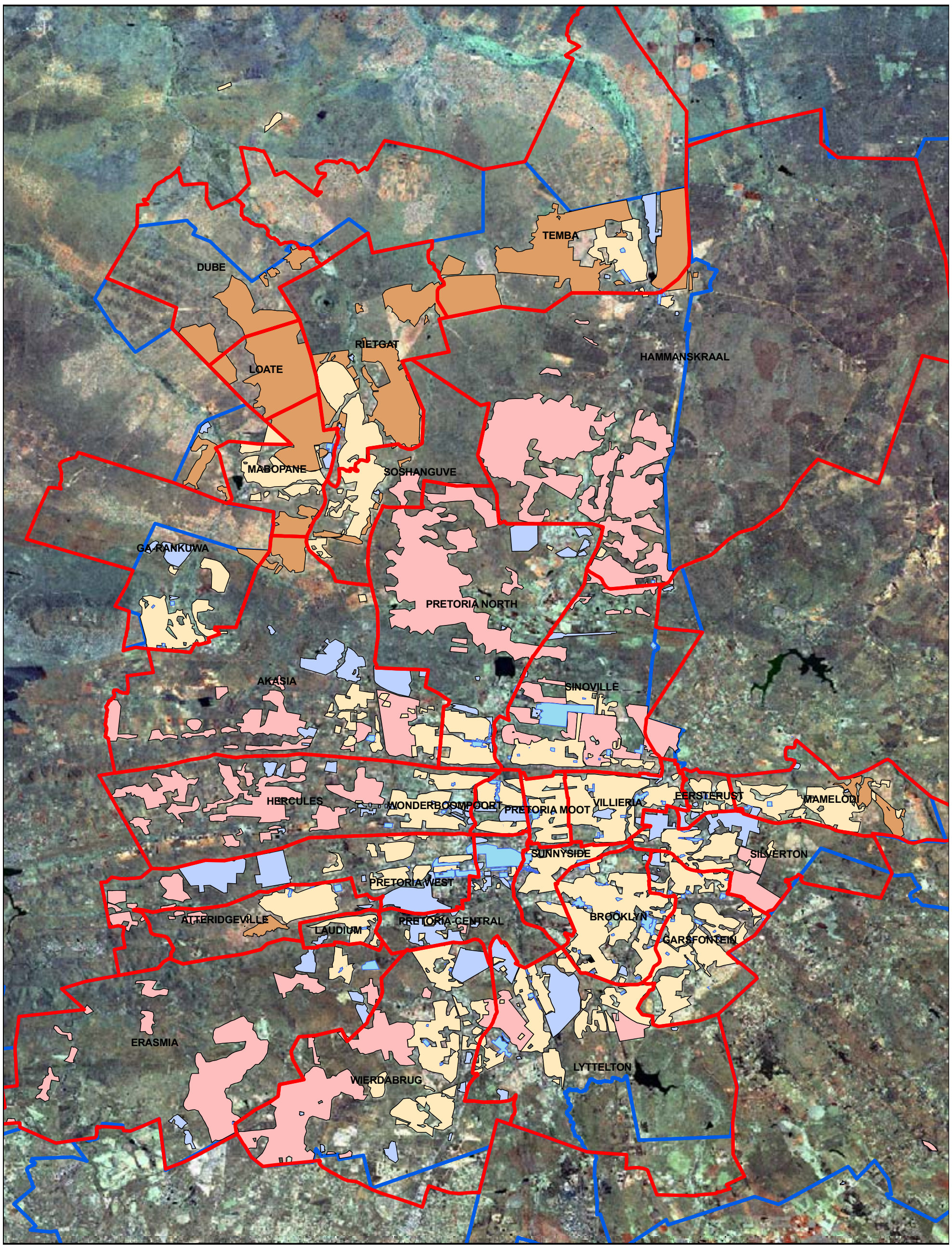


Figure 4.12: Landsat image used to demarcate land use classes for 1996

Legend

- 94_96_commercial_shp
- 94_96_industrial_shp
- 94_96_informal_shp
- 94_96_residential_hd_shp
- 94_96_residential_ld_shp

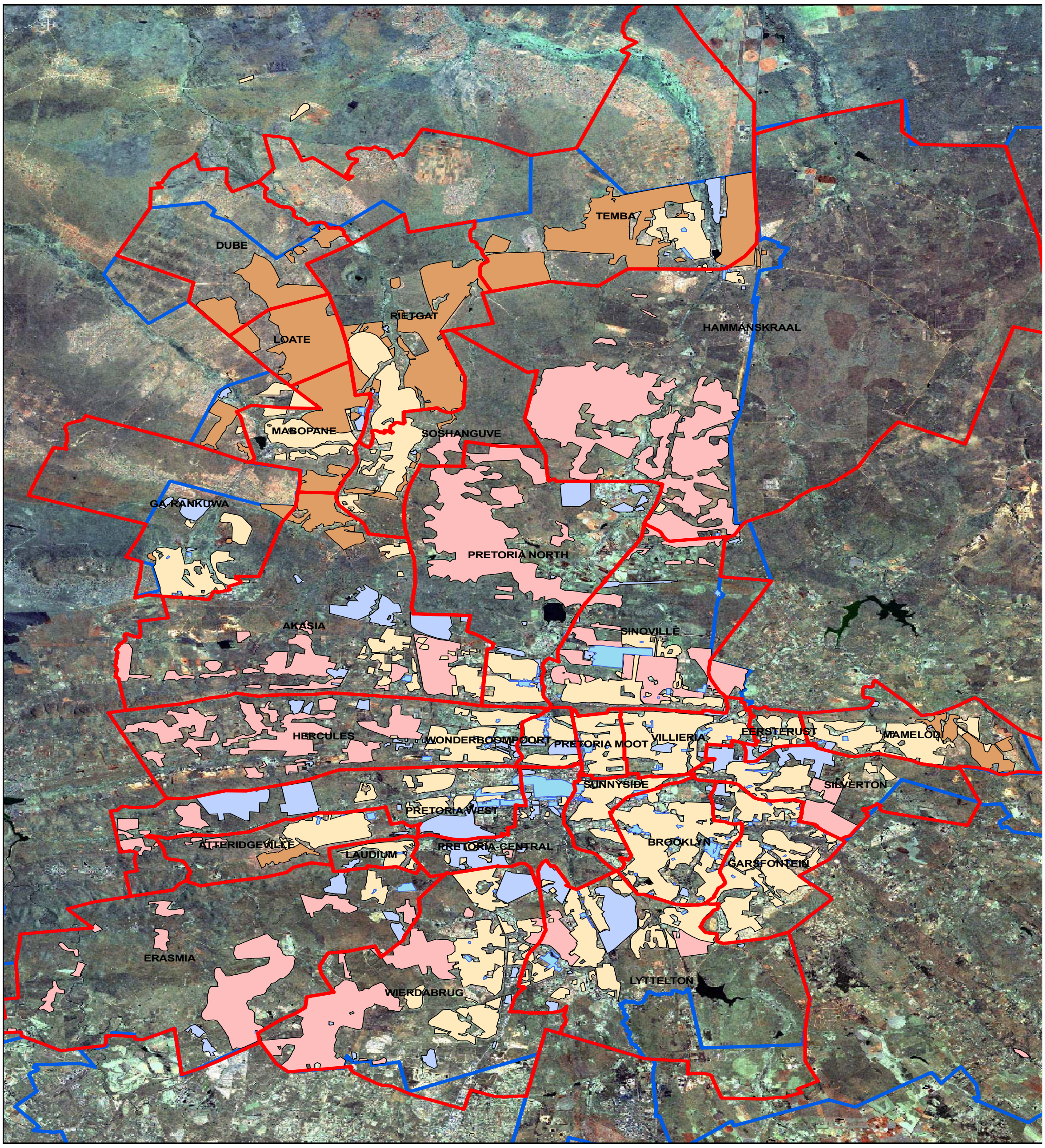
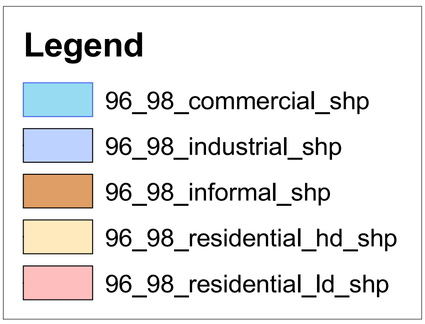


Figure 4.13: Landsat image used to demarcate land use classes for 1998



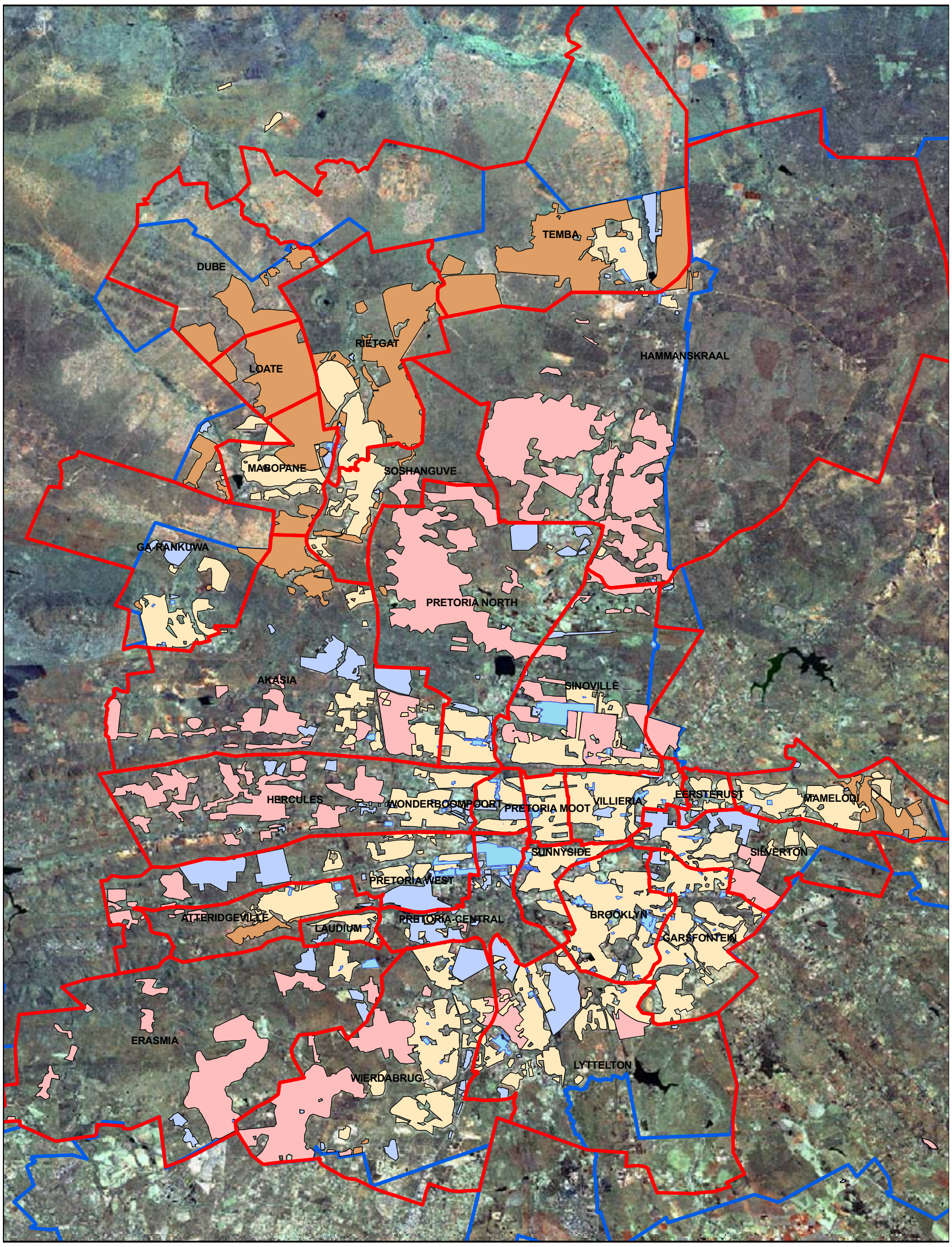
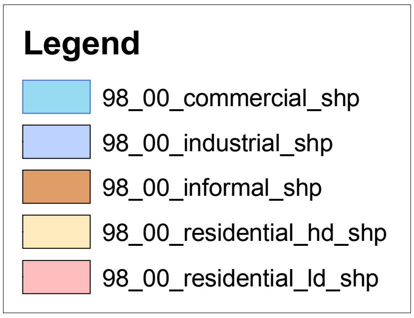


Figure 4.14: **Landsat image used to demarcate land use classes for 2000**



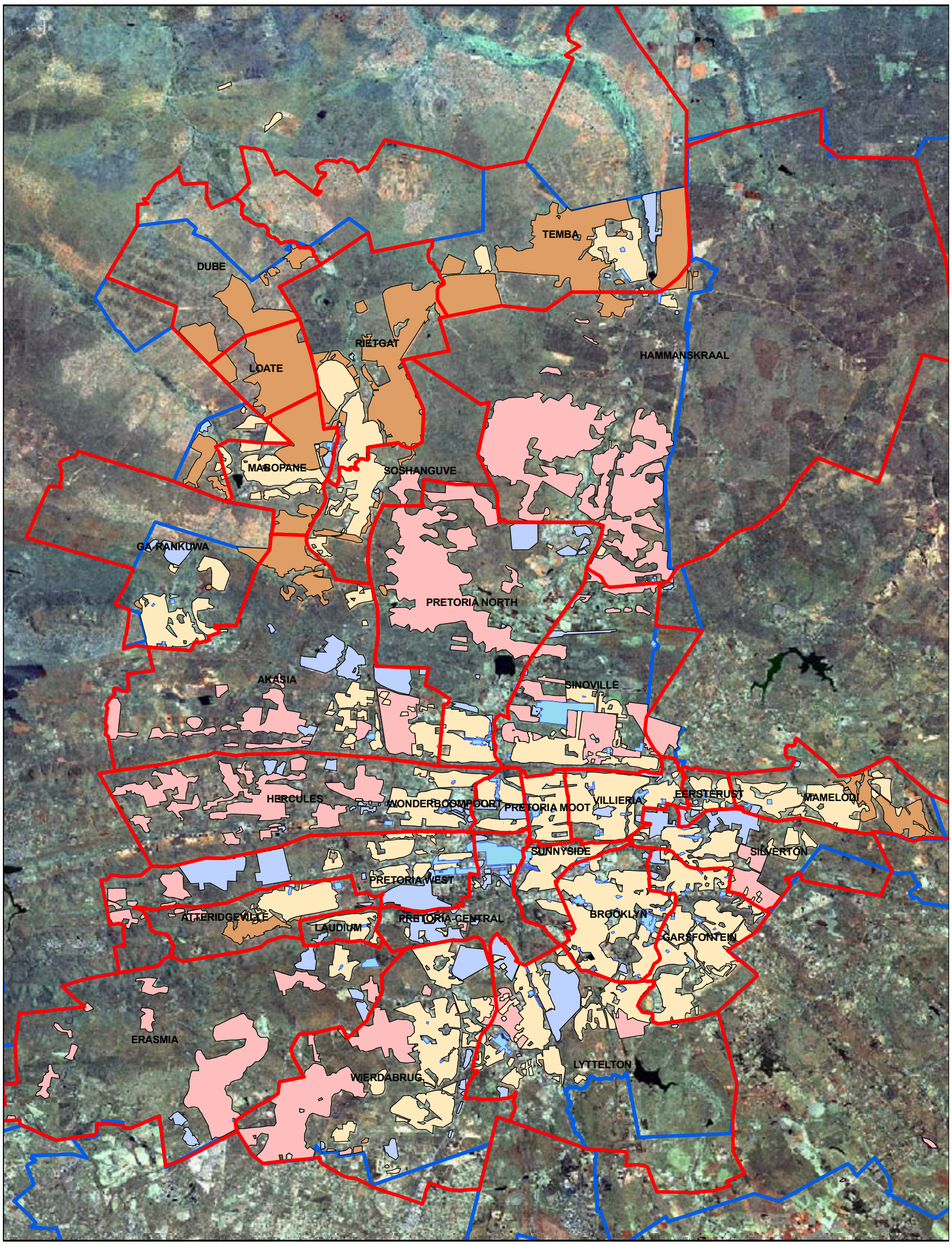


Figure 4.15: Landsat image used to demarcate land use classes for 2002

Legend

- 00_02_commercial_shp
- 00_02_industrial_shp
- 00_02_informal_shp
- 00_02_residential_hd_shp
- 00_02_residential_ld_shp

4.5.2 Thematic maps illustrating bi-annual land use growth (1994 to 2002)

The demarcated polygon areas were clipped to ensure hectare calculations per police precinct area. This defined the master periphery set. The procedure followed to create the final thematic maps to illustrate growth patterns are shown in diagram 4.1 below.

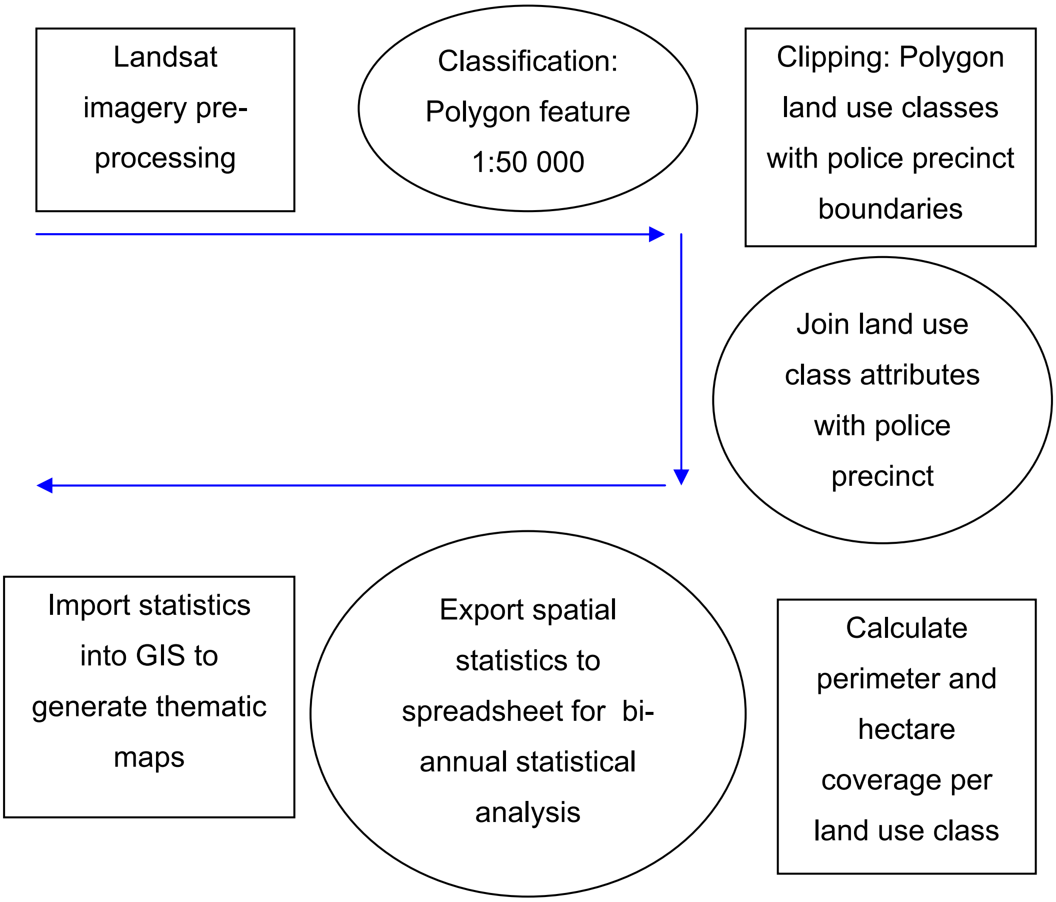


Diagram 4.1: Workflow process to generate thematic maps based on macro analysis

The detail statistical and area coverage results calculated in hectares are given per police precinct boundary. These were used to generate the spatial statistical maps in ArcGIS 9.1 (see tables 4.2 to 4.6) to illustrate the dominance of a specific land use class within a specific police precinct. The diverse dominance of a specific land use class per police precinct provides valuable information to the criminologist in understanding the geo-profile of human activity per police precinct area.

Table 4.2: Commercial land use class area coverage per police precinct area

		1994	1996	1998	2000	2002	MEAN	MEDIAN	STD DevP
COMPNT_NM	**Precinct_Hectares**	**Cm_Hectares**	**Cm_Hectares**	**Cm_Hectares**	**Cm_Hectares**	**Cm_Hectares**			
AKASIA	18 508.53	20.07	20.07	20.07	20.07	20.07	20.07	20.07	0.00
ATTERIDGEVILLE	3 927.22	26.40	26.40	26.40	26.40	26.40	26.40	26.40	0.00
BROOKLYN	4 531.49	155.92	155.92	155.92	155.92	155.92	155.92	155.92	0.00
EERSTERUST	887.13	8.71	8.65	8.65	8.65	8.65	8.66	8.65	0.02
ERASMIA	20 946.73	50.92	50.92	50.92	50.92	50.92	50.92	50.92	0.00
GA-RANKUWA	11 165.43	14.80	14.80	14.80	14.80	14.80	14.80	14.80	0.00
GARSFONTEIN	5 456.95	63.82	63.79	63.79	63.81	63.81	63.80	63.81	0.01
HAMMANSKRAAL	56 402.53	17.45	17.44	17.44	17.44	17.44	17.44	17.44	0.00
HERCULES	12 208.39	29.09	24.52	24.52	24.52	24.52	25.44	24.52	1.83
LAUDIUM	935.04	7.96	7.96	7.96	7.96	7.96	7.96	7.96	0.00
LYTTELTON	17 110.65	88.04	88.04	87.92	87.82	87.82	87.93	87.92	0.10
MABOPANE	3 964.88	17.75	17.75	17.75	17.75	17.75	17.75	17.75	0.00
MAMELODI	5 317.05	13.90	13.90	13.90	13.90	13.90	13.90	13.90	0.00
PRETORIA MOOT	1 189.47	61.63	61.63	61.63	61.63	61.63	61.63	61.63	0.00
PRETORIA NORTH	15 623.57	52.69	52.49	52.49	52.49	52.49	52.53	52.49	0.08
PRETORIA WEST	8 619.55	164.19	164.19	164.19	164.19	164.19	164.19	164.19	0.00
PRETORIA CENTRAL	3 956.11	363.98	359.68	359.68	359.68	359.68	360.54	359.68	1.72
RIETGAT	9 758.61	7.84	7.84	7.84	7.84	7.84	7.84	7.84	0.00
SILVERTON	6 023.89	22.70	22.70	22.70	22.70	22.70	22.70	22.70	0.00
SINOVILLE	10 419.07	372.49	372.49	363.00	363.00	363.00	366.80	363.00	4.65
SUNNYSIDE	1 969.14	61.80	61.80	61.80	61.80	61.80	61.80	61.80	0.00
TEMBA	27 090.98	24.50	24.49	24.49	24.49	24.49	24.49	24.49	0.00
VILLIERIA	2 766.14	50.66	50.66	50.66	50.66	50.66	50.66	50.66	0.00
WIERDABRUG	16 760.06	15.77	15.77	15.77	15.77	15.77	15.77	15.77	0.00
WONDERBOOMPOORT	1 216.74	49.03	48.97	48.97	48.97	48.97	48.98	48.97	0.02

Table 4.3: Industrial land use class area coverage per police precinct area

		1994	1996	1998	2000	2002	MEAN	MEDIAN	STD DevP
COMPNT_NM	**Precinct_Hectares**	**Ind_Hectares**	**Ind_Hectares**	**Ind_Hectares**	**Ind_Hectares**	**Ind_Hectares**			
AKASIA	18 508.53	985.58	1 001.72	1 006.49	1 006.49	1 012.32	1 002.52	1 006.49	9.11
ATTERIDGEVILLE	3 927.22	24.45	24.45	24.45	24.45	24.45	24.45	24.45	0.00
BROOKLYN	20 946.73	39.77	39.77	39.77	39.77	39.77	39.77	39.77	0.00
EERSTERUST	887.13	87.91	87.91	87.91	87.91	87.91	87.91	87.91	0.00
ERASMIA	20 946.73	342.05	346.13	354.02	368.57	379.31	358.02	354.02	13.98
GA-RANKUWA	11 165.43	240.65	240.65	240.65	240.65	240.65	240.65	240.65	0.00
GARSFONTEIN	5 456.95	80.45	80.45	80.45	80.45	80.45	80.45	80.45	0.00
HAMMANSKRAAL	56 402.53	8.01	8.01	8.01	8.01	8.01	8.01	8.01	0.00
HERCULES	12 208.39	304.64	304.64	304.64	304.64	304.64	304.64	304.64	0.00
LAUDIUM	935.04	34.77	34.77	34.77	34.77	34.77	34.77	34.77	0.00
LYTTELTON	17 110.65	988.73	988.73	988.73	988.73	1 010.52	993.09	988.73	8.71
MABOPANE	3 964.88	45.04	45.04	45.04	45.04	45.04	45.04	45.04	0.00
MAMELODI	5 317.05	50.73	50.73	50.73	50.73	50.73	50.73	50.73	0.00
PRETORIA NORTH	15 623.57	532.67	532.67	540.47	540.47	540.47	537.35	540.47	3.82
PRETORIA WEST	8 619.55	1 543.82	1 543.82	1 543.82	1 543.82	1 543.82	1 543.82	1 543.82	0.00
PRETORIA CENTRAL	3 956.11	538.08	538.08	538.08	538.08	538.08	538.08	538.08	0.00
RIETGAT	9 758.61	14.58	14.58	14.58	14.28	14.28	14.46	14.58	0.15
SILVERTON	6 023.89	597.10	597.10	597.10	597.10	597.10	597.10	597.10	0.00
SINOVILLE	10 419.07	136.27	136.27	136.27	136.27	136.27	136.27	136.27	0.00

