

**AN ASSESSMENT OF RANGELAND DEGRADATION IN THE
BAHURUTSHE COMMUNAL GRAZING LANDS USING
REMOTE SENSING TECHNIQUES**

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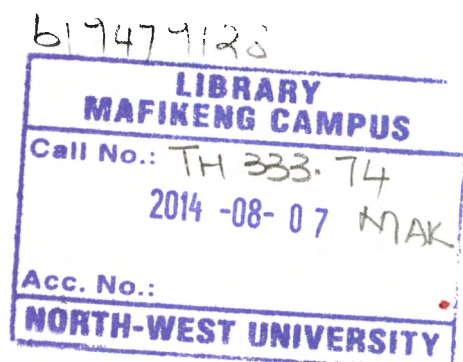


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**Dissertation submitted in fulfilment of the requirements for the
degree of Master of Science in Geography, Mafikeng Campus.**

Supervisor: Dr C Munyati

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DECLARATION

I, David Sediba Makgale, hereby declare that the dissertation for the Master of Science in Geography at North West University hereby submitted, has not previously been submitted by me for a degree at this or any other university, that it is my own work in design and execution and that all material contained herein has been duly acknowledged.

SIGNED:

David Sediba Makgale

DATE:

DEDICATION

I dedicate this dissertation to my late father, Sello Naphtal Makgale, and my late grandfather Stephen Mpugi Makgale. May their souls rest in peace.

ACKNOWLEDGEMENTS

My special thanks go to my dear wife Flora, who stood by me throughout the duration of this study. I thank you very much for standing by me even when things were hard, and for withstanding the long hours of my absence from home while conducting the research.

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I also thank all the villagers in the various villages of Lehurutshe who helped in any way they could during field work for this research, none more so than the old man in Madutle who, despite his being apparently over 75 years old, was willing to share his views about grazing management in the area at length, including how he tragically lost his herd to cattle thieves in the communal rangelands in 1955.

Lastly, but certainly not the least, I express warmest gratitude to Dr Chris Munyati for providing academic guidance and support, as well as encouragement, that made this research successful.

Most of all, I thank the Lord for making this study a success.

ABSTRACT

The Bahurutshe Tswana people of Lehurutshe district in South Africa's North West Province are traditionally cattle keepers who graze their livestock in communal rangelands. This study sought to establish whether these communal rangelands had degraded in the recent past, as well as map and quantify the degradation, using remote sensing techniques. Based on established theory that the veldt degradation process in South Africa ultimately results in bare land, in addition to loss and replacement of palatable rangeland species, bare land in the rangelands was used as indicator of degradation, primarily due to lack of palatable rangeland species spectral signatures.

January 1995 and 2005 Landsat TM images of the area were used for the degradation assessment. January images were selected based on the expectation that bare land in the rangelands would not have emerging grass just after the start of the summer rains. Image statistics and visual inspection revealed no image noise. Following geometric registration, with sub-pixel root mean square error, the images were separately classified by hybrid classification into six classes considered adequate for the rangeland degradation assessment, namely: water, bare land, very sparse vegetation, sparse vegetation, dense vegetation, and other dry land. Ground truthing was undertaken in January 2006, so only the indicative bare land class could be assessed for classification accuracy due to the fact that vegetation is not time stable. Classified image recoding isolated the indicative bare land class. GIS overlay analysis enabled mapping degradation. The results indicate moderate rangeland degradation, up to 4% in some grazing blocks, particularly in southern parts of the district where most settlements are located. The study shows that remote sensing techniques are vital for rapid rangeland degradation and other multitemporal spatial analyses. The technology should be taken advantage of in South Africa with the launch of the country's own environmental satellite.

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ABBREVIATIONS

DN	Digital Number
ERDAS	Earth Resources Data Analysis System
EROS	Earth Resources Observation System
GHz	Giga Hertz
GIG	Giga Bytes
HRV	High Resolution Visible
HRVIR	High Resolution Visible Infrared
IKONOS	Satellite name, Greek for 'image'
Landsat	Land Satellite
MB	Mega Bytes
MSS	Multi Spectral Scanner
PC	Personal Computer
RAM	Readily Available Memory
RGB	Red, Green, Blue
RMSE	Root Mean Square Error
SPOT	<i>Système Pour l'Observation de la Terre</i>
TM	Thematic Mapper
WRS	Worldwide Reference System

INTRODUCTION

1.1 The Problem of Land Degradation in the Bahurutshe Tribal Lands

This research investigates change in quality of communal rangelands in the past decade in Lehurutshe district, whose native inhabitants are the Bahurutshe clan of the Tswana tribe. The district is in South Africa's North West Province (Figure 1.1), in the former Bantustan of Bophuthatswana.

According to Oettle (1998), nearly 25 percent of the land in the magisterial districts of South Africa is badly degraded. Land degradation in South Africa has historically been accelerated by land use changes associated with intensification of subsistence production achieved by cultivating marginal lands, as well as overgrazing in the increasingly overcrowded and overstocked native reserves/homelands or Bantustans. In the past many of the black South Africans were entitled to only 13 percent of the land in South Africa. The 'social engineering' history of South Africa during apartheid has impacted on this area as well. Milton *et al* (2003) point out that, as a legacy of apartheid, 72% of the rural South African population lives on 12% of land zoned for agriculture, which results in overexploitation of land. This scenario applies to the former Bophuthatswana in which Lehurutshe district is located.

In addition to the historical institutionalised marginalisation that could precipitate land degradation in Lehurutshe, there are cultural aspects. The inhabiting Bahurutshe clan of the Tswana people are pastoral, to whom cattle are both a source of income and symbol of wealth. Therefore, traditionally, owning more cattle enhances social status in this society. Much of the people's land was lost to large commercial farms that were established in the past, with the result that the Tswana people were concentrated in more marginal lands to practice both arable and pastoral farming. The animals in Bahurutshe are grazed in communal grazing areas. The community has agreed on rotational grazing in 'camps', but even if it is practised, there is soon overgrazing due

