THE FEASIBILITY OF USING AN AUTOMATIC, DEMARCATION PROCESS ON SATELLITE IMAGERY TO IDENTIFY SETTLEMENT CHANGE FOR CENSUS PURPOSES

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ABSTRACT

The study was initiated from the specific need to provide planners, managers and other GIS users with geographically accurate population data derived during the census surveying process. A basic assumption is that settlements can be digitally demarcated through an automatic classification process using spectral values from satellite imagery. The classification process was combined with a texture analysis to improve the accuracy of the automatic classification. The bulk of the investigation was to suggest a scientifically appropriate classification procedure and to evaluate the results using classifications derived from a combination of satellite imagery and orthophoto's. The outcome of the automatic classification process proved to be highly accurate except for the high "chance" element when verifying results where only two classes are present.

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- *“God is more interested in your character than in your comfort”.*

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CHAPTER 1: Introduction

"Although world population has shown signs of a lowering growth rate as a result of declining global fertility since 1981, the net addition still amounts to 80 million per year. It was estimate by the United Nations that by the year 2110 the world population could stabilize itself at 10.5 billion, which will be nearly two and a half times larger than the present population of 4.4 billion" (Lo, 1986:41).

The increase in world population contributes to incessant pressure and impact on the global resources, global development and global environment (Lo, 1986). Human impacts on the environment, therefore, represent the most challenging issues of the 21'st century. Monitoring population changes, consequently, is crucial to planning and development and for this, various tools have been utilized. Remote sensing has been used as such a tool for monitoring population dynamics. The utilization of satellite imagery for census purposes has previously been limited to general, settlement change mapping, while for decades aerial photography was used as a platform for collecting demographic data; a commonly used example is counting houses (Stern, 1985). Even with the current availability of high resolution aerial photography, an area cannot be precisely enumerated, but population estimates can be made based on the average number of people living in each dwelling per household (Donnay *et al.*, 2001). The average number of people in each household is determined using ground based sample surveys.

It is clear that enumeration of human population using satellite imagery is as problematic as, and possibly even more complex than the use of aerial photography. David (2000:1) clearly identifies the key issue "*It is not possible to conduct the census by flying a satellite over the country and counting all the people. That is science fiction …*". The idea of using satellite imagery in the census demarcation process is not new; this technology was investigated in the mid 1970's when the resolution of satellite imagery was so low that even the identification of a road was very difficult, let alone individual buildings (David, 2000). Images with a spatial resolution greater than one meter are accessible with the high-resolution satellite imagery that is currently available. The scale of analysis varies from 1:10 000 to 1:25 000, which is typical of projects dealing with urban planning and analysis (Donnay *et al.*, 2001). Recent developments highlighted above, have stimulated research towards using satellite imagery for census demarcation.

The use of satellite imagery for nationwide population census purposes is still in its infancy, even in many First World countries (David, 2000). In the case of South Africa, satellite imagery was used in Census 2001 and contributed to the current tendency of using First World technology for the solution of Third World problems (South Africa, 2000). High population growth rates, together with an absence of adequate aerial photographic coverage and cost effective data processing are possibly the reason for the success (or potential success) of First World satellite technology being used for census purposes in Third World countries, despite the relative "expense" of the methodology (South Africa, 2000). A number of African countries, notably Tanzania, Nigeria and Sudan, have already experimented with the use of satellite imagery for demarcation of new settlements (Olorunfemi, 1983; Stern, 1985).

In the South African 2001 census, five broad settlement types were identified for demarcation purposes; namely, Formal Urban, Informal Urban, Rural, Tribal and Institutions (Stern, 1985). The use of satellite imagery focused primarily on the settlement changes in rural and tribal areas, where fieldwork was difficult due to the relative inaccessibility of these areas (Stern, 1985). Settlement changes in the rural areas differs from urban change in cities and towns, in the sense that the boundary of these settlements are not defined and that large open spaces within these "rural" settlements make the boundary between settlements and the non-populated open areas more vague (Stern, 1985).

Compared to the satellite assisted 2001 census, the demarcation process during the 1996 Census in South Africa was a labour-intensive process where enumerator areas were mostly demarcated from the 1:50 000 topographical maps (South Africa, 1996). The whole country was divided into Enumerator areas (EA's) or land parcels by field surveying all the areas and demarcating these areas on 1:50 000 topographical maps (South Africa, 1996).

The manual demarcation process of 1996 was changed radically during the 2001 Census where satellite imagery was used as the data source (replacing the 1:50 000 topographical maps) and the 1996 Enumerator areas were used as a basemap, from where urban population changes (comparing the settlements as identified on the 2001 satellite imagery with the 1996 EA's) were identified and manually mapped from satellite imagery. High-resolution satellite imagery, namely SPOT Panchromatic imagery with 10m spatial resolution was used in the pre-census cartography process. Digital aerial photography was then used to survey and further map in more detail these specific areas (South Africa, 2000). This was the first time nationally that visual interpretation from satellite imagery was used for census purposes, with relatively great success in this project.

1.1. The Academic problem, aims and objectives

The importance of using technology to support decision making in demographic applications is increasing, and to emphasize the importance of using technology such as remote sensing in census applications, it is necessary to first examine the current status quo and analyse the benefits that remote sensing (satellite imagery) could hold in for census purposes.

The main problem confronting the census managers, Statistics South Africa (STATS SA), was that the spatial and attribute data used in the demarcation of Enumeration Areas (EA) had shortcomings and were incomplete or non-existent, specifically the cadastral and topographical backdrop for informal urban areas and informal rural areas. The boundary description for Enumerator Areas was outdated and in many cases no longer applied, because of rapid changes that had taken place in settlement areas. An example of such an incomplete and vague description is (Bezuidenhout, 2000: 2): "*EA number 0195 Ba Ga Phuduhutswana Tribal Authority – Painted in Baby Blue. Start at house no. 154C moving northeast along the main road up until house no. 114C. Turn and move westwards up until house no. 117C then turn and move southwards up until house no. 154C, your starting point*."

Before the fieldworkers were sent to demarcate the different Enumerator Areas, it was necessary to determine where urban expansion and economic development appeared (Bezuidenhout, 2000). Traditionally the fieldworkers were sent to certain areas where they would search for new developments and update Enumerator Areas on 1:50 000 hardcopy maps. The process was time consuming and expensive, not to mention inaccurate, since many developments could be missed in this way (Bezuidenhout, 2000).

For the 2001 Census in South Africa, urban change detection was undertaken from satellite imagery, using manual mapping and visual interpretation procedures. The process is relatively accurate but time consuming since every area must be mapped manually. Satellite imagery was able to solve many of the previously highlighted problems, changes and new developments were easily identified. Demarcation of Enumerator Areas was possible by means of "heads-up" or "on-screen" digitising using recent imagery, which improved the demarcation process drastically from the previous census in 1996 (Bezuidenhout, 2000).

To improve demarcation of Enumerator areas an automated classification process is necessary, which is faster and more cost-effective than the visual interpretation and manual mapping of settlement change. A combination of classifications, texture analysis and filters can be applied to assist in the identification process of settlements. If the process is successful, the use of automatic classification could be useful for a wide range of applications for example urban and regional planning, transport and resource management.

In order to achieve the goal to investigate and evaluate the possibility of using automatic, computerised, demarcation processes in demarcating the urban settlement changes from satellite imagery a few aims and objectives were set, namely:

- To evaluate the suitability of SPOT – Landsat merged satellite imagery as remote sensing data source in the demarcation of settlement change.
- To provide a relative, accurate, automatic classification procedure that could be used for future census demarcation. The procedure must be repeatable to enable accuracy to be monitored.
- To evaluate the feasibility of the combination of automatic classification and texture analysis in demarcating settlements.

1.2. Conceptualisation

Given the technical nature of remote sensing, a number of concepts are fundamental to understand the scope, methodology, and objectives of the study; these are outlined below.

1.2.1. Remote sensing

In this study, remote sensing is used as a tool for improving demarcation of Enumerator Areas and, indirectly, the population census process. It is, therefore, crucial to define remote sensing and to understand what the technology encompasses. Remote sensing is said to be a range of techniques for obtaining information about objects through the analysis of data collected by special instruments that are not in physical contact with the objects of investigation (Berlin, 1998; Lillesand & Kiefer, 1979). A range of digital, satellite-based sensor systems, as well as photogrammetry and conventional analogue sensors, including aerial photography are the instruments used in remote sensing (Donnay *et al*., 2001; Spencer, 2000). The most widely recognised remote sensing platforms are satellites that use an orbital or sub-orbital platform from where the electromagnetic radiation reflected or emitted from the underlying terrain is measured (Jensen & Jackson, 1997).

1.2.2. Classification

Different processes are applied in the analysis of satellite imagery, but the main procedure used to automatically identify settlements is classification. The foundation for classification is spectral pattern recognition, where each pixel in the image data set is labelled according to the category of which it is part. If the classification is automated it can either be conducted with human supervision (Supervised Classification) or be totally automated (Unsupervised Classification) (Lillesand & Kiefer, 1979; SPOT IMAGE, 1989). Supervised Classification involves the extraction of representative spectral features of the different land cover types by the analyst, and these sample regions associated with each potential class are used to train the classifier (Donnay *et al*., 2001). Every pixel in the image is then classified depending on how close the spectral value of the pixel is to the spectral feature of the training sample (Anon, 1997).

Unsupervised Classification occurs when the computer automatically groups the features with equivalent spectral values in different classes depending on the spectral values of the specific feature (Lillesand & Kiefer, 1979; SPOT IMAGE, 1989; Anon, 1997); the process is based on statistical grouping of similar spectral values (Lillesand & Kiefer, 1979; SPOT IMAGE, 1989; Anon, 1997). Following automatic grouping of spectral values, the remote sensing analyst assigns a specific land cover type to the different clusters (Anon, 1997 SPOT IMAGE, 1989; Lillesand & Kiefer, 1979).

1.2.3. Change detection

The dynamic nature of population and settlements make it necessary to be able to identify change over a specific time period. For this study it is the main rationale when developing a classification process for identification of settlements. Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Deer, 1995; Ferreira, Sevenhuysen & Treurnich, 1998). In most cases, the primary objective of change detection on an urban scale is to detect urban growth areas.

1.2.4. Population census

"*A population Census is the process of counting the number of people, at a given point in time in a country and collecting additional information about their demographic, social and economic characteristics*" (South Africa, 2000:4). A sample survey is done by selecting specific areas (samples) and performing the census process only on these sample areas. Sample surveying is generally undertaken between population censuses to estimate the extent of population growth in certain areas (Stern, 1985). In the case of this study, the need to develop a model from where settlements could be identified automatically is to support population census, which occur every five years in South Africa.

1.2.5. Enumerator, enumerate, Enumeration Areas (EA's)

The people and products aimed at, when developing this new classification model are the enumerators and Enumeration Areas. Enumerators are people who collect the demographic data on the people living in households in private accommodation, for example flats, houses, shacks *etc.;* these people are temporary appointed staff that enumerates the people on census night. Each enumerator is assigned to enumerate a specific Enumerator Area. An Enumerator Area is a unit; which has approximately equal population size, and has distinct boundaries that are describable. The size of an Enumerator Area varies, depending on a number of factors such as population density, land use, social boundaries *etc* (South Africa, 2000).

1.2.6. Demarcation

Before enumeration is undertaken, the country is divided into land parcels (EA's) of approximately equal population size. Demarcation is the process of dividing the country into different Enumerator Area's, where the boundaries, types, and number of communally based services are identified and described (South Africa, 2000).

CHAPTER 2: Remote sensing

To be able to understand the science behind remote sensing and thus make sense of it as the tool in the identification process of settlements, it is necessary to be informed about the how, what and when of remote sensing. Knowledge relating to the function, interpretation, reflection of specific features, and selection of specific satellite imagery and bands in this case study, would contribute to a more comprehensive understanding.

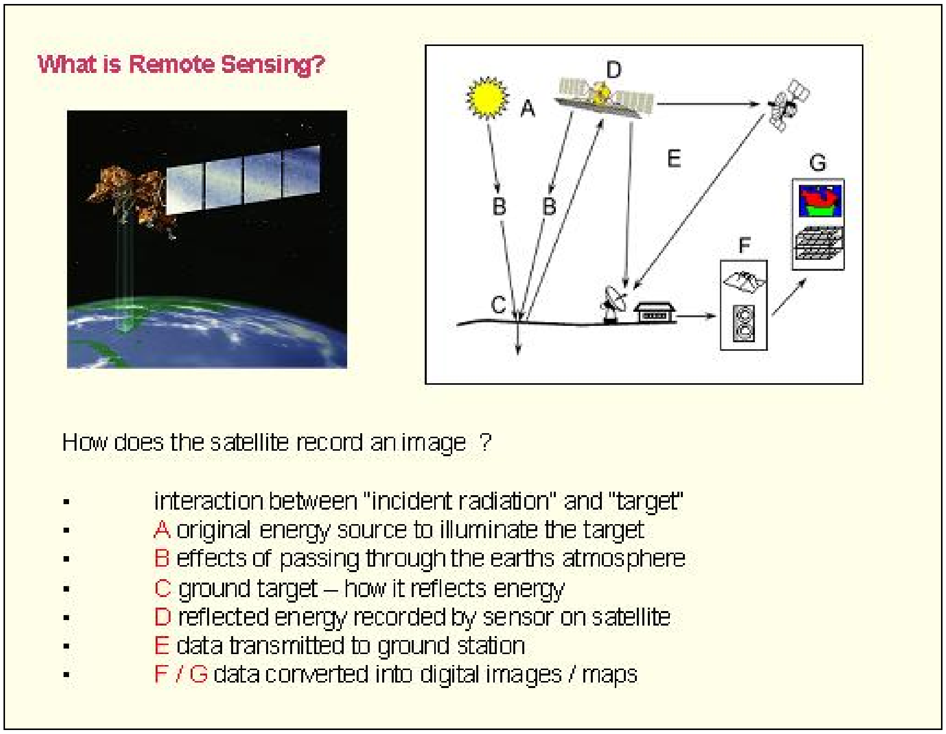
2.1. Historical background

Remote sensing as a technology started with the first photographs in the early nineteenth century (Lillesand & Kiefer., 1979). The photographic camera was the prime remote sensor for more than 150 years and was only replace by the aerial photo in the 1840's (Lillesand & Kiefer., 1979). The first aerial photographs were taken from balloons (Lillesand & Kiefer., 1979). At the time of the First World War, cameras mounted on airplanes provided valuable information on large surface areas for military reconnaissance and aerial photo's remained the standard tool for providing photographs from a vertical or oblique perspective (Lillesand & Kiefer., 1979).

Remote sensing above the atmosphere, originated early in the space age (1946), when V-2 rockets, acquired from Germany after World War II, were launched by the US army (Lillesand & Kiefer., 1979). The first non-photo camera sensors mounted on unmanned spacecraft were utilized primarily for meteorological purposes in the 1960's with the TIROS-1 satellite (Lillesand & Kiefer., 1979). The development of the TIROS satellite was the start of more sophisticated image sensors that were incorporated in satellites (Lillesand & Kiefer., 1979). The first sensors used were like cameras, which produced low detail (poor resolution) black and white images of clouds and of the Earth's surface, where there was no cloud coverage (Lillesand & Kiefer., 1979). These images were of great value to the meteorological community who needed information on clouds, air, temperatures and wind patterns on a regular basis (Lillesand & Kiefer., 1979).

A significant advance in sensor technology stemmed from the development of multispectral images in the 1960's (Short, 2000). Radiation is subdivided into bands (intervals of continuous wavelengths), allowing sensors to make measurements in discrete bands or ranges (Short, 2000). Multispectral sensors allowed more specific wavelengths to be recorded where features (objects on the earth surface) could be more easily distinguished and separated by means of displaying specific wavelengths in RGB colours (red, green and blue). Some features are more visible in a specific wavelength or band combination, and depending on the application, the necessary bands are chosen accordingly (Lillesand & Kiefer., 1979). The first Apollo programs facilitated the acquisition of multispectral orbital photographs for earth resources studies (Lillesand & Kiefer., 1979). During the course of four days 140 sets of multispectral images were obtained with an electrically driven Hasseblad camera (Lillesand & Kiefer., 1979). By the late 1960's the first unmanned satellite specifically dedicated to multispectral remote sensing was designed and constructed by NASA. ERTS-1 (Earth Resources Technology Satellite) was launched on 23 July 1972 and was renamed Landsat prior to the launching (Lillesand & Kiefer., 1979). Seven of these series satellites have been launched since 1972, with the latest (Landsat 7) satellite launched on 15th of April 1999.

During the 1970's and 1980's Landsat scanners dominated the earth observing sensors, but these instruments contained moving parts, such as oscillating mirrors, that were subject to wear and failure (Fig. 2.1).



What is Remote Sensing?

How does the satellite record an image ?

- interaction between "incident radiation" and "target"
- A original energy source to illuminate the target
- B effects of passing through the earths atmosphere
- C ground target – how it reflects energy
- D reflected energy recorded by sensor on satellite
- E data transmitted to ground station
- F / G data converted into digital images / maps

FIGURE 2.1: Functioning of Landsat scanners (Adapted from: Geospace International, 2002).