SOSHANGUVE	6 150.06	8.52	8.52	8.52	8.52	8.52	8.52	8.52	0.00
TEMBA	27 090.98	212.10	212.10	212.10	212.10	212.10	212.10	212.10	0.00
VILLIERIA	2 766.14	139.75	139.75	139.75	139.75	139.75	139.75	139.75	0.00
WIERDABRUG	16 760.06	491.97	491.97	491.97	523.66	523.66	504.65	491.97	15.53
WONDERBOOMPOORT	1 216.74	168.98	168.98	168.98	168.98	168.98	168.98	168.98	0.00

Table 4.4: Informal land use class area coverage per police precinct area

		1994	1996	1998	2000	2002	MEAN	MEDIAN	STD DevP
COMPNT_NM	**Precinct_Hectares**	**Inf_Hectares**	**Inf_Hectares**	**Inf_Hectares**	**Inf_Hectares**	**Inf_Hectares**			
AKASIA	18 508.53	279.91	463.93	803.76	918.99	956.83	684.68	803.76	266.73
ATTERIDGEVILLE	3 927.22	42.76	161.35	235.06	287.22	377.49	220.77	235.06	113.49
DUBE	8 498.66	1 362.49	1 393.99	1 393.99	1 393.99	1 393.99	1 387.69	1 393.99	12.60
GA-RANKUWA	11 165.43	112.50	112.50	138.38	138.40	138.40	128.03	138.38	12.68
HAMMANSKRAAL	56 402.53	124.15	133.95	133.95	133.95	355.62	176.32	133.95	89.73
LAUDIUM	935.04	0.00	0.00	0.00	0.20	0.20	0.20	0.20	0.00
LOATE	2 653.85	2 035.47	2 050.34	2 050.34	2 050.34	2 050.34	2 047.37	2 050.34	5.95
MABOPANE	3 964.88	1 368.70	1 515.87	1 515.87	1 515.87	1 515.21	1 486.30	1 515.87	58.80
MAMELODI	5 317.05	161.32	430.84	618.02	707.85	797.48	543.10	618.02	226.19
PRETORIA NORTH	15 623.57	0.00	0.00	0.00	21.83	21.83	21.83	21.83	0.00
RIETGAT	9 758.61	2 248.71	2 475.45	2 940.10	2 950.61	2 950.61	2 713.10	2 940.10	295.46
SOSHANGUVE	6 150.06	158.46	189.74	202.74	205.33	205.33	192.32	202.74	17.89
TEMBA	27 090.98	4 191.52	4 301.35	4 425.84	4 565.05	4 588.44	4 414.44	4 425.84	152.03
WIERDABRUG	16 760.06	0.00	0.00	0.00	31.68	31.68	31.68	31.68	0.00

Table 4.5: Residential high-density land use class area coverage per police precinct area

		1994	1996	1998	2000	2002	MEAN	MEDIAN	STD DevP
COMPNT_NM	**Precinct_Hectares**	**Hd_Hectares**	**Hd_Hectares**	**Hd_Hectares**	**Hd_Hectares**	**Hd_Hectares**			
AKASIA	18 508.53	723.07	904.29	1 044.04	1 105.48	1 116.41	978.66	1 044.04	148.45
ATTERIDGEVILLE	3 927.22	753.86	785.82	876.38	889.99	889.99	839.21	876.38	57.75
BROOKLYN	20 946.73	2 740.19	2 757.02	2 757.02	2 818.02	2 819.81	2 778.41	2 757.02	33.64
EERSTERUST	887.13	325.50	325.50	325.50	325.50	325.50	325.50	325.50	0.00
ERASMIA	20 946.73	216.63	216.63	216.63	238.40	238.40	225.34	216.63	10.67
GA-RANKUWA	11 165.43	1 232.00	1 231.02	1 231.02	1 250.32	1 250.32	1 238.94	1 232.00	9.30
GARSFONTEIN	5 456.95	2 250.28	2 507.70	2 601.26	2 792.01	3 007.40	2 631.73	2 601.26	256.37
HAMMANSKRAAL	56 402.53	84.78	84.78	98.72	101.60	101.60	94.30	98.72	7.84
HERCULES	12 208.39	1 087.99	1 121.82	1 121.84	1 121.84	1 121.84	1 115.07	1 121.84	13.54
LAUDIUM	935.04	306.96	315.06	315.06	315.06	315.06	313.44	315.06	3.24
LYTTELTON	17 110.65	1 954.36	1 997.62	2 183.57	2 377.90	2 434.00	2 189.49	2 183.57	193.60
MABOPANE	3 964.88	824.24	885.34	968.89	975.99	1 050.45	940.98	968.89	78.38
MAMELODI	5 317.05	1 273.32	1 342.31	1 432.40	1 465.19	1 465.19	1 395.68	1 432.40	75.94
PRETORIA MOOT	1 189.47	891.99	891.99	891.99	891.99	891.99	891.99	891.99	0.00
PRETORIA NORTH	15 623.57	856.77	856.77	858.20	858.20	872.26	860.44	858.20	5.95
PRETORIA WEST	8 619.55	763.43	826.59	905.45	953.62	983.41	886.50	905.45	81.23
PRETORIA CENTRAL	3 956.11	139.15	139.15	139.15	139.15	139.15	139.15	139.15	0.00
RIETGAT	9 758.61	1 231.40	1 231.40	1 231.40	1 231.40	1 231.40	1 231.40	1 231.40	0.00
SILVERTON	6 023.89	839.30	891.97	984.65	1 151.49	1 177.42	1 008.97	984.65	135.47

SINOVILLE	10 419.07	1 101.72	1 151.40	1 253.01	1 299.83	1 362.97	1 233.78	1 253.01	95.55
SOSHANGUVE	6 150.06	841.78	948.92	948.92	948.92	948.92	927.49	948.92	42.86
SUNNYSIDE	1 969.14	813.81	825.59	825.59	835.82	835.82	827.33	825.59	8.16
TEMBA	27 090.98	734.44	787.79	787.79	787.79	920.58	803.68	787.79	62.00
VILLIERIA	2 766.14	1 717.96	1 732.07	1 750.03	1 754.22	1 760.67	1 742.99	1 750.03	15.71
WIERDABRUG	16 760.06	2 419.78	2 481.30	2 546.96	2 728.97	3 041.79	2 643.76	2 546.96	224.33
WONDERBOOMPOORT	1 216.74	584.28	587.62	587.62	587.62	587.62	586.95	587.62	1.34

Table 4.6: Residential low-density land use class area coverage per police precinct area

		1994	1996	1998	2000	2002	MEAN	MEDIAN	STD DevP
COMPNT_NM	**Precinct_Hectares**	**Ld_Hectares**	**Ld_Hectares**	**Ld_Hectares**	**Ld_Hectares**	**Ld_Hectares**			
AKASIA	18 508.53	2 297.28	2 244.26	2 244.26	2 244.26	2 244.26	2 254.86	2 244.26	21.21
ATTERIDGEVILLE	3 927.22	99.93	99.93	99.93	99.93	99.93	99.93	99.93	0.00
ERASMIA	20 946.73	2 745.62	2 745.62	2 745.62	2 745.62	2 745.62	2 745.62	2 745.62	0.00
GARSFONTEIN	5 456.95	6.50	6.50	6.50	6.50	6.50	6.50	6.50	0.00
HAMMANSKRAAL	56 402.53	6 804.89	6 804.89	6 804.89	6 804.89	6 804.89	6 804.89	6 804.89	0.00
HERCULES	12 208.39	2 726.67	2 720.49	2 720.49	2 720.49	2 720.49	2 721.73	2 720.49	2.47
LYTTELTON	17 110.65	731.08	717.14	674.07	627.52	576.60	665.28	674.07	57.25
PRETORIA NORTH	15 623.57	4 284.39	4 284.39	4 284.39	4 284.39	4 284.39	4 284.39	4 284.39	0.00
PRETORIA WEST	8 619.55	507.52	507.52	507.52	507.52	507.52	507.52	507.52	0.00
PRETORIA CENTRAL	3 956.11	0.00	23.92	23.92	23.92	23.92	19.13	23.92	9.57
SILVERTON	6 023.89	657.47	657.47	657.47	643.57	640.55	651.31	657.47	7.61
SINOVILLE	10 419.07	2 014.11	2 030.74	1 979.57	1 979.57	1 954.74	1 991.74	1 979.57	27.15
SOSHANGUVE	6 150.06	253.51	253.51	253.51	253.51	253.51	253.51	253.51	0.00
TEMBA	27 090.98	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00
WIERDABRUG	16 760.06	3 107.14	3 107.14	3 091.10	3 079.75	3 079.75	3 092.97	3 091.10	12.29

4.5.2.1 Commercial land use class

The highest concentration of commercial activities can be seen in the central areas of Tshwane. The percentage coverage of commercial activities are evident in the following police precinct areas:

- Pretoria Central (9%)
- Pretoria Moot (5%)
- Wonderboompoort (4%)
- Sinoville (3%)
- Brooklyn (3%)
- Sunnyside (3%).

The classification of the large commercial shopping areas highlights an interesting phenomenon, namely a decrease in land coverage with regard to the Hercules (-15.7%) and Sinoville (-2%) areas. The Hammanskraal, Temba, Lyttelton and Garsfontein police precinct areas indicated a small decrease of 0% to -2%. The conclusion of commercial growth from 1994 to 2002 indicates that no major growth with regard to new large commercial shopping centrums was established (see figure 4.16).

4.5.2.2 Industrial land use class

The highest concentration of industrial activities was recorded in the central and western areas of Tshwane. The percentage coverage of the industrial class within the police precinct is listed as follows:

- Pretoria West (18%)
- Pretoria Central (13%)
- Wonderboompoort (13%)
- Silverton (9%)
- Eersterust (9%)
- Akasia (5%)

The growth pattern from 1994 to 2002 illustrates high industrial growth in Erasmia (10%), Wierdabrug (6%), Akasia (2%), Lyttelton (2%) and Pretoria North (1.5%). A slight decrease of industrial activities was evident in Rietgat (-2%). The highest concentration of growth in Tshwane is in the southern part (see figure 4.17). The result of industrial growth is employment opportunities and the socio-economical impact on the surrounding environment. This growth pattern will be analysed against geo-coded crime data to determine whether any relationship between industrial growth and crime can be verified. Figure 4.25 illustrates that moderate to low crime incidents were recorded over the predominantly industrial area of Pretoria West, yet high crime incidents were recorded in Pretoria Central. The correlation between industrial areas and crime is difficult to establish because of the small coverage of the class in the total Tshwane area.

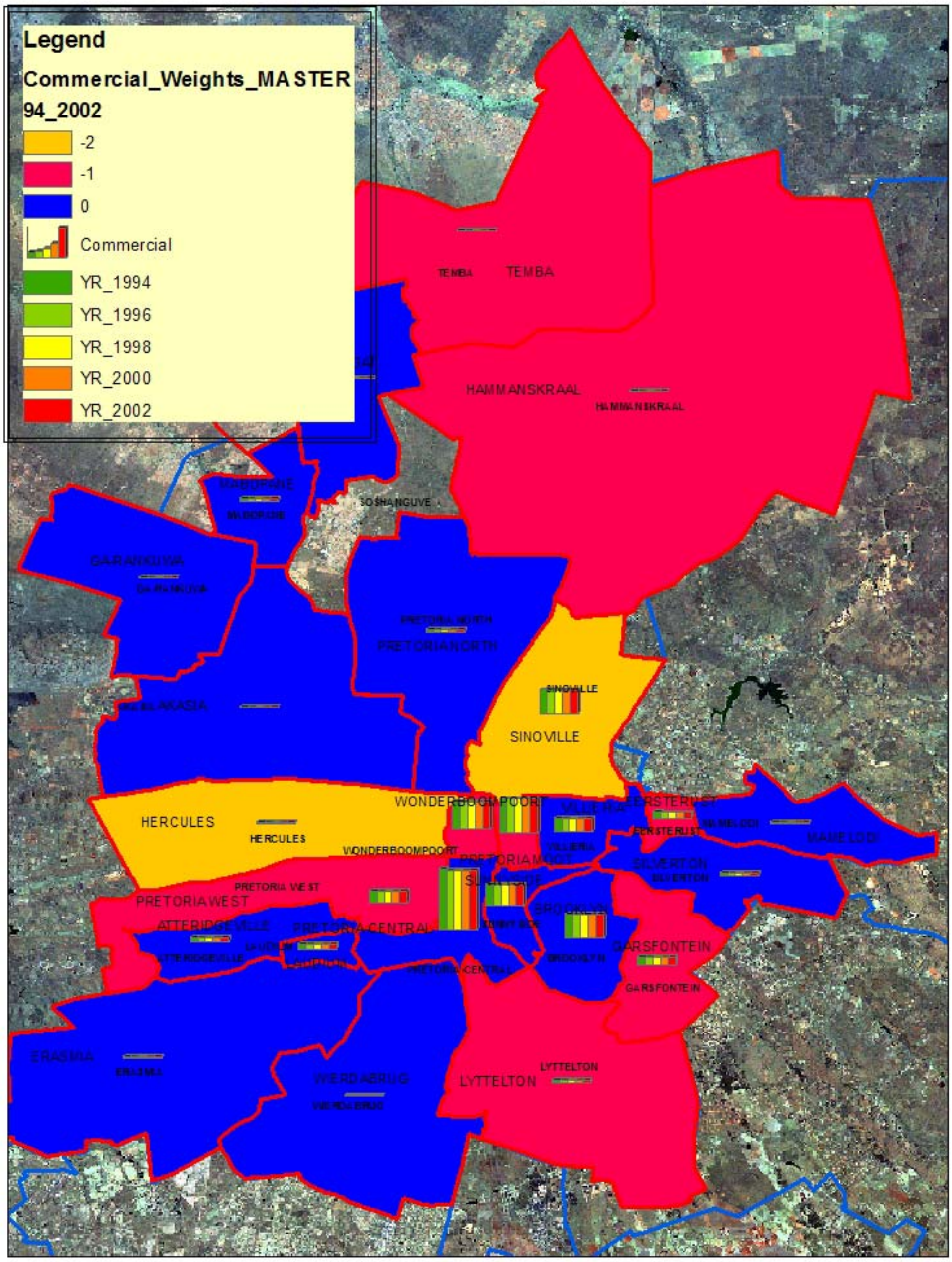


Figure 4.16: Commercial class changes and percentage class coverage

Weights	-2	-2% to -20%	Large decrease
	-1	0% to -2%	Small decrease
	0	No change	No change
	1	0% to 2%	Small increase
	2	2% to 20%	Large increase

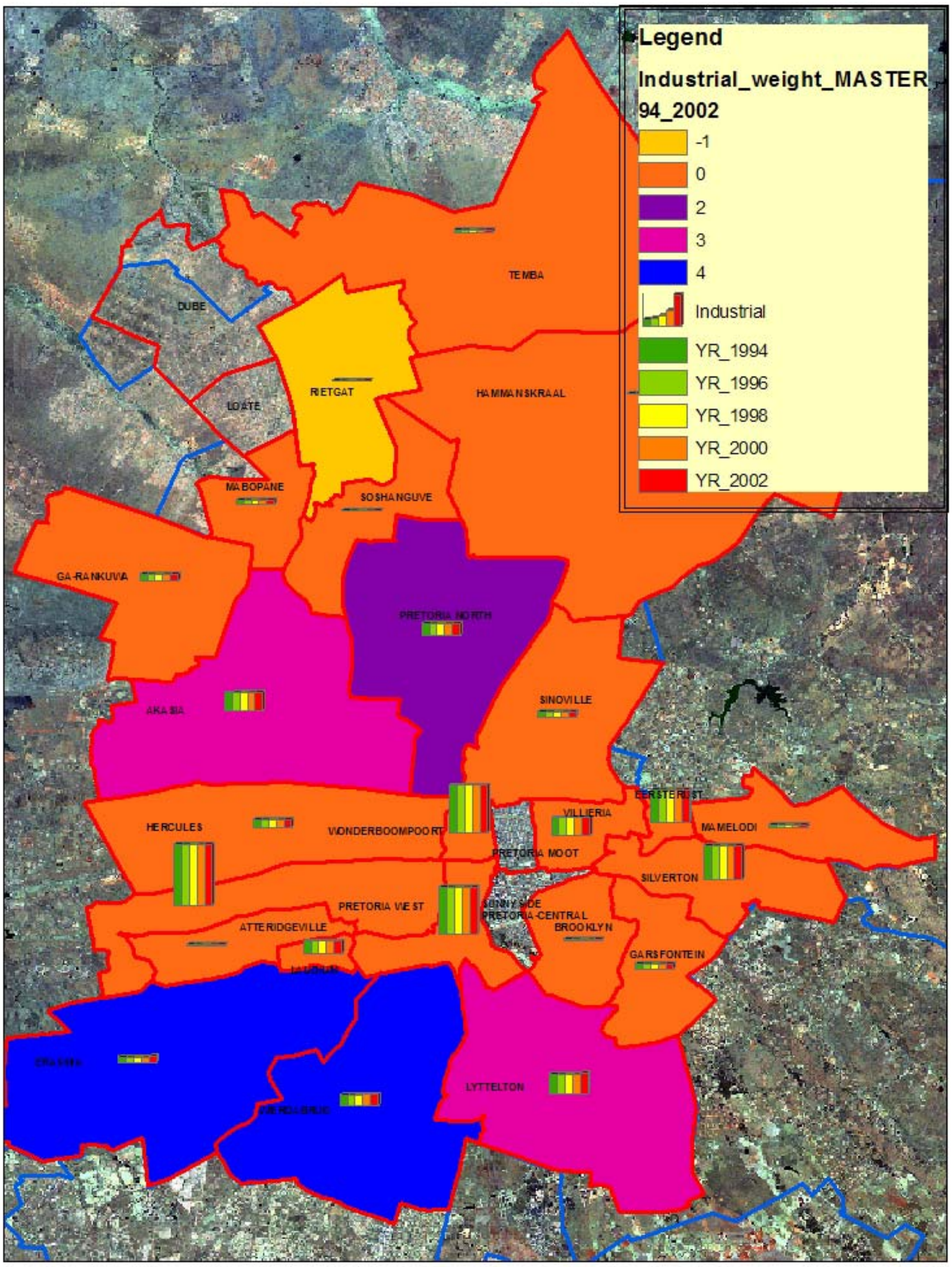


Figure 4.17: Industrial class changes and percentage class coverage

Weights	-1	-0.01% to -5%	Small decrease
	0	No change	No change
	1	0.01% to 1%	Small increase
	2	1.1% to 2%	Moderate increase
	3	2.1% to 5%	High increase
	4	5.1% to 12%	Very high increase

4.5.2.3 Informal land use class

The growth of informal settlement areas and their relation to crime is a focus area of this project. The highest concentration of informal areas is evident in the northern areas of Tshwane. The percentage coverage of informal settlements in specific police precinct areas is as follow:

- Loate (77%)
- Mabopane (38%)
- Rietgat (30%)
- Temba (17%)
- Dube (16%)
- Mamelodi (15%)
- Atteridgeville (9%)
- Akasia (5%)
- Soshanguve (3%)

The highest growth in informal settlement areas was recorded in Mamelodi and Atteridgeville with a growth between 301% to 800% respectively for the period 1994 to 2002. Growth of 201% to 300% was recorded in Akasia and 101% to 200% in the Hammanskraal police precinct area. A small growth of 0,01% to 50% was recorded in the north-western parts of Tshwane. The peripheral growth of informal settlement areas is a serious concern despite the high densification of population in the most of these areas. There is concern regarding high unemployment and the lack of basic municipal services such as water, electricity and sanitation facilities. Socio-economical conditions in these areas differ from those in the residential low and high-density classes and different crime types that dominate these areas will be revealed. The spatial analysis for this class is illustrated in figures 4.18 and 4.24.

A survey by a private company, FutureFact, focused on a multi-dimensional research project, a joint venture between researchers, planners, analysts and futurists (Hoets 2004:20). FutureFact's aim is to make the connection, on a wide variety of issues (from HIV/Aids, unemployment, crime, land distribution, to lifestyle and media), between national and international statistics, the views of experts and opinion leaders and its own surveys of people's attitudes and beliefs (Hoets 2004:4). In 2001, 49% of South Africans were living in poverty. Those most affected were Africans and residents of Eastern Cape and Limpopo provinces. In relative terms the Western Cape and Gauteng were the most prosperous. In 2004 research on poverty revealed that 39% of South African households were rural, and 93% of rural households were black (Hoets 2004:23). The biggest socio-economic problems facing South Africa are (Hoets 2004:24):

- HIV/Aids
- Crime
- Unemployment
- Rape
- Drug abuse
- Poverty
- Child/ women abuse
- HIV/AIDS Orphans
- Housing shortage
- Poor standard of health care and education.

FutureFact believes that South Africans inhabit and move between many worlds and that we have been able to maintain our diversity and cultural identity while embracing a South African identity. Rural South Africans are increasingly living in a global world, a world that is growing incrementally as they acquire electricity, radio, television and cellular phone reception, as better roads bring transport and easier access to larger local areas for banking, shopping, business and work opportunities and as more people learn to speak English (Hoets 2004:64).

Hopefully the social security grant allocated per annum (R166 billion over three years) to alleviate poverty will be better managed and will have a positive impact on the social conditions of the very poor. Unemployment and poverty do have a direct link to crime, and crime will decrease if those individuals involved are rehabilitated into a sustainable social-economic infrastructure.

4.5.2.4 Residential high-density class

The highest concentration of high-density residential classes is evident in the south-eastern part of Tshwane. The high-density residential areas are primarily located in the following police precinct areas as sown by the percentage coverages:

- Pretoria Moot (75%)
- Villieria (64%)
- Garsfontein (55%)
- Wonderboompoort (48%)
- Sunnyside (42%)
- Eersterust (37%)

The highest growth in high-density residential areas from 1994 to 2002 was in Akasia (54%), Silverton (40%), Garsfontein (34%), Pretoria West (29%), Mabopane (28%), Wierdabrug (26%), Temba (25%), Lyttelton (24%) and Sinoville (24%). Densification of residential areas in the Tshwane area is clear evidence of the population growth in this area. The spatial analysis for this class is illustrated by figures 4.19 and 4.22.

4.5.2.5 Residential low-density class

The highest concentration of low-density residential classes is evident in the central part of Tshwane. The low-density residential areas are primarily located in the following police precinct areas as shown by the percentage coverages:

- Pretoria North (27%)
- Hercules (22%)
- Sinoville (19%)
- Wierdabrug (18%)

- Erasmia (13%)
- Akasia (12%)
- Hammanskraal (12%)

No low-density residential area growth was recorded. A decrease in this class was evident and in some areas such as Lyttelton as much as -21% was recorded. The decreased areas in this class from 1994 to 2002 are Lyttelton (-21%), Sinoville (-3%), Silverton (-3%), Akasia (-3%), Wierdabrug (-1%). The reverse effect of the decrease of low-density into a rapid increase in high-density land use classes is an indicator of the overall densification of the Tshwane area. The population and socio-economic growth in Tshwane over the years and its relation to crime is discussed later in this chapter. The spatial analysis of this class is illustrated by figures 4.20 and 4.23.