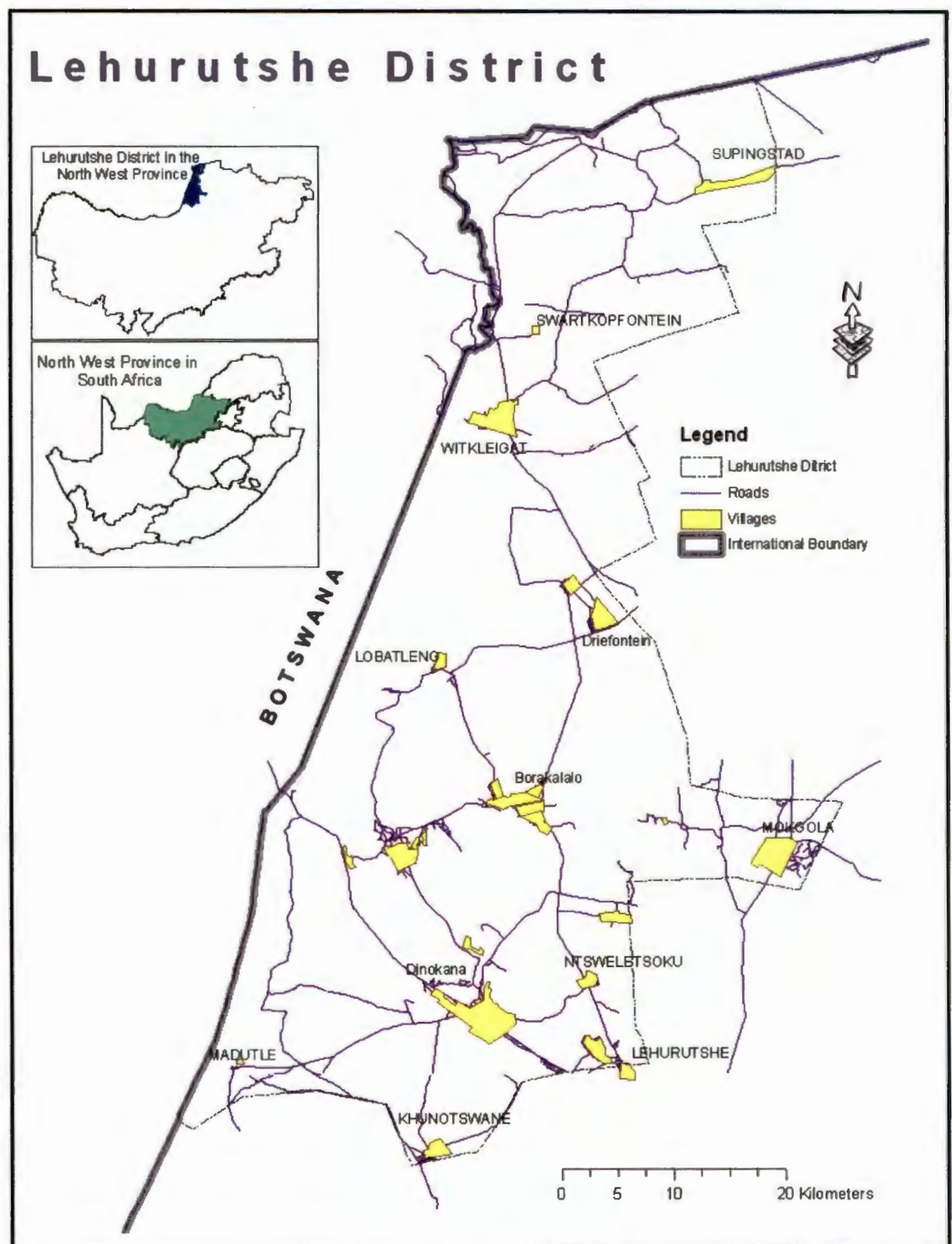


Figure 1.1 Location of Lehurutshe district in South Africa

to overstocking and there are some herdsmen who do not cooperate and who take their cattle to other camps (Propp, 2001). This break down in communal management of rangelands has also been observed in neighbouring Botswana (Makepe, 2006) which also has a traditionally cattle keeping society.

Thus, the potential exists for rangeland degradation in the Bahurutshe tribal lands under Hardin's 'tragedy of the commons' scenario. According to Propp (2001), the real problem in the Bahurutshe area is overpopulation of people and everyone wants to have cattle; thus each household has a few cattle, but together they have too many for the land they have. In South Africa, in general, social problems related to poverty and inequity (understandably) take priority over land degradation and biodiversity for government funding (Milton *et al*, 2003). It is this cultural and historical background to the study area that gave rise to the expectation of land degradation in the study area, and the initiation of the study.

1.2 Scope of the Study

1.2.1 Research Problem

The research problem that was being investigated by this research was as follows:

- Where and to what extent has there been rangeland degradation in the Bahurutshe communal grazing lands?

1.2.2 Aim and Objectives

1.2.2.1 Aim

The aim of the study was to map and quantify rangeland degradation that has taken place in the Bahurutshe tribal lands during the past two decades, using remote sensing techniques.

1.2.2.2 Objectives

The following were the specific objectives of the research:

1. To identify the location of active and sustained rangeland degradation in the Bahurutshe communal grazing areas.
2. To establish the amount of rangeland degradation that has taken place in the Bahurutshe communal grazing areas in the recent past.
3. To establish the link between the observed rangeland degradation and perceived cultural causes.

1.2.3 Research Hypotheses

The research had two related hypotheses, these being that:

1. There has been long-term rangeland degradation on the Bahurutshe tribal lands due to overstocking.
2. Multi temporal remote sensing with high spatial resolution imagery can be used to detect and map the rangeland degradation in Bahurutshe tribal lands.

1.3 Importance of the Study

This research will identify degraded areas. Both mapping and monitoring represent important prerequisites for defining and implementing political decisions and development plans for the protection and sustained use of land resources. It is hoped that the study will help in adding to the database on land degradation for use in the State of the Environment report with respect to the Bahurutshe tribal lands.

There is a crucial need for monitoring changes in natural resources such as vegetation cover. The research could serve as an additional case study for reference in methodological aspects of identifying and mapping land cover degradation in South Africa in general, and the North West Province in particular. There is scant material in the literature on the North West region of South Africa in this regard.

1.4 Definition of Terms

The following terms will be taken to have the following meanings throughout this dissertation:

1. **Land cover** refers to the type of features that are present on the surface of the earth (Lillesand *et al*, 2004; AFRICOVER, 1998; Lo, 1986).
2. **Land use** refers to the human activities or economic functions associated with a piece of land (Lillesand *et al*, 2004).
3. **Rangeland** is land where the potential natural vegetation is predominantly grasses, grass like plants, forbs, or shrubs and where animal grazing is an important influence on its state (Lillesand *et al*, 2004).
4. **Rangeland degradation** refers to the loss of utility or potential utility or the reduction, loss or change of features of the rangeland ecosystem (Chrisholm and Dumsday, 1987). In other words, rangeland degradation involves a reduction in the quantity or nutritional quality of the vegetation available for grazing.
5. A **Geographic Information System (GIS)** is a system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and dissemination information about areas of the earth (Dueker and Kjerne, 1989, pp. 7-8).
6. **Remote sensing** is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand *et al*, 2004, p1).

1.5 Structure of the Dissertation.

The dissertation has seven chapters. Chapter One introduces the research theme and its focus, as well as issues about the study area in relation to the research theme. Chapter Two describes the study area in detail, highlighting aspects of the area that are relevant to the focus of the study. Chapter Three summarizes material from literature concerning theoretical and methodological aspects of land cover change, land cover mapping and change detection, remote sensing and GIS as related to these,

as well as a collation of relevant results from previous and related research. Chapter Four details the methodology used in conducting the study, while Chapter Five presents the results. Chapter Six discusses the results in relation to the aim and objectives of the research, while Chapter Seven states the conclusions emerging from the study and gives suggestions for future work.

DESCRIPTION OF THE STUDY AREA

2.1 Introduction

This chapter briefly describes the study area. It highlights aspects of the study area that are important to the study. These aspects pertain to the location of the area, the settlement and population characteristics, vegetation, soils, land use and agriculture, climate and topography.

2.2 Location

Lehurutshe is located between longitudes 25°35' and 26°15' East and between latitudes 24°40' and 25°35' South. The area is situated in the northern part of the North West Province in South Africa (see Figure 1.1). According to the Department of Agriculture, North West Province, land degradation is serious in the North West, particularly in the communal areas. Lehurutshe has been identified as a hotspot for land degradation in the province. Having been part of the former Bantustan Bophuthatswana, tribal lands and villages dominate it. Lehurutshe shares a 144 km border with Botswana. It covers an area of 255314.9 ha of land in North West Province. The dominant Tswana tribe in the area is the Bahurutshe.

2.3 Settlement and Population

The settlement pattern in the area is nucleated as well as scattered. The nucleated settlement pattern is made up of villages which include Dinokana, Borakalalo, Witkleigat, and Supingstad and the scattered settlements are cattle posts which include Madutle and Swartkopfontein (see Figure 1.1). There are thirty one villages in the district, and one urban settlement, Lehurutshe. The 3171km² area had a population of 59 946 in 1980 (Cowley 1985) and by 2000 the population was about 135 000 (Van Niekerk and Du Pisani, 2006; p. 448, Fig. 3).

2.4 Vegetation

The prevailing vegetation type is of acacia savannah type and consists of a variety of thorn trees, shrubs and dry grasses. The dominant trees that are found in the area are

Acacia karoo, *Acacia mellifera*, *Acacia tortillis*, *Acacia nilotica*, *Dichrostachys cinerea*, and the common grasses are *Eragrostis*, *Lehamanniana*, *Antheophora* etc.

As indicated by Cowley (1985) the Kalahari thorn veldt and shrub bush veldt cover the north-eastern part of the region, while the northern part is covered by mixed bush veldt and the central part by the other turf thorn veldt. The southern part of Lehurutshe is covered by the sourish mixed bush veldt.

2.5 Soils.

The soil type in many parts of Lehuruthse are red-yellow-gray Latesols (Cowley, 1985). These iron rich soils are generally of neutral and loam type with considerable variations in agricultural potential.

2.6 Land Use and Agriculture.

Crop and stock farming are an important aspect of every day life to the majority of the people in the area. Much of the area is being used for livestock farming and only a portion of the area for crop farming. Subsistence or non-market agriculture is still practised today. The main crops grown in the arable lands are maize, sorghum, sunflower and rice. The Tsholofelo irrigation scheme in Lobatleng (see Figure 1.1) once produced cotton and citrus fruits. However since 1981 drought has seriously affected production of cotton and citrus fruits.