A new device namely the "Pushbroom scanner" which uses stationary Charge Coupled Devices (CCDs) as the detector was developed in the 1980's. Instead of having a single detector, multiple small detectors were utilized (Lillesand & Kiefer., 1979). When photons strike the CCD, electronic charges develop and each linear array is sampled very rapidly in sequence, producing an electrical signal that varies with the radiation striking the array (Short, 2000). As the satellite moves over the earth, successive lines of ground coverage are thereby obtained (Short, 2000). This changing signal recording goes through a processor to a recorder, and finally, is used to drive an electro-optical device (Short, 2000). Multispectral images could also be generated by using filters that separated the different wavelengths (Short, 2000). The first use of CCD-based pushbroom scanner was SPOT-1 launched in February 1986 by France, with the participation of Sweden and Belgium (SPOT, 1989). Five SPOT satellites have been launched since then with SPOT–5 higher spatial resolution of 5m for the panchromatic image and 10m for the multispectral image (Donnay *et al.*, 2001).

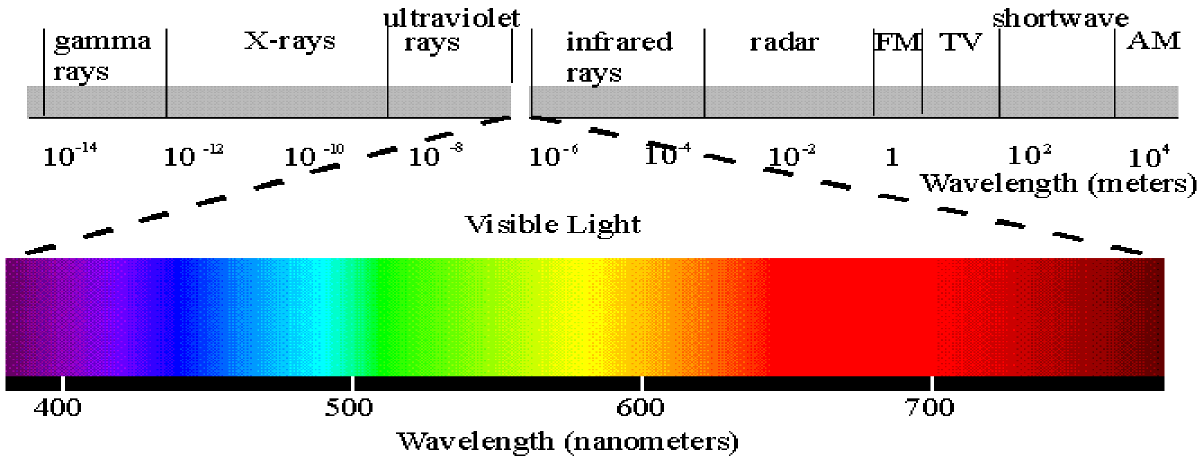
The push-broom scanners have certain advantages over the optical mechanical line scanning (Lillesand & Kiefer., 1979). The push-broom scanner uses less power, is lighter in weight and has no moving parts that make this scanning method preferable to the optical mechanical line scanning (Lillesand & Kiefer., 1979). The disadvantages of push-broom scanners are that available detectors are not suitable for use with longer wavelengths (>1.05µm) (Lillesand & Kiefer., 1979). To produce a uniform response over a scene, each detector in the linear array must be individually calibrated but the detectors tend to be quite stable so that calibration will become a one-time effort (Lillesand & Kiefer., 1979).

The general trend concerning remote sensing in the 1990's was the "commercialization of space", where companies take advantage of the great practical value of satellite imagery concerning certain income-producing applications (Short, 2000). The launch of a new generation of optical satellite sensors, for example IKONOS-1, where higher spatial resolutions could be acquired (up to 1m), contributed to new "commercial" (especially urban-orientated) applications where high level of detail is needed for analysis (Donnay *et al.*,2001).

2.2. From reflectance to image

The underlying basis of remote sensing is the measuring of varying energy levels of a single entity (Short, 2000). The photon is the fundamental unit in the electromagnetic force field (Short, 2000). Variations in the photon energy are the cause of differences in the frequency and wavelength of energy (Short, 2000). Electromagnetic energy has been classified by wavelength and arranged to form the electromagnetic spectrum (Keller, 2000). Visible light only comprises a small part of the electromagnetic spectrum as shown in Fig. 2.2. When internal processes of incoming electromagnetic radiation excite any target material, it will emit photons of various wavelengths typical of a specific feature (Short, 2000).

The sun is the most obvious source of electromagnetic radiation for remote sensing. However, all matter at temperatures above –273 °C continuously emits electromagnetic radiation (Lillesand & Kiefer., 1979). When solar radiation hits an object or target it may be transmitted, absorbed or reflected in different ways depending on the target material and wavelength of the insulation and this leads to the different types of reflectance (Fig. 2.1) (Anon, 1997). Some objects are capable of transmitting the light through especially surface materials like water, without significant dispersion (beam emerges more or less at the same angle). Other objects absorbed energy by converting energy to heat or emitted with a change in wavelength and a time delay. Energy could also be reflected (move away from the target) at the same angle or scattered in all directions in most cases because of the nature of the object's surface (microscopic roughness) (Anon, 1997; Short, 2000).



Violet:	0.4	-	0.446µm
Blue:	0.446	-	0.500µm
Green:	0.500	-	0.578µm
Yellow:	0.578	-	0.592µm
Orange:	0.592	-	0.620µm
Red:	0.620	-	0.7µm

FIGURE 2.2: The electromagnetic spectrum (Geospace International, 2002).

Remote sensing depends largely on the recording of the reflection of solar energy, which could be smooth or rough depending on the reflecting surface and condition. Differences in reflectance make it possible to distinguish between various features and to differentiate between the “state” of surfaces (Lillesand & Kiefer, 1979). Natural surfaces are in general rough in the shorter wavelengths, infrared and less so in the microwave region (Short, 2000). “*The roughness of an object is a function of the relief variation in relation to the wavelength of the reflected energy”* (Lillesand & Kiefer, 1979:504). Rough surfaces tend to scatter the reflected energy in all directions so that most of the energy reflects away from the sensor and therefore causing a low return signal (Lillesand & Kiefer, 1979). This is important in order to understand why certain features appear “darker” or “lighter” in the various bands and this is very useful especially when certain band combinations must be selected to emphasize certain features.

Gamma rays, x-rays, and most ultraviolet energy are very energetic (high frequency and short wavelength) but do not penetrate the atmosphere and are therefore not used in Remote Sensing (Fig. 2.2). The “visible” portion of the spectrum, which is detected by the human eye, ranges from 0.4µm - 0.7µm in the spectrum. The colour blue is ascribed to the approximate range of 0.4µm to 0.5µm, “green” to 0.5µm – 0.6µm and “red” to 0.6-0.7 (Lillesand & Kiefer., 1979; Short, 2000). The infrared band ranges between 0.7µm and 100µm for the “reflected” infrared. The thermal bands range between 3µm-5µm and 8µm-14µm (Fig. 2.2). The thermal infrared band is directly related to heat while the “reflected” infrared is not (Lillesand & Kiefer., 1979).

Two characteristics of microwaves that distinguish these wavelengths from the rest of the electromagnetic spectrum is that they can penetrate the atmosphere under any weather conditions including haze, light, rain, snow, smoke, clouds *etc.* (Lillesand & Kiefer, 1979). The reason for this is the fact that the longer wavelengths experience less scattering by atmospheric particles than the shorter wavelengths (Lillesand & Kiefer, 1979). Microwave reflection from materials differ from other wavelengths in the visible and thermal spectrum, in the sense that features which could appear “rough” in the visible spectrum could appear “smooth” in the microwave region (Lillesand & Kiefer, 1979). The infrared and microwave (radar) produce a totally different “view” of the environment and could therefore be very useful in addition to energy at visible wavelengths especially when dealing with areas where cloud cover, snow *etc* occur on a regular basis. Thus one must always keep in mind when interpreting satellite imagery that it is not a picture of the earth, but it is data that could be both visible or invisible to the human eye (outside the visible spectrum) depending on the wavelengths and bands used. Contributing further to the possible confusion experience when interpreting imagery is the fact that certain bands have been awarded false colours for example vegetation could be awarded a red colour (Anon, 1997).

The microwave region spreads across 0.1-100cm (longer wavelengths are measured in mm to cm to meters) and includes all the wavelengths used by radar systems (Short, 2000). These systems generate their own radiation and direct this to targets, the fraction returned is measured and these sensors are known as active radar sensors (Short, 2000). A more detailed discussion concerning active and passive sensors would be given later in the study.

The distance between two peaks of a wave is called the wavelength and the total number of peaks that pass by a reference in a second is that wave's frequency (Short, 2000) (Fig 2.3). The longer the wavelength, the shorter the frequency and *vice versa* (Fig 2.3). In the remote sensing environment it is most common to categorize the electromagnetic spectrum according to wavelength and frequency. The most prevalent unit to measure wavelength is micrometer and one micrometer equals 10^{-6}m. The longer the wavelength involved for example the microwaves, the lower its energy content and the more difficult it is to detect radiation. Therefore systems operating in the long wavelengths need to "view" large areas of the earth at a specific time in order to detect energy signals (Lillesand & Kiefer., 1979).

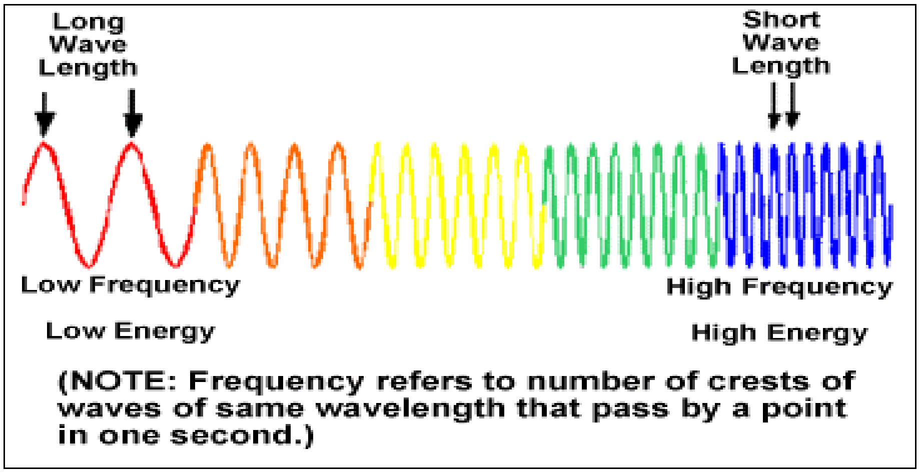


FIGURE 2.3: Wavelengths and frequency (Short, 2000).

Different features for example: soil, water, urban and vegetation has different reflectance characteristics and are therefore spectrally separable. The degree of seperability will differ from band to band. The spectral response permits an assessment of the type and /or condition of the features and has been referred to as spectral signature (Lillesand & Kiefer., 1979) (Fig. 2.4). Vegetation and dry, bare soil are the most separable in the longer wavelengths (>1.8µm), which is the infrared band (ranges between 0.7µm and 100µm for the "reflected" infrared) (Fig. 2.4). Thus, selecting the infrared band would be valuable when performing vegetation analysis and on similar principles the informative bands could be determined when performing analysis on urban areas as in the case of this study.

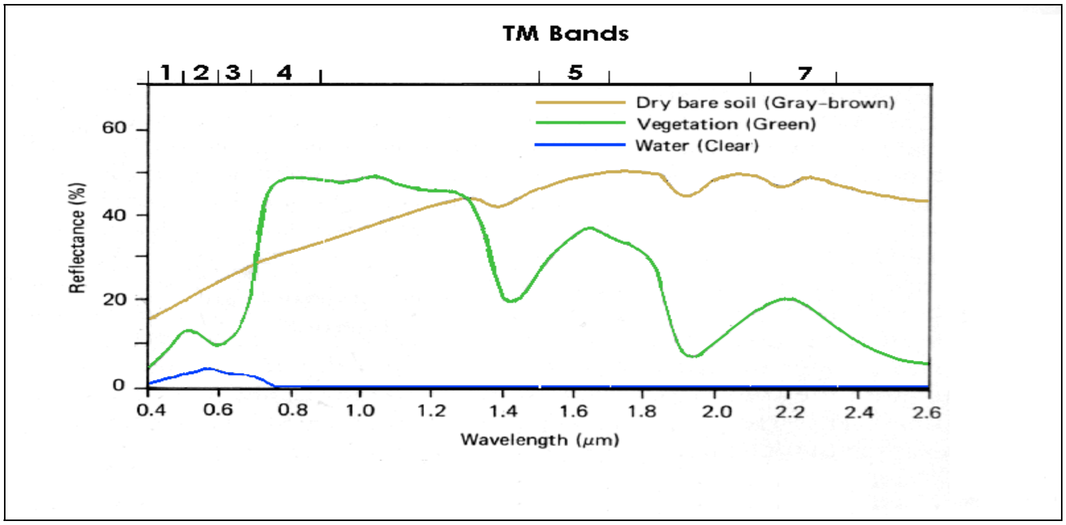


FIGURE 2.4: Spectral signatures (Geospace International, 2002).

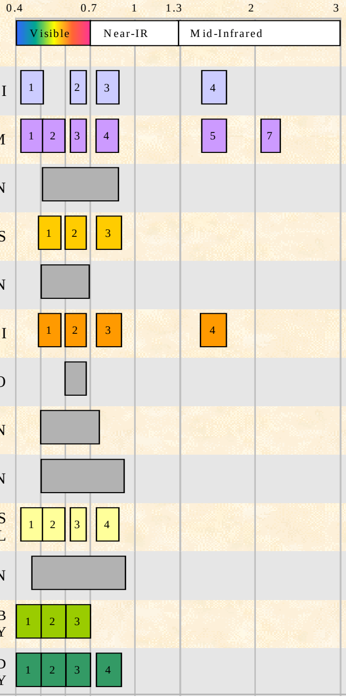
2.3. Types of satellite imagery

Different types of satellite imagery are available and can be acquired depending on the need of the customer. Satellite applications differ and therefore so do the requirements and expectations of the user when selecting the most "useful" type of satellite imagery. Satellite imagery can be categorized in terms of the variation in radiometric, spectral, spatial and temporal resolution and the costs thereof will vary accordingly (Table 2.1). Radiometric resolution refers to the sensitivity of the sensor to incoming radiation. This sensitivity to different signal levels will determine the amount of values that could be generated by the sensor.

The minimum distance between two objects identifiable on an image is the spatial resolution that is determined by sensor altitude, detector size, focal size and system configuration. The pixel size of an image serves as a guideline of what the spatial resolution of an image is. A pixel is the smallest element that an image consists of. In the case of an image it would be the "blocks" which the image consists of. Different sensors record different bands as well as segments of the electromagnetic spectrum, thus the number and size of the bands recorded will differ and is known as the spectral resolution. Temporal resolution refers to the time period before the sensor return to a previously recorded location. This aspect is especially important when change detection is the basis of research (Jensen, 1986).

Distinctions between sensors can also be made in terms of passive and active sensors. Passive sensors intercept reflective energy from the earth's surface and convert this radiation in digital format. The energy source is external and is usually the sun and Landsat and SPOT sensors are examples of these sensors. Active sensors sends out energy and then intercept and measure the fraction returned from the surface for example radarsat (Anon, 1997).

TABLE 2.1: Comparisons of different satellite imagery in terms of resolution and cost (Geospace International, 2002).



Sensor	Spectral Resolution	Spatial Resolution	Temporal Resolution	Spatial Coverage	Cost (ZAR) per km²
SPOT VI	1 2 3 4	1km	daily	2250x2250 km	0.01
LANDSAT 7 TM	1 2 3 4 5 7	30m	16 days	180 x 180 km	0.17
LANDSAT 7 PAN		15m	16 days	180 x 180 km	0.17
SPOT 1,2,3 XS	1 2 3	20m	26 days	60 x 60 km	4.72
SPOT 1,2,3 PAN		10m	26 days	60 x 60 km	4.72
SPOT 4 XI	1 2 3 4	20m	26 days	60 x 60 km	4.72
SPOT 4 MONO		10m	26 days	60 x 60 km	4.72
IRS PAN		5.8m	24 days	70 x 70 km	2.50
EROS PAN		1.8m	4 days	12.5 x 12.5 km	125.00
IKONOS MULTISPECTRAL	1 2 3 4	4m	2.9 days	11 x 11 km	247.00
IKONOS PAN		1m	2.9 days	11 x 11 km	247.00
DIGITAL RGB PHOTOGRAPHY	1 2 3	0.5m to 2m	On request	Variable	300.00
DIGITAL INFRARED PHOTOGRAPHY	1 2 3 4	0.5m to 2m	On request	Variable	300.00

Two types of optical imaging systems are commonly in use: the panchromatic and the multispectral imaging system (Anon, 1997). A single channel detector system within a broad wavelength range would look like a "black-and-white" photograph and the spectral information, or "colour", of the targets is lost and called a panchromatic image (Anon, 1997). Much of the imagery available (*e.g.* SPOT and IKONOS) can be ordered as panchromatic images.

A Multispectral imaging system is a multi-channel detector and each channel is sensitive to radiation within a narrow wavelength band (Anon, 1997). The brightness and spectral (colour) information of the targets are part of the product (image) for example SPOT multispectral (XS) and Landsat Thematic Mapper (TM) imagery (Anon, 1997). The different bands can be selected and displayed using any three bands and visualizing it with any combination of the red, green and blue colours in remote sensing software packages (Anon, 1997).

The more detail required for a specific application, the more expensive the image (Jensen & Jackson, 1997). The current availability of "third generation" satellite imagery (spatial resolution <5m) has stimulated urban applications due to the higher level of detail (Donnay *et al.,* 2001). Landsat and SPOT imagery are part of the "second generation" imagery (pixels between 10m and 30m) and provide sufficient detail for general land use and land cover applications (Donnay *et al.,* 2001). To decide which type of imagery must be accessed, not only must resolution be considered, but also satellite coverage; for example, in applications where access to large areas is required, Landsat with a coverage of 185km x 185km could be more suitable than SPOT (60m x 60km). SPOT imagery, on the other hand, provides the user with higher resolution (more detail) information and therefore combining SPOT and Landsat imagery could be beneficial when taking into account the cost and spatial resolution requirements. For this study the focus is on a combination of SPOT and Landsat imagery.