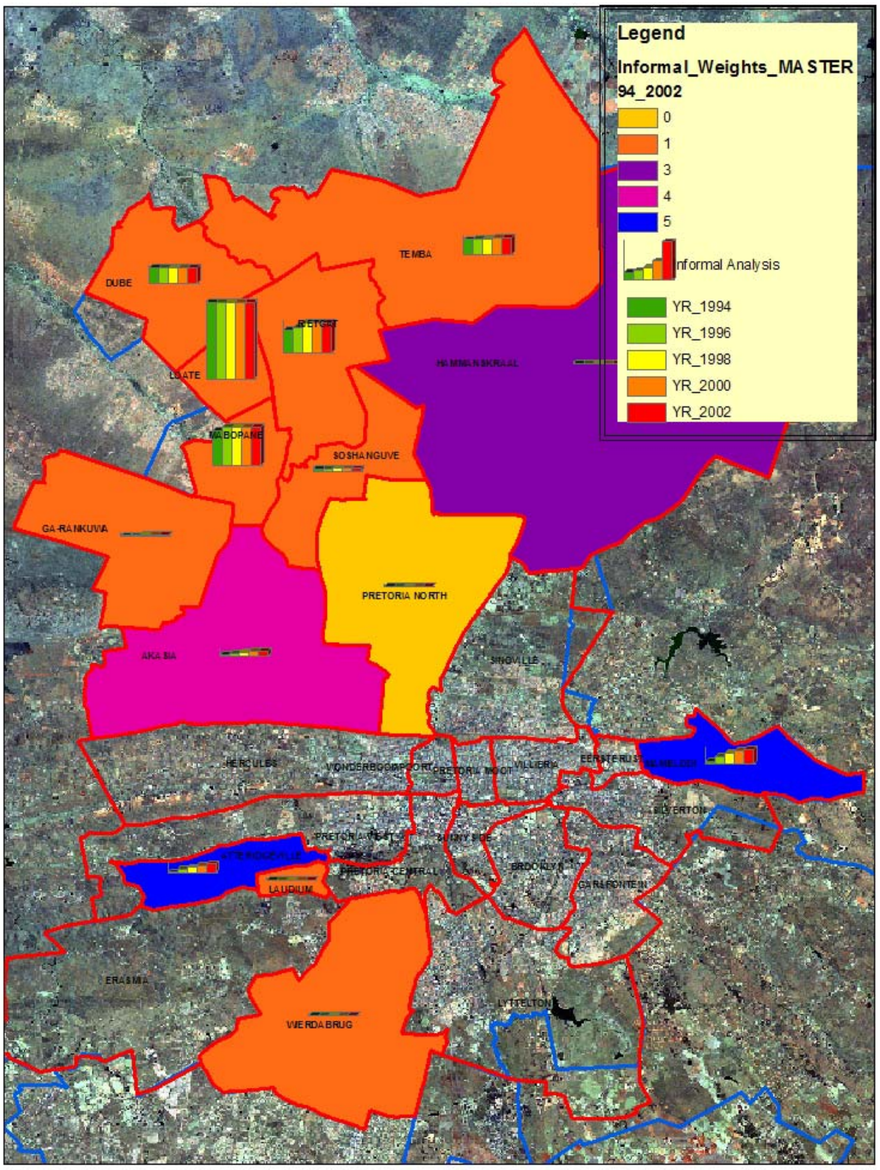


Figure 4.18: Informal class changes and percentage class coverage

Weights	-1	-0.01% to -10%	Small decrease
	0	No change	No change
	1	0.01% to 50%	Small increase
	2	51% to 100%	Moderate increase
	3	101% to 200%	High increase
	4	201% to 300%	Very high increase
	5	301% to 800%	Extreme increase

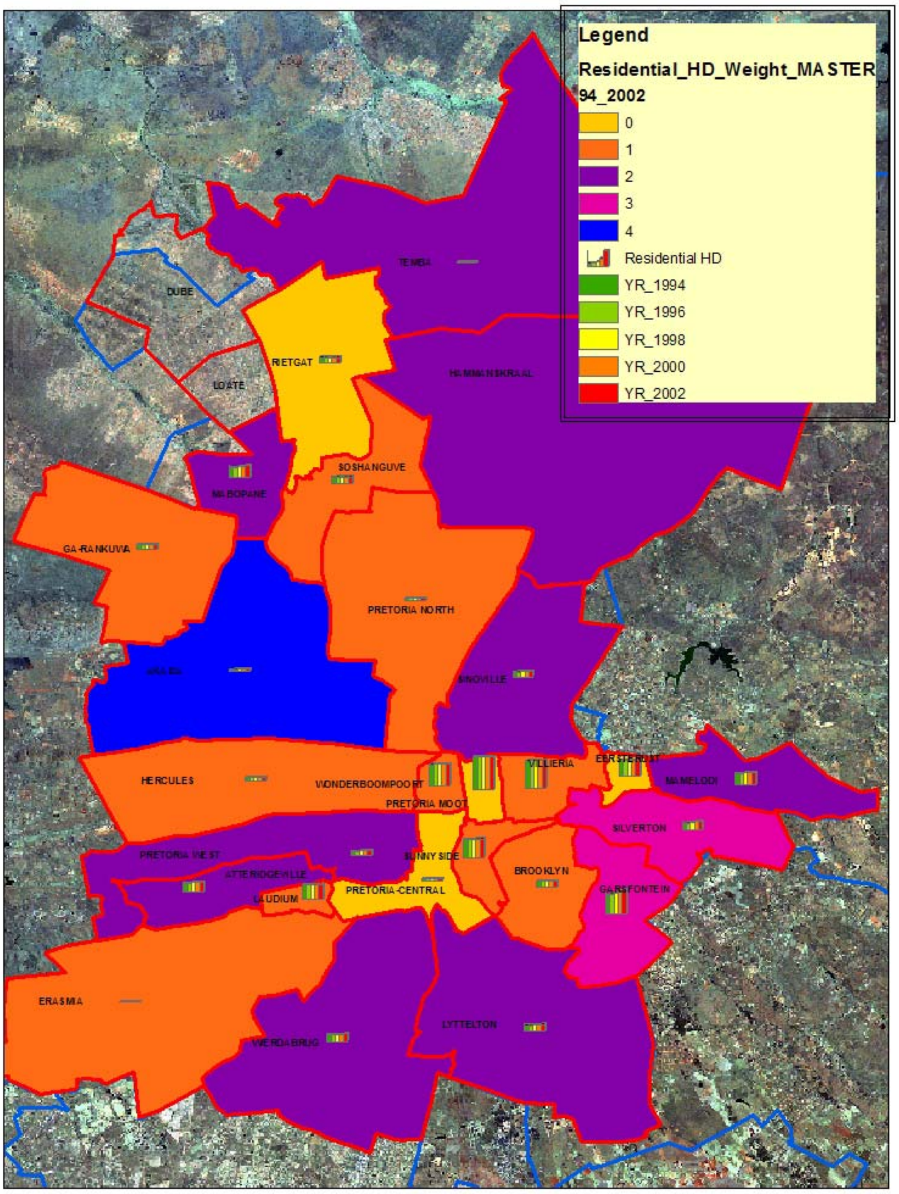


Figure 4.19: Residential high-density class changes and percentage class coverage

Weight	-1	-0.01% to -5%	Small decrease
	0	No hange	No change
	1	0.01% to 15%	Small increase
	2	16% to 30%	Moderate increase
	3	31% to 45%	High increase
	4	46% to 60%	Very high increase

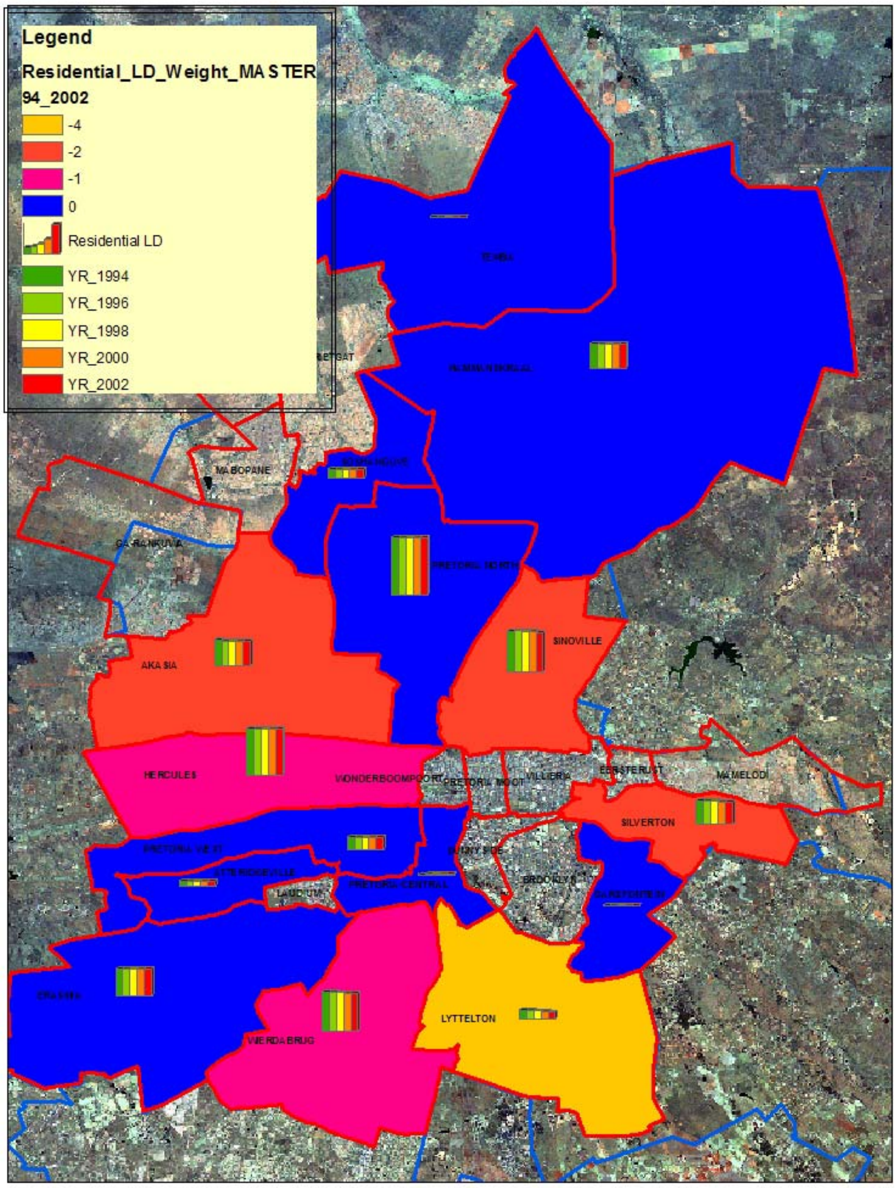


Figure 4.20: Residential low-density class changes and percentage class coverage

Weight	-4	-11% to -25%	Very high decrease
	-3	-5% to 10%	High decrease
	-2	-2% to 4%	Moderate decrease
	-1	-0.01% to -1.99%	Small decrease
	0	No change	No change
	1	0.01% to 2%	Small increase

4.6 MICRO ANALYSIS RESULTS

4.6.1 Consolidated micro analysis

The difference in numbers between the housing structures (formal houses, smallholdings, informal) and townhouse units in 2003 and 2004 is reflected in table 4.7 below and figure 4.21. The concentrations of growth occur in the eastern and western areas of Tshwane.

Table 4.7: The difference in numbers between housing structures (formal houses, smallholdings, informal) and townhouse units in 2003 and 2004

Police Precinct	Total 2003	Total 2004	Total Diff
AKASIA	35 205	37 633	2 428
ATTERIDGEVILLE	37 127	40 814	3 687
BROOKLYN	18 325	18 427	102
DUBE	4 256	4 271	15
EERSTERUST	4 946	4 950	4
ERASMIA	10 075	10 399	324
GA-RANKUWA	19 253	19 254	1
GARSFONTEIN	31 569	33 352	1 783
HAMMANSKRAAL	9 957	10 086	129
HERCULES	11 891	12 033	142
LAUDIUM	10 288	10 546	258
LOATE	8 862	8 793	-69
LYTTELTON	26 474	27 970	1 496
MABOPANE	34 854	35 006	152
MAMELODI	69 021	79 928	10 907
PRETORIA MOOT	7 320	7 357	37
PRETORIA NORTH	8 670	8 683	13
PRETORIA WEST	10 135	14 082	3 947
PRETORIA CENTRAL	3 344	3 342	-2
RIETGAT	51 178	51 070	-108
SILVERTON	15 147	16 192	1 045
SINOVILLE	15 092	16 048	956
SOSHANGUVE	28 769	30 942	2 173
SUNNYSIDE	5 714	5 705	-9

TEMBA	39 466	39 586	120
VILLIERIA	12 613	12 757	144
WIERDABRUG	40 773	43 019	2 246
WONDERBOOMPOORT	6 123	6 125	2

The Mamelodi, Pretoria West and Atteridgeville police precincts show the highest overall growth from 2003 to 2004. The highest counts of land use activities were recorded in the Mamelodi, Rietgat, Wierdabrug, Temba, Atteridgeville, Akasia, Mabopane, Garsfontein, Soshanguve and Lyttelton. Extreme growth was evident in the Mamelodi police precinct, within which more than 10 782 new units occurred, primarily informal dwellings.

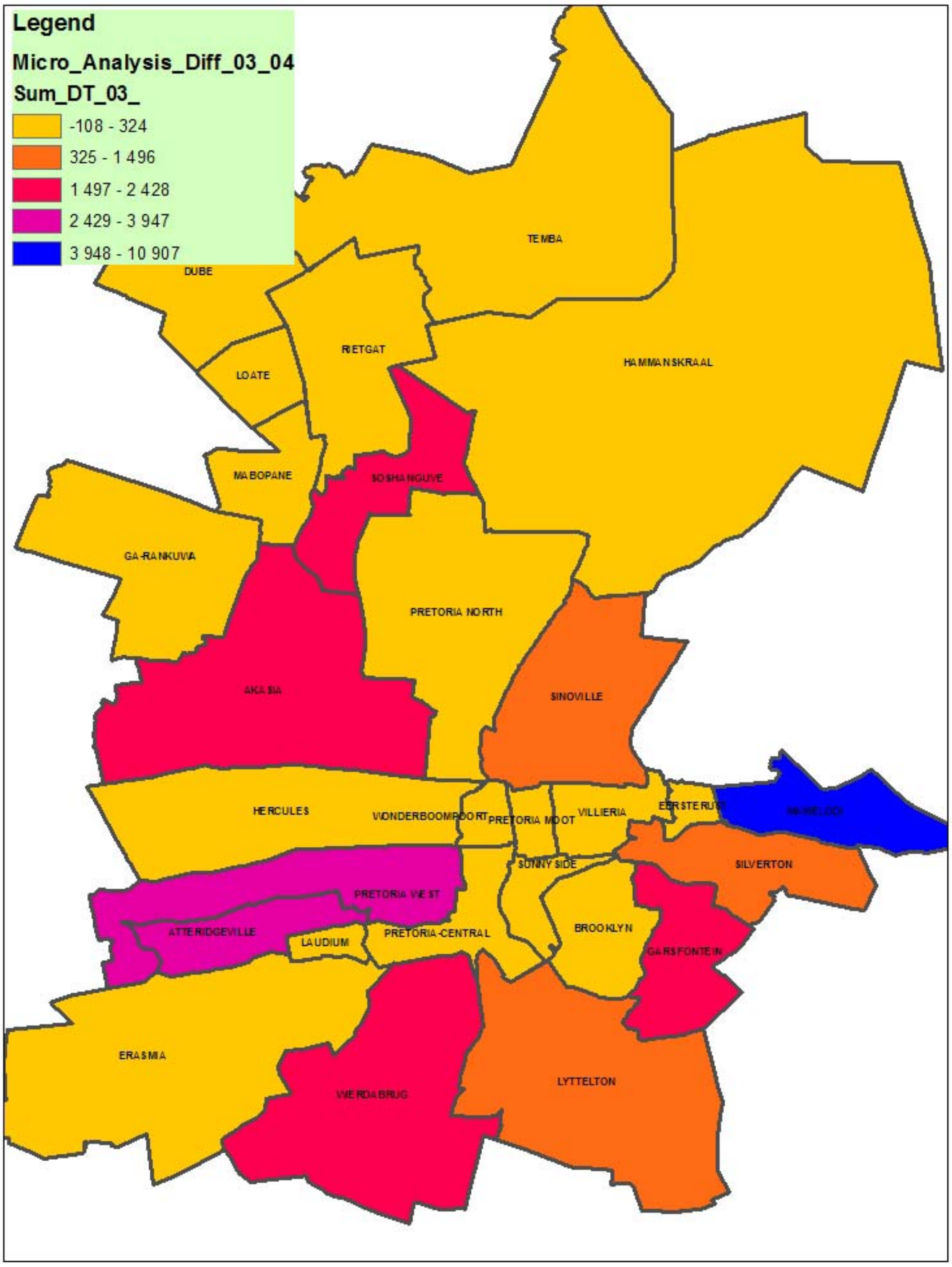


Figure 4.21: Spatial illustration of difference in numbers between housing structures (formal houses, smallholdings, informal) and townhouse units in 2003 and 2004

4.6.2 High-density houses

The difference in numbers between formal houses (high density) in 2003 and 2004 are given in table 4.8 and figure 4.22. The western and southern parts of Tshwane show the highest concentration of high-density house growth. Pretoria West and Atteridgeville are the highest followed by Wierdabrug and Lyttelton police precincts. The highest concentrations of this land use class were recorded in Mamelodi, Wierdabrug, Atteridgevllle, Garsfontein and Lyttelton as the top five police precinct areas. New houses recorded in the Pretoria West and Atteridgeville areas exceed 3 000 units, and the areas therefore show extreme growth and property development activities.

Table 4.8: The difference in numbers between formal houses (high density) in 2003 and 2004

Police Precinct	HD Houses 2003	HD Houses 2004	Diff HD
AKASIA	11 825	11 975	150
ATTERIDGEVILLE	19 784	23 217	3 433
BROOKLYN	14 112	14 144	32
DUBE	13	14	1
EERSTERUST	4 925	4 929	4
ERASMIA	3 579	3 624	45
GA-RANKUWA	14 032	14 033	1
GARSFONTEIN	19 627	20 007	380
HAMMANSKRAAL	988	1 102	114
HERCULES	10 142	10 251	109
LAUDIUM	4 950	4 953	3
LOATE	1 242	1 297	55
LYTTELTON	15 764	16 472	708
MABOPANE	15 701	15 855	154
MAMELODI	47 152	47 277	125
PRETORIA MOOT	6 497	6 534	37
PRETORIA NORTH	6 289	6 326	37
PRETORIA WEST	9 435	13 398	3 963
PRETORIA CENTRAL	3 290	3 290	0

RIETGAT	15 236	15 235	-1
SILVERTON	11 964	11 997	33
SINOVILLE	11 413	11 787	374
SOSHANGUVE	14 792	14 792	0
SUNNYSIDE	4 722	4 713	-9
TEMBA	8 981	9 096	115
VILLIERIA	11 563	11 639	76
WIERDABRUG	28 512	29 463	951
WONDERBOOMPOORT	5 587	5 589	2

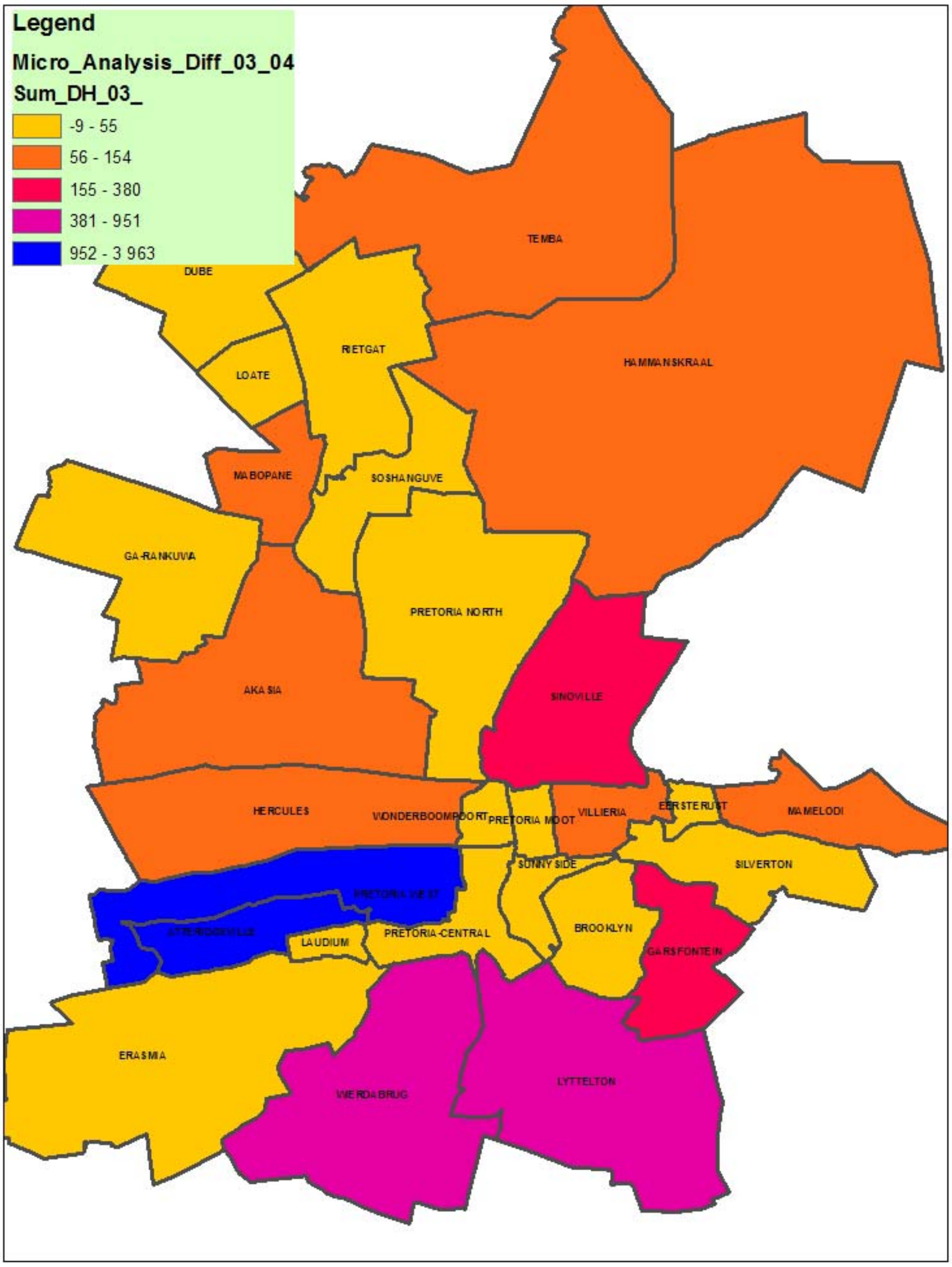


Figure 4.22: Spatial illustration of difference in numbers between formal houses (high density) in 2003 and 2004

4.6.3 Low-density houses

The difference in numbers between formal houses (low density) in 2003 and 2004 are given in table 4.9 and figure 4.23. The northern and southern parts of Tshwane show the highest concentration of low-density house growth. Lyttelton and Erasmia have the highest growth in the southern area, followed by the Akasia, Sinoville, Pretoria North and Hammanskraal police precincts in the north. The highest concentrations of this land use class were recorded in Pretoria North, Hercules, Akasia, Wierdabrug and Hammanskraal as the top five police precinct areas. The highest count for new houses recorded was in the Lyttelton area (25). The overall conclusion is that the number count of low-density house growth is very low in the Tshwane area compared to high-density house growth.

Table 4.9: The difference in numbers between formal houses (low density) in 2003 and 2004

Police Precinct	LD Houses 2003	LD Houses 2004	LD Diff
AKASIA	1 252	1 260	8
ATTERIDGEVILLE	295	297	2
BROOKLYN	19	19	0
DUBE	1	1	0
EERSTERUST	10	10	0
ERASMIA	1 038	1 048	10
GA-RANKUWA	154	154	0
GARSFONTEIN	235	218	-17
HAMMANSKRAAL	1 154	1 166	12
HERCULES	1 295	1 296	1
LAUDIUM	54	55	1
LOATE	0	0	0
LYTTELTON	346	371	25
MABOPANE	0	0	0
MAMELODI	5	5	0
PRETORIA MOOT	1	1	0
PRETORIA NORTH	1 385	1 393	8
PRETORIA WEST	433	434	1

PRETORIA CENTRAL	23	21	-2
RIETGAT	71	71	0
SILVERTON	243	228	-15
SINOVILLE	1 128	1 136	8
SOSHANGUVE	521	524	3
SUNNYSIDE	14	14	0
TEMBA	104	104	0
VILLIERIA	18	18	0
WIERDABRUG	1 207	1 210	3
WONDERBOOMPOORT	1	1	0

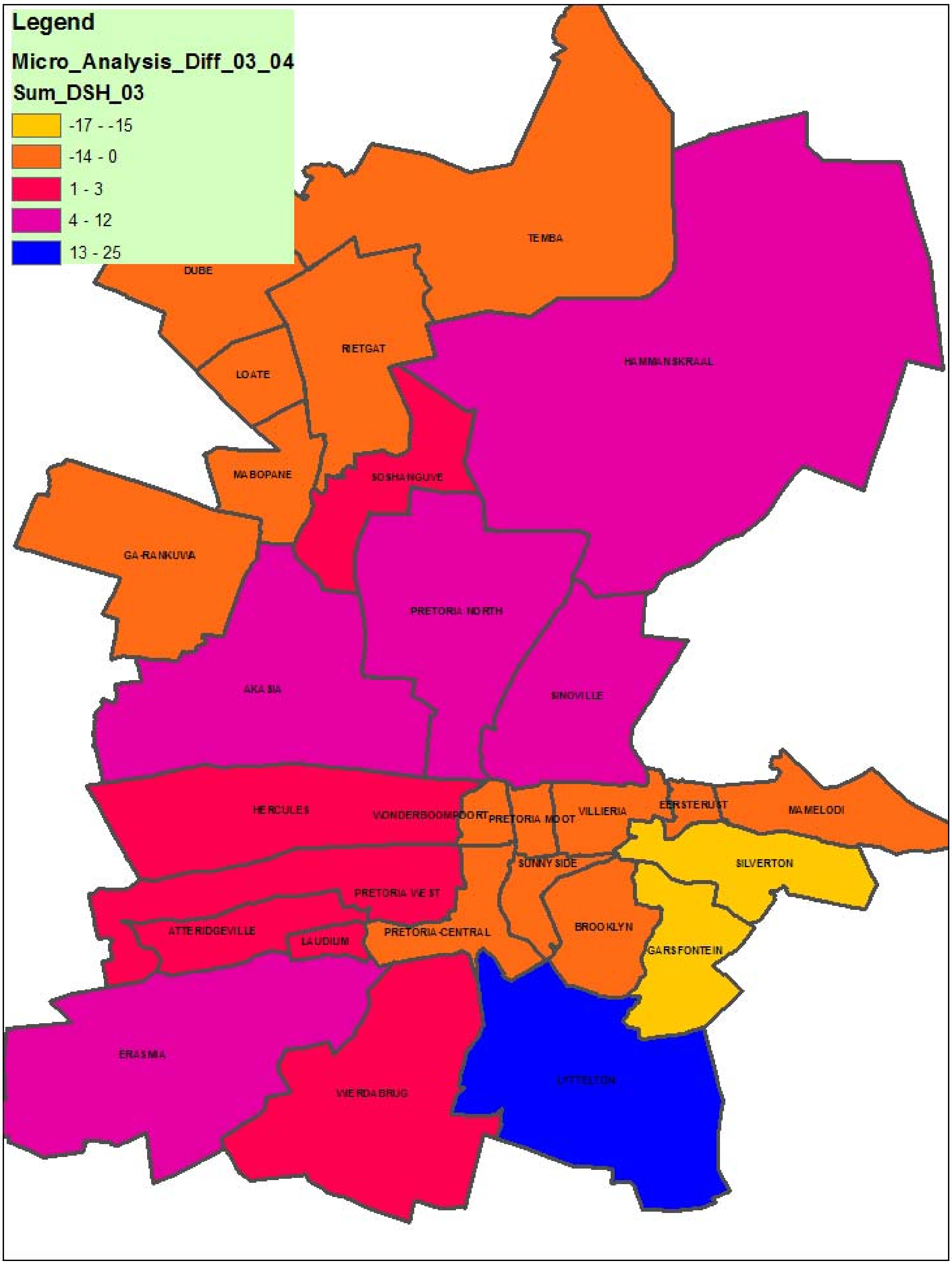


Figure 4.23: Spatial illustration of difference in numbers between formal houses (low density) in 2003 and 2004

4.6.4 Informal settlement areas

The difference in numbers between informal settlement areas in 2003 and 2004 are given in table 4.10 and figure 4.24. The eastern and western parts of Tshwane show the highest concentration of informal settlement growth. The highest concentrations of this land use class were recorded in Rietgat, Temba, Mamelodi, Akasia and Mabopane as the top five police precinct areas. The highest count for new informal dwellings was in the Mamelodi area (10 782), Akasia (2 195) and Soshanguve (2 170). Informal settlement growth is very large in specific police precinct areas as also revealed by the macro study in section 4.5.2.3.