According to Drummond (1995), the area has experienced declining agricultural production and change in irrigation system. Drummond (1995) focussed on Dinokana in the southern part of the district (Figure 1.1).

2.7 Rainfall and Temperature

Lehurutshe area is arid to semi-arid (Van Niekerk and Du Pisani, 2006). The climate in Lehurutshe has generally been recognized as dry type. The area is generally warm. Figure 2.1 illustrates the rainfall seasonal pattern of Lehurutshe from August 2005 to July 2006. The rainfall in the area is unpredictable and unreliable, often fluctuating widely around the annual mean. Drought is an ever-present problem in the area. Drought in the area is often severe and can last for several years (Cowley, 1985).

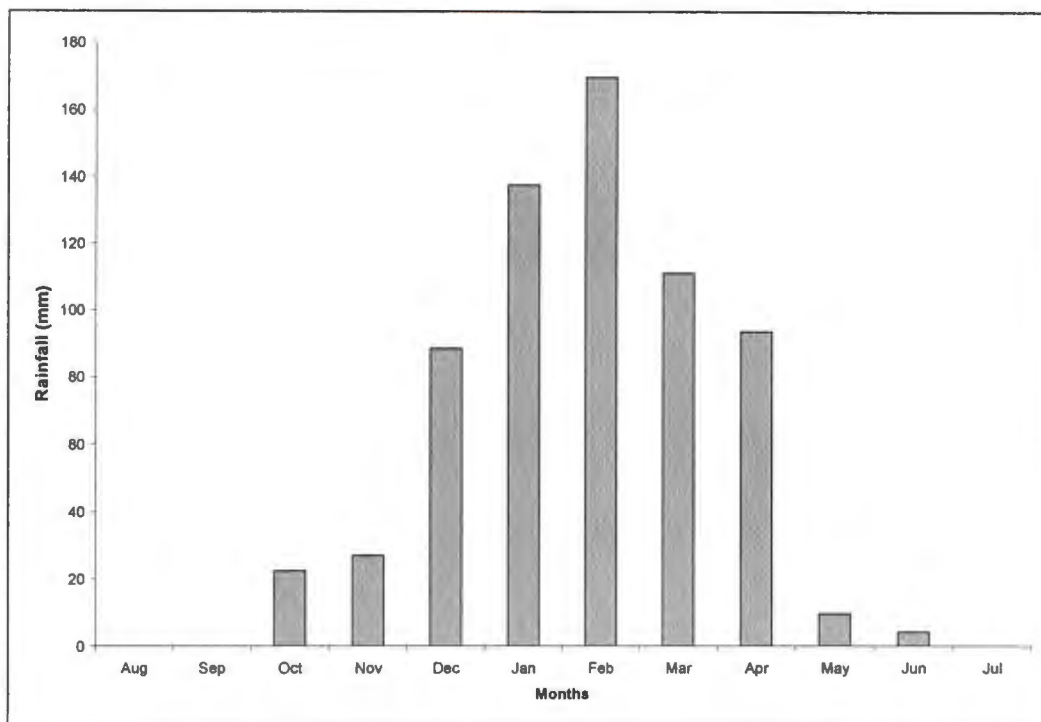


Figure 2.1 Monthly rainfall for Lehurutshe district in the 2005 / 2006 season (Data: North West University weather station).

According to Cowley (1985) Lehurutshe region falls within the summer rainfall regime in which the rain occurs from November to March, which is accompanied by violent thunderstorms producing torrential downpours. Devastating floods often follow severe drought, which undermines the ecological balance. The seasons 1978 / 1979 and 1981 / 1983 were characterized by abnormal rainfall distribution (Cowley, 1985). The area receives an annual rainfall of 500 mm to 600 mm, whereas some of the areas receive 600 mm to 700 mm (Cowley, 1985; Van Niekerk and Du Pisani, 2006).

2.8 Drainage and Relief

Lehurutshe has some great variation in landscape through a combination of river down cutting and alternating hard and soft rock strata. The highest elevation in the area is approximately 1600m. Sehujwane and Ngotwane (see Figure 2.2) are the only perennial rivers in the area. The provision of water supply in the area is through dolomite eyes. Driefontein, Gopane, and Dinokana are the most important water sources in the area. Hill ranges include Tloe and Makadima Hills (Figure 2.2).

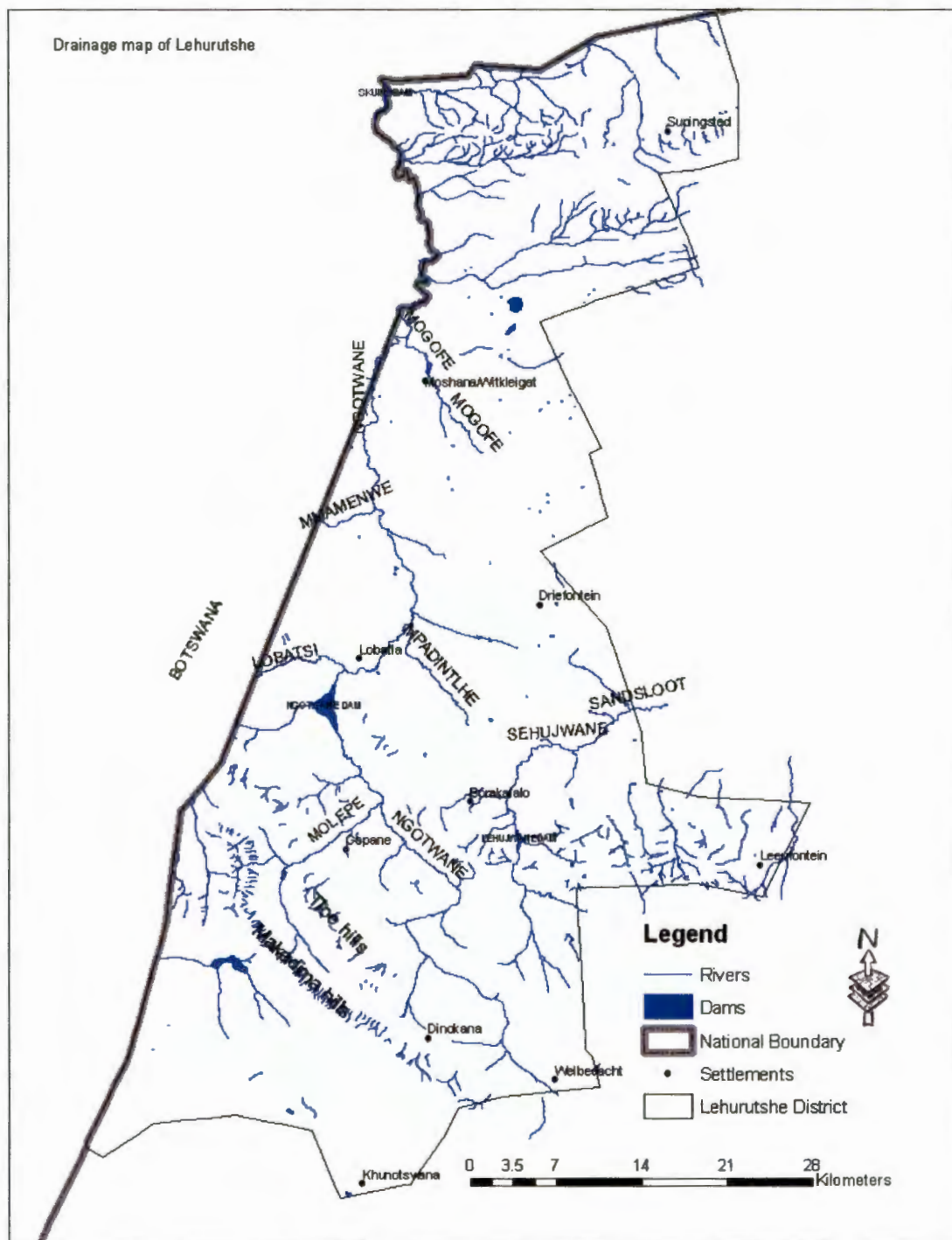


Figure 2.2 Drainage map of Lehurutshe

LITERATURE REVIEW

3.1 Introduction.

This chapter summarises material from literature concerning rangeland degradation in general and in the region in which the study area is located, as well as the use of remote sensing in rangeland assessment.