2.3.1. SPOT imagery

One of the most common earth observation satellites used in monitoring urban areas is the French satellite: SPOT (Donnay *et al.,* 2001). HRV (High Resolution Visible) SPOT sensors provide a single panchromatic image at 10m resolution and three multispectral images XS1, XS2, XS3 at 20m resolution (Donnay *et al.,* 2001). The SPOT 4 satellite carries an enhanced version of the HRV sensor, known as HRVIR (High Resolution Visible Infra-Red), which provides spectral data in the same wavelengths as the SPOT 1,2,3 multispectral (XS) images but with a additional short-wave infrared band (Donnay *et al.,* 2001).

A vegetation monitoring facility, with a spatial resolution of 1km and the same spectral resolution as HRVIR was launched on the SPOT 4 satellite in March 1998 and has been commercial since March 1999 (Donnay *et al.,* 2001). The vegetation instrument provides the receiving station with global data almost on a daily basis.

The SPOT 5 Earth observation satellite was launched in 2001 and is part of the new-generation satellites (high spatial resolution) (Frank-May, 2000). A spatial resolution of 2.5m is acquired in the panchromatic mode of the new SPOT 5 imagery while still maintaining an aerial coverage of 60km x 60km (Frank-May, 2000). The cost of a SPOT full scene 20m multispectral or 10m panchromatic is €1900, while the 10m colour or 5m panchromatic cost in the range of €7 000 and the 2.5m Panchromatic SPOT 5 image will cost around €5 400 each (SPOT Image, 2002).

2.3.2. Landsat imagery

The first three Landsat satellites (1,2,3) were part of the MSS (Multispectral Scanning Systems) and comprised four channels. In 1981 Landsat 4 was launched and carried an advanced multispectral scanner called the Thematic Mapper (TM). The name related to the intended application of this satellite which was to produce classified images (thematic maps) and the system's data were especially useful for spectral pattern recognition. The Thematic Mapper scanner is a seven-channel scanner designed to maximize vegetation analysis capabilities for for especially agricultural applications. Landsat 7 was launched on the 15th of April 1999 with the Enhanced Thematic Mapper Plus (ETM+) as an earth-observing instrument. This satellite has similar orbits and repeats patterns as the previously launched Landsat satellites. As with the Landsat 6 the Landsat 7 ETM+ satellite is designed to collect 15m resolution panchromatic data and multispectral components of seven bands (as with the Landsat 6 imagery) as follows:

- Band 1 (0.45µm-0.52µm) is designed to penetrate water bodies and support analysis of soil, vegetation and land use (Lillesand & Kiefer., 1979).
- Band 2 (0.52µm-0.60µm) is designed for vigour assessment and vegetation analysis purposes and specifically the visible green reflectance peak of the vegetation (Lillesand & Kiefer., 1979).
- Band 3 (0.63µm-0.69µm) is the most important band for vegetation discrimination and emphasizes contrast between vegetated and non-vegetated features (Lillesand & Kiefer., 1979).
- Band 4 (0.76µm-0.90µm) give you an idea about vegetation biomass present in a scene and will assist in crop identification, soil-crop and land-water contrasts (Lillesand & Kiefer., 1979).
- Band 5 (1.55µm-1.75µm) responds to moisture conditions, crop water content and crop type (Lillesand & Kiefer., 1979).
- Band 6 (2.08µm-2.35µm) is important regarding to rock formations (Lillesand & Kiefer., 1979).
- Band 7 (10.40µm-12.50µm) is the thermal infrared channel, stresses thermal related phenomena for instance vegetation stress analysis, soil moisture discrimination and vegetation classification (Lillesand & Kiefer., 1979).

Bands 1-6 of the Thematic Mapper have a spatial resolution of 30m while Band 7 has a spatial resolution of 120m (Lillesand & Kiefer., 1979).

2.4. Case studies on possible applications of satellite imagery

The applications of using remote sensing as a decision support system in combination with GIS to update theme-orientated information and mapping are numerous. Applications include vegetation mapping, land use or land cover mapping, urban sprawl and expansion, geological structure mapping, erosion and soil degradation mapping, and change detection in all these and other fields. Four case studies in the urban environment are briefly described to show the utilization of satellite imagery in environmental management. The case studies show satellite imagery being used as a tool to manage the urban environment and the significance of developing new ideas, concepts and methodologies that could apply to this study.

- In Enschede in The Netherlands, land use or land cover mapping was undertaken using high resolution satellite data, and computer aided GIS techniques in assessing the land use change dynamics between 1993 and 1998 (Nigam, 1998). Urbanization caused changes in city morphology, and social and economic activities, especially near the urban-rural fringe where urban sprawl occurred. High-resolution satellite imagery and rectified aerial photography for 1993 and 1998 were used and land use and land cover were mapped from this imagery. Data from 1993 and 1998 were compared and statistics of the changes were generated to quantify the changes.
- A further case study of urban mapping was the expert system used with Landsat TM to derive a land cover classification for the semi-arid Phoenix metropolitan portion of the Central Arizona-Phoenix Long Term Ecological Research site (Stefanov *et al.*, 2001). An expert system allows for the integration of other sources of georeferenced information such as land use data, spatial texture and digital elevation models (DEM) with remotely sensed data. The use of the other data sources above improves the accuracy of the land use or land cover classification. The additional spatial datasets used in the case study were texture, land use, water rights, city boundaries and Native American reservation boundaries. These datasets were used to perform post-classification sorting. The texture layer was created and referred to the frequency of tonal change, thus areas with the same tonal appearances were classified in an additional layer and stacked as part of the Landsat image. High accuracy levels ranging within 73% to 99% were achieved.
- In Sudan a test area was selected to evaluate the possibility of using remote sensing to support traditional censuses (Stern, 1985). The basic idea was that the people lived in villages and that the size of villages correlated to the number of inhabitants. Settlements were mapped from Landsat imagery and “new” settlements were visited by fieldworkers to update the population census database. The size of the villages was calculated and an algorithm was developed to determine the number of inhabitants in these villages.
- A local case study where SPOT scenes were used to demarcate urban change near the Winterveld region just north of Pretoria was undertaken to enable more effective planning (Franck-May, 2000). Multi-temporal images from 1989 and 1995 SPOT

panchromatic images were compared and used to identify the urban growth of 96 000 people in this specific location in South Africa.

It should be apparent that satellite imagery is both useful and has a wide range of applications. Research conducted uses a combination of previous methodologies to facilitate census enumeration in South Africa. The following discussion approach census enumeration and remote sensing from a methodological perspective.

CHAPTER 3: Census: From hardcopy map to remote sensing

An overview on the theoretical background of remote sensing and possible applications of this tool in the urban environment have been presented. However, it is important to evaluate the use of this tool in practical terms when conducting a population census. An important question before commencing such research is: How is a country divided into the different Enumerator Areas? To answer this census related question it is necessary to consider the theoretical background to urban systems and their functioning within the census framework by discussing the different settlement types and demarcation of these settlement types.

3.1. General background

Urbanisation is a global tendency where people migrate from rural to the urban areas. Available data indicate that the world urbanisation rate has increased from 3% in the 1880's to 55% in the year 2000 (Jianfa, 2000). In Western Europe alone, urbanization has increased from 20% to 75% between the 1800's and 2000's (Jianfa, 2000). This tendency stressed the necessity to develop technology so that urban planning can be undertaken in an efficient and effective manner (Jianfa, 2000). Effective planning largely depends if the governance is based on accurate information and this is where an accurate census is of crucial importance.

In many countries, especially in the developing world, censuses have been faced with accuracy problems due to certain organizational defects, such as the lack of adequate information on the number of settlements and inaccurate delineation of Enumeration Areas (Olorunfemi, 1983). Therefore, measures are required to improve the accuracy and completeness of the census data (Olorunfemi, 1983). Settlement identification from aerial photographs is an accurate method for demarcating enumerator areas, but is time consuming and expensive, if the photographs are available at all therefore researchers have been experimenting with the identification of settlements from satellite imagery (Landsat), both manually and automatically (Stern, 1985). Reining (1980) evaluated the use of Landsat imagery to map population density and carrying capacity in the rural Upper Volta and Niger. A study on using radar imagery as tool for urban studies was compiled by Jensen (1986). Several researchers have suggested remote sensing as tool in census-type enumeration (Stern, 1985). The type of imagery used largely depends on the required resolution needed for a specific project (Table 3.1). Currently aerial photography is still the most common data source used in population estimates, but with the improvements in satellite based technology, medium and lower resolution satellite imagery have become a more cost effective substitute for aerial photography. The new generation high resolution satellite imagery could be replacing the higher resolution aerial photography (Olorunfemi, 1983) (Table 3.1).

TABLE 3.1: Population estimates and suggested remote sensing sources (After Stern, 1985).

VARIABLE	**DATA**	**REFERENCE**
Land use	Landsat	Morrison (1980)
Urban land use	Aerial photos	Kraus *et al* (1974)
		Olorunfemi (1984)
	High resolution satellite imagery: EROS, Quickbird, IKONOS	Frank-May (2000) Stefanov (2001)
Settlement size	Landsat	Welch (1980)
	Aerial photos	Anderson & Anderson (1973)
	Radar	Harris (1985)
	High resolution satellite imagery: EROS, Quickbird, IKONOS, SPOT 5	Frank-May (2000)
Physical factors (Distance from highway to larger urban neighbourhood)	Landsat	Ogrosky (1975)
House count	Aerial photos	Lo & Chan (1980)
		Eyre *et al* (1970)

3.1.1. South African Experience

Statistics SA is the agency that was required, by government proclamation, to conduct the 2001 Population Census for South Africa (South Africa, 2000). Previously the census, particularly the demarcation, was undertaken using labour-intensive methods (South Africa, 2000). From the 2001 Census a "high route" was followed, where cutting edge technology was implemented (South Africa, 2000). The use of remote sensing during the demarcation process demonstrated the advantages of using the "high route" for census applications (Fig. 3.1). Videography, as an additional remote sensing source was only used to quantify the change demarcated from the medium resolution satellite imagery since videography was a more costly data source than satellite imagery.

The first South African National Census following democratisation of the country was conducted in 1996. Between the 1996 Population Census and the 2001 Census, the Enumeration Areas (EA's) were expected to undergo various changes, including:

- Urban expansion especially in the informal areas where the boundaries of the EA's could change or some of the EA's have to be sub-divided (split internally) into several new EA's.
- Where large vacant areas were not included in the EA's the previous census, these areas need to be demarcated into logical entities, but left vacant.

- In cases where an EA cuts across the social boundaries (District council, Local Authority, Place name *etc*) the boundary needs to be changed so that the social boundaries are respected.
- Some EA's could be vacant due to migration to other areas.

To assist in the demarcation process, satellite imagery was acquired and used to identify areas where settlement change has occurred (Fig. 3.1).

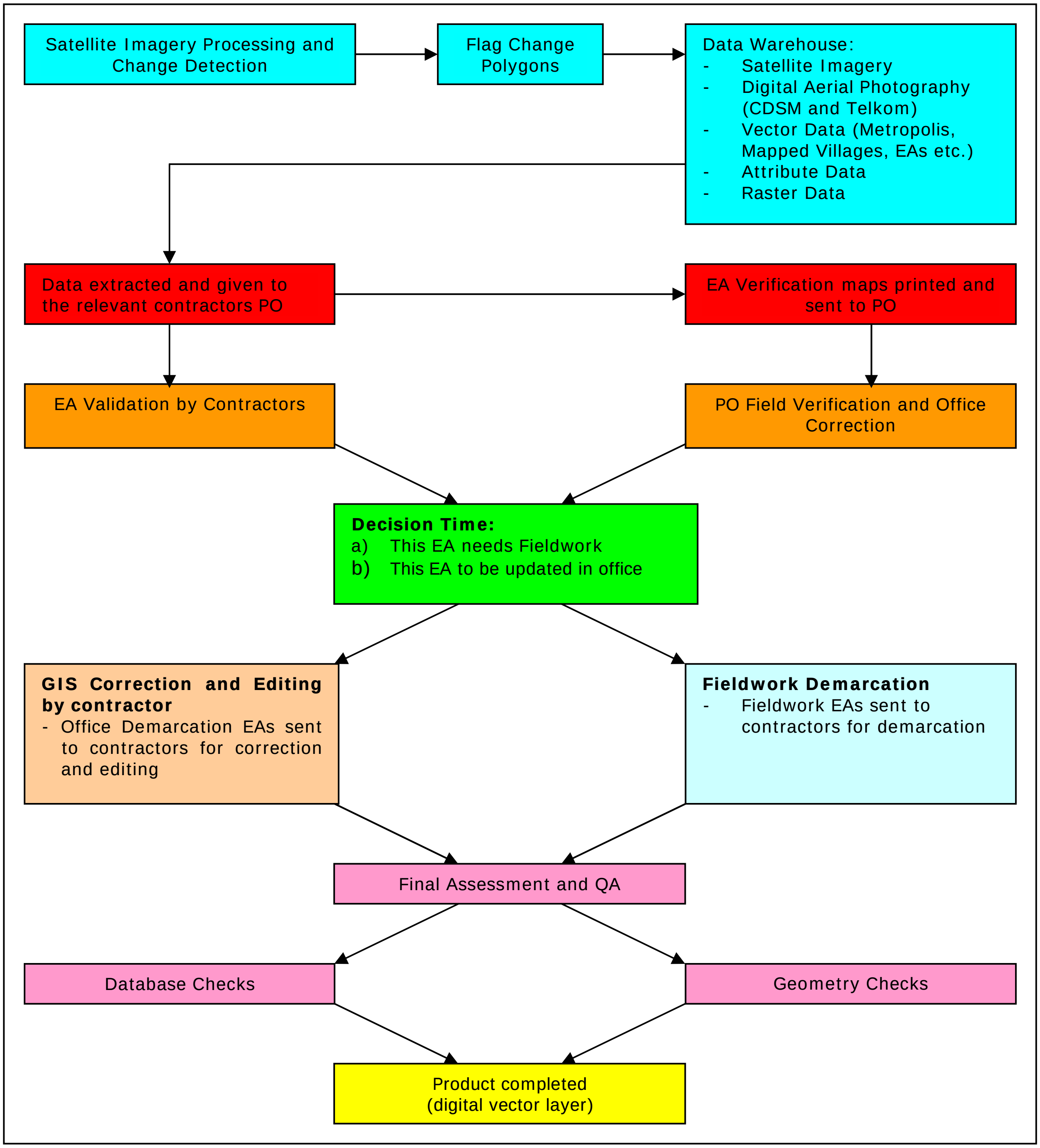


FIGURE 3.1: The census framework (2001) for EA demarcation (South Africa, 2000).

SPOT Panchromatic imagery was used to flag settlements where urban expansion or decline has occurred (Fig. 3.1) (South Africa, 2000). Fieldworkers were sent to the above (changed) areas to determine whether demarcation was required and whether this could be undertaken in the office or through fieldwork (South Africa, 2000). If it was decided that the EA needed to be demarcated more accurately in the office, digital aerial photography of these areas was accessed. Due to the rapid changes occurring in urban areas, this photography had to be recent (South Africa, 2000). Demarcation, correction, and editing of the changed, urban environments was performed from the aerial photography and approved by STATS SA (South Africa, 2000). If the extent of the EA change was unsure, fieldworkers were sent into the field to demarcate and verify the change (South Africa, 2000). When the updated EA's were stored in the database, each enumerator had a specific EA assigned to, from where social information regarding the population would be collected and existing databases would be updated (South Africa, 2000).

3.2. Settlement systems and types

A settlement refers to the population grouped together into occupancy units including the necessary facilities and infrastructure (South Africa, 2000). These residence units vary according to structure, complexity, and distribution over a given area. For the South African Census purposes, settlements were classified as individual units and not classified as part of a settlement system, where a few settlements could be classified by pattern and function and therefore be part of one specific system. By describing the different settlement systems, a holistic overview of the relationship and interaction between settlements could be understood. In South Africa it would be possible to divide all the different settlements into the three different settlement systems as described by Chase-Dunn & Willard (1993). These settlement systems could then be subdivided into the different settlement types as proposed by Statistics SA.

The settlement system could be studied on a hierarchical basis and the consideration of the distribution of settlement sizes within a region. The different settlement systems that could be studied are "primate", "normal" and "flat" systems (Chase-Dunn & Willard, 1993). The "primate" system occurs where a single larger settlement in the centre is surrounded by smaller settlements (Chase-Dunn & Willard, 1993). When the second largest settlement is half the size of the largest, the third largest settlement is one-third the size of the largest, *etc*.; a normal settlement system occur or rank-size rule system (Chase-Dunn & Willard, 1993). Some settlement systems are "flat" in the sense that the towns, villages, townships and cities that comprised these systems are more or less the equal in size (Chase-Dunn & Willard, 1993). The study area at Pietersburg (Polokwane) in the Northern Province of South Africa is an example of such a "flat" system.

The central place theory developed by Christaller in 1933 is another urban system concept. According to this theory the location, number, size, spacing and function of the urban system could be explained in terms of the services performed for surrounding hinterlands. A central place is a service centre or settlement that provides the surrounding areas (hinterland) with a range of goods and services (Jianfa, 2000). These systems could be used as classification systems when comparing different settlements in different countries (Chase-Dunn & Willard, 1993).