Table 4.10: The difference in numbers between informal settlement areas in 2003 and 2004

Police Precinct	Informal 03	Informal 04	Informal Diff
AKASIA	21 161	23 356	2 195
ATTERIDGEVILLE	17 048	17 300	252
BROOKLYN	0	0	0
DUBE	4 242	4 256	14
EERSTERUST	0	0	0
ERASMIA	5 277	5 532	255
GA-RANKUWA	5 067	5 067	0
GARSFONTEIN	0	0	0
HAMMANSKRAAL	7 815	7 818	3
HERCULES	3	3	0
LAUDIUM	5 242	5 496	254
LOATE	7 620	7 496	-124
LYTTELTON	0	0	0
MABOPANE	19 153	19 151	-2
MAMELODI	21 864	32 646	10 782
PRETORIA MOOT	0	0	0
PRETORIA NORTH	265	233	-32
PRETORIA WEST	60	43	-17
PRETORIA CENTRAL	0	0	0
RIETGAT	35 871	35 764	-107
SILVERTON	0	0	0

SINOVILLE	0	0	0
SOSHANGUVE	13 456	15 626	2 170
SUNNYSIDE	0	0	0
TEMBA	30 381	30 386	5
VILLIERIA	0	0	0
WIERDABRUG	4 495	4 985	490
WONDERBOOMPOORT	0	0	0

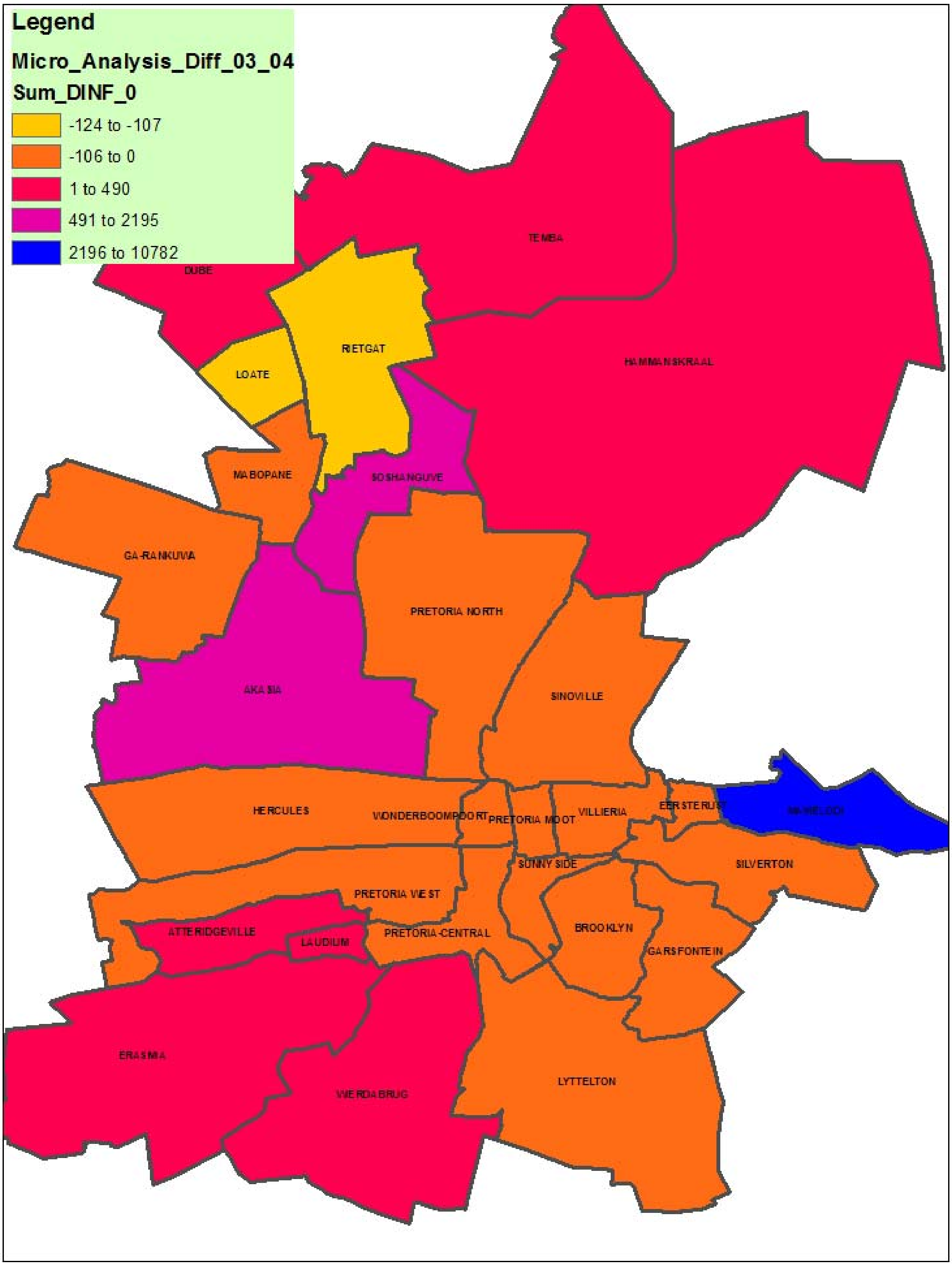


Figure 4.24: Spatial illustration of difference in numbers between informal settlement areas in 2003 and 2004

4.7 CRIME ANALYSIS

4.7.1 Crime incidents

The crime analysis was based on 28 police precinct areas. The crime incidents were calculated based on geo-coded crime with geodetic spatial reference and represent the priority crime types as defined by the 46 categories of the codes of the SAPS Daily Statistics for Serious Crime (DSSC). The geo-coded data used in this study represent the calendar years 2002 to 2004. The 46 categories of serious crime types are given in table 4.11. The green colour-coded fields illustrate the crime types selected for this study to prove the spatial analysis concept which can be applied to any of the other fields.

Table 4.11: DSSC crime codes as per SAPS Business Intelligence System

DSSC_CLASS_NR	CLASSIFICATION_DESCR
1	(DSSC01) MURDER
2	(DSSC02) ATTEMPTED MURDER
3	(DSSC03) CULPABLE HOMICIDE
4	(DSSC04) ROBBERY AGGRAVATING
5	(DSSC05) PUBLIC VIOLENCE
6	(DSSC06) RAPE
7	(DSSC07) INDECENT ASSAULT
8	(DSSC08) CRIMEN INJURIA
9	(DSSC09) CHILD ABUSE
10	(DSSC10) KIDNAPPING
11	(DSSC11) ABDUCTION
12	(DSSC12) ASSAULT GBH
13	(DSSC13) ASSAULT COMMON
14	(DSSC14) BURGLARY (EXCLUDING RESIDENTIAL PREMISES)
15	(DSSC15) BURGLARY (HOUSES)
16	(DSSC16) THEFT OF ALL STOCK
17	(DSSC17) SHOPLIFTING
18	(DSSC18) THEFT OF MOTOR VEHICLE AND MOTOR CYCLE
19	(DSSC19) THEFT OF/FROM MOTOR VEHICLE
20	(DSSC20) THEFT (OTHER)

21	(DSSC21) ARSON
22	(DSSC22) MALICIOUS DAMAGE TO PROPERTY
23	(DSSC23) FRAUD
24	(DSSC24) DRUG-RELATED CRIME
25	(DSSC25) DRIVING UNDER THE INFLUENCE OF ALCOHOL OR DRUGS
26	(DSSC26) ILLEGAL POSSESSION OF FIREARMS AND AMMUNITION + 490024
27	(DSSC27) CAR JACKING *
28	(DSSC28) TRUCK HIJACKING *
29	(DSSC29) ROBBERY CASH IN TRANSIT *
30	(DSSC30) BANK ROBBERIES *
31	(DSSC31) HOUSE ROBBERY *
32	(DSSC32) BUSINESS ROBBERY *
33	(DSSC33) ATTEMPTED ROBBERY: AGGRAVATED: WITH FIRE-ARMS
34	(DSSC34) COMMON ROBBERY
35	(DSSC35) ATTEMPTED COMMON ROBBERY
36	(DSSC36) FARM MURDER *
37	(DSSC37) ATTEMPTED RAPE
38	(DSSC38) ATTEMPTED BURGLARIES (BUSINESS)
39	(DSSC39) ATTEMPTED BURGLARIES (HOUSES)
40	(DSSC40) ATTEMPTED THEFT OF MOTOR VEHICLE AND MOTOR CYCLE
41	(DSSC41) ATTEMPTED THEFT FROM/OF MOTOR VEHICLE
42	(DSSC42) ATTEMPTED THEFT (OTHER)
43	(DSSC43) ATTEMPTED BUSINESS ROBBERY
44	(DSSC44) EXPLOSIVES ACT
45	(DSSC45) ATTEMPTED HOUSE ROBBERIES
46	(DSSC46) ROBBERY WITH WEAPON OTHER THAN FIREARM
47	(DSSC47) OTHER OFFENCES RELATED TO LIVESTOCK, POULTRY AND BIRDS

Table 4.12: Crime incidents as per geo-coded crime recorded for 28 police precincts areas covering the Tshwane municipality boundary

POLICE_ST	YR02	YR03	YR04
AKASIA	6071	7 084	6 950
ATTERIDGEVILLE	7 723	7 880	7 090
BROOKLYN	15 027	15 198	13 784
DUBE	9	19	136
EERSTERUST	2 649	3 212	3 126
ERASMIA	1 422	1 440	1 374
GA-RANKUWA	5 289	5 296	4 821
GARSFONTEIN	7 551	7 869	6 915
HAMMANSKRAAL	1 745	1 650	1 848
HERCULES	4 262	4 161	3 743
LAUDIUM	1 608	1 895	1 796
LOATE	4 737	5 141	4 476
LYTTELTON	9 781	10 262	9 846
MABOPANE	3 915	4 776	4 953
MAMELODI	13 429	14 676	12 410
PRETORIA MOOT	3 226	3 391	3 010
PRETORIA NORTH	3 774	4 201	3 808
PRETORIA WEST	7 433	7 357	7 506
PRETORIA CENTRAL	21 533	21 942	19 406
RIETGAT	7 172	7 209	7 008
SILVERTON	5 855	6 152	6 167
SINOVILLE	3 462	4 615	4 652
SOSHANGUVE	4 803	4 834	3 890
SUNNYSIDE	14 622	15 334	13 894
TEMBA	7 068	10 196	9 781
VILLIERIA	4 430	4 542	4 394
WIERDABRUG	7 160	7 539	8 139
WONDERBOOMPOORT	2 454	2 779	2 871

Table 4.13: Crime incident growth table from 2002 to 2004 per police precinct area

GROWTH %				
POLICE_ST	**YR02**	**YR03**	**YR04**	**YR02_04**
AKASIA	6 071	16.69%	-1.89%	14.48%
ATTERIDGEVILLE	7 723	2.03%	-10.03%	-8.20%
BROOKLYN	15 027	1.14%	-9.30%	-8.27%
DUBE	9	111.11%	615.79%	1 411.11%
EERSTERUST	2 649	21.25%	-2.68%	18.01%
ERASMIA	1 422	1.27%	-4.58%	-3.38%
GA-RANKUWA	5 289	0.13%	-8.97%	-8.85%
GARSFONTEIN	7 551	4.21%	-12.12%	-8.42%
HAMMANSKRAAL	1 745	-5.44%	12.00%	5.90%
HERCULES	4 262	-2.37%	-10.05%	-12.18%
LAUDIUM	1 608	17.85%	-5.22%	11.69%
LOATE	4 737	8.53%	-12.94%	-5.51%
LYTTELTON	9 781	4.92%	-4.05%	0.66%
MABOPANE	3 915	21.99%	3.71%	26.51%
MAMELODI	13 429	9.29%	-15.44%	-7.59%
PRETORIA MOOT	3 226	5.11%	-11.24%	-6.70%
PRETORIA NORTH	3 774	11.31%	-9.35%	0.90%
PRETORIA WEST	7 433	-1.02%	2.03%	0.98%
PRETORIA CENTRAL	21 533	1.90%	-11.56%	-9.88%
RIETGAT	7 172	0.52%	-2.79%	-2.29%
SILVERTON	5 855	5.07%	0.24%	5.33%
SINOVILLE	3 462	33.30%	0.80%	34.37%
SOSHANGUVE	4 803	0.65%	-19.53%	-19.01%
SUNNYSIDE	14 622	4.87%	-9.39%	-4.98%
TEMBA	7 068	44.26%	-4.07%	38.38%
VILLIERIA	4 430	2.53%	-3.26%	-0.81%
WIERDABRUG	7 160	5.29%	7.96%	13.67%
WONDERBOOMPOORT	2 454	13.24%	3.31%	16.99%

Table 4.13 illustrates the year-on-year growth or decline in crime in a specific police precinct area. The growth or decline in crime had to be interpreted within the context of the quantity of crime. Dube had a very large increase in crime: from 2002 to 2004 it experienced a 1 411.11% growth, i.e. from 9 to

136 incidents. Although the growth is high, the number of incidents compared to the surrounding police precinct areas is very low. This study focuses more on the spatial distribution of crime and the nature of spatial change taking place in each police precinct as opposed to pure statistical analysis.

Table 4.14: Crime incidents divided by hectare coverage per police precinct

POLICE_ST	Hectares	YR02	YR03	YR04	MEAN
AKASIA	18 508.53	32.80%	38.27%	37.55%	36.21%
ATTERIDGEVILLE	3 927.22	196.65%	200.65%	180.53%	192.61%
BROOKLYN	4 531.49	331.61%	335.39%	304.18%	323.73%
DUBE	8 498.66	0.11%	0.22%	1.60%	0.64%
EERSTERUST	887.13	298.60%	362.06%	352.37%	337.68%
ERASMIA	20 946.73	6.79%	6.87%	6.56%	6.74%
GA-RANKUWA	11 165.43	47.37%	47.43%	43.18%	45.99%
GARSFONTEIN	5 456.95	138.37%	144.20%	126.72%	136.43%
HAMMANSKRAAL	56 402.53	3.09%	2.93%	3.28%	3.10%
HERCULES	12 208.39	34.91%	34.08%	30.66%	33.22%
LAUDIUM	935.04	171.97%	202.66%	192.08%	188.90%
LOATE	2 653.85	178.50%	193.72%	168.66%	180.29%
LYTTELTON	17 110.65	57.16%	59.97%	57.54%	58.23%
MABOPANE	3 964.88	98.74%	120.46%	124.92%	114.71%
MAMELODI	5 317.05	252.56%	276.02%	233.40%	253.99%
PRETORIA MOOT	1 189.47	271.21%	285.08%	253.05%	269.78%
PRETORIA NORTH	15 623.57	24.16%	26.89%	24.37%	25.14%
PRETORIA WEST	8 619.55	86.23%	85.35%	87.08%	86.22%
PRETORIA CENTRAL	3 956.11	544.30%	554.64%	490.53%	529.82%
RIETGAT	9 758.61	73.49%	73.87%	71.81%	73.06%
SILVERTON	6 023.89	97.20%	102.13%	102.38%	100.57%
SINOVILLE	10 419.07	33.23%	44.29%	44.65%	40.72%
SOSHANGUVE	6 150.06	78.10%	78.60%	63.25%	73.32%
SUNNYSIDE	1 969.14	742.56%	778.71%	705.59%	742.29%
TEMBA	27 090.98	26.09%	37.64%	36.10%	33.28%
VILLIERIA	2 766.14	160.15%	164.20%	158.85%	161.07%
WIERDABRUG	16 760.06	42.72%	44.98%	48.56%	45.42%
WONDERBOOMPOORT	1 216.74	201.69%	228.40%	235.96%	222.01%

Figure 4.25 was created from the mean value given in table 4.14 to illustrate a density ratio. High percentages represent high numbers of crime incidents in a small spatial area. Sunnyside and Pretoria Central are the police precincts with the highest crime density in the Tshwane municipality area. Mamelodi, Brooklyn, Eersterust and Pretoria Moot have the second highest value for crime density.

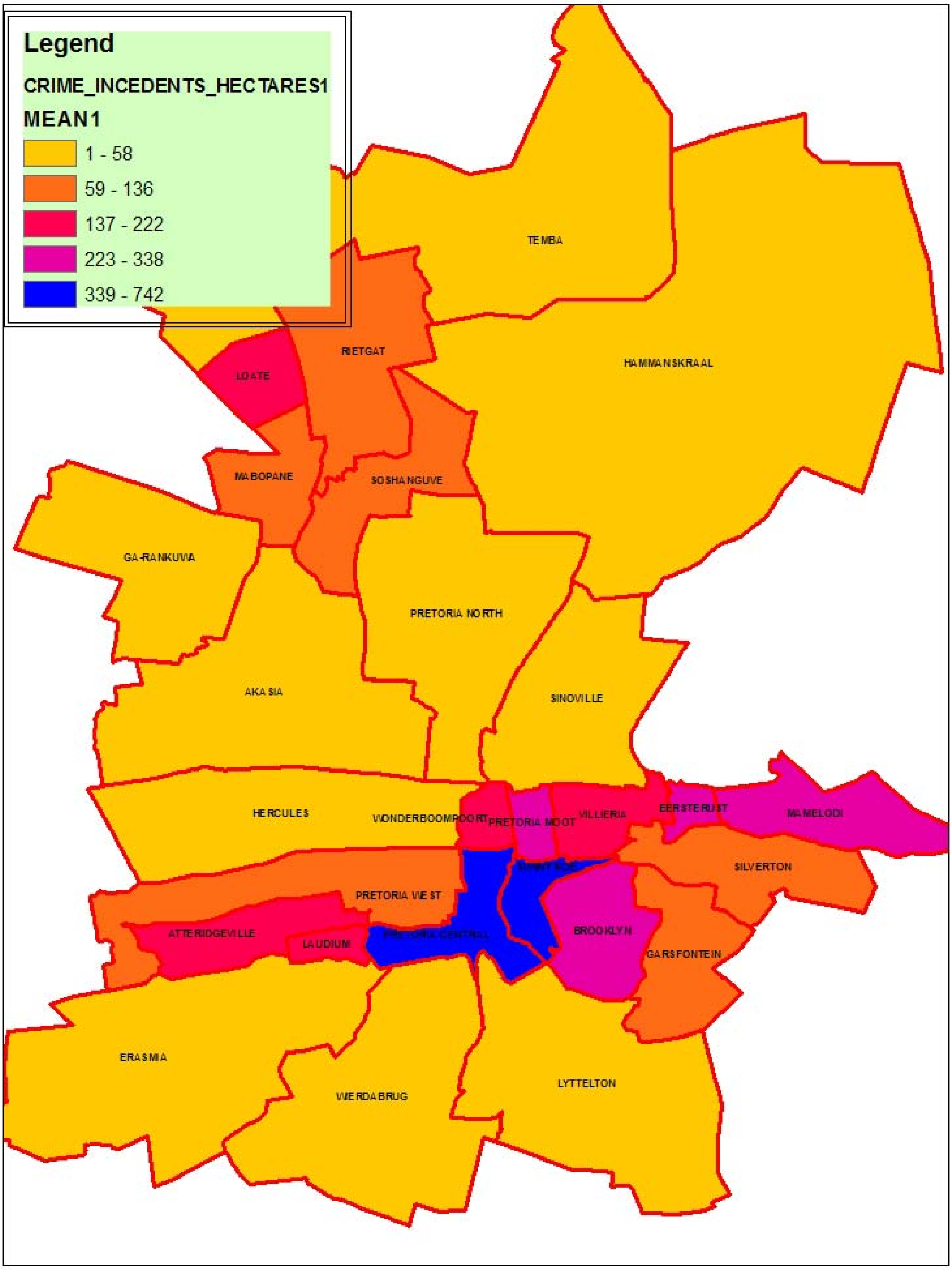


Figure 4.25: Spatial density distribution of crime incidents per police precinct

Figures 4.26 to 4.28 represent the spatial distribution of crime incidents per police precinct area from 2002 to 2004. These colour-coded maps were created from the summarised statistics from the 46 DSSC crime codes. The pattern from 2002 to 2004 indicates very little change except for an increase in the Akasia, Wonderboompoort and Eersterust areas. The highest number of incidents for each year was recorded in the Pretoria Central, Sunnyside, Brooklyn and Mamelodi areas. The high density of crime also corresponds to this result as indicated in figure 4.25.

The fact that the spatial distribution and density patterns of crime did not change rapidly over the three-year analysis period gives rise to concern about the effectiveness of policing methods in these areas. The constant spatial pattern of crime could be a lack of knowledge or insight into the actual crime patterns and the correct policing strategy to prevent specific crime types that differ from police precinct to police precinct. A generic policing strategy cannot be applied within such a diverse area as Tshwane.

Four specific crime types were selected for further spatial analysis because of the availability of data collected from a victimisation survey done by the International Crime Victim Survey (ICVS) in which South Africa participated for the fourth time in 2004 (Prinsloo 2006:1). The ICVS data, analysed quantitatively by the Department of Criminology, UNISA, yielded the following key results:

- The highest levels of fear of crime when at home at night were suffered by respondents who experienced victimisation as a result of burglary and sexual offences. These associations were also confirmed by victims of burglary and sexual offences who were also noticeably more afraid of being alone at night in their neighbourhoods than the other respondents (Prinsloo 2006:8).
- Sexual offences as a general category of victimisation impacted negatively on the lives of 68% of the respondents, who indicated unsafe feelings in their residential areas. Fear of crime in the area

emerged prominently in association with rape and attempted rape (Prinsloo 2006:14).

- Car theft and car hijacking contributed to the second and third highest levels of respondents' concern about crime in their areas (Prinsloo 2006:16).
- Murder is a logical crime type to be selected as loss of life due to criminal behaviour by an offender is a very serious matter.

The gender and socio-economic conditions of the above-mentioned respondents seem to be closely related to their fear and concern about crime. There is more crime in some places than others, coinciding with the fact that the physical environment is different from place to place. The focus here is not only on the psychological dynamics associated with the physical environment manifesting as fear of crime, but also on related social dynamics such as residents' willingness to intervene and on ecological processes such as social and physical incivilities that are perceived to be crime related. The focus of environmental criminology goes beyond mere relations between the physical environment and crime. It is linked to offender-based dynamics and resident-based dynamics and human territorial functioning (Prinsloo 2006:16).

The direct contribution of this study to criminological science is the spatial distribution of human activity in the form of land use classes and their correlation with specific crime types and the dynamics between them. The incivility thesis, also known as the "broken window", "crime and grime" and "decline and disorder" theories, emerged from the human ecology model discussed in detail in chapter 2, sections 2.2.6.1 and 2.2.6.2, as part of the social disorganisation theory cluster. The understanding of crime patterns and their dominance in specific land use classes that are geographically heterogeneous in metropolitan and rural areas will contribute towards better control and proactive formulation of strategies to prevent crime. The discussion in sections 4.7.2 to 4.7.5 focus on murder, burglary, car hijacking and rape and their relationship to specific land use classes.