Williams and Kepner (2002) and Lillesand *et al* (2004) outline the importance rangelands, pointing out that rangelands are important natural resources that provide forage for livestock as well as wildlife habitat. However, rangelands also represent areas potentially supporting land uses as varied as intensive agriculture, recreation and housing. These potential land uses give pressure on the maintenance of rangelands to rangeland managers. Loss of rangelands, however, can result in ecosystem disturbances. Rangelands regulate the quantity and quality of water for the surrounding watersheds (Williams and Kepner, 2002). Rangeland vegetation has the ability to intercept runoff from rain events, and increase water infiltration to the soil, allowing for aquifer recharge. Rangeland soils contribute to water quality by immobilising and transforming nutrients and contaminants and act as a groundwater filter.

3.2 Rangeland Degradation: Nature and Causes.

As stated in Section 1.4, rangeland degradation involves a reduction in the quantity or nutritional quality of the vegetation available for grazing (Chrisholm and Dumsday, 1987).

According to Tainton (1999), there are distinct phases in the process of rangeland degradation. The first stage, which Tainton (1999) terms primary degradation, is characterised by a rapid degradation of the original plant community and it involves the reduction in productive capacity which occurs when the density of the valuable, productive and soil protecting species decline. Such species include *Themeda triandra*, *Fingerhuthia Africana*, *Panicum* and *Pennisetum* species (Tainton, 1999). These valuable species are then replaced by less palatable grazing tolerant pioneer

species. This process, according to Tainton (1999), is much slower than the elimination of the original species. During the second phase in the process, the ground cover is poor and this leads to active soil erosion. This phase is called the primary depopulation phase and is followed by re-colonization.

A number of causes of rangeland degradation are identified by several authors in the literature (e.g. Williams and Kepner, 2002; Milton *et al*, 2003; Ringrose *et al*, 1990; Makhanya, 1993). These causes of rangeland degradation include:

- **Grazing pressure / intensity** – high grazing pressure may lead to loss of desirable or palatable forage species, encroachment of non palatable species, and topsoil erosion due to overall groundcover loss.
- **Human (land use) factors** – which include population growth (leading to land use encroachment onto rangelands), inappropriate policy initiatives, overgrazing / overstocking, collection of firewood, and encroachment by subsistence farmers.
- **Climatic factors** – in semi arid and arid zones, where fire is also a factor (Trodd and Dougill, 1998), drought is large determinant of vegetation change, and trends in vegetative cover can be directly related to climatic fluctuations.

3.3 Remote Sensing and Rangeland Degradation Assessment.

The spatial technologies of remote sensing and GIS provide an opportunity for mapping the status of rangelands, as well as their degradation (Trodd and Dougill, 1998; Palmer and Fortescue, 2003; Lillesand *et al*, 2004; Ringrose *et al*, 1996). Assessment of rangeland degradation using remote sensing, as does all change detection with remote sensing, requires the selection of a minimum of two image scenes, with the following requirements (Jensen, 1986; Lillesand *et al*, 2004):

- Holding sensor system variables as constant as possible (e.g. spatial, spectral, temporal and radiometric resolutions, view angle);
- Holding environmental variables as constant as possible (time of year, time of day, soil moisture, phenological cycle), and;
- The extraction of thematic information from each date of imagery and the application of the change detection algorithm.

The accuracy of change detection will, in addition to sensor and time differences, be influenced by such factors as accuracy of spatial registration of the multi temporal images, differences in atmospheric composition at the time of image acquisition, and the spatial size of the changes in relation to the sensor's spatial resolution (Jensen, 2000). Registration with a root mean square (RMS) error within 0.25 to 0.50 pixel is generally required in change detection with multi temporal images (Lillesand *et al*, 2004).

Ideally, unbiased ground reference data at the time of image acquisition by the sensor needs to be collected, to aid image interpretation. Unfortunately, this is rarely possible when historical images have to be used. Therefore, while it may be possible to collect ground reference information for the most recent image, it is impossible to go back in time and collect the historical reference information (Jensen, 1986; Lillesand *et al*, 2004). To deal with differences such as sun angle, earth/sun distance, detector calibration differences between sensors, atmospheric composition and sun/target/sensor (phase angle) geometry, all of which can affect pixel digital numbers, radiometric scene normalisation (Schott *et al*, 1988) can be undertaken.

Once the multi temporal image data set has been selected, a number of change detection methods (algorithms) can be employed, as summarised by Lillesand *et al*, 2004:

- **Post classification comparison** – in which two dates of imagery are independently classified and registered. Then an algorithm can be employed to determine those pixels with a change in classification between dates, and statistics (and change maps) can be compiled to express the specific nature of the changes between the dates of imagery.

The disadvantage with this method is that the accuracy of the independent classifications affects the accuracy of the change detection. According to Lillesand *et al* (2004), the errors contained in each of the initial classifications are compounded in the change detection process (e.g. two classifications with an 80% classification accuracy each will result in a change detection image with 64%

accuracy), necessitating the need for high classification accuracy. Post classification comparison is one of the most widely used change detection methods (Jensen, 1986; Milne, 1988).

- **Classification of multitemporal data sets** - in which a single classification is performed on a combined data set for the two or more dates of interest.

According to Lillesand *et al* (2004), this approach has two disadvantages:

- i. The success of change detection depends upon the extent to which “change classes” are significantly different from the “no change” classes.
 - ii. The dimensionality and complexity of the classification can be large, and if all bands from each date are used, there may be substantial redundancy in their information content.
- **Principal components analysis (PCA)** – PCA of multi temporal images can also be used for change detection. The multi temporal images are registered to form a new multi band image containing various bands from each date. Several of the uncorrelated principal components computed from the combined data set can often be related to areas of change (Lillesand *et al*, 2004).

According to Lillesand *et al* (2004), one disadvantage of the method is that it is often difficult to interpret and identify the specific nature of the changes involved.

- **Image differencing** – in which digital numbers (DNs) from one date are simply subtracted from those of another. The difference in areas of no change will be very small (approaching zero), and change areas will have larger negative or positive values (Lillesand *et al*, 2004).
- **Image ratioing** – which involves dividing one image’s DNs by those of another. Ratios for areas of no change will tend toward one, and areas of change will have higher or lower ratio values,

Lillesand *et al* (2004) point out one advantage of the technique, being that it tends to normalise the data for changes in such extraneous factors as sun angle and shadows.

Tanser and Palmer (1999) proposed a change detection technique called the moving standard deviation index (MSDI), derived by passing a moving standard deviation filter across the Landsat TM band 3 (red band). According to the authors, degraded / unstable landscapes exhibit higher MSDI values than their undisturbed / stable counterparts. This technique was developed using imagery over the Great Fish River Basin in the Eastern Cape, South Africa.

3.4 Previous Rangeland Degradation Remote Sensing Work

3.4.1 General

Degradation of rangelands can involve total loss of forage, or change in vigour, abundance or species composition of forage to less desired species for grazing purposes (Chrisholm and Dumsday, 1987). Where the degradation involves change in vigour, abundance or species composition of forage, the fine (narrow) and selective spectral resolution of hyperspectral scanners (Lillesand *et al*, 2004) could serve as the identification tool for rangeland degradation mapping and quantification. Hyperspectral remote sensing has been used to detect and map undesired range plant species (Koger *et al*, 2004; Lass *et al*, 2005; Lawrence *et al*, 2006; Parker Williams and Raymond Hunt, 2004;). Everitt *et al* (2004) evaluated airborne hyperspectral imagery for differentiating among rangeland ecological variables and found that several band combinations can be used successfully to differentiate among rangeland parameters. Bork *et al* (1999 a & b) employed both broad and narrow band imagery in studying rangeland vegetative cover, and point out that field based spectral measurements of rangeland vegetation cover is essential for determination of the vegetative components using overhead imagery.