On a micro-scale, settlement systems could be divided into areas of different settlement types. In the past settlements were classified according to racial groupings. During the 2001 Population Census the following settlement types were identified and demarcated: Formal Urban, Informal Urban, Rural (farms), Tribal and Institutions (South Africa, 2000). The Formal Urban areas are well-planned and surveyed areas and are shown on 1:50 000 Topocadastral maps (South Africa, 2000); such areas are under the jurisdiction of a municipality or other recognized body. The streets and houses are well planned and of permanent nature. Houses could be constructed of temporary or semi-permanent material as long as they have been planned and surveyed (South Africa, 2000). Informal Urban areas are within the municipal boundaries but are not planned or surveyed and therefore don't exist on the conventional maps (South Africa, 2000). Another type of informal settlements, also known as squatter settlements, is characterised by houses built from temporary materials for example: zinc, mud, wood, plastic *etc.* (South Africa, 2000). Farms or rural areas normally cover extensive areas where the settlements are, in general, not as dense as that of urban areas (South Africa, 2000). The dwellings may comprise of a solitary house for the farm owner and a few dwellings for the farm workers (South Africa, 2000). Outside the urban areas and commercial farms, villages occur where the jurisdictional governance is under either tribal authority body (chief, headman) or a recognised body; *e.g.* a community council (South Africa, 2000). Institutions are temporary or permanent places of residence where inhabitants have a common trait; *e.g.* old age homes, hospitals *etc.* (South Africa, 2000)

The above settlement types were used to classify the different EA's in the 2001 South African Census (South Africa, 2000). In urban settlements, EA's were demarcated when 120-250 houses existed and in the case of informal settlements between 120-170 dwellings (South

Africa, 2000). Tribal and Commercial farms were divided in areas where 80-120 dwelling units existed and institutions where there were more than 500 inhabitants (South Africa, 2000).

In order for the study to be representative, it was important that formal urban and informal urban settlement types existed. The areas selected and rational behind such selection are discussed below.

3.3. Remote sensing and census: The connection point

In Jamaica the following problems were encountered during the census process:

- omission of existent population,
- inclusion of non-existent population, and
- inappropriate definition of urban population.

Apart from the accuracy problems, the population changes so fast that census data is already outdated when it is published (Lo, 1986). A similar situation existed in South Africa, where Third World urbanisation problems prevail. There is, therefore, a need to regularly update census data from a source that is accessible, recent, relatively cost effective, and provides decision makers with maps (Stern, 1985). Remotely sensed data (*e.g.* satellite imagery) could fulfil the above requirements to facilitate decision making (Stern, 1985).

Satellite imagery has to provide planners with certain key data sets to make it useful for urban planning for example (Donnay *et al*., 2001):

- the location and extent of urban areas,
- spatial distribution and nature of land use, within and outside urban areas,
- infrastructure,
- 3-D structure of urban areas, and
- the ability to monitor change in the above features over time.

Remote sensing can provide census applications, valuable inputs especially in the following areas (Olorunfemi, 1983):

- identification of settlements,
- settlement size and ordering,
- demarcation of enumeration areas, and
- inter-census population estimates.

3.3.2. Identification of settlements

The identification and demarcation of urban settlements have a twofold nature; first, detecting the morphological (structural) differences of settlements, and second, delimiting areas that will have relevance for national and international statistical systems, where the features could be compared over space and time (Donnay *et al*., 2001).

Unfortunately, especially in developing countries, topographical maps are sometimes out of print and outdated and, therefore, a monitoring system must be set up that will record an monitor all settlements. The lack of accurate information on the location and distribution of settlements could lead to an inaccurate population census. In Nigeria, Landsat imagery was used as data source in the drier, northern parts, where cloud-free imagery could be accessed (Olorunfemi, 1983). In the coastal areas, radar imagery was used (radar is not affected by the weather as it consists of an active sensor), as a result of the cloud cover to identify settlements and with large success rates (Olorunfemi, 1983). The new datasets could be used to update and revise existing data sources, such as the topographical maps, and prove to be more cost effective in terms of field work (time of compilation of settlement numbers and less labour intensive since field survey activities were limited to only predetermined areas of settlement change (Olorunfemi, 1983).

3.3.3. Settlement size and ordering

Settlement size can easily be calculated from satellite imagery and can be especially useful to estimating the urbanization and urban expansion rate. Settlements can be classified into certain hierarchy of settlements with size as the determinant (Olorunfemi, 1983).

3.3.4. Demarcation of enumeration area

The enumeration areas on which field data will be aggregated can be delineated from aerial photography or high-resolution satellite imagery. Land use within urban areas must be distinguished so that for instance industrial areas must not be included in the house count system. In developing countries, the house count system has been used with great success to determine the extent of squatter settlements on the urban fringes (Lo, 1986).

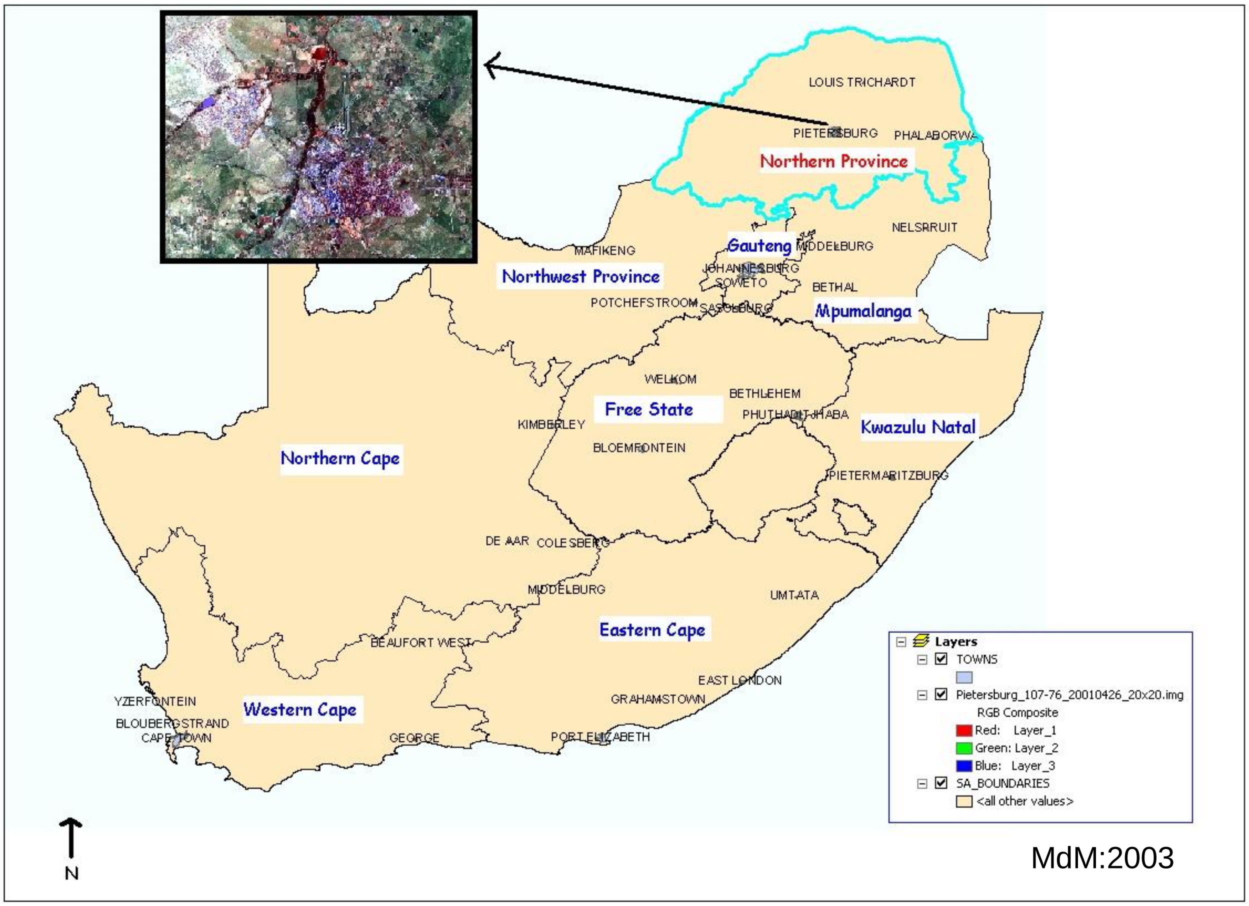
The spatial resolution of the data sources is significant, since single houses must be identifiable and counted (Table 3.1). The spatial scale of an image is important in identifying texture and pattern of urban settlements; for instance, if a satellite image with a large pixel size of 30m (Landsat) were used to count houses, the buildings smaller than 30m could disappear and merged into other non-urban classes and be less accurate (Donnay, 2001). The image scale of Landsat 5 of 1:1 000 000 is to small to use in such applications (Olorunfemi, 1983). Low altitude aerial photographs usually have an image scale of 1:20 000 and cover an area 21km^2 per frame. The higher altitude aerial photographs have an image scale of 1:120 000 and cover 760m^2 per frame and this is very similar to the scale one would get from the higher resolution satellite images (*e.g.* IKONOS, EROS, *etc.*). The latter, smaller scale, data sources are sufficient to perform house counts (Lillesand & Kiefer, 1979).

3.3.5. Inter-census population estimation

Censuses are often gigantic operations performed with long time intervals in between, and because of the rapid population changes that can occur especially in the Third World countries, intercensal counts are needed to support the population projection from the latest census. Intercensal counts are performed as total surveys of an area with approximate inhabitant number estimates for each settlement. A possible methodology of determining population estimates is to determine the relationship between the population size and the aerial extent of settlements or using the crowding index (number of people per house) when using the house counting technique (Olorunfemi, 1983). According to Stern (1985), such censuses may also be conducted at a comparatively low cost compared to the house counting technique to estimate population data that have been used worldwide and seen as a more cost effective alternative (Olorunfemi, 1983).

CHAPTER 4: Study Area

A study area of 20 x 20km was chosen in the Limpopo Province (previously known as the Northern Province) of South Africa with the town of Polokwane (previously known as Pietersburg) as the focus (Fig. 4.1). The area covers the urban, tribal and rural areas surrounding Polokwane and was selected upon the assumption that urban change here is rapid and dynamic. The Polokwane local municipality, in which the study area is located, has a population of just over 500 000 that is predominantly from the Black population group (Fig. 4.2). Given the relative poverty (Fig. 4.3), high unemployment (Fig. 4.4), and range of dwelling types (Fig 4.5), it is clear that there exists a need for adequate planning and development. Without data, planning is not possible, and the basis for evaluating priorities is a census.



MdM:2003

FIGURE 4.1: The study area: Polokwane local Municipality

The availability of other related data sets such as the EA vectors, digital aerial photography, land use datasets and visual interpretation vectors covering the study area also contributed in the selection process of the study area. Polokwane was one of the areas where all these datasets were available and one of the fastest growing towns in South Africa which made this area ideal as a study area. A raster land use classification derived from orthophoto's (2002) and mapped by GeoSpace International for the use of urban planning was used as reference dataset to verify the test dataset derived from the automatic classification. Rural, urban and tribal areas were the focus of this study area since it is here that settlement change mostly occurs. Thus, for census purposes these areas are the most important and need to be identified with the use of satellite imagery.

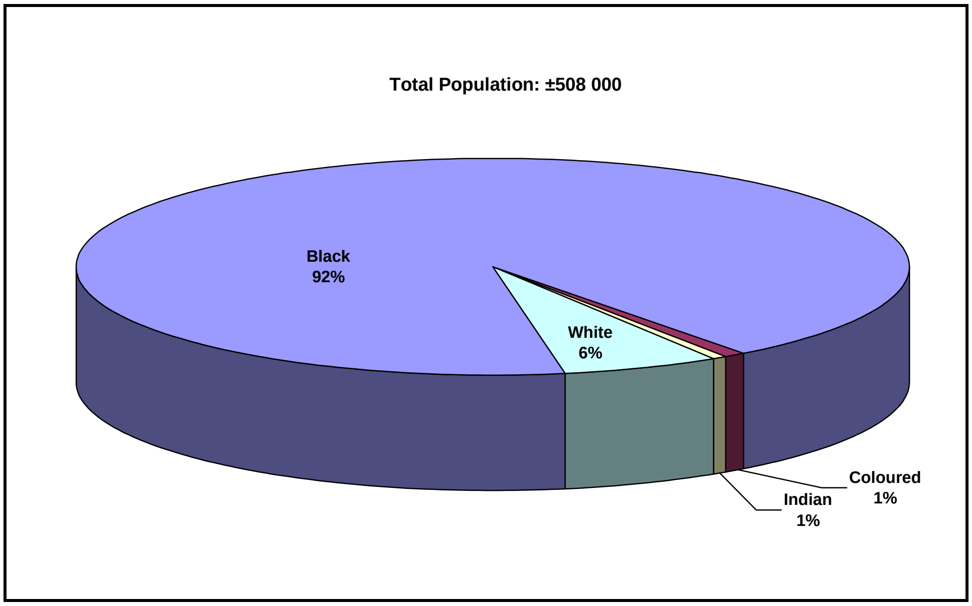


FIGURE 4.2: Population in the Polokwane Municipal Area (After SSA, 2003).

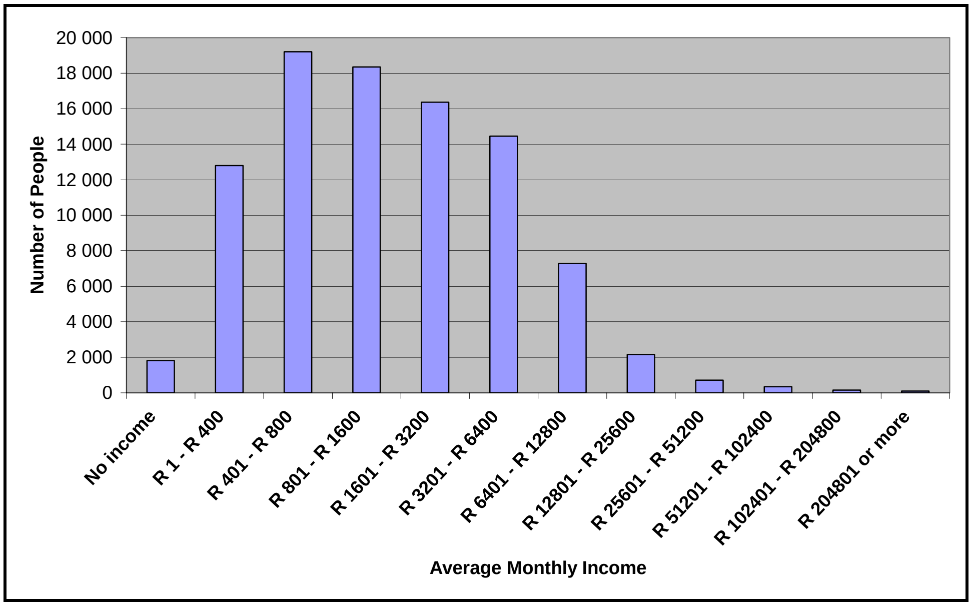


FIGURE 4.3: Income distribution for people living in the Polokwane Municipal Area (After SSA, 2003).

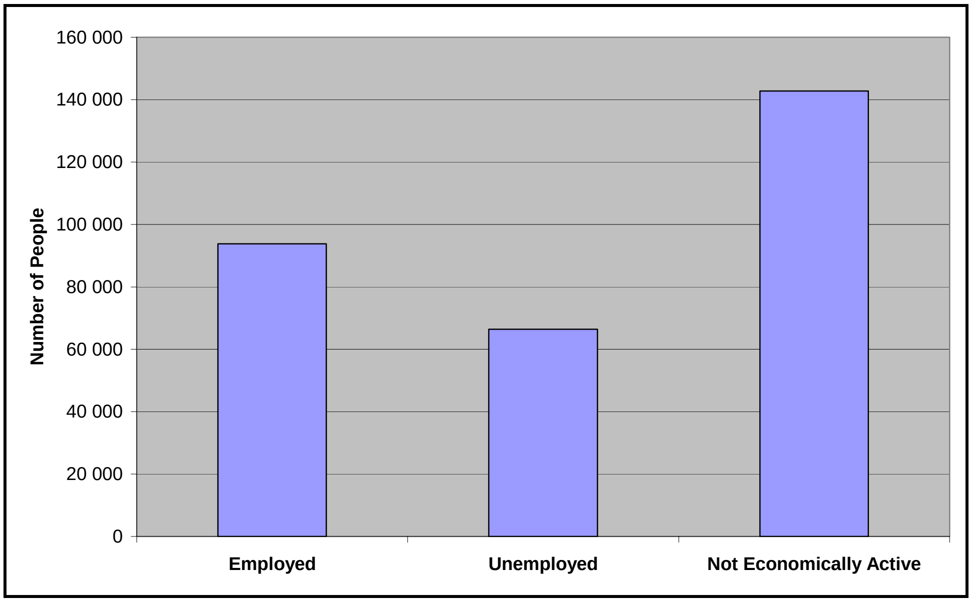


FIGURE 4.4: Employment status for people living in the Polokwane Municipal Area (After SSA, 2003).