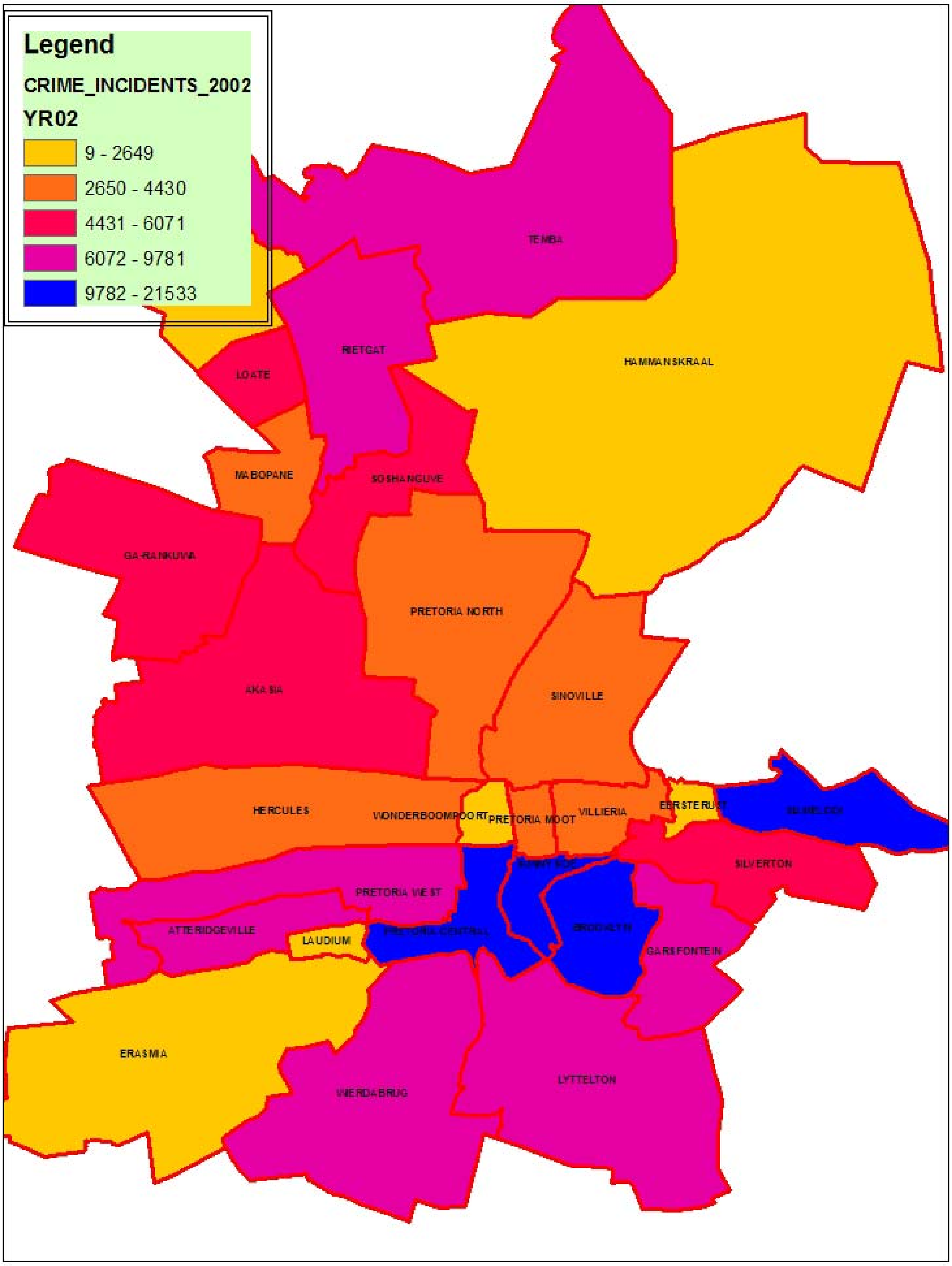


Figure 4.26: Spatial distribution of crime incidents in 2002

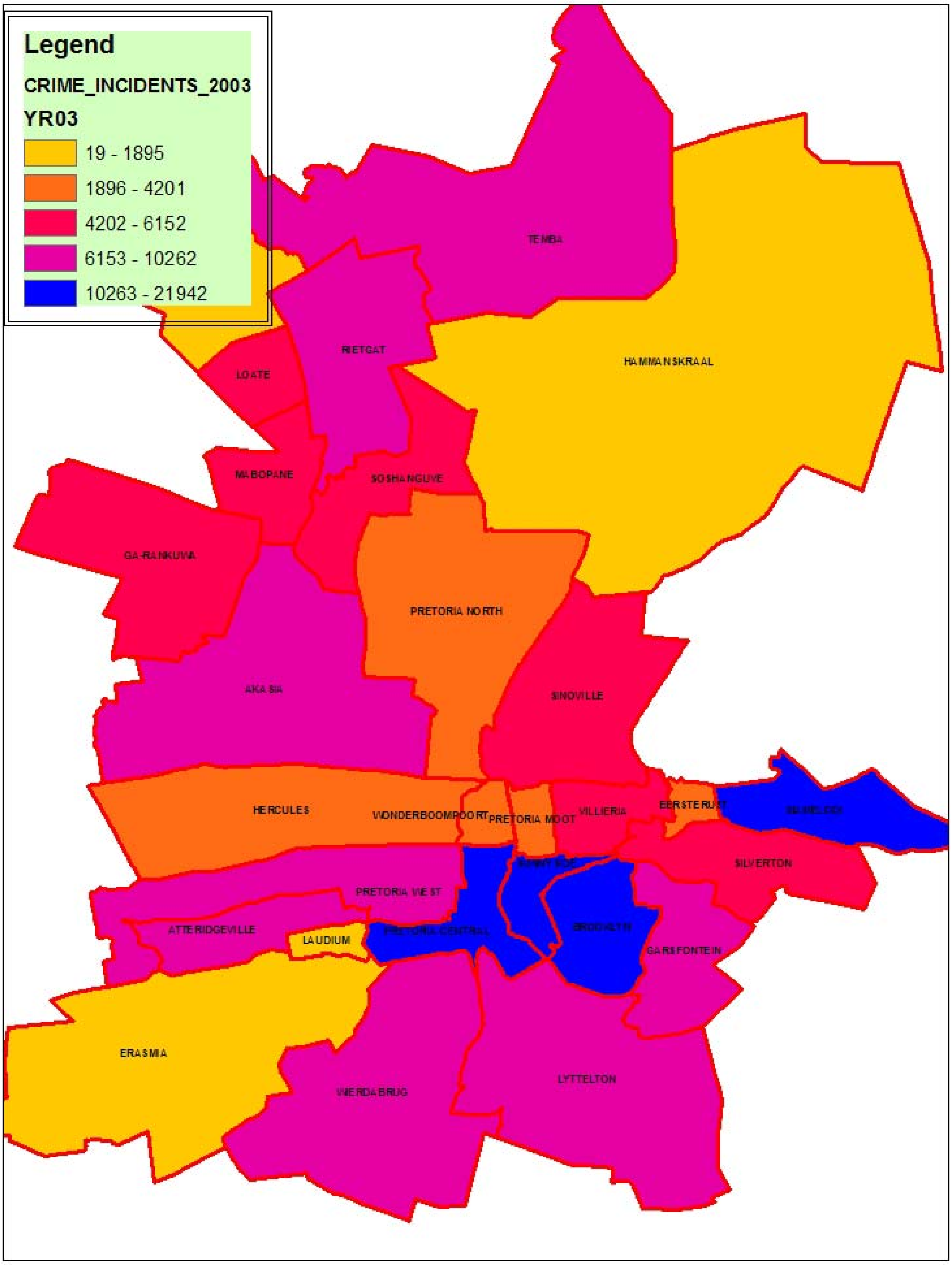


Figure 4.27: Spatial distribution of crime incidents in 2003

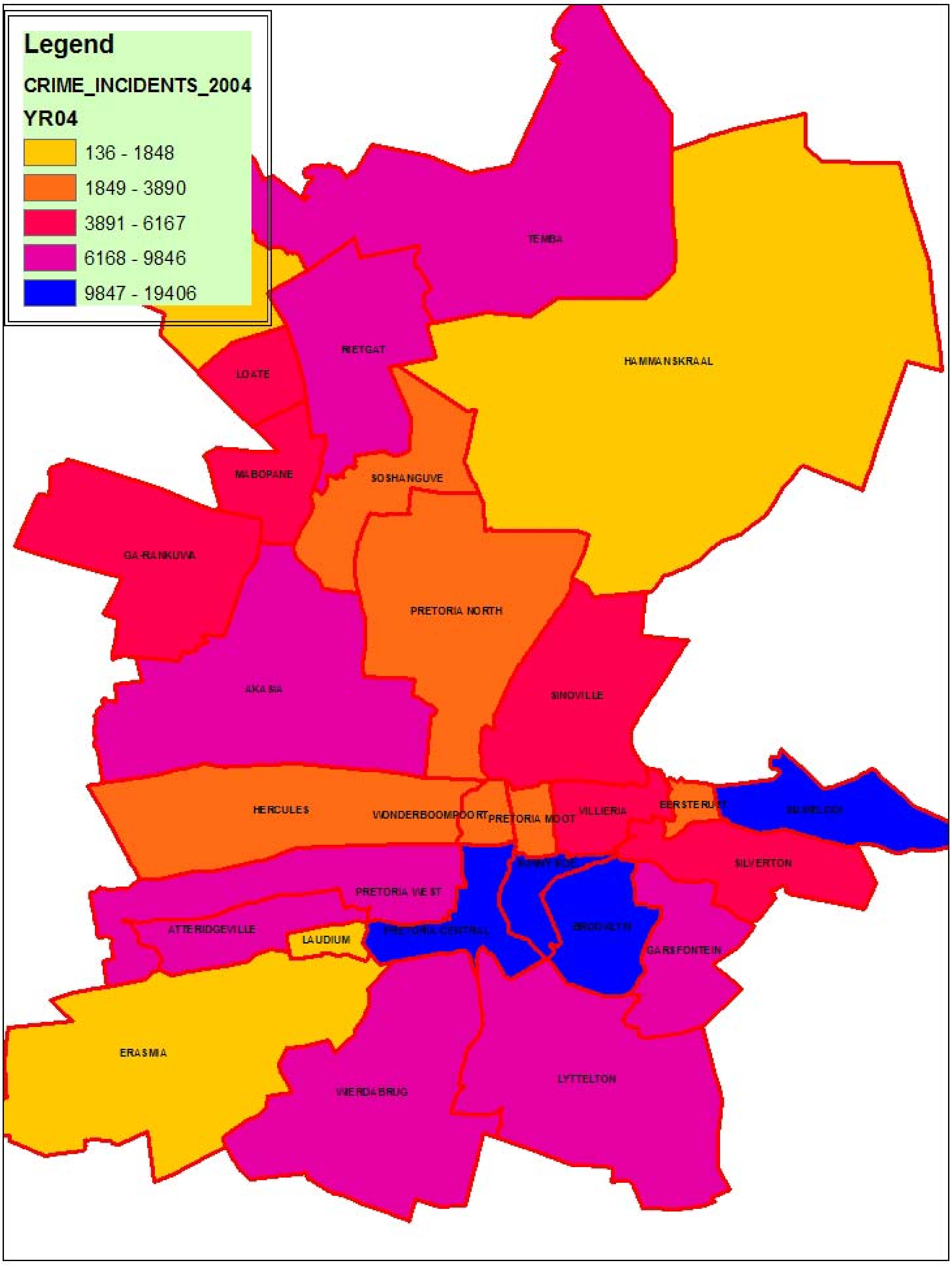


Figure 4.28: Spatial distribution of crime incidents in 2004

4.7.2 Murder incident analysis

A decrease of 14% in murders from 2002 through to 2004 is evident. The spatial distributions of murder are very similar over the years and are dominant in the north-west areas of Tshwane (Loate, Rietgat and Temba). High incidents of murder were also recorded in Mamelodi and Atteridgevile. The dominant land use class in these areas is informal settlement areas as per sections 4.5.2.3 and 4.6.4.

Murder as a crime type has a high spatial correlation with a specific land use class, in this case informal settlement areas. An interesting phenomenon is the decrease in murder in Mamelodi and Atteridgeville despite the high population growth since 1994 as per sections 4.5.2.3 and 4.6.4. Thus, a negative correlation between informal land use class growth and murder in specific areas is evident. Loate consist of 77% informal settlement coverage with less than 50% growth from 1994. This area also experienced a decrease in murder from 53 to 38 incidents as per table 4.15. The opposite is true for Temba, which experienced a murder incident growth from 62 to 78 and then a decrease to 70 in 2004 with only a small land use class growth from 1994. Phenomena such as the latter create opportunities for further qualitative research in these areas to better understand the characteristics of each murder incident and how to prevent murder (see figures 4.29 to 4.31).

Table 4.15: Number of murder incidents per police precinct area

POLICE_ST	YR02	YR03	YR04
AKASIA	28	34	34
ATTERIDGEVILLE	75	49	48
BROOKLYN	10	9	8
DUBE	0	0	1
EERSTERUST	18	13	9
ERASMIA	12	18	11
GA-RANKUWA	41	29	24
GARSFONTEIN	8	7	4
HAMMANSKRAAL	15	6	12
HERCULES	10	10	11
LAUDIUM	6	3	4
LOATE	53	50	38
LYTTELTON	15	14	16
MABOPANE	40	30	38
MAMELODI	124	114	105
PRETORIA MOOT	1	3	2
PRETORIA NORTH	12	14	7
PRETORIA WEST	30	20	23
PRETORIA CENTRAL	28	20	26
RIETGAT	60	53	50
SILVERTON	15	19	16
SINOVILLE	2	7	4
SOSHANGUVE	31	26	22
SUNNYSIDE	17	18	21
TEMBA	62	78	70
VILLIERIA	14	12	7
WIERDABRUG	22	30	30
WONDERBOOMPOORT	4	6	4
	753	**692**	**645**

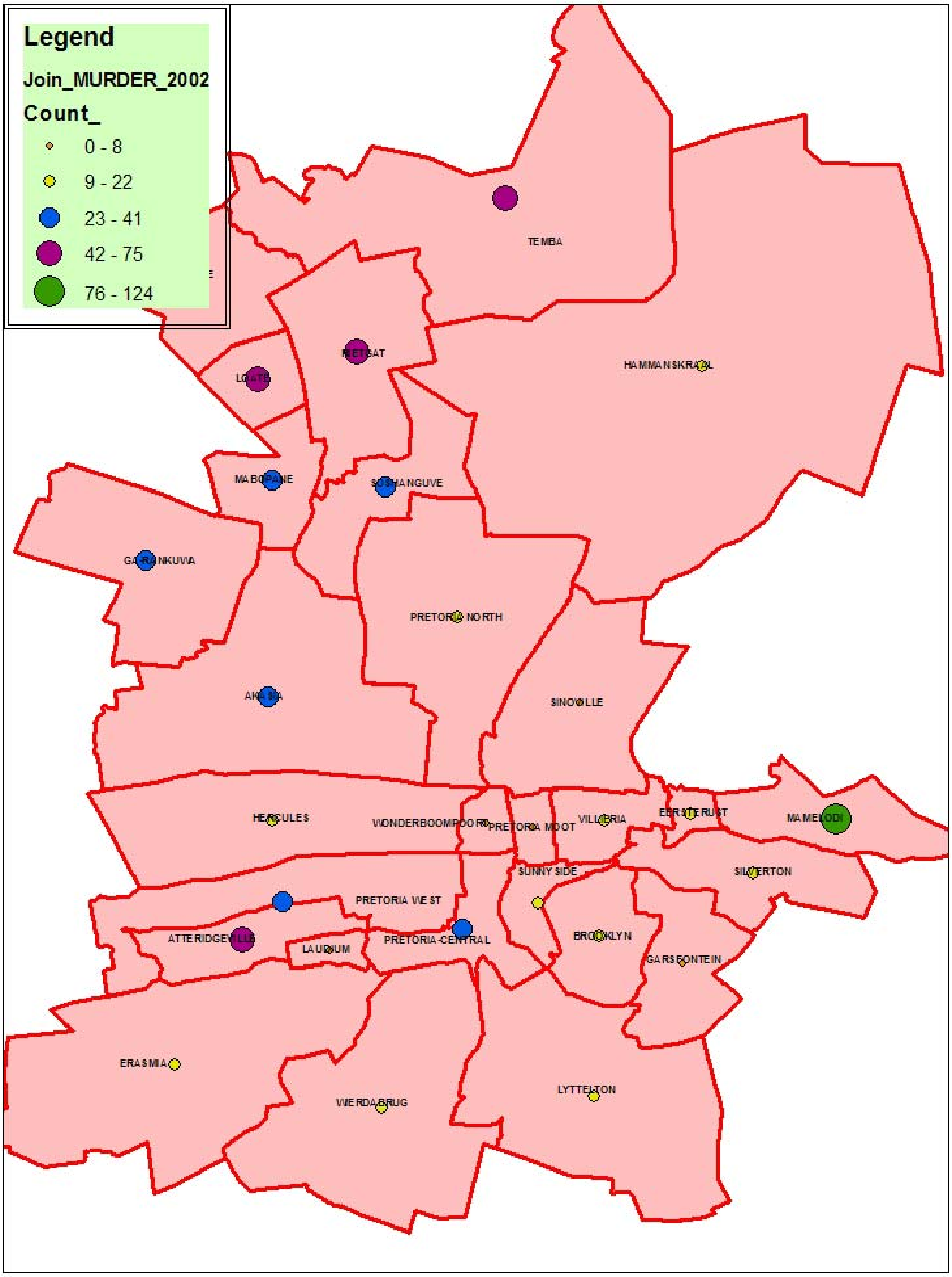


Figure 4.29: Murder incidents during 2002

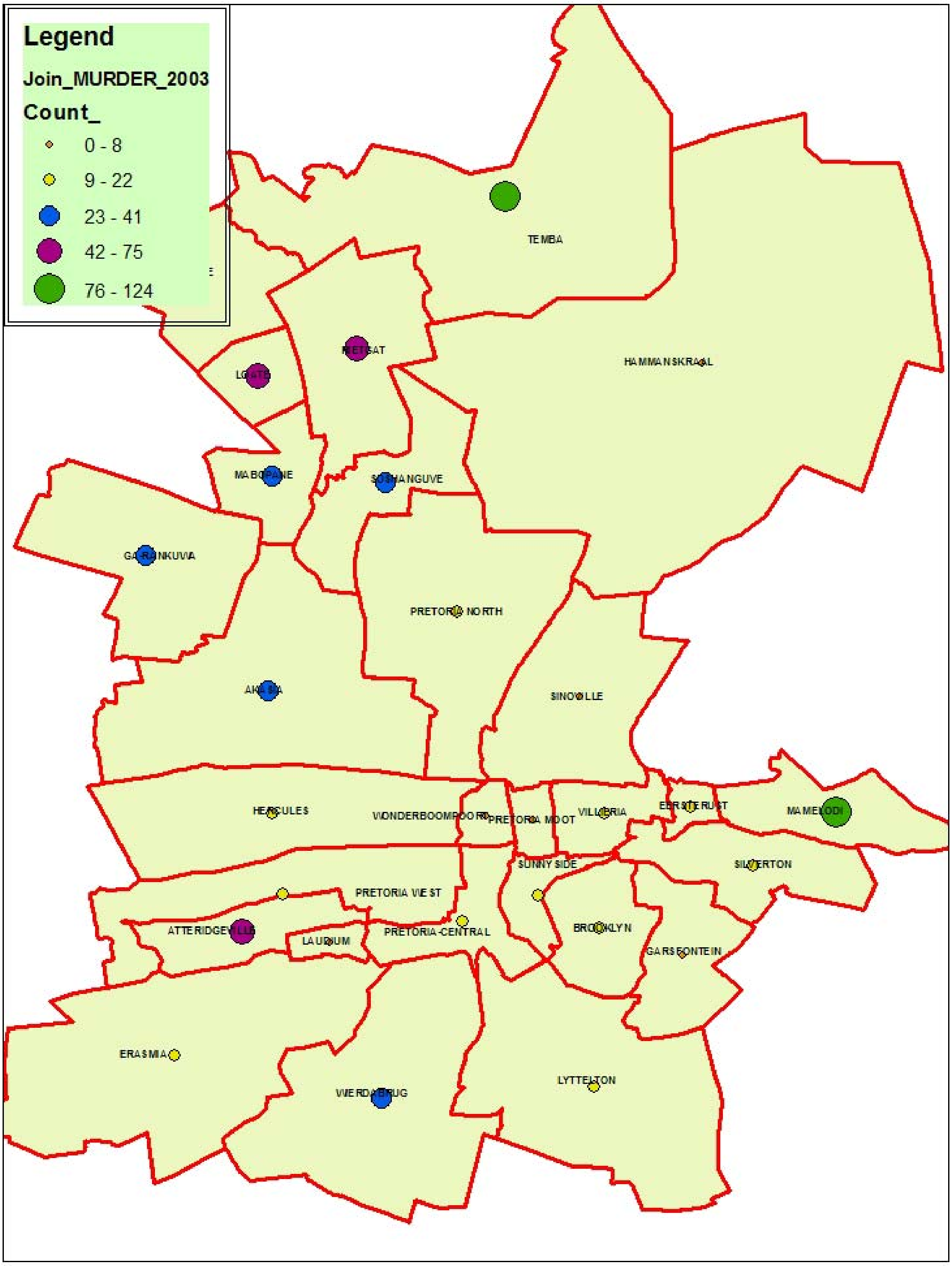


Figure 4.30: Murder incidents during 2003

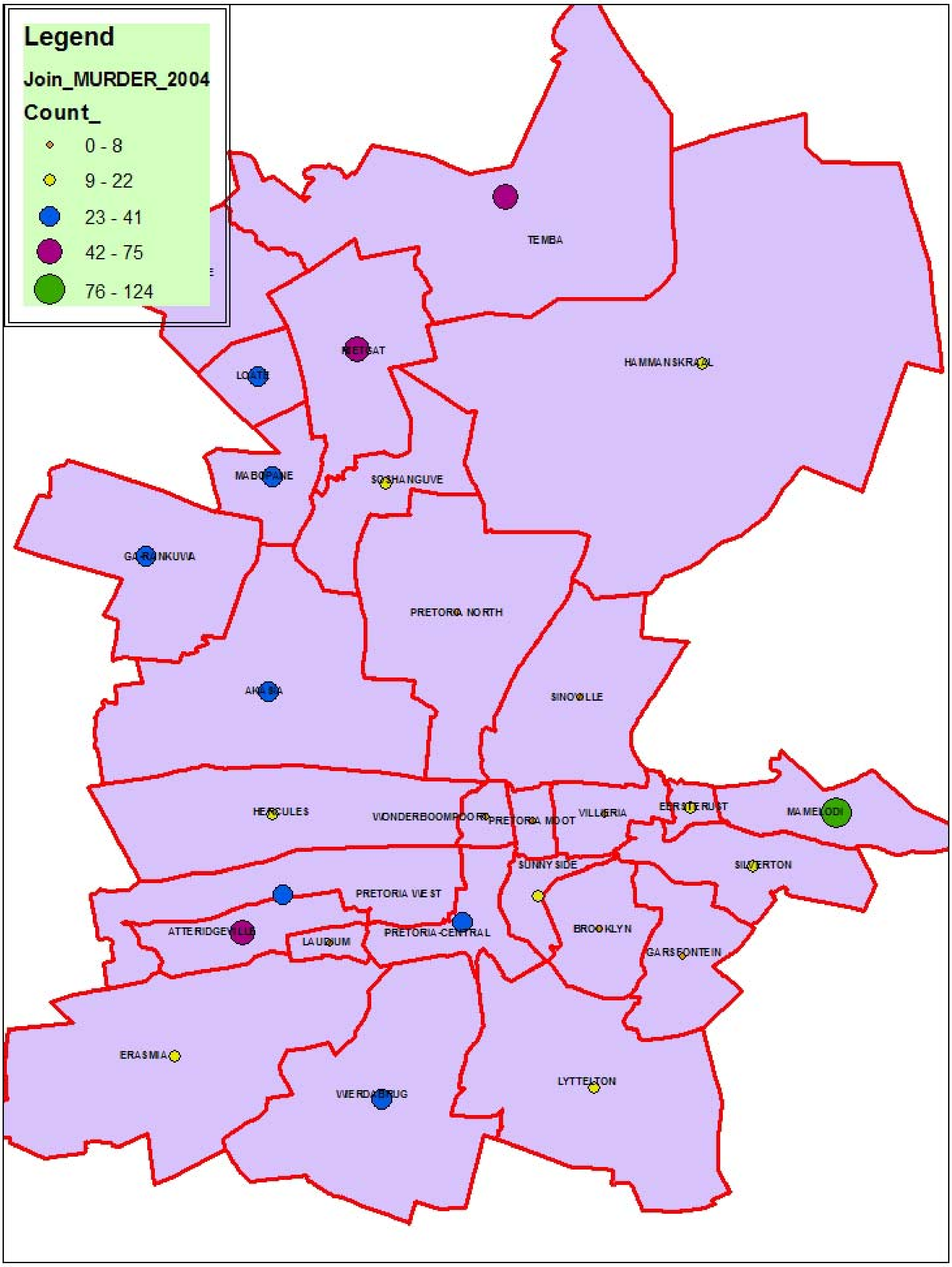


Figure 4.31: Murder incidents during 2004

4.7.3 Burglary incident analysis

A decrease of 8.7% in house burglaries from 2002 to 2004 was recorded. Table 4.16 indicates the number of burglaries per police precinct. This crime type dominates the south-eastern part of Tshwane. The highest number of incidents from 2002 until 2004 on average were recorded in Silverton (832), Mamelodi (1 043), Akasia (1 068), Sunnyside (1 157), Temba (1 179), Brooklyn (1 476), Garsfontein (1 491), Lyttelton (1 497) and Wierdabrug (1 620).

The south-eastern part of Tshwane is primarily covered by the high-density residential land use class as per section 4.5.2.4. There is a high correlation between high-density residential land use class and house burglaries in these areas. The areas that showed high-density residential growth since 1994 also correspond to the dominant areas affected by burglaries. It is also evident that areas that showed high growth in the high-density residential land use class had a decrease in house burglaries from 2002 to 2004, such as Atteridgeville (see table 4.16).

Thus there is also a negative correlation between high-density residential land use class growth and burglary. Areas such as Temba and Mamelodi showed growth in house burglaries. The western part of Tshwane such as the Hercules and Pretoria West areas showed growth in house burglaries, although this was not as dominant as in the south-eastern part of Tshwane. The overall pattern of house burglaries was not effectively displaced or prevented from 2002 until 2004. The highest occurrence of house burglaries in the Tshwane area has stayed the same year after year as indicated by figures 4.32 to 4.34.