If rangeland degradation involves loss of forage the result can be barren, exposed soil (Tainton, 1999) which is susceptible to erosion by wind and water and, as the degradation continues, gullies may develop on the rangeland. Degraded rangeland with such exposed soil can easily be identified on remotely sensed images acquired by

broad band sensors operating in various parts of the spectrum, particularly the visible, mid and thermal infrared, although such sensors are not able to detect subtle changes (Williams and Kepner, 2002).

3.4.2 Southern Africa and the Bahurutshe Area.

There is an apparent paucity of literature on remote sensing of rangeland degradation in the Bahurutshe communal grazing lands, although there has been work on rangelands and land degradation in general elsewhere in South Africa (e.g. Dean and Macdonald, 1994; Makhanya, 1993; Van Rooyen, 1999; Milton *et al*, 2003). High stock numbers are recognised as a major cause of rangeland degradation in South Africa (Milton *et al*, 2003) and in Mafikeng, Taung and Vryburg (all in the North West Province of South Africa, like the Bahurutshe area), stocking rates have increased (Dean and Macdonald, 1994).

Hyperspectral remote sensing of wild animal (as opposed to domestic animal) rangelands in Kruger National Park has been undertaken by Mutanga and Sidmore (2004). In their study using the technique of continuum removal on absorption features, Mutanga *et al* (2004) conclude that with high quality radiometric and geometric calibration of hyperspectral imagery, the techniques involved in what they call 'continuum removal on absorption features' may also be applied on data acquired by airborne and spaceborne imaging spectrometers to predict and ultimately to map the concentration of macronutrients in tropical rangelands. Such techniques, it appears, can be used in rangeland degradation assessment if the indicator of degradation is nutrition status of the forage species. Mutanga and Skidmore (2004), using the integration of the red edge position and neural networks ('continuum-removed absorption features') similarly conclude that there is potential in using airborne hyperspectral data and neural networks to estimate and ultimately to map nitrogen concentration in the mixed species environments of Southern Africa.

In neighbouring Botswana, however, a lot of rangeland degradation remote sensing work is reported. Some of the earliest work on remote sensing of rangelands using broad band sensors in Botswana includes that of Prince (1986), Prince and Tucker (1986), Ringrose and Matheson (1987), and Ringrose *et al* (1990). With respect to using Landsat Multi Spectral Scanner (MSS) data, Ringrose and Matheson (1987)

point out that the two different approaches that have been applied to problems of rangeland monitoring, referred to as the near infrared over red ratio (applied successfully to areas of relatively dense vegetation in the humid zone) and the darkening effect (applicable in the sparsely vegetated semiarid zone), data from Botswana suggests that neither is singularly appropriate in the savannah woodland zone in southern Africa. In savannah woodland environments which contain both elements of both the near infrared to red ratio and the darkening approach, the most suitable indicators of range condition and degrees of desertification can be obtained by directly applying spectral ranges from the red band (Ringrose and Matheson, 1987).

3.5 Remotely Sensed Image Classification Classes in South Africa.

Thompson (1996) has detected a lack of a standard approach to classification of remotely sensed images in South Africa, with researchers using their own, varied land cover / land use classes. Consequently, Thompson (1996) devised a land cover classification scheme for remotely sensed data in South Africa, which appears to have been derived based on the USGS system as in Table 4.3, page 217 in Lillesand *et al* (2004). According to Thompson (1996), any land cover standard classification system for South Africa should satisfy the following criteria:

- The classification should be broad enough so that it can meet the needs of a wide variety of users.
- The priori classification should be independent of the area to be mapped, the data, and the mapping techniques that are used.

Thompson's classification scheme is divided into three hierarchical levels (Table 3.1):

- Level I - with 12 broad land cover types that can be identified off high-resolution satellite Imagery such as Landsat TM and SPOT without the use of ancillary data.
- Level II - with 23 subclasses that can be identified from remote sensing data without the use of ancillary data if the data format is suitable.
- Level III – which is flexible, defines subcategories developed by individual planners.

Table 3.1 Thompson's Proposed Standard Land Cover Classification Classes for Use With Remotely Sensed Data in South Africa

Level I	Level II
Forest and woodland	Forest Woodland Wooded grassland
Thicket, bush land, scrub, forest and high fynbos.	Thicket Scrub forest Bush land Bush clumps High health land (high fynbos)
Shrubland and low fynbos	Shrub land Low fynbos (health land)
Herbland	
Grassland	Unimproved grassland Improved grassland
Forest plantation.	Pine species Eucalyptus species Wattle / other species Indigenous species
Water bodies.	
Wetlands	
Barren lands	Bare rock / soil Degraded land
Cultivated land	Permanent crops Temporary crops
Urban / built up land	Residential Commercial Industrial / transport
Mines and quarries.	

Thompson's classification scheme is scale independent although the expected operating range was envisaged to be at scales between 1:50 000 and 1:250 000, based on typical Landsat and SPOT applications (Thompson, 1996).

3.6 Summary.

A review of the literature reveals the following:

1. Rangelands are important not just for providing forage but also for having ecosystem stability roles which could be lost if the rangelands are degraded. These roles include encouraging aquifer recharge, filtering ground water, regulating watershed water flows and encouraging infiltration into soils. Rangelands face the pressure of being potential land for uses like recreation, agriculture and housing.
2. Rangeland degradation results in a reduction in the ability of rangelands to serve as sources of forage. In South Africa the process proceeds in phases, the first involving loss palatable forage species and vegetation cover in general, the second involving soil erosion and recolonization.
3. The causes of rangeland degradation are natural and anthropogenic. Drought is a major cause of vegetation change in rangelands. High grazing intensity/pressure also causes rangeland degradation. The anthropogenic issues causing rangeland degradation include population growth (leading to land use encroachment onto rangelands), inappropriate policy initiatives, overgrazing / overstocking, collection of firewood, and encroachment by subsistence farmers.
4. Remotely sensed data of rangelands can be processed in a GIS to serve as a monitoring tool for rangeland degradation. This requires careful selection of sensor and time of imaging, as well as image processing procedures. The procedures involved in such change detection using remote sensing include image registration with high accuracy, image normalisation, and the application of a change detection method. Change detection methods are varied, some well established, others being refined and proposed by researchers, while some are simple and others complex. They include post classification comparison, which appears attractive because of ease of interpreting change, classification of multi

temporal images, which does not appear easy to use, principal component analysis (PCA), which is also complex, and image ratioing and differencing, which appear too simplistic and more applicable between two image dates at a time.

5. Both broad band and narrow band hyperspectral scanner images can be used in remotely sensing rangeland degradation. Globally, a lot of researchers have used images in both categories. Hyperspectral scanners appear more accurate at detecting and monitoring rangeland species composition, compared to broad band sensors like Landsat TM and MSS, SPOT HRV and HRVIR, and AVHRR. However, this is newer technology and it, therefore, poses limitations in terms of how far back in time the rangeland monitoring can go.
6. There is scant material in the literature addressing the assessment of rangeland degradation by remote sensing in the North West region of South Africa in which the Bahurusthe communal grazing lands are located. In comparison, however, a lot of work is reported in the literature reporting successful use of mainly broad band remote sensing of rangeland degradation in neighbouring Botswana, where the perceived cultural causes of rangeland degradation (overstocking) are similar, in addition to environmental similarities (semi arid climates bordering desert transition zones).

There is no standard approach to classification of remotely sensed images in South Africa. This has prompted proposals for a standard system along the lines of the USGS (United States Geological Survey) land use / land cover classification scheme for use with remotely sensed data.

7. Hyperspectral remote sensing of rangelands is useful at detecting detailed aspects of the rangeland ecosystem, including forage nutrient content and species in the mixed species of Southern Africa's rangelands.

METHODOLOGY

4.1 Introduction

In this chapter, the procedures employed in addressing the aim and objectives of the research stated in Section 1.2.2 are detailed. The procedures, and the inter linkages between them, are summarised in Figure 4.1. The sections that follow elaborate upon the procedures stated in Figure 4.1.

4.2 Design of the Study

The availability of forage in rangelands in this semi arid region is dictated primarily by the rain season. Therefore, it was envisaged that high grazing pressure in the dry months after the end of the rain season around April/May (see Figure 2.1) would progressively deplete the available forage until the first rains in each season.