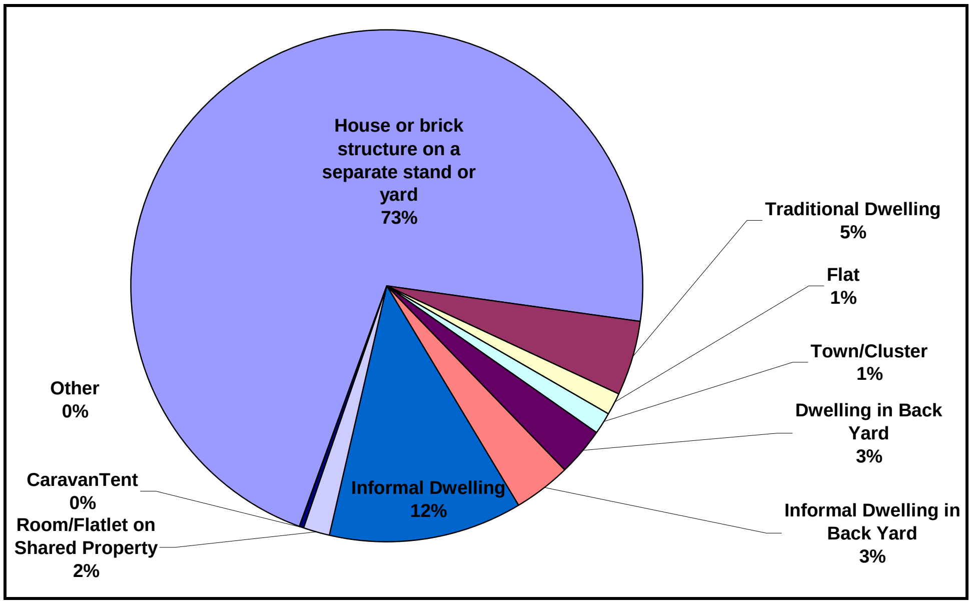


FIGURE 4.5: Types of dwelling occupied by residents in the Polokwane Municipal Area (After SSA, 2003).

CHAPTER 5: Methodology

5.1. Relevant data sources.

Satellite imagery is an important tool in the identification process of settlements for census purposes. The aim of the research conducted for this thesis was the employment of a theoretical framework for a practical, market-driven process and approach that could be economically viable for census purposes in South Africa? A methodological framework was developed for the utilisation of satellite imagery to demarcate census areas in the Polokwane Municipality of the Limpopo Province, which was applied and evaluated (Fig. 5.1).

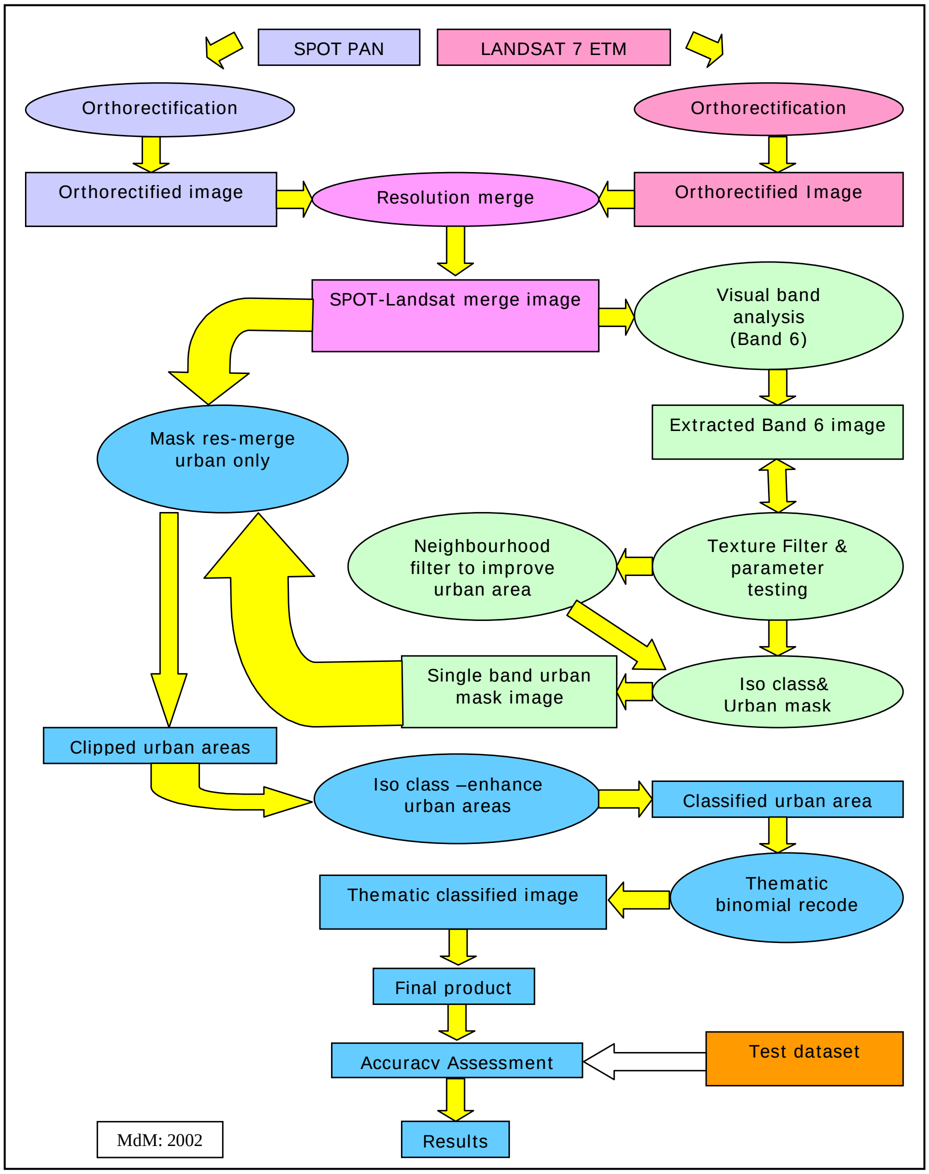


FIGURE 5.1: The methodological framework utilised to apply satellite imagery for census demarcation at a site in the Polokwane Municipality, Limpopo Province.

The first step in the methodological process was to access all the relevant data sources required for the study. All the data used for this study was the property of GeoSpace International and most of this was already available; the only data ordered for the specific research was the Landsat and SPOT imagery from 2001.

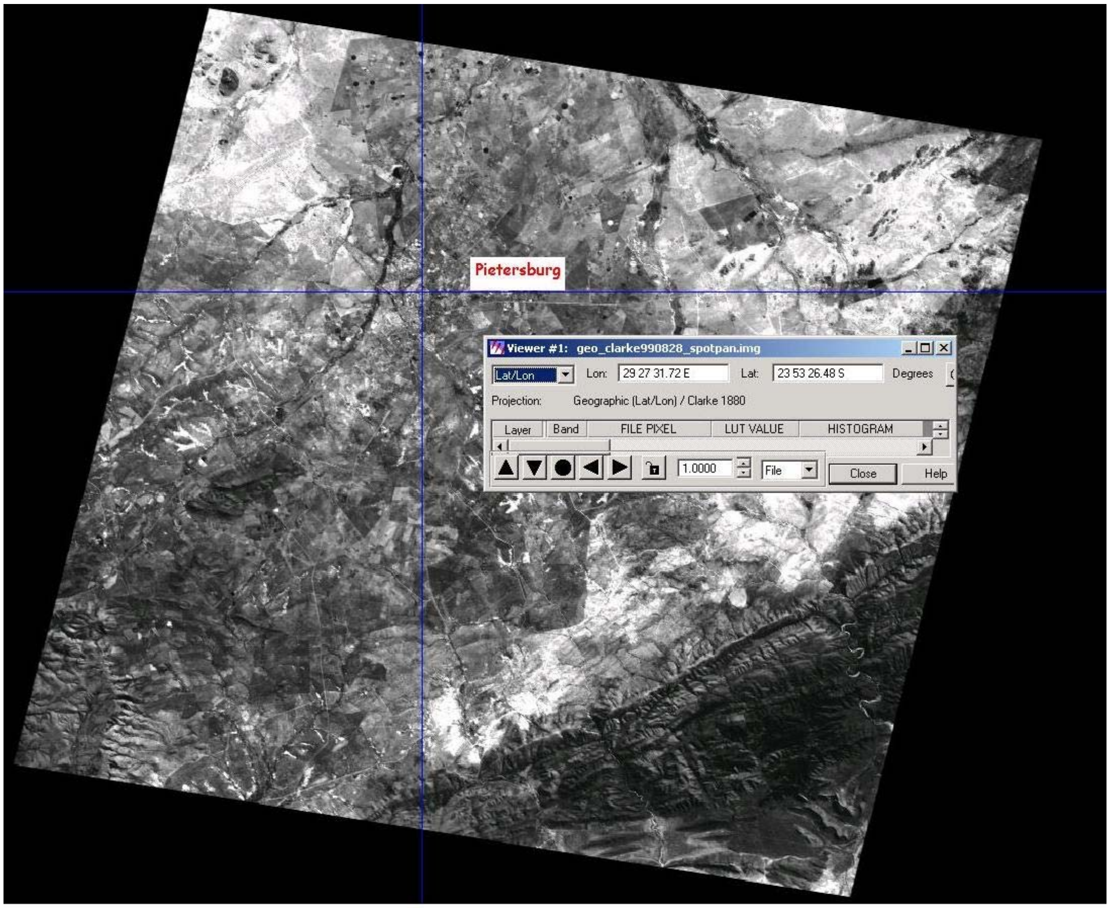
The ideal methodology for the study would have been the use of higher resolution satellite imagery or aerial photographs, but because of the higher cost implication, this option wouldn't be viable in a Third World country where this methodology would be mostly implemented (Stern, 1985). A combination of Landsat and SPOT imagery was necessary for the study as Landsat satellite imagery's spatial resolution of 30m was found to be insufficient for urban applications. Higher resolution SPOT Panchromatic imagery (10m spatial resolution) was, therefore, chosen in conjunction with the Landsat images. The advantage of merging these two data sources was an improvement in the spatial resolution, while the higher spectral resolution (bands) of Landsat facilitated the spectral classification process. While it may also have been possible to use the Panchromatic Band from the Landsat 7 ETM image, which has a spatial resolution of 15m, in conjunction with the multispectral Landsat 7 bands, this was not considered to be ideal for the study because of the spatial resolution of only 15m achieved with this process. Further, it has been shown that the multi-temporal data from SPOT are superior to single-season data and therefore the merging of August image with an April image had additional advantages (Stern, 1985). It was not possible to use Band 6 of the Landsat image with SPOT IV image spectral resolution due to conflicting bandwidths; consequently, Band 6 of Landsat 7 ETM was used together in conjunction with the SPOT IV panchromatic image (Table 5.1).

Substantial pre-processing was required on the relevant imagery before it could be utilised for demarcation. The imagery was orthorectified separately and then the SPOT and Landsat images were merged from where the Landsat Band 6 was extracted for texture analysis. Filters were applied on Band 6 to create an urban mask, which was then used to extract the urban areas from the merged image. An automatic unsupervised classification process was then run on the clipped (urban) image to classify the urban areas more accurately. When the urban areas were extracted it was classified into an urban and rural class and the accuracy of this dataset was verified by comparing the test dataset with a reference dataset (created from aerial photography). The methodology: image processing, enhancements, texture analysis and classification process are described in more detail in the methodology framework (Fig. 5.1).

5.2. Data Acquisition

The SPOT and Landsat images were ordered through the Satellite Application Centre (SAC) website (http://www.sac.co.za). Images were ordered using the input criteria of centre coordinates (the latitude and longitude in degrees, minutes and seconds) of Polokwane (Pietersburg), and preferable acquisition dates for the images (Fig. 5.2; Fig. 5.3). Only recent imagery (1999-2001) was considered for ordering because of the changing nature of the urban environment, the data needed to be recent to be viable.

A SPOT panchromatic (black and white) image, KJ 134-0-398 and date 1999/08/28 was and a LANDSAT image KJ 170-76 and date 2001/04/26 were deemed to be suitable and were utilised for the study. The images covered Polokwane (Pietersburg) and the surrounding areas (Fig. 5.2; Fig. 5.3).



Lon: 29 27 31.72 E

Lat: 23 53 26.48 S

Projection: Geographic (Lat/Lon) / Clarke 1880

FIGURE 5.2: Spot Panchromatic image (134-0-398) with Polokwane centre coordinates.

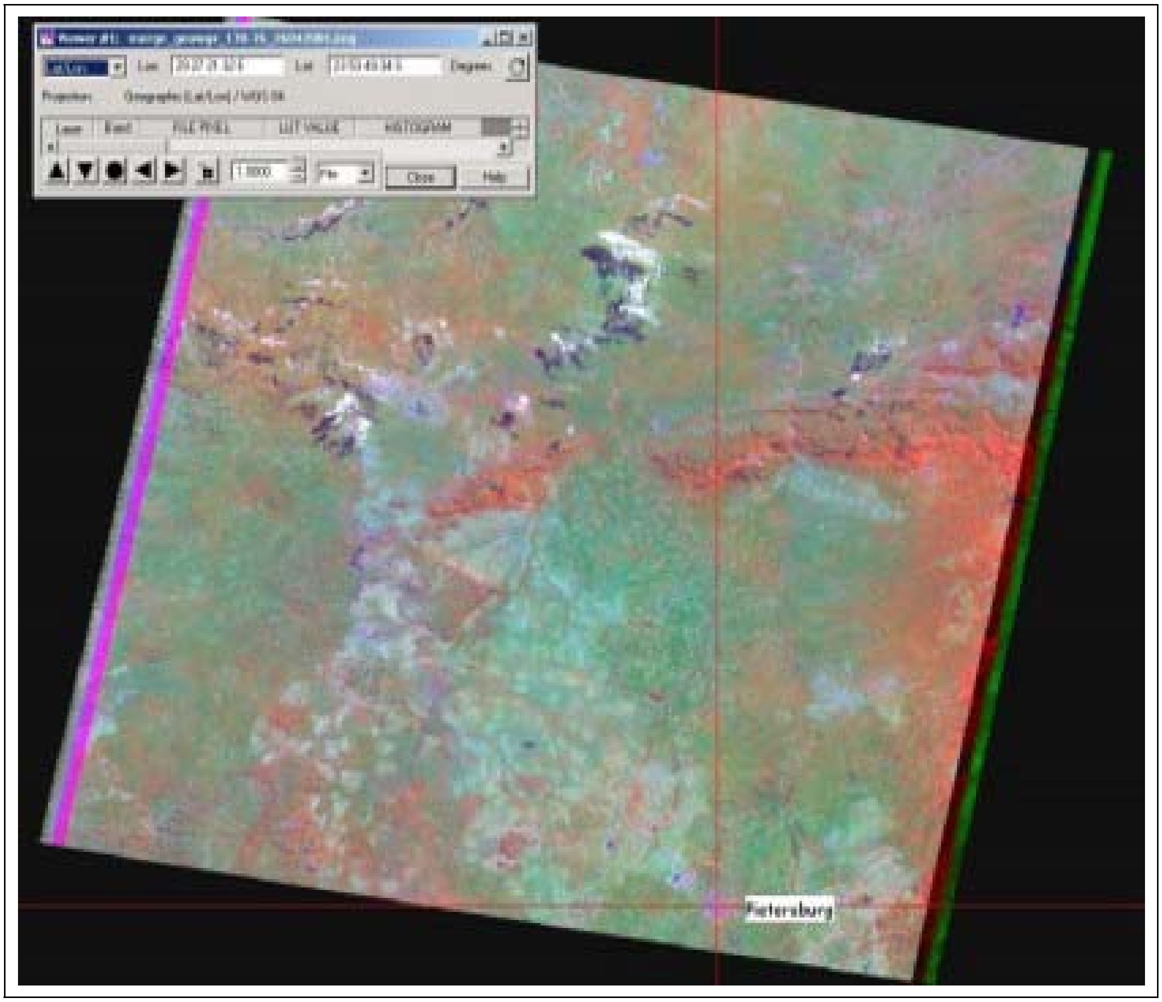


FIGURE 5.3: Landsat 7 ETM+ (170-76) merged (Pan and Multispectral) of the Polokwane area.

The SPOT image could be ordered at different levels of processing, from raw images (level 1A) where no geometric corrections were performed, to georeferenced images (level 2 & S) (SPOT IMAGE, 1989). The incidence angle of the ordered SPOT image was 27.2 degrees, which could make the orthorectification process difficult. Fortunately, the relative flat topography of the landscape in the study area made the orthorectification process easier.

Two separate Landsat 7 ETM+ images (panchromatic and multispectral) were acquired, orthorectified separately, and merged into one Landsat image with a spatial resolution of 20m (multispectral 30m and panchromatic 15m). The Landsat image (merged) was merged with the SPOT PAN image, with the higher resolution of the SPOT PAN image (10m). This merge process is beneficial because the advantages of both the SPOT Pan data (higher spatial resolution) as well as the LANDSAT data (colour) are incorporated in one merged image (BLM, 1999).

Other data sources needed for the orthorectification process of the above imagery, were the 1:50 000 topographical maps as well as the Digital Elevation Model (DEM) (Table 5.1). The georeferenced 1:50 000 topographical maps, 2930DC and 2930DD, were ordered from NETPLAN, which is a local supplier of digital topographical maps, for South Africa. Only the maps covering the study area were ordered and supplied in digital format (Geotiff). As depicted in table 2 below, the Digital Elevation Model (DEM), which were needed for the orthorectification process was also acquired from NETPLAN. The DEM were generated from digitizing contours from the 1:50 000 topographical maps (SPOT IMAGE, 1989).

FIGURE 5.4: Data sources utilised in the study.