Table 4.16: Number of burglary (houses) incidents per police precinct area

POLICE_ST	YR02	YR03	YR04
AKASIA	1 126	1 070	1 009
ATTERIDGEVILLE	658	850	630
BROOKLYN	1 470	1 516	1 443
DUBE	0	0	10
EERSTERUST	294	377	349
ERASMIA	276	268	273
GA-RANKUWA	753	552	601
GARSFONTEIN	1 731	1 538	1 203
HAMMANSKRAAL	315	297	349
HERCULES	502	498	509
LAUDIUM	178	129	151
LOATE	339	331	333
LYTTELTON	1 629	1 510	1 351
MABOPANE	513	538	600
MAMELODI	981	1 063	1 085
PRETORIA MOOT	405	355	378
PRETORIA NORTH	320	238	167
PRETORIA WEST	577	727	601
PRETORIA CENTRAL	578	472	433
RIETGAT	708	739	699
SILVERTON	793	793	911
SINOVILLE	641	602	583
SOSHANGUVE	331	285	183
SUNNYSIDE	1 324	1 093	1 055
TEMBA	973	1 365	1 200
VILLIERIA	824	650	605
WIERDABRUG	1 685	1 687	1 487
WONDERBOOMPOORT	286	253	253
	20 210	**19 796**	**18 451**

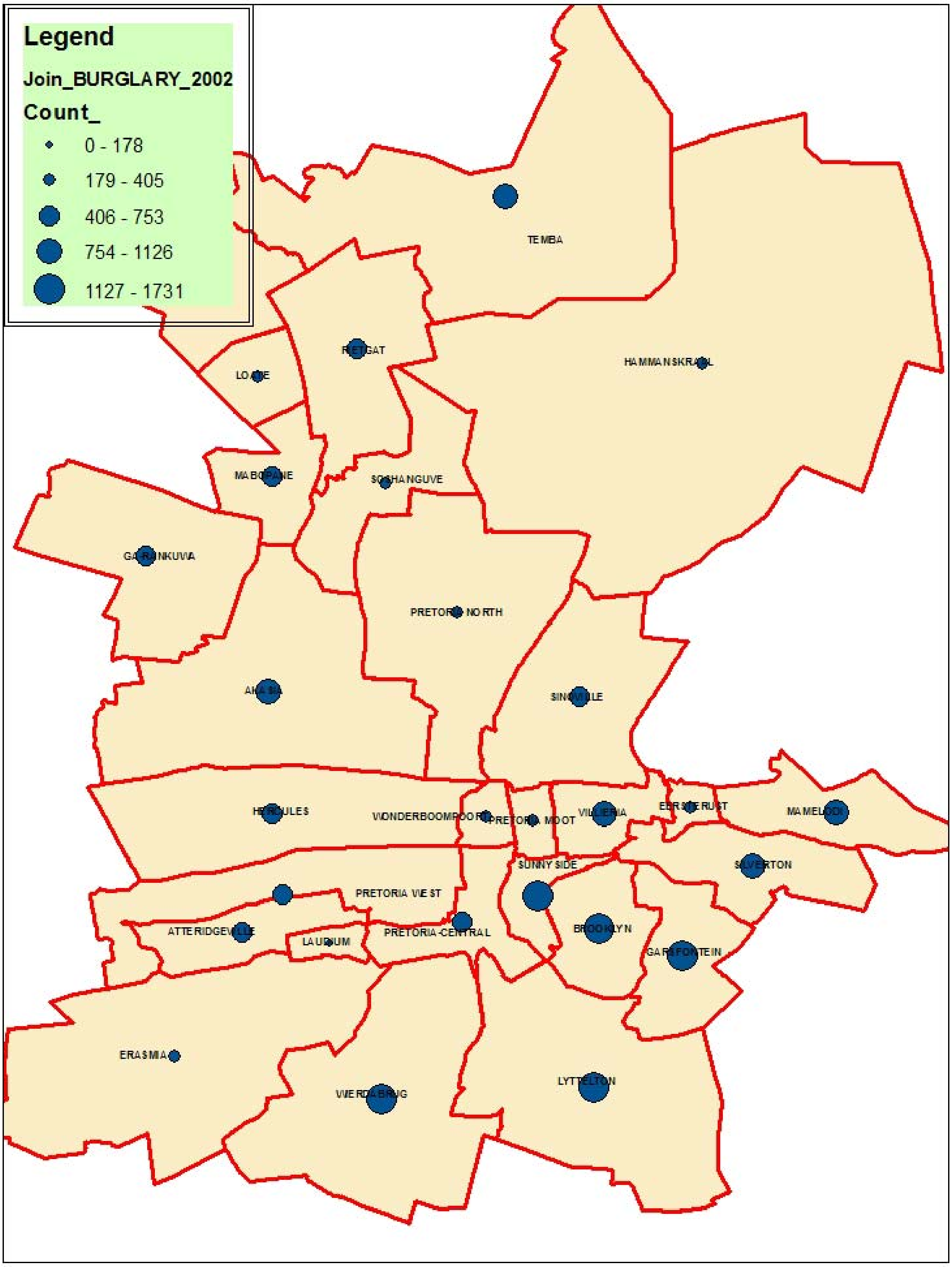


Figure 4.32: Burglary (houses) incidents during 2002

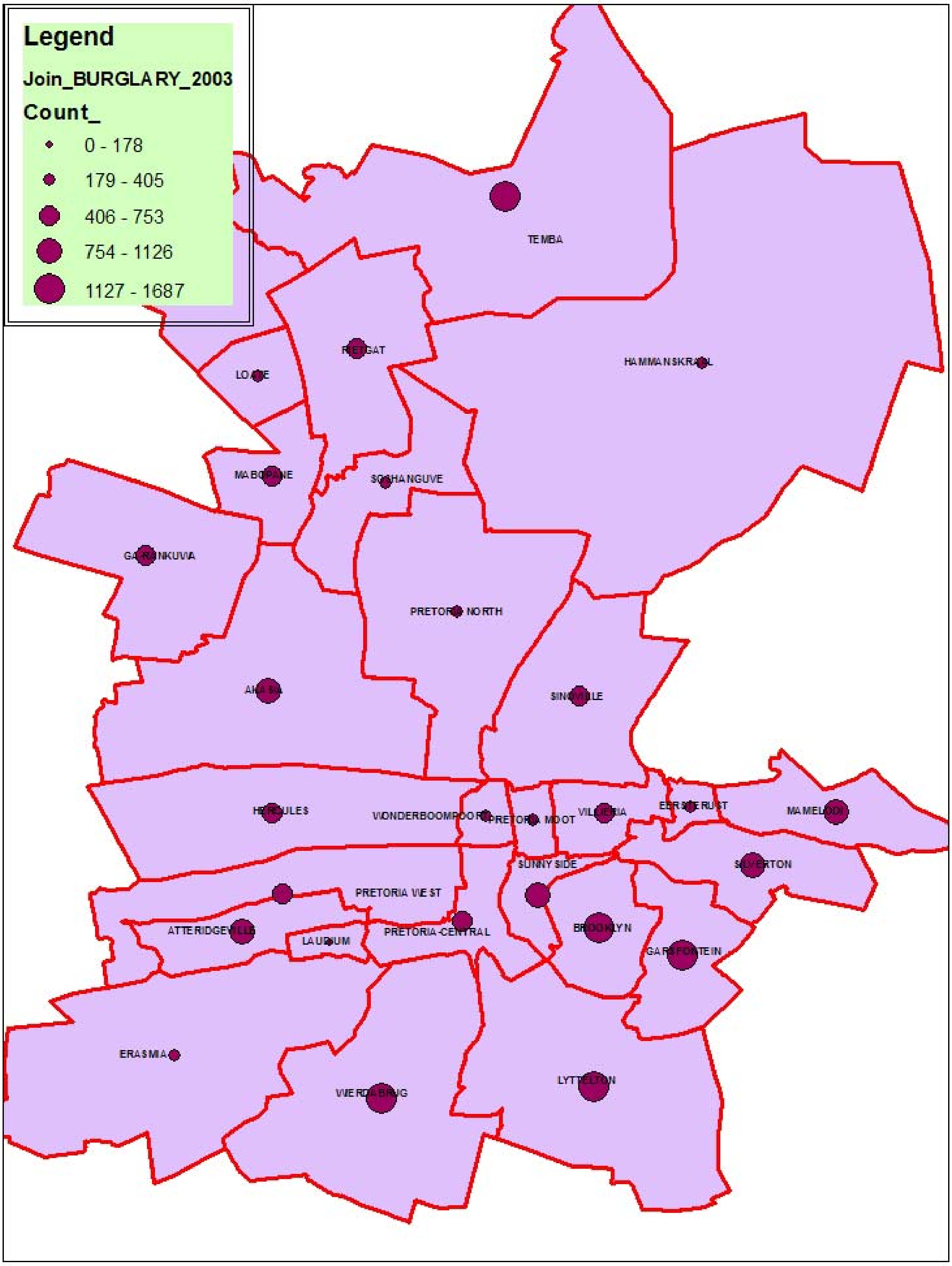


Figure 4.33: Burglary (houses) incidents during 2003

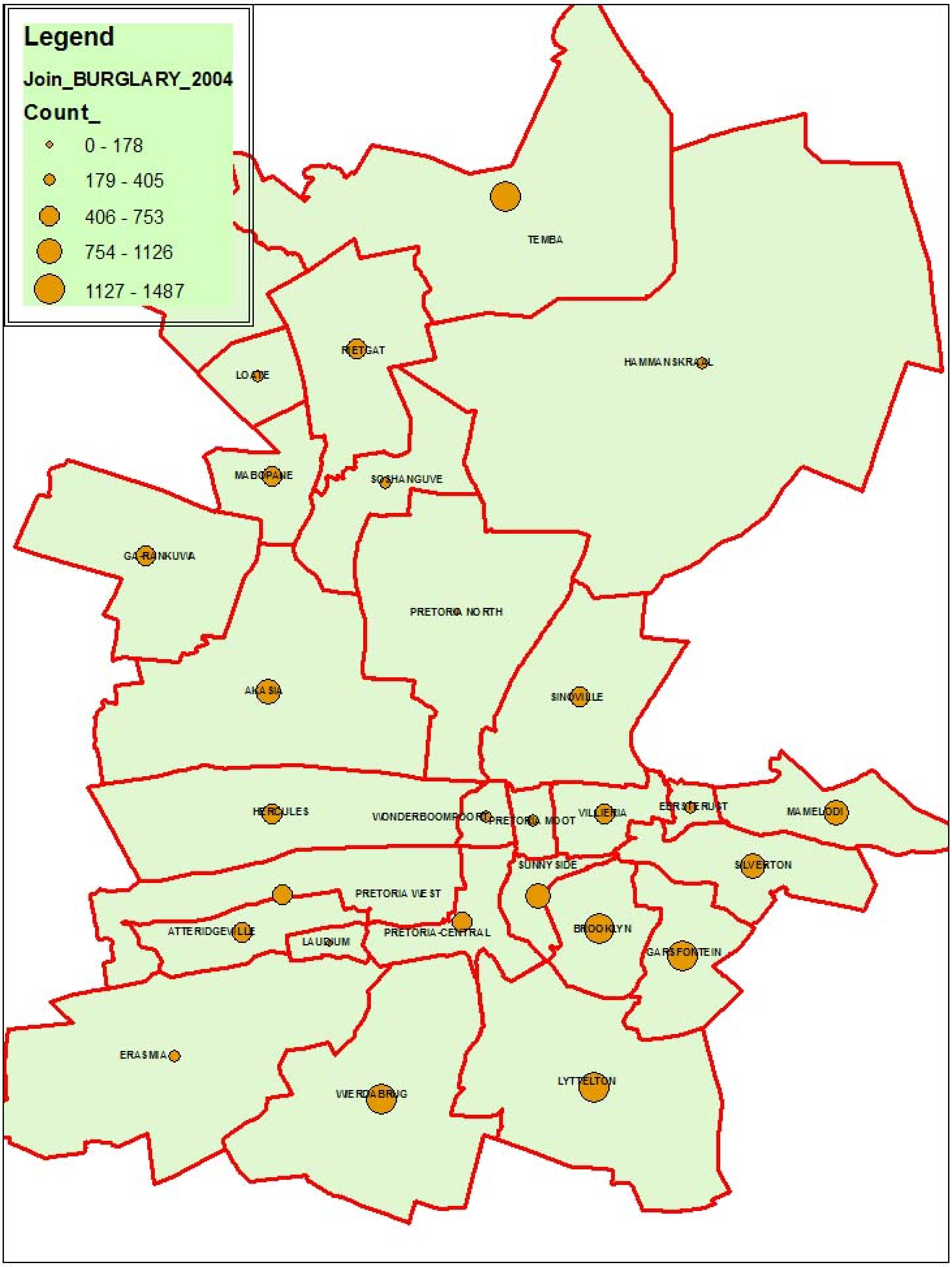


Figure 4.34: Burglary (houses) incidents during 2004

4.7.4 Car hijacking incident analysis

An increase of 15,7% in car hijackings from 2002 to 2003 was recorded. A smaller increase of 1,4% from 2002 to 2004 was also recorded. Table 4.17 indicates the number of car hijackings per police precinct. This crime type dominates the southern, central and north-western areas of Tshwane. The highest number of incidents from 2002 until 2004 on average was recorded in Akasia (70), Temba (70), Mabopane (71), Lyttelton (79), Pretoria Central (85), Mamelodi (87), Ga-Rankuwa (92), Rietgat (95) and Sunnyside (127).

The southern part of Tshwane is primarily covered by high-density residential, industrial and to a lesser extent low-density residential class land use classes as per figures 4.17, 4.19 and 4.20. The central area of Tshwane consists primarily of high-density residential and commercial land use classes as per figures 4.16 and 4.19. The north-western part of Tshwane is dominated by informal settlement areas as per figures 4.18 and section 4.5.2.3.

There is a high correlation between high-density residential land use class, informal settlement areas and car hijackings as per figure 4.35. The areas that showed high-density residential and informal settlement growth since 1994 also correspond to the dominant areas affected by car hijackings. The pattern of car hijackings yet again shows very little change or displacement from 2002 until 2004 as indicated by figures 4.36 to 4.38.

Table 4.17: Number of car hijackings incidents per police precinct area

POLICE_ST	YR02	YR03	YR04
AKASIA	63	75	72
ATTERIDGEVILLE	36	39	39
BROOKLYN	48	40	44
DUBE	0	0	0
EERSTERUST	8	5	7
ERASMIA	9	14	11
GA-RANKUWA	95	98	83
GARSFONTEIN	53	63	38
HAMMANSKRAAL	16	5	4
HERCULES	6	4	11
LAUDIUM	13	14	12
LOATE	19	25	35
LYTTELTON	65	83	89
MABOPANE	36	87	90
MAMELODI	104	110	48
PRETORIA MOOT	7	5	6
PRETORIA NORTH	12	21	4
PRETORIA WEST	41	45	50
PRETORIA CENTRAL	74	122	58
RIETGAT	95	106	85
SILVERTON	20	31	25
SINOVILLE	9	12	12
SOSHANGUVE	53	45	25
SUNNYSIDE	103	167	111
TEMBA	61	51	99
VILLIERIA	20	15	14
WIERDABRUG	53	15	68
WONDERBOOMPOORT	9	8	4
	1 128	**1 305**	**1 144**

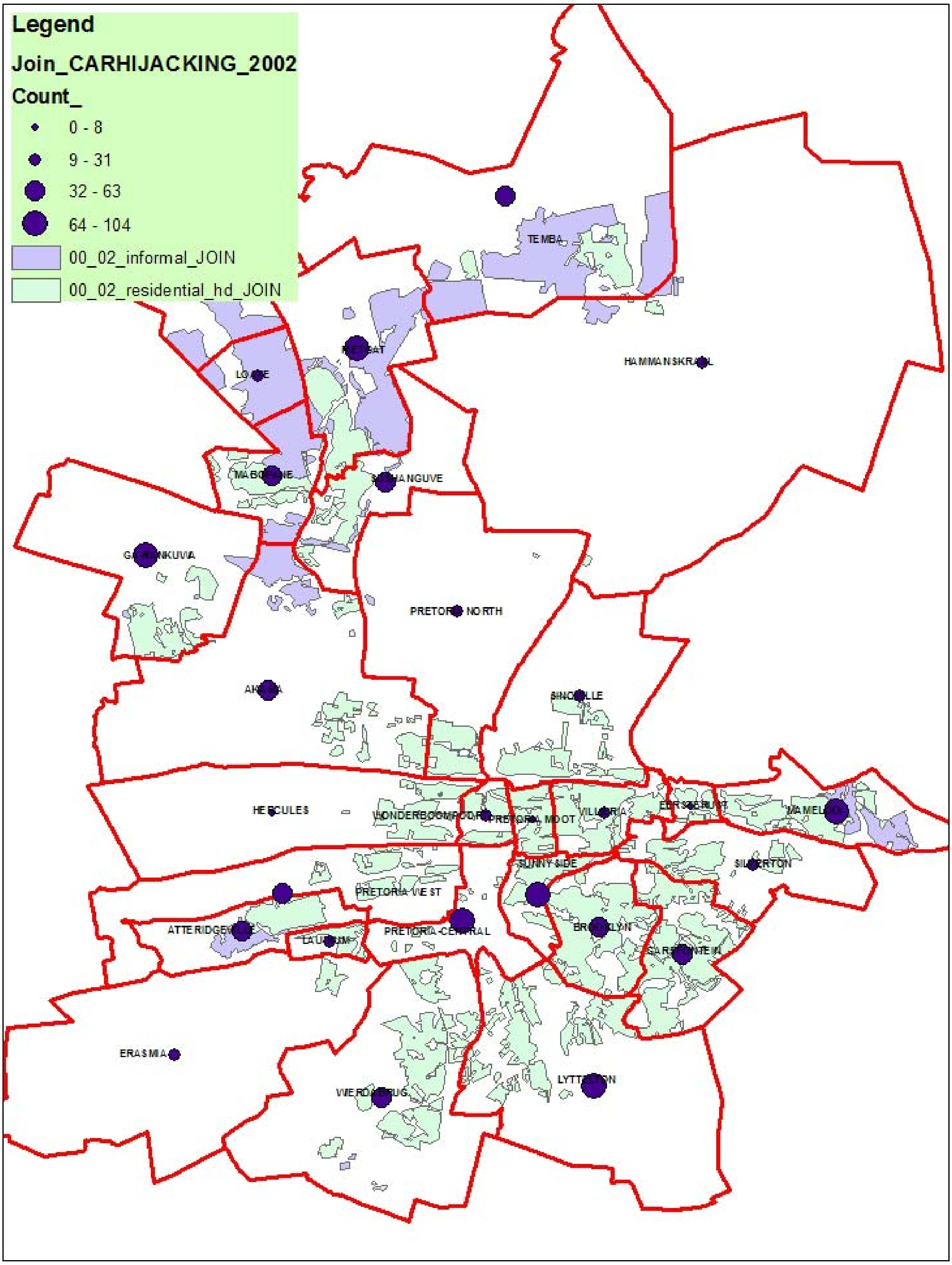


Figure 4.35: Car hijacking incidents overlaid with high-density residential and informal land use classes, 2002