For severely degraded rangelands that are barren (in the primary depopulation phase; Tainton, 1999), it was hypothesised that recovery of forage vegetation species would be slow, due to soil erosion. It was, therefore, hypothesised that the best time of year to identify such degraded rangelands would be just after the start of the rain season. Because the rains in the area can sometimes only start in earnest in December, January was selected as the time of year to identify these degraded rangelands on remotely sensed images. Therefore, only January images covering the study area were selected for the rangeland degradation assessment, in accordance with the requirement for near anniversary dates in change detection (Lillesand *et al*, 2004).

Ideally, images from the same sensor should be used in change detection by remote sensing, to minimise change detection error introduced by detector calibration differences, spatial and radiometric resolution differences, etc (Lillesand *et al*, 2004). High spatial resolution was required in this research, as well as dates going back historically as far as possible. Only Landsat TM images satisfied the requirements of going back far in history and high spatial resolution, although the new generation of satellites (e.g. OrbView, EROS, IKONOS, Quickbird and SPOT-4, 5) provide higher spatial resolution of the order 1-5m (Lillesand *et al*, 2004).

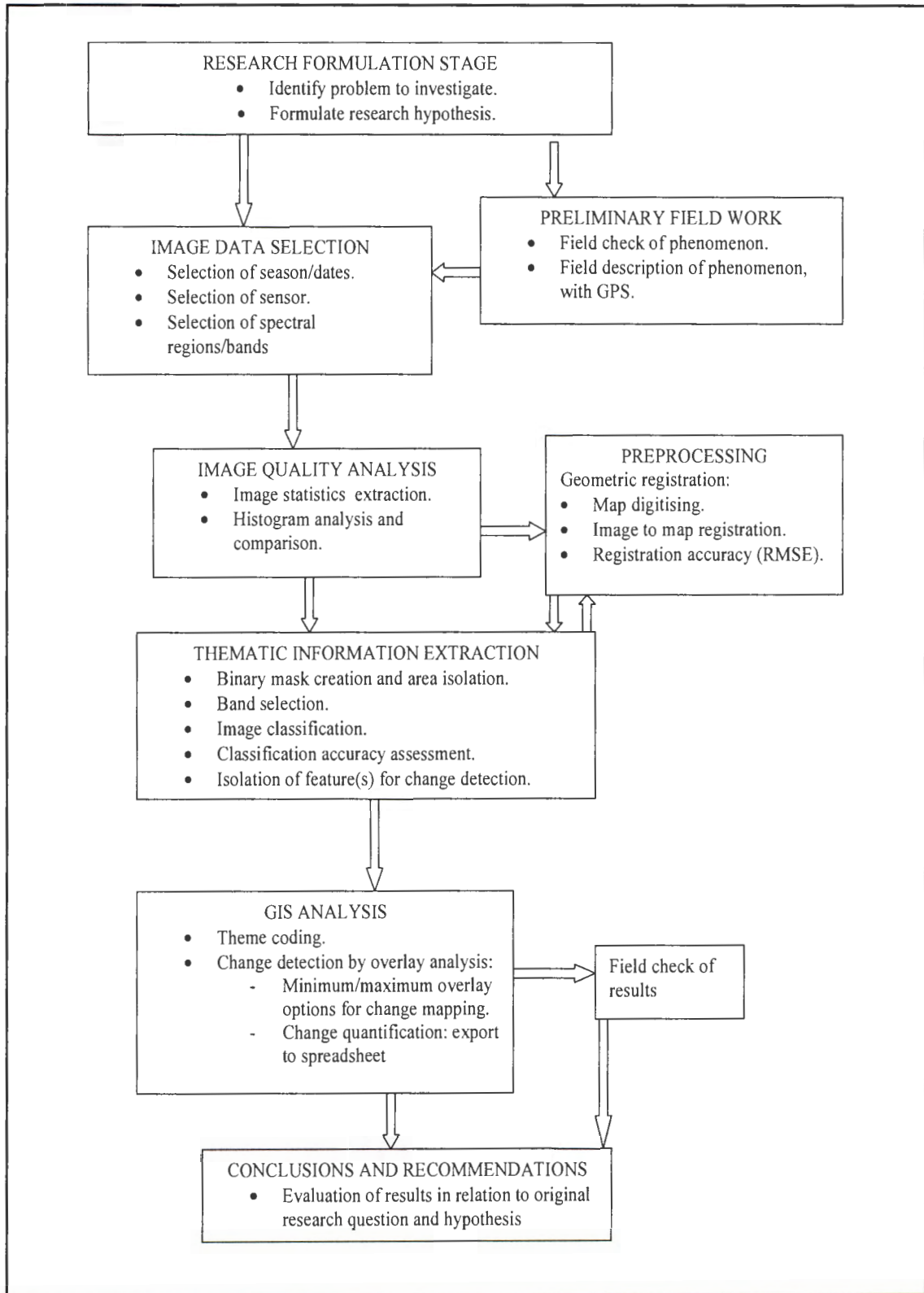


Figure 4.1 Flow diagram of methodology procedures

4.3 Image Data

Landsat TM images of the area available in archive at the Council for Scientific and Industrial Research (CSIR) Satellite Applications Centre (SAC) were ordered and supplied on CDROM. The study area does not fall inside one TM image scene, so adjacent scenes (WRS 172-0-077, WRS 172-0-078) had to be ordered for mosaicing later.

The TM image archive at SAC, however, went back only up to 1989 so 1989, 1995 and 2005 images (Table 4.1) were acquired. There were no suitable and cloud free January images in the other years encompassed by the archive period at SAC. For January 2006, no image at was in the SAC archive. The images were acquired in the .img format for ease of importing into the ERDAS Imagine 9.0 GIS software that was used for subsequent image analysis and processing.

Table 4.1 List of Landsat Images Acquired for the Rangeland Degradation Study

Date	Sensor	WRS Scene ID
05 January 2005	Landsat TM (all 7 bands)	172 – 077
05 January 2005	Landsat TM (all 7 bands)	172 – 078
26 January 1995	Landsat TM (all 7 bands)	172 – 077
26 January 1995	Landsat TM (all 7 bands)	172 – 078
26 January 1989	Landsat TM (all 7 bands)	172 – 077
26 January 1989	Landsat TM (all 7 bands)	172 – 078

The band statistics of the images that were acquired are shown in Table 4.2. Analysis of the image statistics and histograms was undertaken in order to assess the quality of the images and, consequently, to identify which radiometric correction procedures would be necessary. The histograms of the images indicated no abnormalities indicative of noise such as line dropout or band striping. Visual inspection of the images confirmed that the images were free from radiometric noise.

Table 4.2 Band Statistics of the Landsat TM Images Used

a) 2005 Image

TM Band	Minimum	Maximum	Mean	Median	Mode	Standard deviation
1	52	200	67.205	66	65	5.426
2	15	131	32.622	32	29	4.281
3	18	138	40.460	39	41	8.467
4	8	144	68.130	68	62	8.474
5	4	233	114.070	113	110	20.967
6	132	177	154.672	154	153	6.678
7	4	142	55.159	55	53	13.553

b) 1995 Image

TM Band	Minimum	Maximum	Mean	Median	Mode	Standard deviation
1	28	147	62.374	61	59	5.743
2	12	88	30.936	30	29	4.866
3	13	121	38.464	37	34	9.675
4	9	141	63.785	63	62	9.122
5	4	212	100.087	98	94	21.039
6	67	157	143.369	144	145	4.378
7	1	219	51.920	51	50	15.018

c) 1989 Image

TM Band	Minimum	Maximum	Mean	Median	Mode	Standard deviation
1	44	255	62.385	60	59	17.120
2	14	255	28.844	27	27	11.368
3	10	255	29.548	27	26	13.986
4	6	255	61.755	61	59	12.912
5	3	255	73.980	71	69	19.728
6	105	144	128.418	129	129	2.392
7	1	214	32.283	30	26	13.046

Figures 4.2, 4.3 and 4.4 show the histograms of the image data, and indicate that the 1995 and 2005 images were generally quite similar in terms of image statistics. However, at the time the 1989 image was acquired, the area was more vegetated than was the case on the other two images (see Figure 4.5). Because of considerable cloud cover, the 1989 image was excluded from further processing and change detection procedures. The maximum DN values of 255 (on an 8 bit scale) for the 1989 image (Table 4.2c) can be attributed to reflectance from clouds.