Imagery	**Path (KJ)**	**Date**	**Resolution**
Landsat 7 ETM+	170-76	4/26/2001	15m (panchromatic)
SPOT Panchromatic	134-0-398	8/28/1999	10m
Topographical maps (1:50 000)	2329CD 2329DC		
Digital Elevation Model	South Africa	Created from topographical maps	100m
Vector data			
Urban Land use data	Pietersburg	Created January 2002	1:10 000 scale
			MdM: 2002

An additional data source used in the study during the verification stage of the product was acquired from GeoSpace International, and consisted of the urban land use data for Polokwane (Pietersburg), captured for urban planning purposes from orthophoto's dated January 2002 (Table 5.1). The data were captured in ERDAS (ESRI software package) as AOI (Area of Interest) layers and converted to imagine file format (img). All the datasets in the study were reprojected to the working projection used during this study; *i.e.* Geographic Lat Long coordinates, using the Cape Datum and Clarke 1880 spheroid, since most of the data were already in this projection.

5.3. Preprocessing

Prior to the classification process, certain procedures are performed on the image to prepare it and extract as much relevant information as possible. Some of the procedures were already performed on the images before the data was delivered to the user. Examples of standard procedures include radiometric correction (where the uneven sensor responses over the whole image are corrected), and geometric correction (Anon, 1997; Jensen, 1986). It is important to note the difference between radiometric corrections and image enhancements. Although similar techniques (such as histogram manipulation and resampling) might be used, radiometric corrections only correct raw data to represent the original scene, while image enhancements are utilised to emphasize certain features, depending on the research and application (Curran, 1986). In this study both of the above techniques were applied to the imagery to assist with the interpretation and classification of the settlements.

5.4. Radiometric corrections

The radiometric corrections were performed on the raw images prior to delivery. It is important to be aware of all the processes performed on the imagery prior to the classification to enable correct interpretation of results derived from the classification process; the preprocessing could influence the pixel values when adjusting the radiometric properties (Lunetta & Elvidge, 1999).

In addition to preprocessing, the effects of the atmosphere on electro-magnetic radiation may account for substantial distortion in pixel values and along with sensor and detector errors these are the two most important radiometric distortions (Richards, 1993). Atmospheric distortions occur when the atmosphere influences the brightness value recorded at a single pixel. The atmosphere can either scatter or absorb electromagnetic radiation. Atmospheric absorption is caused by water vapour and other gasses and decreases the brightness value in certain wavebands (Jensen, 1986). However, satellites are designed so that they do not use these particular wavebands and thereby largely eliminating atmospheric absorption. Scattering is therefore the dominant reason for atmospheric distortion increasing brightness values (Richards, 1993).

Scattering, caused by air molecules is called Raileigh scattering and scattering caused by smoke, haze and fumes is called Mie scattering (Jensen, 1986). Considering that atmospheric scattering is also waveband dependent for example in the case of Landsat imagery, the infrared bands (4-7) of Landsat TM, are largely free of scattering, while the visible spectrum (Bands 1-3) is significantly influenced (Jensen, 1986). The impact of scattering will then largely depend on the application and thus the bands of importance for a project (Jensen, 1986).

Regression adjustment can be used to correct severe atmospheric absorption distortions (Richards, 1993). The technique is complex and based on accurate information from weather stations where temperature, relative humidity, atmospheric pressure and visibility at a given time are all taken into account and the image corrected by using these parameters (Richards, 1993). As mentioned above, modern sensor platforms have been designed to record data in wavelengths, not influenced by atmospheric absorption, and this type of correction is therefore only used in specific research studies or when extreme atmospheric conditions are encountered (Richards, 1993).

5.5. Data import

The data employed for this study were obtained from several sources, in a variety of formats and software packages. It was, therefore, necessary to import all the data to a standard format. The data sets needed for the orthorectification were imported to ERDAS format (img.). The 1:50 000 topographical maps were imported from GeoTiff format. During the import process the data looses the projection (header file) and therefore the projection info was updated to the newly created IMG file. The Digital Elevation Models (DEM's) were imported from USGS DEM format to the IMG format of ERDAS IMAGINE and the projection info of the DEM was added. SPOT and Landsat 7 EROS FAST format images were converted to the IMG format. Map models (image info) were then deleted because the images were calibrated and, therefore, had relative positioning. For the process of orthorectification the images were rectified using the 1:50 000 maps (for this study) and the map model was ignored.

5.6. Accuracy assessment

When the data is in the correct format (img), the accuracy and integrity of the data must be validated before commencing with the orthorectification process. Corner coordinates of the relevant maps where then used to test the accuracy of the maps. The DEM was checked for spikes (wrong heights of contours) and incorrect interpolation methods. A spike would appear as a black hole or a very white spot on the DEM that differs totally from the surrounding heights (colours).

Images were checked for pixel shifts, dropouts, striping or incorrect resampling techniques. Resampling is the process where the cell sizes of the image may be altered to correspond to other raster files and this is only necessary to check, if the image was projected before (Lillesand & Kiefer., 1979). Striping occurs when one of the detectors records too high or low values. Every 16th line will then show a significant deviation in brightness value from the rest. This above problem is corrected by calculating the average pixel value and standard deviation for one specific detector. These values are then compared to that of the other detectors, thereby allowing the values recorded by the erroneous detector to be adjusted (Jensen, 1986).

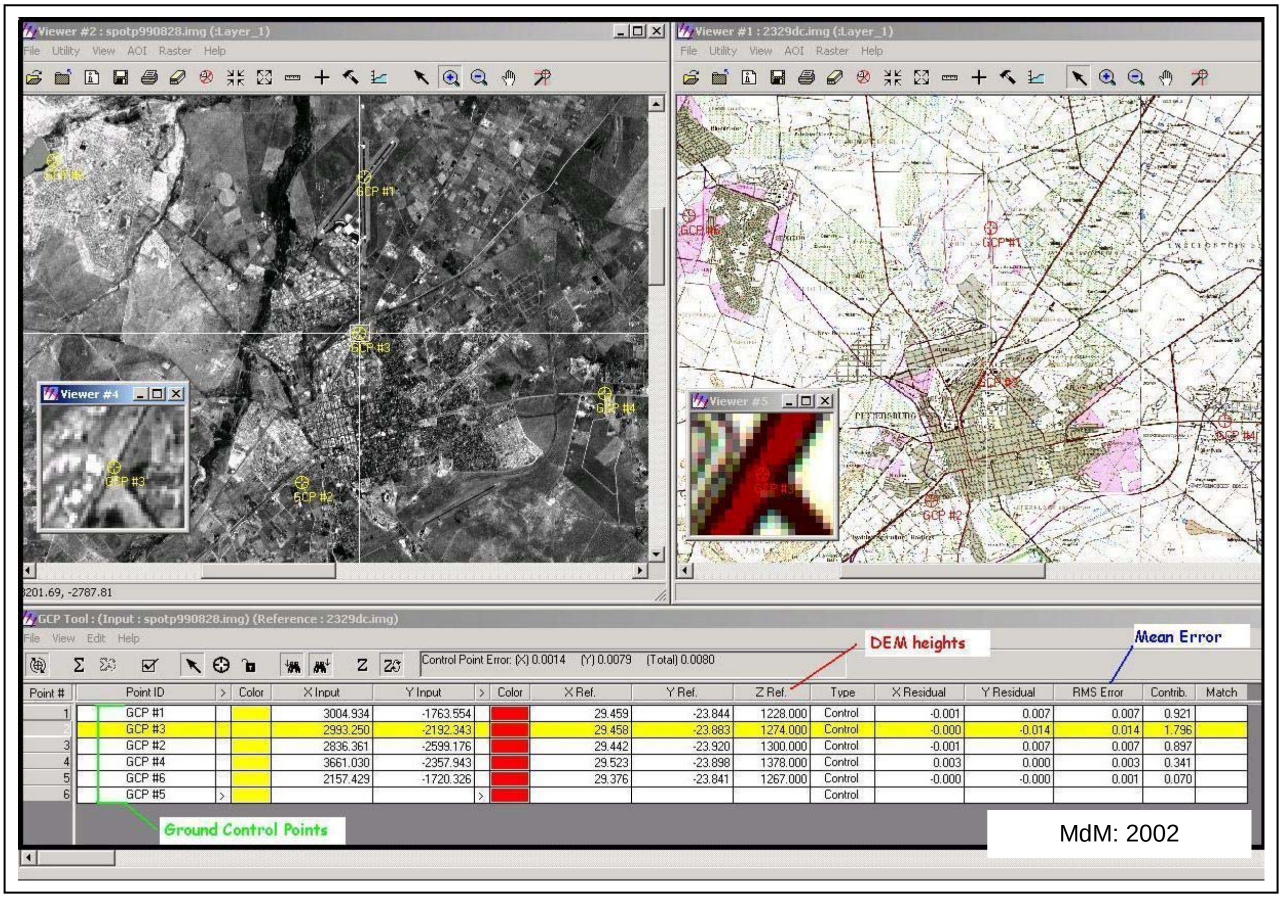
Another common detector error in satellite imagery is line dropouts, which occurs when a detector fails completely and registers a brightness value of zero (Jensen, 1986). Although the values of these pixels can't be retrieved, the adjacent pixel values could be used in estimating the pixel values of the dropouts. This process cannot produce any real values but could aid in further interpretation of the image (Jensen, 1986). When the data quality control was completed, the data was ready to commence with the orthorectification.

5.7. Orthorectification

Accurate spatial registration is essential for any image that will supply information for use in a GIS as this allows for the measurement of distance and area as well as to determine position (Jensen, 1986; Ridd, 1991). The process of registering an image to a specific map projection is called georeferencing (ERDAS, 1994). Geometrical correction or georeferencing corrects distortion due to the earth's rotation and other imaging conditions such as oblique viewing, altitude and uncontrolled movements of the scanners (Anon, 1997; Richards, 1993). The georeferencing process generally involves correcting the image on the x and y cartesian axes. Furthermore, orthorectification may also involve the referencing of an image to the x, y and z axes; the DEM provides the z value from reading the altitude of each pixel while rectifying the image. Orthorectification provides data with a high degree spatial accuracy (horizontal and vertical) and was, therefore, necessary for this study (ERDAS, 1997).

The SPOT PAN image was orthorectified using a 100m DEM covering the specific area, while the 1:50 000 topographical maps were used as the reference data and an image to map orthorectification were applied (Fig. 5.5). Features like road intersections, river bends, fence intersections and other prominent features were used as Ground Control Points (G.C.P.) The mean error of each G.C.P. was calculated and those with substantial errors were discarded (Fig. 5.5) to prevent incorrect G.C.P.'s from influencing the geometric correction process (Richards, 1993). A Root Mean Square (RMS) of 1.6 was obtained which implied an error of approximate 16 meters.

The next phase of geometric correction, entailed the adjustment of brightness values from input pixels to the output pixels. Jensen (1986) refers to this process as intensity interpolation since the values of the input pixels are often changed in the output image. Where the output projection differs from the original, the original raw pixel may not fit exactly on the output grid and, if this is the case, resampling is required. Three types of resampling can be applied: nearest neighbour, cubic convolution and bilinear interpolation. The nearest neighbour method transfers the pixel value of the nearest pixel and therefore is relatively simple to compute. Another geometrically accurate resampling process is bilinear interpolation where the transfer proximity weighted average of nearest 4 pixels. The cubic convolution technique uses values from the nearest 16 pixels values, which are evaluated to determine the transferred pixel values (Lunetta & Elvidge, 1999).



201.69, -2787.81

GCP Tool : (Input : spotp990828.img) (Reference : 2329dc.img)

Control Point Error: (X) 0.0014 (Y) 0.0079 (Total) 0.0080

Point #	Point ID	>	Color	X Input	Y Input	>	Color	X Ref.	Y Ref.	Z Ref.	Type	X Residual	Y Residual	RMS Error	Contrib.	Match
1	GCP #1		🟨	3004.934	-1763.554		🟥	29.459	-23.844	1228.000	Control	-0.001	0.007	0.007	0.921	
2	GCP #3		🟨	2993.250	-2192.343		🟥	29.458	-23.883	1274.000	Control	-0.000	-0.014	0.014	1.796	
3	GCP #2		🟨	2836.361	-2599.176		🟥	29.442	-23.920	1300.000	Control	-0.001	0.007	0.007	0.897	
4	GCP #4		🟨	3661.030	-2357.943		🟥	29.523	-23.898	1378.000	Control	0.003	0.000	0.003	0.341	
5	GCP #6		🟨	2157.429	-1720.326		🟥	29.376	-23.841	1267.000	Control	-0.000	-0.000	0.001	0.070	
6	GCP #5	>	🟨			>	🟥				Control					

MdM: 2002

FIGURE 5.5: Orthorectification of SPOT panchromatic image (134-0-398).

The image was resampled to 10m and the cubic convolution method was used for resampling to eliminate the disjointed appearance caused by the nearest neighbour method. In addition, cubic convolution sharpens the image and is, therefore, useful when interpretation of linear features is involved (Lillesand & Kiefer., 1979). Cubic convolution changes the content of the image, but makes it closer to spectral and geometric reality (Stern, 1985).

The LANDSAT image was orthorectified to the already registered SPOT PAN images and an image-to-image process was used for orthorectification. The SPOT PAN image was orthorectified first because of the higher spatial resolution of SPOT imagery; higher accuracy levels were therefore possible when orthorectifying the image. Ground Control Points are also more easily identifiable on the higher resolution images. A Root Mean Square (RMS) of less than 0.6 was acquired which implied an error of less than 18 meters on the LANDSAT image.

The SPOT PAN and Landsat ETM images were clipped to an area covering Polokwane (Pietersburg) urban area as well as the surrounding informal towns. An area of 20km by 20km was clipped and used for the study. The images of the study area were merged into one image and resampled to the 10m pixel size of the SPOT PAN image using the cubic convolution method, which resulted in a higher resolution image than the Landsat image.

5.8. Texture analysis

"*Urban areas constitute spectrally heterogeneous land cover classes and call for the application of intelligent, texture-based image processing methods*" (Moller-Jensen, 1997:291). It was assumed that when using the texture filter in this study, the spatial variability within the urban areas could be utilized and transformed into a class where spectral contrast between the urban and rural features could be emphasized. Texture is band sensitive and therefore the features appearance will vary in each different band. The relationship between building density/structure and local variance are grouped into different clusters of variance where urban and non urban detail could be distinguished (Donnay *et al*., 2001)

Structure, texture and context are characteristics always involved in manual interpretation. Texture is the pattern of detail of a given area, and descriptions such as smooth, fine and rough could be used in describing the texture of an area. According to Jensen and Toll (1982) using texture and spectral data is more accurate than using spectral data alone in the classification process. Haralick & Shanmugam (1974) quantified the improved accuracy of using texture data in their study where accuracy levels increased from 74% to 83.5% (Stern, 1985).

Textural analysis was conducted prior to the normal unsupervised classification to enhance the spectral variability between urban and non – urban areas. The similar reflectance properties of specific features (*e.g.* bare soil and buildings), could lead to difficulty in spectral separation (Donnay *et al*., 2001). Textural information may provide additional information where spectral separation between classes is small (Donnay *et al*., 2001).

Two approaches to utilize texture for image analysis can be followed: The first option is to quantify the spatial variability using a textural measure and combine it with spectral data in the classifier. A second approach, which was chosen for this study, is to reduce spatial variability of a scene by smoothing or removing within-field variability for example by using a low – pass filter or neighbourhood filter (Berberoglu *et al*., 2000). The texture layer was used to separate classes that did not exist in the spectral domain and was added as an additional input channel into the classifier (Stern, 1985). The approach where remotely sensed data are integrated with other sources of geographical information (*i.e.* land use data, spatial texture *etc*.), are expert systems that provide the user with high classification accuracy (Stefanov *et al*., 2001; Moller-Jensen, 1997).

Each band in the SPOT Pan – Landsat merge accentuated different features depending on the wavelength, different features will reflect energy differently. All the bands were analysed to find the specific band most suitable to separate urban and non-urban features and for this study. Band 6 of the merged image was found to be the most appropriate (Fig. 5.6), and was selected because of the clarity of spectral signatures. The SPOT Pan image spectral resolution is between 0.5µm and 0.7µm in the visible spectrum and according to Stern (1985) the reflectance value of concrete is the highest (25%) in these electromagnetic ranges (using only the visible and near infra-red portions of the spectrum) in comparison with the other bands. The contrast between urban features and non-urban features was therefore highest in the spectral range comprised by the SPOT Panchromatic image and in combination with band 6 accentuate urban features.