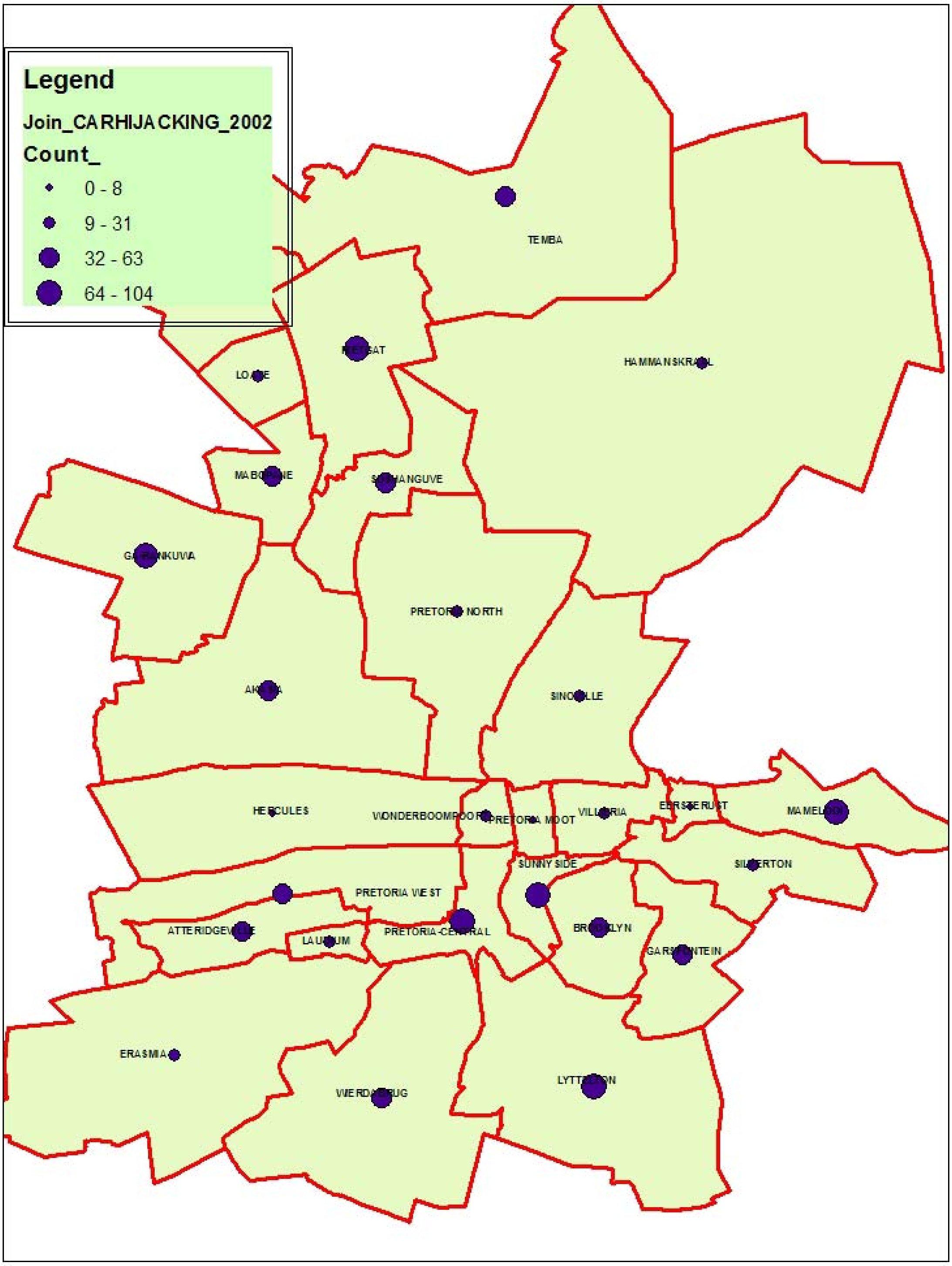


Figure 4.36: Car hijacking incidents during 2002

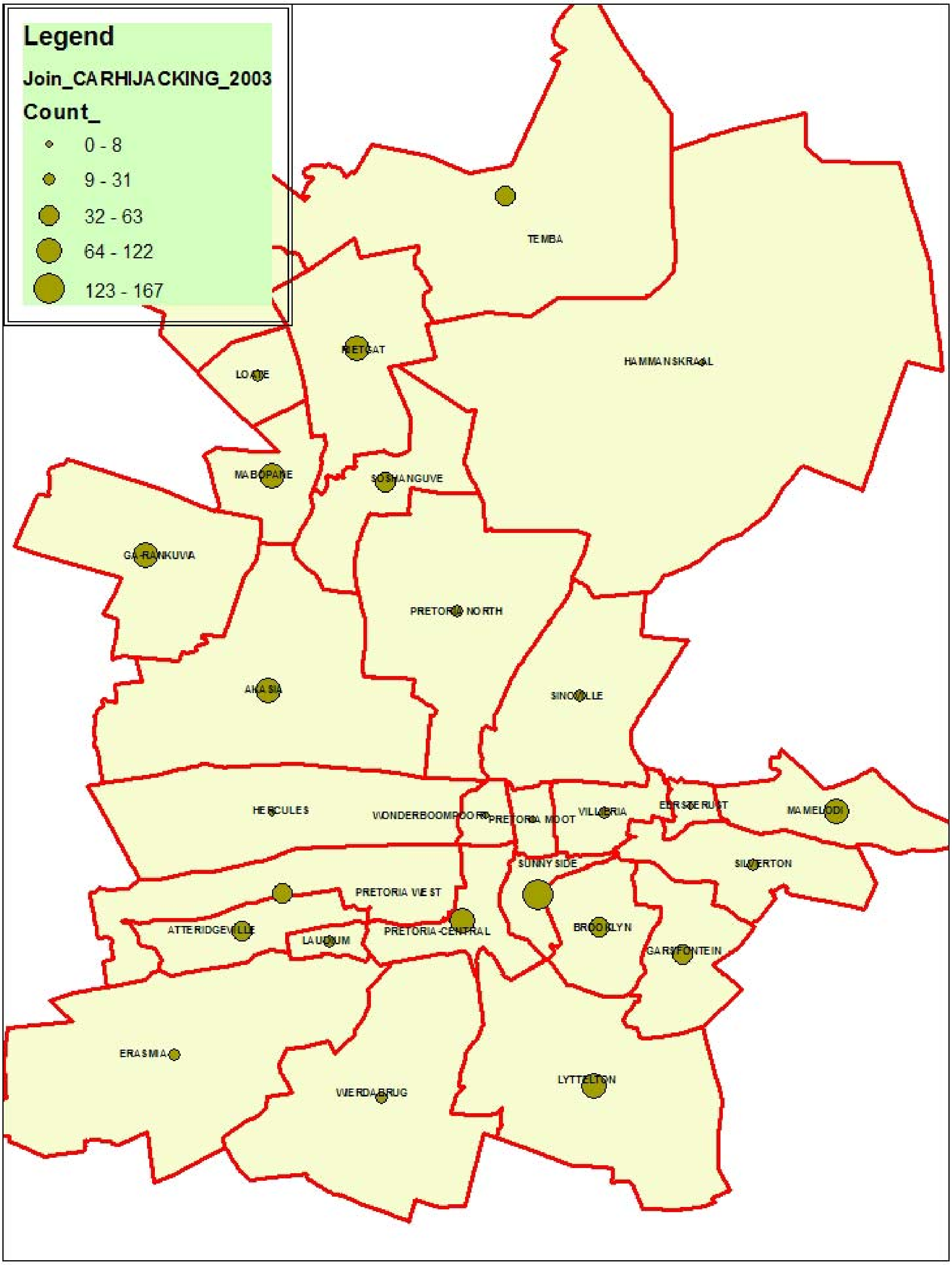


Figure 4.37: Car hijacking incidents during 2003

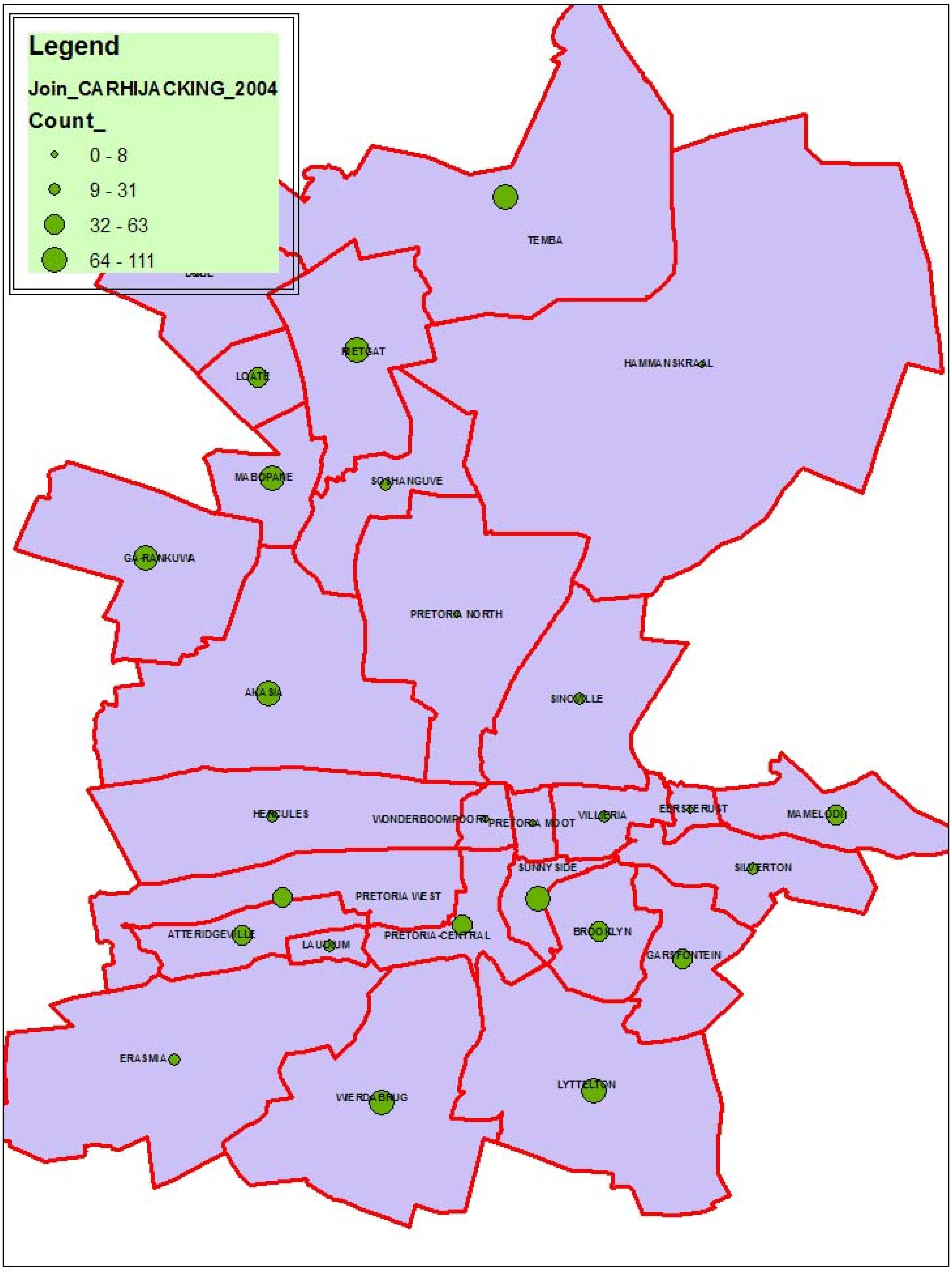


Figure 4.38: Car hijacking incidents during 2004

4.7.5 Rape incident analysis

An increase of 0,4% in rape incidents from 2002 to 2003 was recorded. A higher increase of 0,8% from 2002 to 2004 was recorded. Table 4.18 indicates the number of rape incidents per police precinct. This crime type dominates the central and north-western areas of Tshwane. The highest number of incidents from 2002 until 2004 on average was recorded in Soshanguve (126), Ga-Rankuwa (136), Mabopane (137), Akasia (156), Pretoria Central (158), Loate (184), Atteridgeville (239), Rietgat (258), Temba (296) and Mamelodi (420).

The central area of Tshwane is primarily high-density residential and commercial land use classes as per figures 4.16 and 4.19. The north-western part of Tshwane is dominated by informal settlement areas as per figure 4.18. Mamelodi, which has the highest number of rape incidents, is situated in the eastern part of Tshwane and is dominated by informal settlement and high-density residential land use classes as discussed in sections 4.5.2.3 and 4.5.2.4.

There is a high correlation of rape with high-density residential land use class and informal settlement areas as shown in figure 4.39. The areas that showed high-density residential and informal settlement growth since 1994 also correspond to the dominant areas affected by rape incidents. The pattern of rape incidents shows very little change or displacement from 2002 until 2004 as indicated by figures 4.40 to 4.42.

Table 4.18: Number of rape incidents per police precinct area

POLICE_ST	YR02	YR03	YR04
AKASIA	142	164	162
ATTERIDGEVILLE	255	245	218
BROOKLYN	35	29	39
DUBE	5	12	18
EERSTERUST	36	48	34
ERASMIA	25	21	34
GA-RANKUWA	137	137	135
GARSFONTEIN	24	22	23
HAMMANSKRAAL	42	47	53
HERCULES	37	40	42
LAUDIUM	35	20	37
LOATE	190	180	183
LYTTELTON	31	33	49
MABOPANE	137	130	143
MAMELODI	432	445	382
PRETORIA MOOT	16	14	8
PRETORIA NORTH	53	38	43
PRETORIA WEST	88	95	105
PRETORIA CENTRAL	168	144	162
RIETGAT	288	250	237
SILVERTON	74	93	108
SINOVILLE	16	23	16
SOSHANGUVE	162	116	101
SUNNYSIDE	84	100	88
TEMBA	245	314	330
VILLIERIA	33	36	33
WIERDABRUG	51	52	77
WONDERBOOMPOORT	16	16	20
	2 857	**2 864**	**2 880**

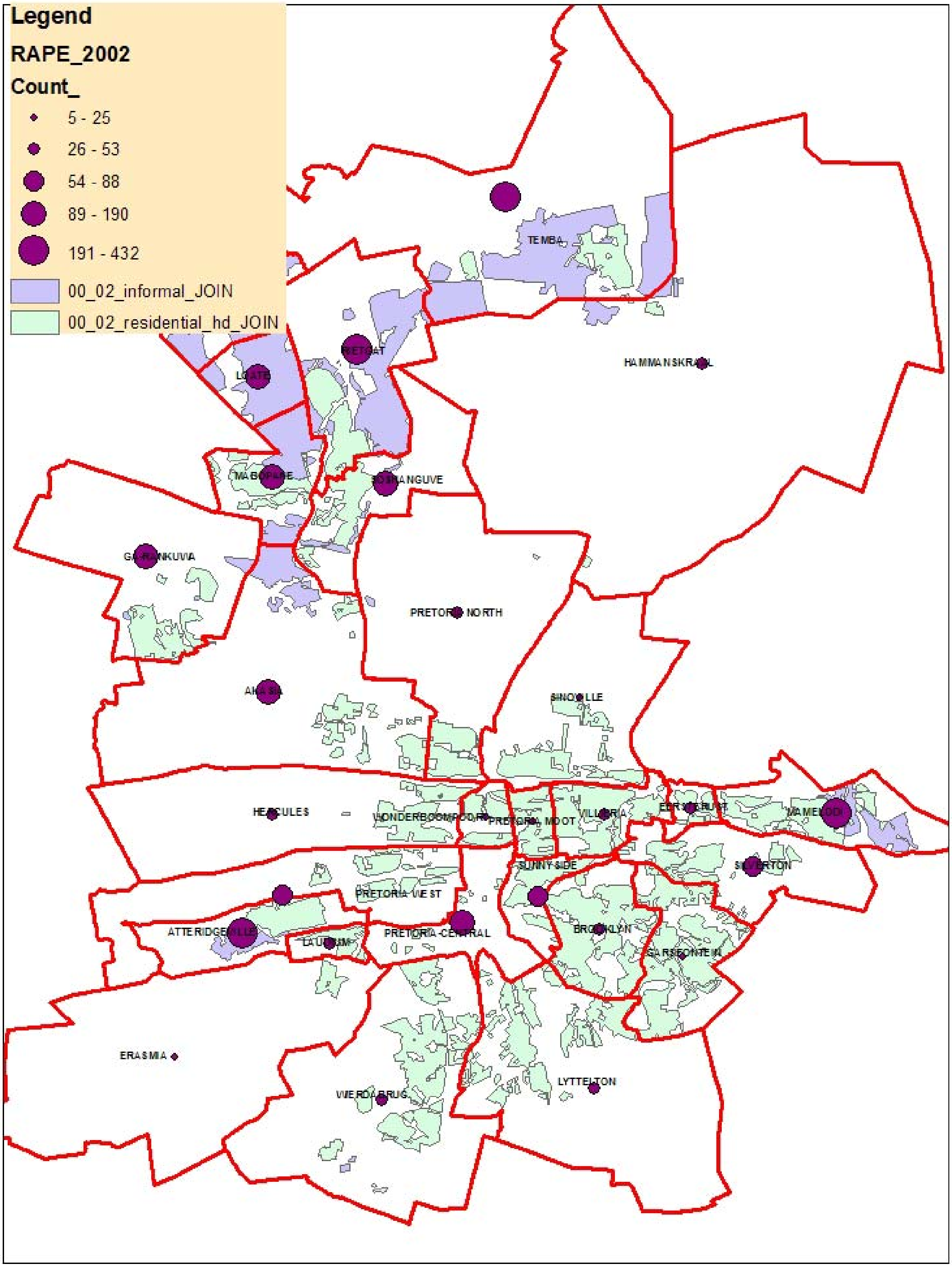


Figure 4.39: Rape incidents overlaid with high-density residential and informal land use classes, 2002

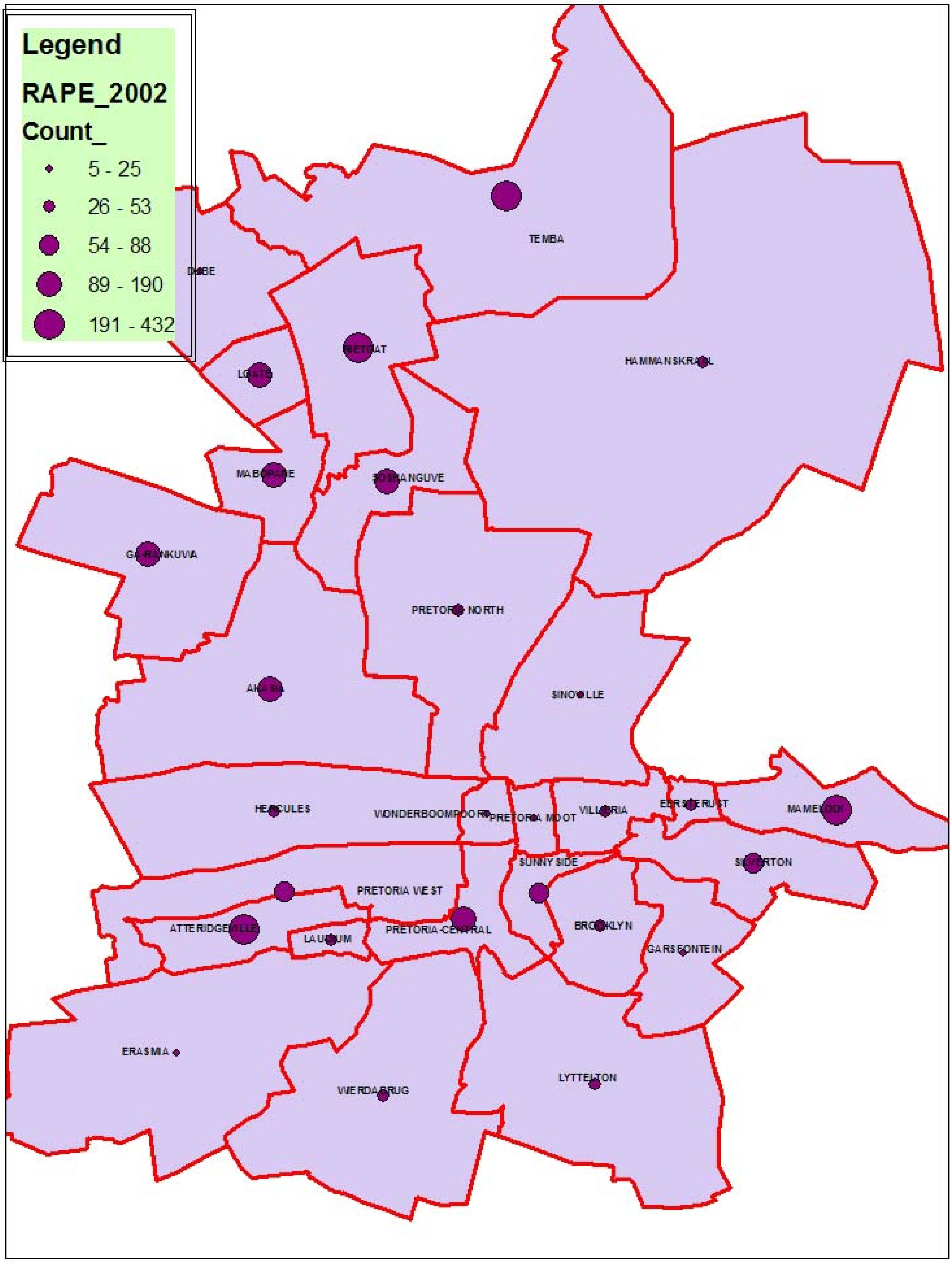


Figure 4.40: Rape incidents during 2002

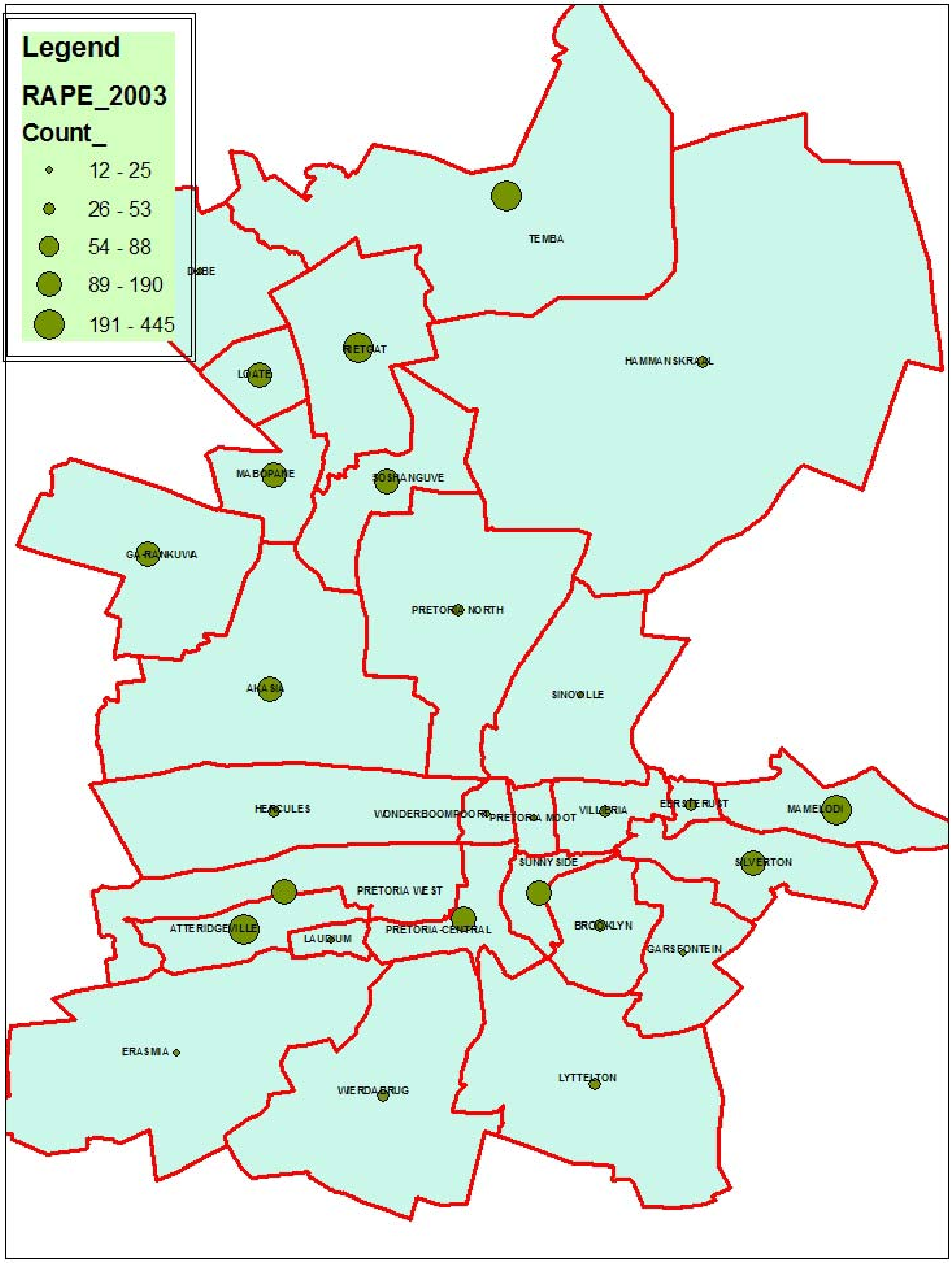


Figure 4.41: Rape incidents during 2003

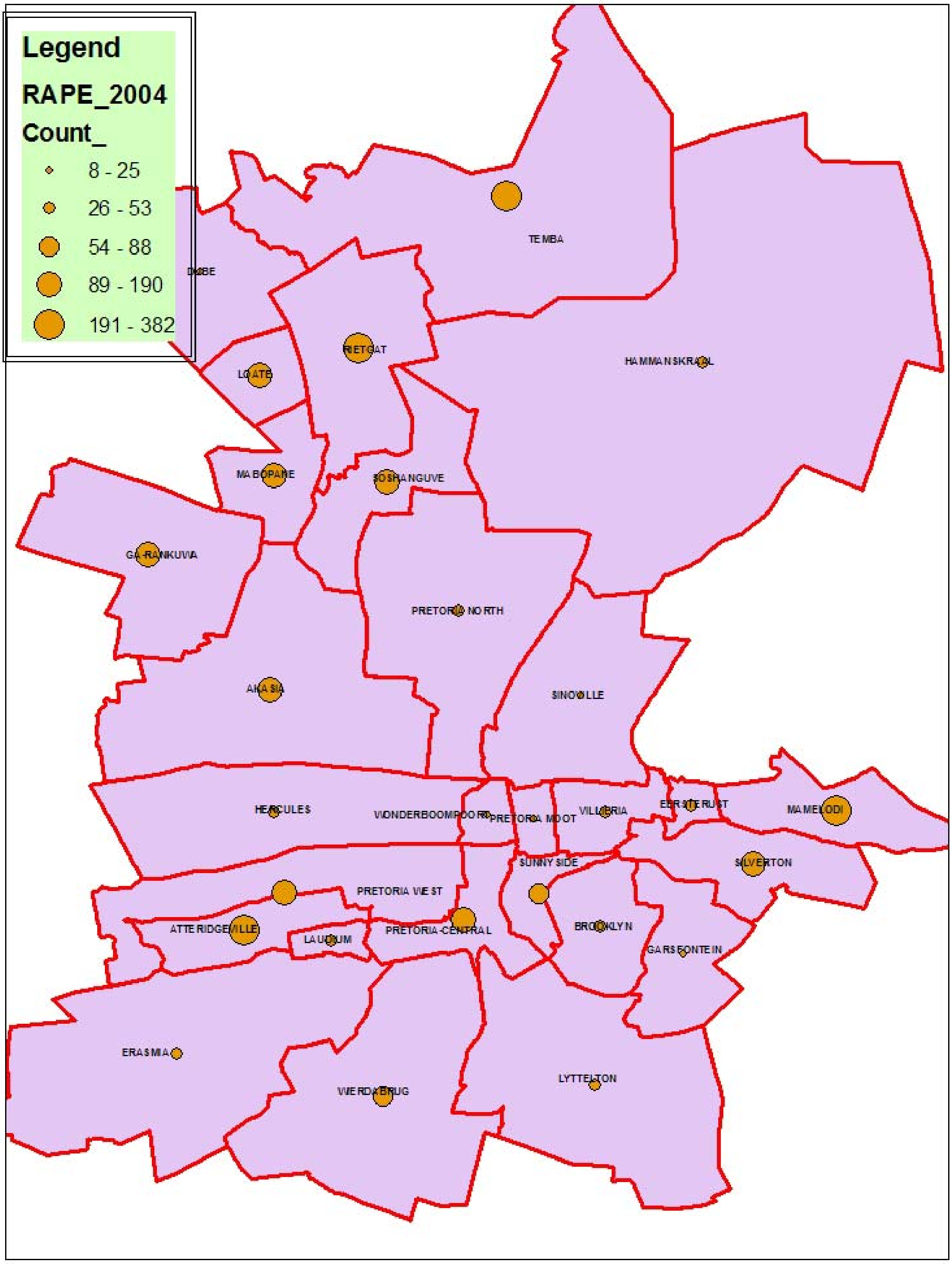


Figure 4.42: Rape incidents during 2004

Table 4.19: Rape incident growth from 2002 until 2004

POLICE_ST	YR02	YR03	YR04	Growth
PRETORIA MOOT	16	14	8	-50.00%
SOSHANGUVE	162	116	101	-37.65%
PRETORIA NORTH	53	38	43	-18.87%
RIETGAT	288	250	237	-17.71%
ATTERIDGEVILLE	255	245	218	-14.51%
MAMELODI	432	445	382	-11.57%
EERSTERUST	36	48	34	-5.56%
GARSFONTEIN	24	22	23	-4.17%
LOATE	190	180	183	-3.68%
PRETORIA CENTRAL	168	144	162	-3.57%
GA-RANKUWA	137	137	135	-1.46%
SINOVILLE	16	23	16	0.00%
VILLIERIA	33	36	33	0.00%
MABOPANE	137	130	143	4.38%
SUNNYSIDE	84	100	88	4.76%
LAUDIUM	35	20	37	5.71%
BROOKLYN	35	29	39	11.43%
HERCULES	37	40	42	13.51%
AKASIA	142	164	162	14.08%
PRETORIA WEST	88	95	105	19.32%
WONDERBOOMPOORT	16	16	20	25.00%
HAMMANSKRAAL	42	47	53	26.19%
TEMBA	245	314	330	34.69%
ERASMIA	25	21	34	36.00%
SILVERTON	74	93	108	45.95%
WIERDABRUG	51	52	77	50.98%
LYTTELTON	31	33	49	58.06%
DUBE	5	12	18	260.00%

Table 4.19 shows the fluctuations in rape incidents from 2002 to 2004. Although Dube has the highest increase in rape incidents, the number of incidents is still low compared to the overall average for the Tshwane area - 102 rape incidents on average over the three calendar years. Areas of concern include Temba, Pretoria West and Akasia, which have high numbers

of incidents with steady a growth from 2002 through to 2004. Prevention of this crime type is definitely not effective in these areas. Mamelodi, which is the highest rape incident area, shows a decrease of 11.57% from 2002 to 2004, yet it prevails as the area with the highest rape incidents recorded in all three calendar years. Mamelodi is also the area that showed extremely high growth in the informal settlement class as per figures 4.18 and 4.24. The growth measured in hectares from 1994 (161 ha) until 2002 (797 ha) was 394%. It is interesting to note the extreme growth in the latter, yet a decrease in rape incidents. It can thus be concluded that there is a higher ratio per capita for this crime type.

4.8 OVERVIEW OF CRIME ANALYSIS

The crime analysis was based on advanced statistical and geo-information system (GIS) skills acquired by the researcher over more than 10 years. The implementation of spatial analysis in any safety and security department therefore requires staff with at least basic statistical and GIS skills.

The crime analysis was based on geo-coded crime data from 2002 to 2004. The DSSC-coded crime, which consists of 46 crime types, was used for a consolidated analysis. This consolidated analysis showed that Sunnyside and Pretoria Central were the police precincts with the highest crime density in the Tshwane municipality area. The pattern from 2002 to 2004 indicates very few changes or displacement except for an increase in the Akasia, Wonderboompoort and Eersterust areas. The highest numbers of incidents each year were recorded in the Pretoria Central, Sunnyside, Brooklyn and Mamelodi areas.