One method of correcting images for atmospheric additive effects is the zero minimum (dark object subtraction) technique (Lillesand *et al*, 2004; Gonima, 1993), in which it is assumed that there is a zero reflector, particularly for the visible and near infrared bands. If, upon inspection of the statistics of the images, the minimum is not zero, then the actual minimum DN value for each band is subtracted from each pixel in the respective bands. This method can, however, be criticised due to the fact that there may not really be a zero reflector in the scene and, therefore, subsequent subtraction can result in reduction of genuine spectral response from the features in the image scene, resulting in image degradation. Rather than risk this degradation based on an assumption, this method was not employed. The fact that the band minima are low except for band 1 (Table 4.2), however, indicates few additive effects, which gives support to the decision not to use this technique. The other methods of atmospheric correction (radiance to reflectance conversion, modelling methods) either require field data about reflectance from the field at the time of image acquisition, using spectroradiometers for example, or data on the meteorological conditions at the time of image acquisition. Such data were unavailable owing to the historical nature of the images. Therefore, no atmospheric corrections were performed for the images in the pre-processing stage.

4.4 Image Processing

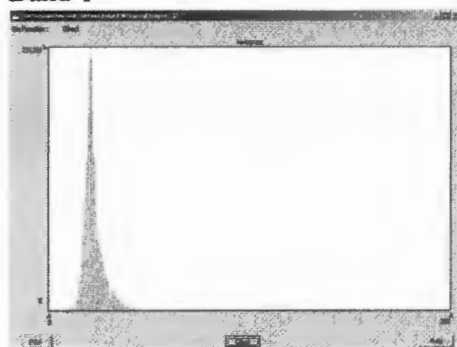
Image processing involved procedures for geometric registration, mosaicing, masking, image classification, accuracy assessment and change detection in a GIS framework. All the image processing work was undertaken using ERDAS Imagine 9.0 GIS software running on an Intel Pentium 4 PC with a 2.80 GHz processor, 512 MB RAM, a 40 GIG hard drive and a 19 inch monitor.



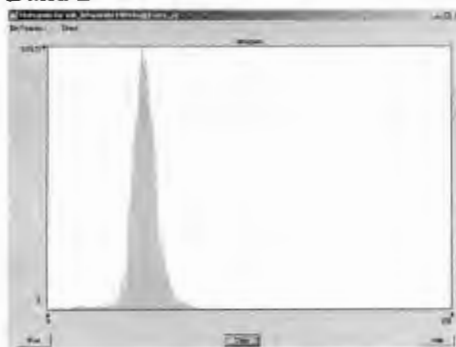
Band 1



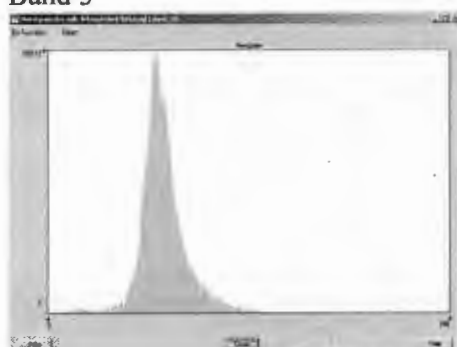
Band 2



Band 3



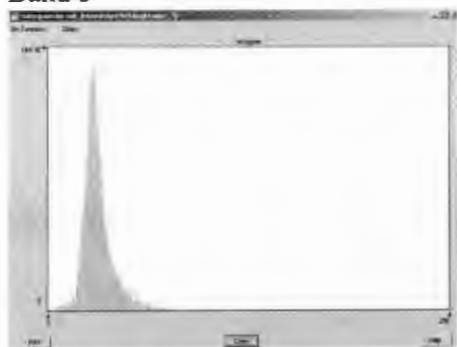
Band 4



Band 5

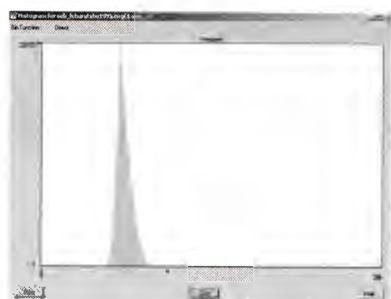


Band 6



Band 7

Figure 4.2 Histograms of the 1989 Landsat TM image (X-axes: DN values on 8 bit scale 0-255, Y-axes: frequency).



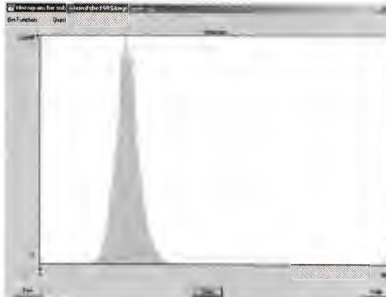
Band 1



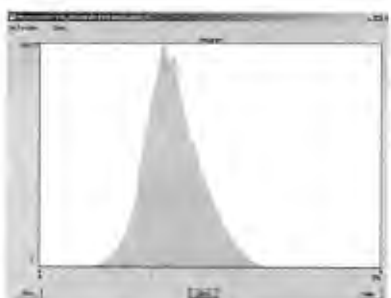
Band 2



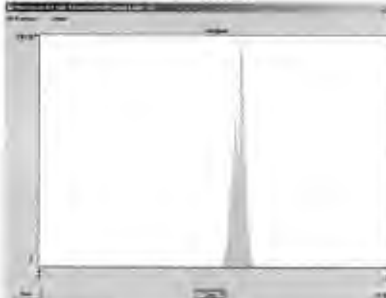
Band 3



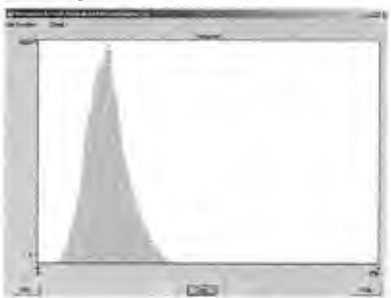
Band 4



Band 5



Band 6



Band 7

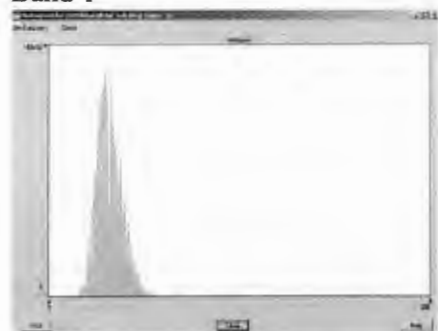
Figure 4.3 Histograms of the 1995 Landsat TM image (X-axes: DN values on 8 bit scale 0-255, Y-axes: frequency).



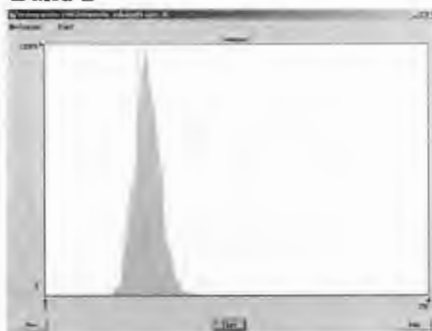
Band 1



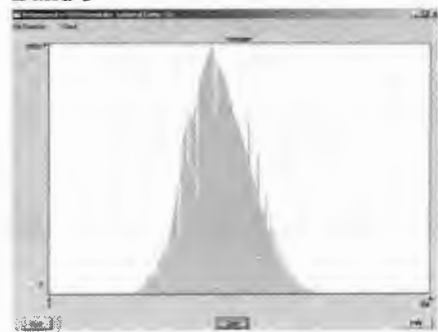
Band 2



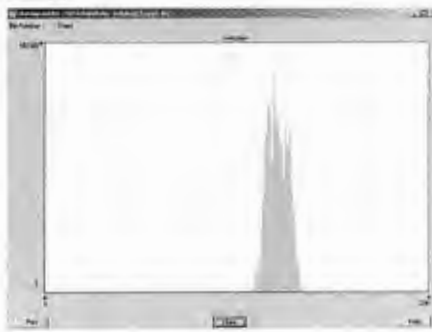
Band 3



Band 4



Band 5



Band 6



Band 7

Figure 4.4 Histograms of the 2005 Landsat TM image (X-axes: DN values on 8 bit scale 0-255, Y-axes: frequency).