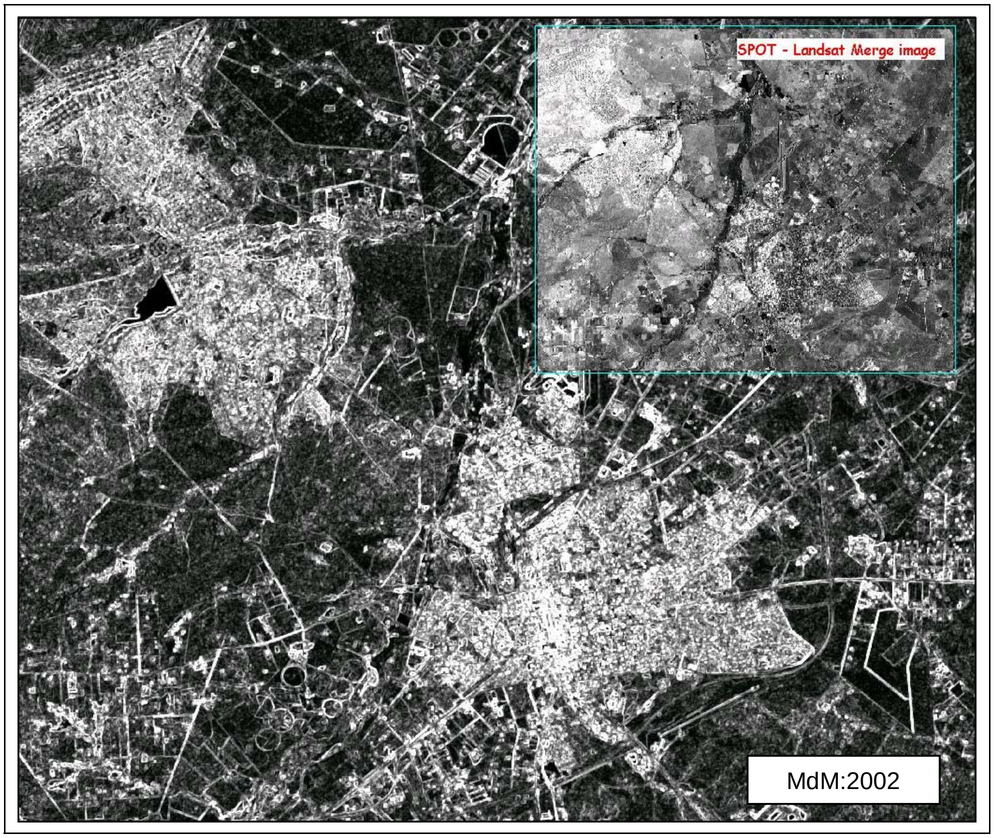


FIGURE 5.6: Texture analysis from the SPOT Landsat merge (Band 6).

The spectral signature of dry, bare soil reflects the highest in the long wave spectrum (1.4µm - 2.2µm), which is covered by Band 6 of the Landsat 7 ETM imagery; urban features have a very similar spectral signature (Fig. 5.6). Both concrete (urban features) and bare soil have high reflectance values and would appear bright "white" on a satellite image (Lillesand & Kiefer, 1979). It is, therefore, assumed that the application of a texture filter on a combination of these bands (Band 6 of Landsat and SPOT Pan) was best suited to the study.

Band 6 of the SPOT – Landsat merged image (10m pixel size) was extracted and a single-band image was created that comprised only Band 6 and a texture filter within a 5m x 5m window were run on the image (Fig. 5.6). According to Gurney & Townshend (1983) a 5 pixel x 5 pixel window is superior to 3m x 3m and 7m x 7m pixel windows when classifying land cover types. The concept textural filtering implies that the centre pixel in a 5m x 5m pixel window is exchanged by a value calculated from all the pixels in the window (Stern, 1985). As the window moves over the image, a new feature is created. A suitable window size may vary, however, the larger the window, the greater the risk of including pixels of other classes (Stern, 1985).

The texture layer had a high spatial frequency, which implies that a "salt and pepper effect" occurred, and strained interpretation of the textural layer; a more homogenous appearance was required for further analysis. Operations that de-emphasize abrupt changes are useful to "block" the high spatial frequency values and this process of smoothing is called low-pass filtering (Lillesand & Kiefer, 1979). At the opposite extreme, high-pass filtering could also be used to attenuate the high frequency components and, therefore, sharpen and edge-enhance features (Lillesand & Kiefer, 1979).

A neighbourhood filter, which is a type of low-pass filter, was run on the texture image to eliminate the "salt and pepper effect" within the urban and rural areas, and to enhance the contrast between the areas. The most effective neighbourhood filter was the maximum filter to highlight the urban areas and the minimum filter for emphasizing the non-urban areas. A window size of 3m x 3m pixels was found to be the most suitable for the specific filters (Hsu, 1978), since the 5m x 5m and 7m x 7m windows have substantial edge effects because of the larger window area from which the value is calculated (Stern, 1985). First, the minimum filter, with a 3m x 3m window size was run on the whole image, and that resulted in all the rural areas appearing "darker" and therefore more separable from the urban areas. The minimum filter outputs the least or smallest class value within the window, which was used to emphasize classes with a low value in this case the rural areas (ERDAS, 1997).

After the minimum filter was applied, a maximum filter, within a 3m x 3m pixel window size was performed on the whole image; with this filter, the greatest class value within the window was calculated. The higher class values were emphasised to eliminate boundaries and stress linear features (ERDAS, 1997); the result was a texture thematic layer with significant distinction between the urban and non-urban areas.

5.9. Classification Phase

After the texture layer was created, an unsupervised classification was run on the texture layer to facilitate classification into urban and non-urban classes. The reason for the creation of urban and non-urban classes was to create a preliminarily mask on the SPOT-Landsat merged image and thus allow a more focused classification of the urban class. An unsupervised classification was chosen as minimum human intervention was required and the classes were determined only by spectral distinction. However, the interpretation of the classes that were created by the unsupervised classification depends on the analyst and therefore experience and knowledge of remote sensing was required. Unsupervised classification is also called clustering, because it is based on the natural groupings of pixels of an image dataset (ERDAS, 1997).

If a supervised classification were chosen, the image analyst would “supervise” the classification process by selecting classes that are relevant and then selecting training samples which are representative of these classes (Lillesand & Kiefer., 1979). A training sample is a set of selected pixels that represent a potential class and is used as reference dataset to classify the image. Specific spectral signatures for all the relevant classes are generated and used as an input file in the classification process. Spectral signatures are created by the different response patterns from various features measured by remote sensors; this implies a pattern that is absolute and unique (Lillesand & Kiefer., 1979).

An unsupervised classification was run on the one band texture layer and 120 classes were defined. The maximum number of times (iterations) that the data would be re-clustered was set as 99 for this study, since this is the maximum number of reclustering and thus the most accurate. A convergence threshold of 0.99 was selected, which means that the classification process must proceed until the percentage of pixels whose assignments are unchanged since the last iteration reaches 99%. The urban and rural classes were identified from this classification and recoded to 1 and 0 respectively. Recoding is a function that assigns a new class value to a specific class, as defined by the user (ERDAS, 1997).

Single isolated pixels contributed to the “salt and pepper” appearance of the classification on the thematic layer. To eliminate these stray pixels, a “clump” and thereafter a "eliminate" procedure was undertaken. The clump process concerns the way in which pixels of a class are grouped and this could be manipulated by the size of these groups or clumps (ERDAS, 1997). For this study a grouping size of 4x4 pixels were used. After the clump a neighbourhood filter with a window area of 8x8 was run on the image and thus eliminating any groupings of clumped pixels smaller than 8x8 (Fig. 5.7) (ERDAS, 1997). With the eliminate function all the clusters smaller than 8x8 pixels were deleted but the boundaries of the features were not altered (ERDAS, 1997) (Fig. 5.7).

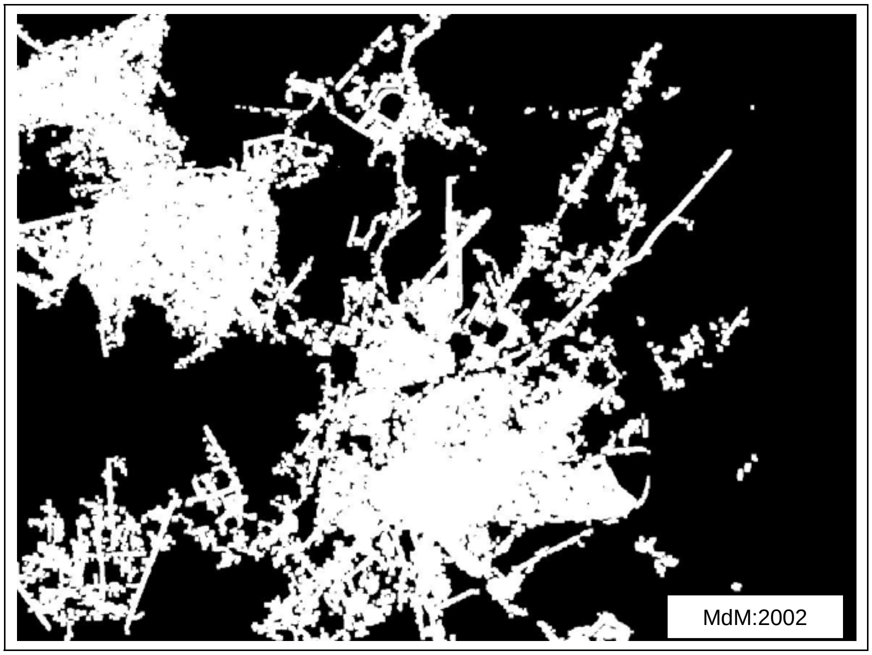


FIGURE 5.7: Texture layer after the clump and eliminate processes

The urban class in the classification of the texture layer was selected and converted to AOI (Area of Interest) layer (Fig. 5.8). The AOI can be a point, line or polygon layer created from an image or a vector file and is used as an image area where operations on only these specific areas can be performed (ERDAS, 1997). The AOI, created from the classification layer, was then used to subset or mask out the urban areas in the SPOT-Landsat merged image. The process of sub-setting an image occurs when a large image file is "cut" into smaller portions (ERDAS, 1997). The result was an image layer, comprising mainly urban areas (Fig. 5.8).

An unsupervised classification was then run on the masked image (sub-set), using the same parameters as mentioned in the unsupervised classification process performed on the texture layer. The classification process on the merged image was necessary to define the urban areas more accurately within the masked or clipped image parcels (Fig. 5.9). Within these urban areas the classification process were run to eliminate any misclassified areas. The classes were recoded again to 0 and 1, where 0 represented all the rural areas and 1 the urban areas. The classes were then compared to the test dataset to verify the accuracy of the automatic classification and texture analysis.

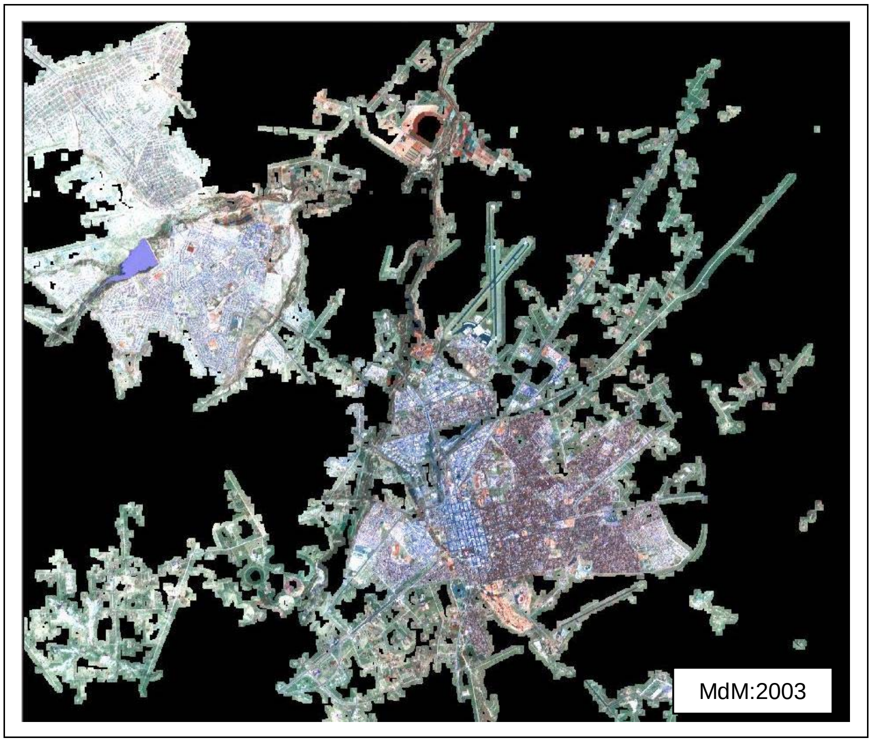


FIGURE 5.8: SPOT-Landsat merged image clipped using the AOI layer created from texture layer.

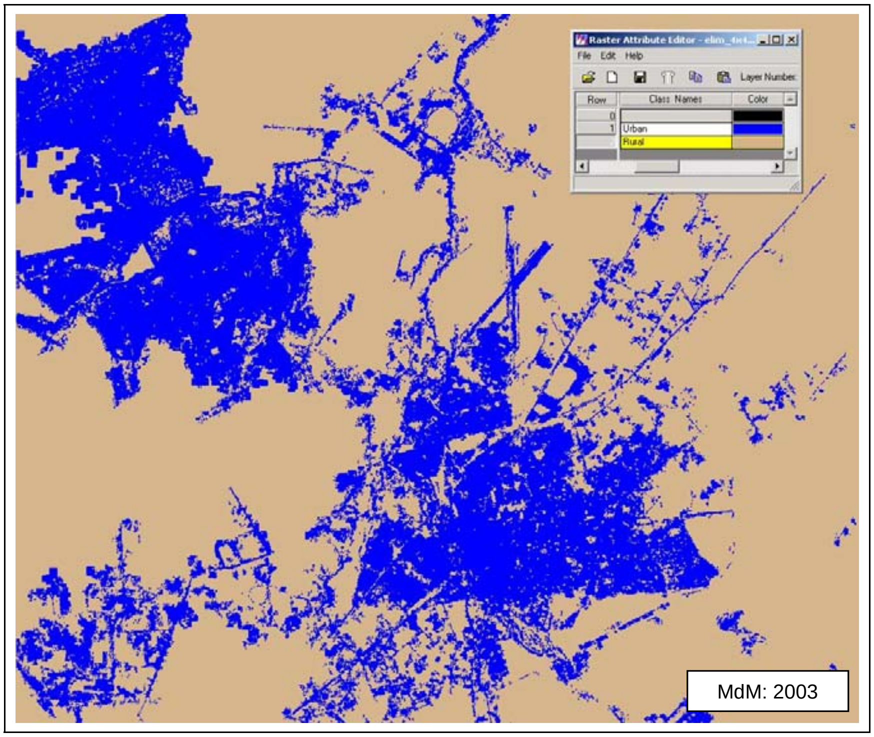
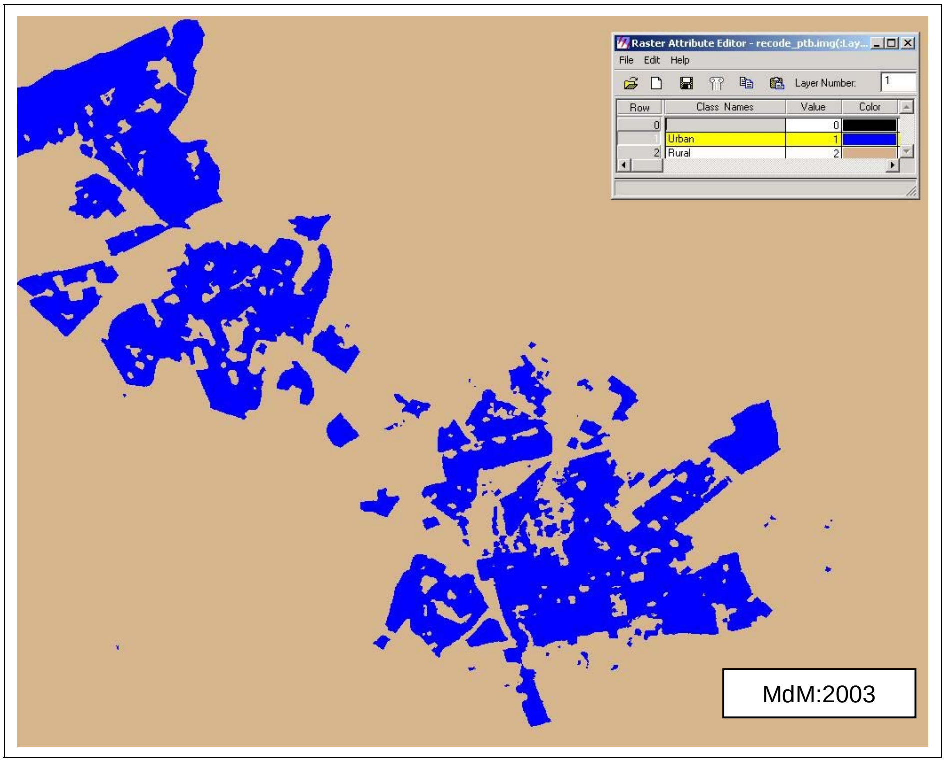


FIGURE 5.9: Settlements identified as created from classification of SPOT-Landsat merge image

5.10. Data verification phase

5.10.1. Preparing the datasets

The end product of the classification of images was an image in ERDAS ".img" format with two identifiable classes, namely urban and rural. The urban areas were recoded to a value of 1 and the rural areas were assigned a value of 2 (Fig. 5.10).



Row	Class Names	Value	Color
0		0	■
1	Urban	1	■
2	Rural	2	■

FIGURE 5.10: Reference dataset with urban and rural classification.

Different methods of verifying datasets could be used; for example, sample data could be derived from fieldwork or higher accuracy datasets, to assess the accuracy of the newly created classification (Stern, 1985). The time of creation of the verification dataset and scale of mapping must be similar to the data that needs to be verified.

A land use dataset covering the same area as the study area was used to verify the accuracy of the results derived from the unsupervised classification. The land use dataset was manually captured from orthophoto's at a 1:10 000 scale during February 2002. It was, therefore, assumed that the accuracy of this dataset would be more accurate and effective when comparing with the dataset created from the SPOT – Landsat merge image when concerning the larger scale and up-to-date nature of the reference dataset.