The spatial distribution of murder is very similar for the years studied and is dominant in the north-western areas of Tshwane (Loate, Rietgat and Temba). High incidents of murder were also recorded in Mamelodi and Atteridgevile. The dominant land use class within these areas are informal settlements. The explanation for this can be linked to criminological theories such as the conflict theory (section 2.2.4), with the focus on the cluster of sociological theories (section 2.2.6). The desire not to belong to a struggling class and the influence of the environment could lead an individual to commit murder to reach his personal goals.

House burglary dominates the south-eastern part of Tshwane. This area is primarily covered by high-density residential land use class. Therefore there is a high correlation between high-density residential land use and house burglaries. Property crime can be explained by the Strain theory cluster and the anomie and relative deprivation theory (section 2.2.6.1). Anomie may occur as a pervasive condition in society due to the failure of individuals to internalise and adjust to the changing norms of society, or even due to conflict within the norms themselves. Social trends in modern urban-industrial societies result in changing norms, confusion and lessened social control over the individual. Individualism increases and new life styles emerge, perhaps yielding even greater freedom but also increasing the possibility of deviant behaviour. A conflict between goals and means can result if there is unequal distribution of wealth and power leading to frustration. Alternative methods of achievement are sought such as stealing from a more upper class community. Accessibility by road and public transport bring struggling classes closer to middle and upper class communities. This theory is being corroborated by the trend of house burglaries that dominate in the formal residential house areas.

Car hijackings dominate in the southern, central and north-western areas of Tshwane. There is in fact a high correlation between high-density residential land use class, informal settlement areas and car hijackings. The types of vehicles that are being hijacked differ from area to area as a diverse community class exists within the boundaries of Tshwane. Luxury vehicles are more likely to be present in upper residential classes compared to informal areas. The theories applicable to car hijackings correlate with those pertaining to property crime.

Rape incidents dominate the central and north-western areas of Tshwane. A high correlation between high-density residential land use class, informal settlement areas and rape was highlighted during this analysis. Rape as a violent sexual crime specifically against a female is difficult to explain through a set of generalised criminological theories. However, social disorganisation (section 2.2.6.2) theories stress the environment “place” has a direct influence on an individual's life. *Disorganisation* operates “through the processes of value and norm conflicts, cultural change and cultural vacuums, and the weakening of primary relationships. Characteristics of the community, including *urbanisation, residential mobility, racial or ethic heterogeneity, socioeconomic status (SES), family disruption or single-parent households,* and others, inhibit a community’s ability to impose social controls over people in the community. A society with low morality and low ethical values could more easily fall into behaviour of frequent sexual offences than a more stable and disciplined society" (Paulsen & Robinson 2004:64).

4.9 CONCLUSION

The Tshwane municipality boundary was selected for the temporal spatial analysis as it represents an area with a diverse environmental and socio-economic profile. The heterogenous representation of race and social classes makes it the ideal area to test multi-land use types and their relationship to crime. The area consists of 28 police precincts and a coverage of 284,057 ha. The methodology applied in this study consisted of GIS project management principles, remote sensing macro analysis and remote sensing micro analysis with advance GIS modelling techniques. The primary land use classes created from the macro analysis were commercial, industrial, informal residential, high-density residential and low-density residential. The layers used in the micro analysis were high-density residential, low-density residential and informal residential point feature data.

The result of the macro analysis can be summarised as follows: commercial land use classes did not show any large growth from 1994 to 2002 compared to industrial growth, which was concentrated in the southern part of Tshwane. The land use class that revealed the highest growth patterns was the informal residential class. High growth was recorded in the Mamelodi and Atteridgeville areas with a high concentration of this class in the northern part of Tshwane. High-density residential classes were concentrated in the south-eastern part, and high growth was recorded in the southern and eastern part. The Akasia and Pretoria West areas in the western part of Tshwane were the only areas that showed high growth. Low-density residential class overall showed no growth. Decreases in this class were recorded especially in the southern part of Tshwane such as the Lyttelton police precinct area.

The consolidated result of the micro analysis showed high growth in the eastern and western parts of Tshwane. The Mamelodi, Pretoria West and Atteridgeville police precincts showed the highest overall growth from 2003 to 2004. High-density houses were primarily recorded in the western and southern parts. The highest growth was in Pretoria West and Atteridgeville. Low-density houses were concentrated in the northern and southern areas. The Lyttelton area showed 25 new houses built from 2003 to 2004. Informal settlement areas showed the highest concentration in the eastern and western areas. The highest count for new informal dwellings was in the Mamelodi area (10 782), Akasia (2 195) and Soshanguve (2 170).

A high number of murder, car hijacking and rape incidents showed a direct correlation with informal settlement areas. House burglaries as defined by law are logically dominant in the high-density residential land use class and occur to a much lesser extent in the low-density residential land use class. The crime trend needs to be analysed over a longer time period than only three years to prove a greater significance between land use growth and crime incident growth on a micro level.

The pattern of specific crime types and their relationship to a dominant land use class is therefore evident. A high correlation does exist, even in a heterogeneous environment. The displacement of crime over the three years of study is very low and a constant pattern of serious crime exists over the same areas year after year. The high numbers of incidents that occurred in such a small area really highlights the severity of crime in South Africa, affecting all social classes. The sciences of urban planning, remote sensing and GIS, and specific statistical and crime analysis techniques combined into an integrated system can assist in better understanding and preventing crime from a macro to a micro level. The challenge for South Africa is to educate the safety and security institutions so that they can build up the necessary skills to apply spatial information into a workable crime prevention strategy up to police precinct level.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This study examined criminological theories, specifically the ecological dynamics thereof, and addressed the basic science of remote sensing and temporal analysis using a combination of multi-sensors and geographical information systems (GIS). The researcher gained skill and experience in GIS over a period of 10 years during a pilot study which was started in 1996 in the north-eastern Johannesburg area. That project involved strategic research on vehicle hijackings. A database was set up to record specific qualitative information from victim surveys and was linked to a GIS that contained all the spatial crime incident attributes. This proved for the first time the value of spatial intelligence to the SAPS. The know-how gained during this project and recognition of its value led to the development of the Business Intelligence (BI)/ GIS system of the SAPS, which was further developed and maintained by the State Information Technology Agency (SITA). The researcher realised when he joined the Satellite Applications Centre in 2000, which is a national research centre of the Council for Scientific and Industrial Research (CSIR), that remote sensing technology had not been incorporated in the BI/GIS system as an information layer. The present study introduced the utilisation of remote sensing as a complementary technology to analyse the land use profile and environment within each police precinct to enable better spatial crime analysis and to formulate improved prevention strategies.

An important aspect which is addressed in this chapter is the relevance of spatial technology to criminology. Recommendations are made to integrate this technology into the SAPS procedures for a better understanding of crime patterns. This will allow law enforcement agencies to act preventatively rather than reactively on the basis of sound information layers and will improve strategic decisions.

5.2 REALISING RESEARCH OBJECTIVES

The researcher integrated technology derived from the natural sciences into the social sciences with the focus on criminology. In this study it was proved that remote sensing technology could be used as a spatial tool to better analyse and understand crime in a specific area. The behaviour of humans in an area with specific crime types provides a valuable profile for the crime analyst to elucidate crime and take measures to reduce crime.

The objectives of this study, listed in section 1.4, are to:

- Introduce the basic science of remote sensing.
- Integrate spatial technology into specific criminological theories.
- Apply remote sensing, GIS and crime data into a practical case study to illustrate the integration potential of these technologies.
- Illustrate the relationship between specific land use classes, their behaviour over time and certain serious crime types, e.g. murder, vehicle hijacking, house burglaries and rape.
- Contribute to the science of criminology by introducing new spatial technologies that can contribute to the reduction of crime.

In Chapter 2, the core criminological theories and how to apply the theory in practice were discussed. The ecological theories of crime can be practically analysed by using spatial technology to prove their value. Therefore a positive correlation exists between some criminological theories and spatial technology when it is used as a tool to analyse crime.

In Chapter 3 the science of remote sensing and the satellite platforms on which it operates were briefly discussed. A wide range of applications can be created from multi-sensors at different ground resolution such as agriculture, forestry, urban planning, change detection, land use/land cover mapping, safety and security planning, etc. The discussion focused on operational as well as strategic applications within the safety and security cluster and was practically illustrated. Future satellite systems and instrumentation were discussed to inform the reader about new technology trends that will improve current application methodologies and their benefits.

Chapter 4 discussed a practical analysis utilising remote sensing imagery and vector data layers coupled with relevant auxiliary data to determine whether there is a relationship between land use growth and specific crime types. The Tshwane municipality boundary was selected for the study which consists of 28 police precinct areas with a heterogeneous socio-economic profile. The crime incidents from 2002 to 2004 showed that the displacement of crime was minimal and that crime trends stayed the same from year to year.

A high number of murder, car hijacking and rape incidents showed a direct correlation with informal settlement areas. House burglaries as defined by law are logically dominant in the high-density residential land use class and occur to a much lesser extent in the low-density residential land use class. The crime trend needs to be analysed over a longer time period than only three years to prove a greater significance between land use growth and crime incident growth on a micro level. The methodology used in this study does, however, provide a platform for such research in the future.

In this, the last chapter, the ultimate objective of this thesis is discussed, namely the relevance of spatial technology and its contribution to the science of criminology to provide an information gateway for law enforcement agencies to better understand human behaviour and crime patterns to optimise crime reduction efforts.

5.3 CONTRIBUTIONS TO CRIMINOLOGY

The contributions to the science of criminology are explained by way of specific extracts from research articles and comments regarding their relevance to this study.

- The ecological school of criminology stresses the correlation between "place" and crime. The Chicago school study confirmed the difference in crime per concentric zone (section 2.2.6.2a). The ecological theory was applied in practice during this study, confirming the difference in crime types per dominant land use class and the crime density per area. It must be emphasised that criminological theories such as the ecological theory are not practically implemented in South Africa. According to Naudé (in Naudé & Stevens 1992:4) criminological studies do not only concentrate on the description and explanation of crime. One of the most important aspects is to prevent and control crime as it impacts negatively on individuals or communities quality of life. This study introduced the technique to include remote sensing technology through temporal analysis to better understand the dynamics of a police precinct's environment and the dominant crime types within it.

- According to the researcher, an important aspect of spatial crime analysis is the identification of hotspots, i.e. areas of the highest crime concentration. The Getis and Ord Gi and Gi* statistics are well known techniques for delineating hotspots within complex crime patterns, particularly when a simple binary classification into significant and insignificant regions is sought to compare with those delimited using police precinct boundaries (Ratcliffe & McCullagh 1999: 13). The illustration of hotspot areas through statistical and GIS modelling have limited visualisation information to illustrate the actual environment where they occur. Very high resolution satellite imagery contributes to better understanding of the physical environment and the socio-economic conditions that dominate a specific hot spot area (see section 4.6). Therefore remote sensing provides a visual layer for macro and micro analysis to classify growth patterns per land use class as well as an image backdrop for image interpretation purposes.

- Over the past decade, crime mapping, which is limited in South Africa, has become an important tool for law enforcement and criminal justice agencies. Its importance to criminology and criminal justice policy analysis is increasing. In criminology curricula it is an historical link to early ecological ideas of crime and crime pattern communities. There is room for improvement in environmental criminology in the South African context, as well as in the integration of specific natural science concepts within criminology to expand the knowledge base of future criminologists to apply new technologies to improved crime prevention strategies and crime analysis. Thus the use of various geographic and mapping paradigms in the study of crime has a natural appeal to criminology students (Althausen & Mieczkowski 2001:367). The researcher believes that this study has introduced new technologies from the natural sciences which can be integrated logically through specific methodologies to contribute to the science of criminology. The results of this study show that new technological thinking can be integrated into current criminology curricula.

- In the researcher's view there is a seemingly endless quest for the development of viable crime control strategies, and criminal justice research and law enforcement agencies have expressed an urgent need for accurate and timely crime data and related contextual information.

- Crime geographic information systems are important tools for developing crime analysis strategies in a spatial context. The linking of crime and census information for map production is very important in the analysis of crime (Brassel & Utano 1979:15). The alignment of police precinct boundaries with official statistical boundaries will contribute to more accurate auxiliary data that can be linked spatially for purposes of analysis (see section 4.3).

- An increasingly popular strategy in community-oriented and problem-oriented policing is to provide patrol officers with crime analysis information in the form of crime maps. The strategy is designed to encourage officers to use maps to determine problem areas in their beats and to modify their patrol strategies accordingly. Despite the promise of crime maps and GIS in general, no research has evaluated the use of crime maps by patrol officers. Such research will help to adapt police training and to assess the actual spatial technology skills of the SAPS. Results in the United States indicate that simply providing officers with maps of crime distributions does not alone improve their understanding of crime patterns within their jurisdiction. Moreover, in order to have any real impact on officer perception and subsequent policing activities, agencies need to invest in training and infrastructure to allow the full capabilities of crime mapping to be realised (Paulsen 2004:234). The researcher emphasises the importance of spatial training for police officials and sees it as a step forward in the context of this study.

- The urbanisation process is a major change factor in South Africa's metropolitan areas, where pre-urban cities and new urban settlements have arisen over the past decades. Several cities rapidly became regional centres or international nodes according to economic and political pressures. Urbanisation (and informal settlement) causes land cover changes which can lead to more fundamental social, economic and environmental changes (see section 4.5).

  In a study in the United States satellite imagery was used (1986 – 1996 SPOT XS) to extract the land cover uses, identify the urbanisation processes and estimate the changes. One of the main aims was to locate informal settlement areas which grow significantly. Results showed a global progression of built-up areas of 13% in 10 years. In a second step, the urban growth evolution was approached by using a model that provides general trends of feasible urban expansion, taking into account protection laws of natural and agricultural land. This type of model has not been tested on developing cities, but it could develop into a new planning tool for planners who have no spatial concept of how their urban areas have changed over time and where the growth is occurring. In the US study, it was calibrated over the period of 1986 – 1996 and then applied to predict the location of built-up growth over the succeeding 10 years (1996 – 2006). These results can provide local authorities and other stakeholders with information for decision-support plans for future planning and monitoring. Moreover, they can be updated systematically through the integration of remote sensing data (Weber & Puissant 2003:341).

This study used a similar methodology using Landsat imagery from 1994 to 2002 and then very-high resolution imagery for 2003 to 2004 to extract point features per land use class. The contribution is a local study result that confirms the serious growth in informal settlement areas and high-density residential areas over the 10-year period.

- Research showed that technological advances, primarily in computer capabilities, are fundamental to recent analytical advances in the methods available for analysing place-based crime data. The advent of computer mapping applications and accompanying geographic information systems (GIS) are crucial to being able to measure and represent the spatial relationships in data. Perhaps the most powerful analytical tools emerging from GIS technologies are (1) flexible spatial aggregation capabilities to facilitate the measurement of place-based crime, and (2) simple contiguity matrices for representing neighbour relationships between different areal units. In addition to these analytical advances, computerised police records management systems and computer aided dispatch (CAD) systems of citizen calls to police make it possible to systematically quantify varying levels of criminal activity at different places within a city (Anselin *et al*. 2000:215). The technological systems designed and maintained by SITA for the SAPS have improved over the past five years with a strong BI/GIS capability. The hosting of remote sensing layers and change detection layers create opportunity for improvement. The integration of the Satellite Applications Centre's advanced remote sensing supply chain into the SAPS BI/GIS system will contribute to a powerful system architecture for the SAPS. The data integrity from the Crime Administration System (CAS) and the accuracy of geo-coded crime as base data as a pre-requisite for advanced analysis are of utmost importance.

The integration of geographical concepts and criminology was discussed in previous sections. GIS and statistical algorithms have already been integrated since the late 1970s. There is scope for further research into remote sensing as a technology to assess land use growth and its relationship to crime, especially with very high resolution sensors coming onto the scene. The thinking behind the ecological theories of criminology and their relevance to understand the “place” in which crime occurs has been of much value during this study. This has contributed to the importance of understanding the diverse land use profile per police precinct and the dominant crime types in each.

Contributions which, in the researcher’s view, are highlighted in this study, are described in the sections below.

5.3.1 Analysing crime incidents using point data

Point data are extremely useful in the analysis of crime patterns, yet there are several problems associated with the mapping of crime at point level. It is difficult to make accurate correlations between point data and other contextual data such as income, poverty, unemployment that are aggregated at the census tract. Without standardising the point data these types of analysis are at best only guesses about the relationships between incident locations and aggregated data. Another related issue is the inability to accurately determine the magnitude of point data concentrations. Techniques such as hot spot analysis and kernel density interpolation can indicate if incident locations are closer than would be expected by change, but without knowing the underlying population data it is impossible to determine whether these areas are unusually high incident areas.

A final problem with point data is the accuracy of location information. Location information for point data is usually derived through a process called geo-coding. Geo-coding is the process of taking specific street addresses of crime incidents and matching them to a reference file containing a range of addresses for a given area.

The National Address Directory (NAD) in South Africa is not fully updated and a serious backlog exists in some municipal areas. There is also an uncompleted cadastre layer. Crime incidents that do not occur within a specific address or occur within informal areas without proper address indexing are fully dependant on accurate global positioning system (GPS) readings for collecting geographical coordinates (ground control points (GCPs)) of the crime incident. This study focused on a police precinct administrative boundary level. For future micro analysis, point data and its associated attributes will have to be addressed to provide more accurate source data for research. This will result in an improved crime analysis system that can assist in operational planning in order to combat crime.

5.3.2 Administrative units

Administrative units are defined as “spatial units designed primarily by government to organise the delivery of services, to provide common units for diverse reporting functions, and to provide and aggregate a basis for government allocations and representations” (Paulsen & Robinson 2004:214).

The misalignment of police precinct boundaries with municipal, subplace and enumerator areas was pointed out in section 4.3. Crime incidents occur across boundaries and clusters of crime are often not within a fixed administrative boundary. It is therefore important not only to analyse crime within fixed administrative boundaries - the population difference per administrative boundary and the number of crime incidents that have occurred means that multi source data are required to provide valuable analytical information. The mapping of land use classes by remote sensing will assist in identifying dominant land use class types compared to fixed administrative boundaries. By distinguishing between socio-economic classes and correlating those classes with specific geo-coded crime types, the environment in which crime analysis can be done is expanded.

5.3.3 Informal land use class

The phenomenon of informal settlement seems to be a crucial issue in urban development. Lack of relevant spatial information may be obviated with remote sensing data. Time-series procedures offer some possibilities for steady surveys of land cover changes. The articulation between statistical approaches (supervised classification and post-processing) and potential modelling capacities provides some support in decision-making documents to elaborate future monitoring scenarios. Regarding sustainability issues, this kind of approach may offer useful information on possible exposed land cover categories regarding increasing urbanisation.

Nevertheless, in order to précis this information and to identify urban objects (for example to distinguish informal housing settlements from industrial settlements), very high spatial resolution data (with a resolution of less than 5 m) has to be used. The availability of SPOT 5 imagery under a multi-government license as from 2006 for the SAPS at no extra cost will allows 2.5 m natural colour products to be generated which will be ideal for higher temporal monitoring of informal areas and the growth of their peripheries. These advanced remote sensing applications will be provided by the CSIR's Satellite Applications Centre under a government-subsidised model.

Sections 4.5.2.3 and 4.6.4 of this study revealed the high growth patterns in the Mamelodi and Atteridgeville police precinct areas. The relationship between specific crimes such as murder and rape were clearly visible within these areas, which therefore creates the opportunity to understand the socio-economic factors. The Loate area is dominated by informal settlements, yet a decrease in violent crime was identified. From a criminological point of view, these areas require more qualitative research into the spatial analysis component that was identified in this study for understanding and preventing crime in these areas. The spatial temporal study of crime discussed in section 4.7.1 indicated that no drastic displacement or decrease in crime patterns had occurred. These facts highlight the importance of adapting policing strategies and crime prevention techniques for a significant impact to be made on crime in these areas.

5.3.4 The use of computerised mapping

One of the reasons presumed for the increase in the use of computerised mapping in policing over the past years is the increase in community policing. Community policing is a policing philosophy that encourages police no longer merely to provide rapid response to calls for service, but actually to attempt to identify and reduce the underlying causes of crime, fear of crime and neighbourhood disorder. At the heart of this focus on crime prevention is an increased effort by police departments to determine the root causes of crime in which computerised mapping supposedly plays an integral part (Paulsen & Robinson 2004:225).

While computerised mapping holds promise for helping to prevent and better understand causes of crime, it can also lead to problems concerning policing strategies if the police simply focus on “attacking the dots” on a crime map. “Attacking the dots” is when police use computerised mapping to identify areas of high crime and then, rather than use community policing principles to try to determine the underlying causes of crime, they respond in the areas with traditional methods such as directed patrol. The problem with this and other similar aggressive policing strategies is that they focus on immediate results which usually result in only short-term crime reduction due to crime displacement (Paulsen & Robinson 2004:225).

Research aimed at sorting out the nature of the relationship between place and crime is crucial and becoming increasingly feasible as spatial data capabilities proliferate. One of the first priorities is research on the nature of crime hot spots, especially the typical life course (or crime "career") of areas with high concentrations of crime, to determine whether the unusually high levels persist for any length of time. While spatial analysis remains a promising tool, the very early stage of research on the relationship between crime and place is reason for a degree of caution. Considerably more research is needed before we look to location as a primary target for crime control efforts. Both basic social science research and well-designed applied research on specific police interventions will be of value.

In the researcher's view, the combination of well-defined spatial information with community policing principles provides a platform for launching preventative measures to combat crime in the long term. Spatial information is a good visual mechanism to monitor human activity (land use) and the behaviour of crime patterns. Spatial technology, combined with a good communication strategy in place with the community to create crime awareness, can only improve the combat against crime.

5.3.5 Implications of remote sensing for future crime mapping and spatial analysis

The improvement in resolution, a greater number of temporal revisits through constellations of satellites and advanced geo-processing with object-orientated image analysis techniques will provide critical monitoring capabilities for the police. The additional spectral capacity with hyperspectral sensors opens the door to further research into change detection applications, such as the identification and monitoring of illicit crops and vegetation changes across borders. The improved spatial resolution of remote sensing enables the monitoring of urban and informal settlement areas. This will contribute to the understanding of changes in human activity and its effect on crime. The affordability and quasi-real time image delivery through advanced geo-processing supply chains also make an important contribution during the management of disasters such as floods and fires. The role of the SAPS in natural disasters will surely benefit from remote sensing data in the form of pre- and post-space maps which will allow assessment of the impact of a disaster during mission planning.

The operational use of remote sensing combined with the science of criminology by the SAPS is still in its early stages. In the gathering of crime intelligence very high resolution imagery is being used in police criminal profiles to assess the environment in which a suspect operates. The use of remote sensing, for example in geo-profiling of serial killers, is becoming common practice to ensure that the environment around a crime scene is spatially well analysed and understood by the investigator (Pistorius 2005:42).

5.3.6 Spatial technology as a science

In the researcher's view this study is pioneering work in criminology. It has introduced the relevance of spatial technology that originated from the natural sciences has created an additional specialist field for criminologists. An intimate knowledge of crime is combined with spatial technology as a tool with which to analyse and combat crime. The methodology described here provides a fresh outlook for up-and-coming criminologists and is an important new occupational field within law enforcement agencies, especially in South Africa.

5.4 CONCLUSION

The advances in information technology and electronic engineering have created the possibility of integrating spatial technologies into crime analysis and crime prevention strategies in new ways.

Some core aspects have been highlighted as contributions to the science of criminology. Various articles and books have been published which discuss the use of spatial information as a valuable tool to combat and prevent crime.

These publications mainly concentrate on geographic information systems (GIS) combined with supplementary information gathered during investigations and from police systems such as the crime administration system (CAS). The application of remote sensing imagery to complement GIS analysis is still lacking. The point data to illustrate a crime incident is automated through a process called geo-coding, but an area without a formal street index or cadastre makes is very difficult and requires physical GPS readings. Now, however, the improvement in the geometric accuracy of very high resolution satellite imagery will enable these points to be gathered directly on the imagery and eliminate physical field work, with savings in costs and time. Remote sensing can be used to update administration boundaries and delineate changes in peripheries, which is essential to understanding of the growth patterns within land use classes.

Informal settlement areas in South Africa bring to light socio-economic problems that need to be addressed. These areas are very difficult to analyse without remote sensing imagery as no formal cadastre exists for them, coupled with a very high diversity in densification and periphery growth. Temporal revisits to assess change over these areas in order to adapt policing strategies will yield an improved information layer to prevent crime.

However, the generation of computerised maps from remote sensing and GIS layers are not the only information that must be used to prevent and combat crime. Only to “attack the dots” is a short-term solution to crime. It is absolutely essential to educate members of the SAPS to use spatial information strategically, and to combine this with police science to ultimately manage and control crime in South Africa.

Spatial technology as a tool to combat and analyse crime is not only "nice to have" but is essential for any police department. The combination of remote sensing and GIS for policing is still in its early stages and will require continuous research to implement it finally as an operational system. Spatial technology is an ideal way of improving and confirming criminological theories such as the ecological theory. During this study mention was made of the

Social Structure Theories, especially the Social Disorganisation Theory cluster which stresses the "place" and the environment that surrounds criminal activity (see section 2.2.6.1).

Criminology is not only a handy science for describing crime, but its core function is to prevent and combat crime. Spatial technology is a tool that will assist with the development of prevention strategies and their monitoring. The challenge in South Africa is to build capacity and specialised skills in the SAPS and related agencies which will eventually turn the tide of crime. The ground-breaking work of this study can be regarded as a cornerstone of new knowledge which is being injected into the science of criminology. It will create a new field of expertise within law enforcement agencies, which will use a combination of remote sensing and GIS to better combat crime through detailed spatial analysis techniques. Applying the spatial analysis techniques in this study into an optimised crime combating plan, creates new research opportunities in the science of criminology.

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