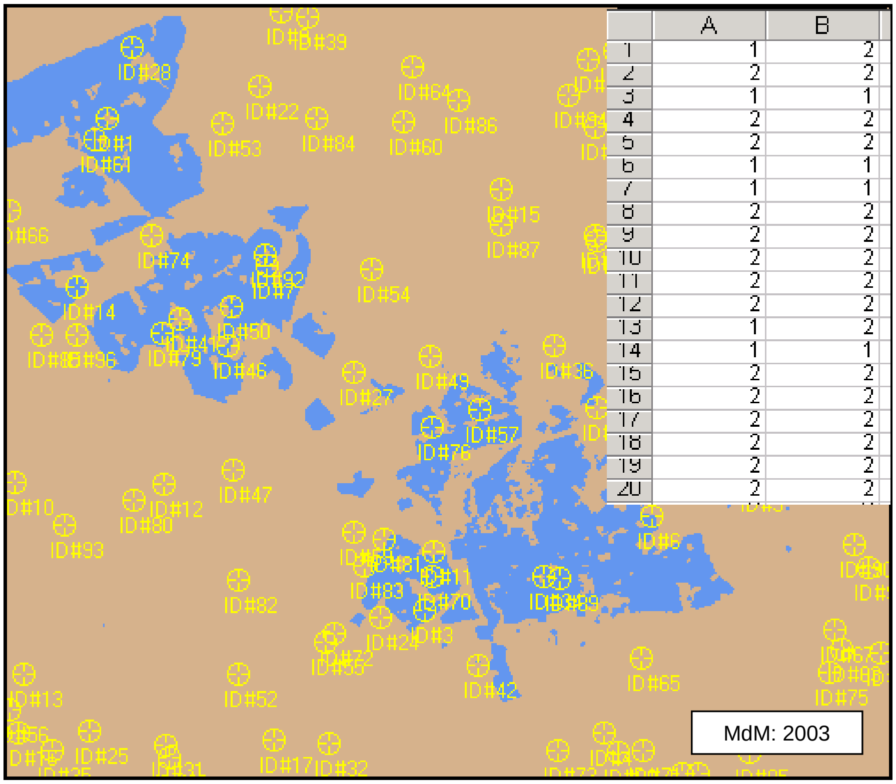
The classes used in the land use classification (verification data) differ from the classification derived for this study, because of the more detailed classification of 15 classes for the study area. The landuse map was clipped so that the area corresponded to the 20km x 20km study area. The 15 classes were merged to 2 classes (rural and urban) and recoded to 1 and 2 respectively to make comparison with the classification simpler.

5.10.2. Accuracy assessment

"*The accuracy of any post-classification change detection is strongly influenced by the accuracies of the independent classifications*" (Lunetta & Elvidge, 1999:81). The data verification process was performed using the ERDAS IMAGINE software package. An accuracy assessment is a general term for the process of determining the accuracy of a classification through comparison with other geographical data, where a high accuracy level is obtained and the data are assumed to be true (ERDAS, 1997). It is not always practical to verify every pixel in the dataset and therefore a set of reference pixels are normally used. The reference pixels must be points where data is available on the classified image as well as on the verification (actual) dataset (ERDAS, 1997). The reference points are randomly selected by the computer and therefore eliminating the possibility of bias of the analyst (Donnay et al., 2001). Different methods of selecting these reference points could be used; for example random, stratified random and equalized random (ERDAS, 1997).

By selecting random, no rules are applied in the selecting process of points. With the stratified random command, the points are stratified according to the distribution of the thematic classes (ERDAS, 1997). The equalized random process selects an equal amount of points for each class (ERDAS, 1997). For this study, a random sampling process was selected due to the fact that there were only 2 classes to evaluate and both these classes had approximately 50% representation in the study area (Fig. 5.11). In cases where there are more classes and some of the classes cover smaller areas, and the area is important to the study, an equalized random process would be necessary to force sampling of all the classes irrespective of the area they covered (Fairbanks & Thompson, 1996).

The analyst is required to select the number of reference points created in the random selection process. This could include both field and aerial photo sample points. In this case, the land use dataset generated from aerial photography was the source to determine overall map accuracy. According to Congalton (1991), 250 reference points for each class are sufficient to estimate the mean accuracy within 5%. For this study area of 20km x 20km the number of reference points was tested to investigate the influence of the number of points on the accuracy. It was determined that selecting more than 100 sampling points did not impact significantly on accuracy levels. Accordingly, 100 sampling points were chosen for optimal accuracy assessment because of the small area covered in the study and to limit the cluttered effect of more reference points (Fig. 5.11).



	A	B
1	1	2
2	2	2
3	1	1
4	2	2
5	2	2
6	1	1
7	1	1
8	2	2
9	2	2
10	2	2
11	2	2
12	2	2
13	1	2
14	1	1
15	2	2
16	2	2
17	2	2
18	2	2
19	2	2
20	2	2

FIGURE 5.11: Accuracy Assessment (Example of point generation and comparison).

These reference points created on the classification image (test data) are displayed on the "ground truth" dataset showing the corresponding class number in a table. The analyst needs to put the corresponding class number of the validation dataset next to the reference point number in the table. Comparisons between these two different datasets could then take place.

5.11. Description of end product.

The results consisted of a summary table where the following accuracy aspects were recorded: omission error, commission error, overall mapping accuracy, confidence limits, and the kappa index. All the accuracy measurements were created from an error matrix generated when comparing the classification with independent samples of the true land use classification derived from higher quality sources. The matrix compared the different classes in terms of omission, commission, overall map accuracy, and confidence limits. The accuracy report was used to calculate statistics regarding the accuracy of the dataset based upon the results of the error matrix (ERDAS, 1997).

The kappa index expresses the proportionate reduction in error of the classification compared with a completely random classification; for example, a value of 0.65 implies that the classification avoids 65% of the errors that would be created by a random classification process (ERDAS, 1997). For most purposes, values larger than 0.8% represent almost perfect agreement while values between 0.4 and 0.8 reflect moderate to substantial agreement while values below 0.4 signify poor agreement (Fairbanks & Thompson, 1996).

The comission error is the index of the amount of misclassification, when one class is misclassified as another, and the ommission error occurs when a class is undetected (Lunetta & Elvidge, 1999). For this study, only the commission error was considered since no fieldwork was undertaken, where classes that were ommitted could be identified and calculated.

The Confidence Interval reports how confident one should be in the overall map accuracy (%); this provides a variance range within which the accuracy would fall within the 90% confidence limit chosen for this study. Two values are reported, a minimum and maximum value and one could assume with 90% confidence that the map accuracy would range within these limits. The map accuracy represents the overall classification accuracy as a percentage of all the correct classified sites assessed versus the misclassified sites (Fairbanks & Thompson, 1996).

CHAPTER 6: Discussion of results

6.1. Results from the confusion/error matrix

The results from the confusion or error matrix are summarized below (Table 6.1).

TABLE 6.1: A summary of the accuracy report derived for the automatic classification

Commission error	11.00	
Omission error	11.00	
Overall map accuracy	89.00	
90 % confidence limits	84.8876	93.1124
	low	high
Kappa Index	65.63	

MdM:2003

According to the results of the error matrix, 25 samples were taken from class 1 (urban) and 75 samples of class 2 (rural). Only 11 samples were misclassified and therefore the commission error of 11%. These 11% could be cases where the spectral values between the different classes were similar for example places where bare soil (spectrally similar to built-up areas) was classified as urban and not as rural. Other reasons why similar misclassification could occur is where the vegetation within the urban areas was classified as urban; to make the image of the urban area more homogeneous, vegetation along the streamlines, and open areas, could also be classified as urban. Differences in methodology used to create the reference and test dataset could also contribute to these misclassifications Lunetta & Elvidge, 1999). The reference dataset was manually mapped and visually interpreted, while the test dataset was created solely using an automated processes and limited human intervention. Other cases where the above situation could influence the accuracy level could be where smallholdings were identified as rural areas with association during the visual interpretation process, but during the automatic classification process, building, roads and other artificial objects, within the smallholdings class were classified as urban areas (spectral signature).

The overall map accuracy for the classification was 89%, which compares well with the common accuracy assessment standard for small-scale, remotely sensed land cover maps where an 85% accuracy level is required (Fairbanks & Thompson, 1996). The high accuracy level is required to make future repeatability by another knowledgeable remote sensing analyst possible (Fairbanks & Thompson, 1996). The range of 90% confidence limits falls between 84.8% and 93.1%.

The kappa index of 65.6% represents a moderate index and is acceptable in this case because of the homogeneity (few classes) of this area. A limited number of classes (2) have resulted in a low % kappa index, as the chance agreement in this case would be high irrespective of the map accuracies. The analysis identified every hit as a 50% chance of being accurate (only 2 classes) and therefore the kappa index appeared to be lower than the desired level (Fairbanks & Thompson, 1996).

6.2. Constraints of the verification process

The accuracy of the verification process largely depends on the human intervention factor when creating both the verification dataset as well as the test dataset; thereby influencing the outcome of the evaluation process, and lead to inaccurate accuracy assessments. In the case of this study, potential errors in the verification process could have resulted from inherent factors during the data capture process of both the test dataset and the reference dataset. The nature of these errors could be positional, acquisition, data processing, data analysis, data conversion or error in the assessment orientated (Lunetta & Elvidge, 1999).

Potential errors that could occur in the verification process could occur if one of the two datasets, reference dataset or test dataset, was mis-registered during the geo-referencing process. The implication of this would be that the two datasets wouldn’t fit exactly on each other and therefore reference points taken during the accuracy assessment on a specific area could fall in another class because of the difference in position of the two datasets (Donnay *et al*., 2001). The scale and minimum mapping unit used in the data capture process could also contribute to an area not classified and mapped in the one dataset but to be identified in the other dataset. The difference of scale between the reference dataset (1:10 000) and the test dataset (1:50 000) could also contribute to areas not classified in the test dataset because of the larger minimum mapping unit (Lunetta & Elvidge, 1999).

Certain aspects relating to the acquisition of the satellite imagery or aerial photography could also lead to an inaccurate verification process. A few of these factors included the geometric aspects, sensor systems, platforms, ground control, and scene considerations of the specific imagery used (Lunetta & Elvidge, 1999). These aspects are difficult identifiable because these aspects are normally dealt with when extracting the imagery and the end-user usually is not informed on the inherent satellite limitations unit (Lunetta & Elvidge, 1999).

Misclassification of the reference dataset by the analyst could also lead to a less accurate dataset, which could lead to a lower accuracy level. Differences in defining the various classification classes could also lead to areas being misclassified; for instance, some analysts may classify smallholdings as part of the urban areas while others would see them class as part of the rural areas. A different perception of definitions could therefore also lead to misclassification during the creation of the reference dataset as well as the test (automatic) classification dataset (Lunetta & Elvidge, 1999).

Data conversion processes (*e.g.* converting vector data to raster data), as in the case of the reference dataset, could lead to boundaries of classes changing because of the difference in the appearance and nature of raster and vector data (Lunetta & Elvidge, 1999). In this study, the reference dataset was created by a manual, vector process, while the test dataset was created using an automatic, raster process, which contributed to the different appearances of these datasets and that influenced the verification between these two datasets.

The accuracy of a random sample is related to the sample size and the variance of the population. The problem with this form of accuracy estimation is that it is based on the hypothesis that the sampled variables are normally distributed (Donnay *et al*., 2001). For demographic applications, the variables do not conform well to the normal distribution model and the effect of such a bias is difficult to predict.

The influence of the temporal aspect shouldn’t be underestimated. Differences in time between the imagery of the two comparative datasets could also lead to seasonal changes of the data sources used for the creation of the datasets. This would highly influence the visual and automatic classification process and then also the outcome of the accuracy assessment (Lunetta & Elvidge, 1999).

Financial and time constraints also restricted verification and sampling within the parameters of the project. Therefore, field verification was excluded from the verification process and that could lead to a more thorough verification process. The relative “older” image dates of SPOT (1999) and Landsat (2001) also limited field verification because of the changes in the environment between the image date and the current status quo of the environment. Field verification would compliment and assist the accuracy assessment process (Fairbanks & Thompson, 1996).

6.3. Remote sensing and urban analysis: A future research agenda

The dichotomy between manual and computer assisted classification methods must be bridged with a change in perception of the users toward the application; this applies to oriented disciplines such as forestry, hydrology, geology and geography on the one hand, and engineering and computer science on the other hand. The advantages of combining automatic classification with manual classification must be stressed and the higher level of accuracy of the end product would be beneficial to any of these users.

To adapt rural and urban analysis to this future approach, and to develop expert systems and advanced algorithms for pattern recognition, requires manufacturers to develop software for semi-automatic interpretation. Examples of possible improvements in the software are functions that support the operator using advanced textural and contextual algorithms, especially when demarcating obscure land cover classes. A post-classification editor is required, where manual correction of incorrectly classified areas could be undertaken to improve the classification process. An intelligent interaction between the unsupervised and supervised classification would be an ideal focus for future software development.

Improvements in hardware for such a study should ideally focus on the development of the mobile computer with a large monitor that is suitable for manual interpretation of imagery and this would make analysis not office based but more flexible and analysis could be done in the field (Donnay *et al*., 2001). Such improvements are already underway and it is envisaged that the problem will no longer exist in a few years.

With the increased availability of higher resolution satellite imagery (*e.g.* IKONOS and EROS), a similar study could be undertaken using such data to determine the influence of the increase in geometric, radiometric, spatial and spectral resolution on the outcome of the automatic classification process. It is predicted that the increase in radiometric and spectral resolution could have a significant effect on the end product (Stern, 1985). In the case of hyperspectral imagery, where several spectral bands are incorporated in one image, cleared distinctions between buildings and bare soil could be expected. In both above cases, the analysis would be considerably more costly than using the medium and lower resolution satellite imagery utilised in this study. The use of aerial photography for census applications has similar, cost related, limitations; however, with the higher resolution of aerial photography, this data source wouldn't only be usable in identifying areas of urban growth, as with the case of the medium and low resolution satellite imagery but could also be utilised for the measurement of size of settlement areas, and counting housing units. Using aerial photography, especially for an automated house count process could be a valuable research arena (Olurunfemi, 1982).

Another approach to assist in future census surveys could be to develop an algorithm where an average number of households in a specific area are determined. According to the size of the urban settlement quick estimations of populations for entire cities could be calculated using satellite imagery. The above land-area-approach could be time saving and cost effective however, research is still required to determine the viability and applicability of this approach in specifically developing countries (Lo, 1986).

The focus of remote sensing in urban applications was mostly centered on the increase and expansion of urban settlement, but with the occurrence of natural disasters, such as floods, droughts, famine and also diseases such as HIV AIDS, the possibility of using remote sensing to monitor the abandonment of settlements must be investigated (Stern, 1985). There is also a need for urban remote sensing to shift from simply understanding urban systems to understanding the functioning of urban systems. To make this paradigm shift possible, remote sensing needs to be integrated more with other sources of georeferenced data (expert systems); for example, incorporating socio-economic data with the traditional land cover. Furthermore, system users should be equipped with a better understanding of the functioning of the urban environment analysis (Donnay *et al.,* 2001; Short, 2000 & Stefanov *et al.*, 2001)

"*In many of the developing countries the conventional urban data sources provide a "what should be" inventory of ownership interests rather than a "what is" representation of formal and informal urban land use*" (Donnay *et al*., 2001:247). In the future, a paradigm shift from "what is" to "what if" is required when data sources are generated from satellite imagery. The outcome of research will determine whether urban remote sensing is to fulfil only a technical role in the updating and maintenance of existing data or whether it might move to play a more central role in quality of life studies and modelling of form and function (Donnay *et al,* 2001).

CHAPTER 7: Conclusion

In South Africa the population increased from 17,396 million in the 1960’s to 37,066 million in 1990, which is more than a 100% growth rate in only 30 years (Deichman, 1990). The total 2001 population was estimated at just over 44 million (SSA, 2003). The impact of land use change is a dynamic process and imagery from satellite platforms provides the ability to analyse large areas and sample repeatedly (every 26 days for SPOT). Satellite imagery provides a baseline against which managers and decision makers can compare future inventories as they continue to monitor land conditions (Department of Defence, 2000).

Most of the errors during past censuses have been attributed to poor organization skills and lack of required basic data. In censuses conducted in other Third World countries, a lack of adequate information on the number and location of settlements, and on the delineation of enumeration areas were significant in reducing their accuracy (Olurunfemi, 1982). In this study remote sensing, specifically focusing on satellite imagery as a data source, with an automatic classification procedure was used to investigate the implementation of more accurate, less time consuming, labour-intensive and more cost effective procedures to support the census survey process. “Flagged” areas or urban classified areas tend to have a high accuracy level (89%), since subjectivity and human error are non-existent in this process (BLM, 1999) and because of the limited human intervention, this process is repeatable and the evaluation of the process quantifiable. The high level of accuracy and repeatability potential of this process make this procedure suitable for all settlement demarcation in the future especially for census purposes Automated techniques for census demarcation contribute to the fieldwork by providing critical data for planning, sampling, and accurately locating field sites (BLM, 1999). Furthermore the suitability of using a SPOT-Landsat merged combination as data source proves to be quite successful as reflected by the high accuracy level of the end product.

.Despite the apparent appeal of automated identification of urban change and for the demarcation of census areas, there are drawbacks to using satellite imagery; for example, the costs involved in acquiring and processing images (David, 2000). The availability of imagery without cloud cover can be problematic, particularly in equatorial areas, and the total reliance on spectral values for settlement change without human interpretation and contextualisation can have a negative influence on the accuracy of the results (Lunetta & Elvidge, 1999). Other constraints to this automatic classification process have been discussed at length above.

Advantages of using an automatic classification process to identify and demarcate urban settlements for census purposes outweigh the disadvantages. The technique utilised in this study must be seen as a tool to support the census surveyor and not a replacement of the existing process. However, there is a real danger that automation could make the Census process a technical and not political process (Olurunfemi, 1982).

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