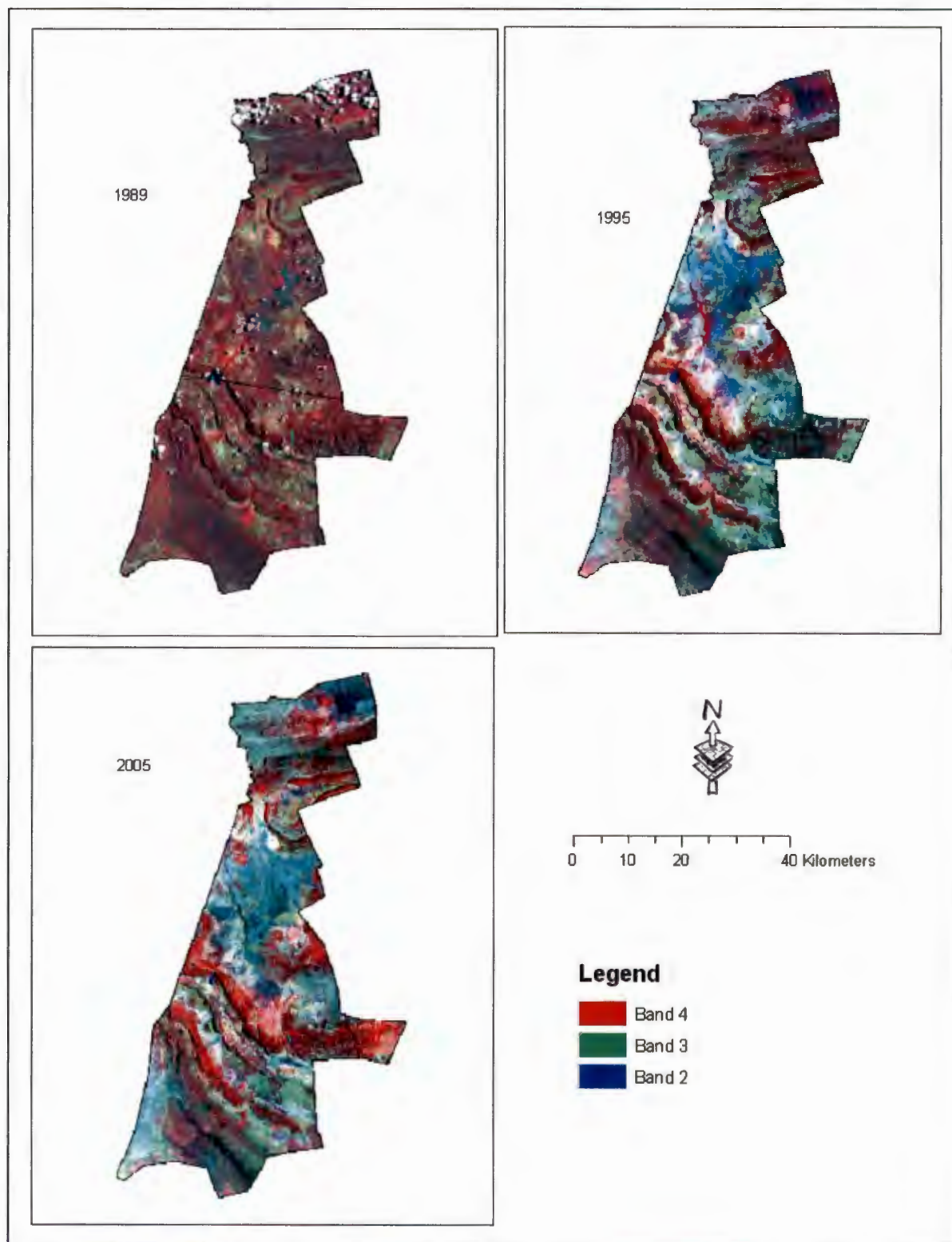


Figure 4.5 The Landsat TM image scenes of Lehurutshe District after masking out of areas outside the district (compare with Figures 1.1 and 2.2). Notice the considerable cloud cover (white patches) on the 1989 image, particularly in the top half.

4.4.1 Geometric Registration

From each of the entire image scenes listed in Table 4.1, a rectangular sub-scene encompassing Lehurutshe district was subset to perform geometric corrections. For purposes of geometric registration of the images, roads on 1:50 000 topographic map sheets covering the study area were digitised using a Calcomp digitising table and ArcView 3.2a software. A total of 8 sheets were needed, namely sheets 2425 DD, 2426 CA, 2426CC, 2525 BA, 2525 BB, 2525BC, 2525BD and 2525 DB. Using ground control points (GCP's) that were mutually identifiable both on the respective images and on the digitised topographic sheets (mainly road junctions), image to map registration was undertaken in order to make the images conform to the WGS84 UTM projection. The nearest neighbour resampling algorithm was used, preferred because it does not alter the digital numbers (DN's) (Lillesand *et al*, 2004). The accuracy of the geometric registration, indicated by the total Root Mean Square Error (RMSE) was as shown in Table 4.3, indicating that the error was 0.43 pixel at the most (i.e. 12.9m for the 30m resolution bands). From the geometrically registered images, Lehurutshe district was then isolated by masking out areas outside a vector map of Lehurutshe district using the masking function within ERDAS, resulting in the images shown in Figure 4.5.

Table 4.3 Geometric Registration Error Factor for the Images Used

Image	Number of GCP's used	Total RMSE
05.01.2005 (two scenes)	11	0.28; 0.26
26.01.1995 (two scenes)	13	0.34; 0.32
26.01.1989 (two scenes)	7	0.43; 0.40

4.4.2 Ground Truthing and Image Classification

Field work for purposes of image interpretation was undertaken in January 2006. During field work, a number of rangelands were visited and their degradation status noted. Degradation of rangelands can involve total loss of forage, or change in vigour, abundance or species composition of forage to less desired species for grazing purposes. In this research, what was sought as an indicator of rangeland degradation was what Tainton (1999) termed the primary depopulation phase of rangeland

degradation, in which valuable grazing / browsing species are replaced by less palatable, grazing tolerant pioneer species, and the ground cover is poor, thus allowing active soil erosion to take place. Based on this criterion, severely degraded, moderately degraded and healthy rangelands were identified (see Figure 4.6), their location noted using a Garmin GPS (with 5m accuracy). It was hoped that these rangelands could then be located on geometrically rectified images to trace their degradation status backwards in time using the images acquired. A total of 38 out of the 41 known farm blocks in Lehurutshe were visited to describe rangeland condition.

The rangeland locations that were visited and identified in the field were then used as ‘training areas’ in a hybrid classification process involving other land cover classes other than rangeland cover types. In this process, a preliminary unsupervised classification was performed with a specification of 15 clusters, using the ISODATA (Iterative Self Organising Data analysis) algorithm in ERDAS. The clusters were then edited by merger and deletion of some, to yield only six classes (see Table 4.4) that were adequate to serve the purpose of classifying the different rangeland cover types. The spectral signatures generated by editing the clusters were used in a supervised maximum likelihood classification of the images of Lehurutshe. Each image was subjected to the same classification procedures, the result being two classified images, each classified into the six classes in Table 4.4.

Table 4.4 Image Interpretation Classes Used in Image Classification

Class	Name	Description
1	Water	Surface water bodies.
2	Bare land	Bare soil, gravel and exposed rock surfaces.
3	Very sparse vegetation	Very sparsely vegetated areas.
4	Sparse vegetation	Sparsely vegetated areas.
5	Dense vegetation	Areas with vigorous, dense vegetation.
6	Other dry land	Any other dry land, particularly dry grassland.

NOTE: Severely degraded rangelands consisted largely of Classes 2 and 3. Moderately degraded rangelands consisted largely of Classes 2 and 4. Healthy rangelands consisted largely of Classes 4 and 5. (See also Figure 4.6).



a) Severely degraded rangeland in Leeufontein 61 block.



b) Moderately degraded rangeland in Moilwas 900 block.



c) Healthy rangeland in Moilwa 900 block.

Figure 4.6 Ground photos showing rangeland degradation categories identified in the Field.

Initial classification using TM bands 2, 3 and 4 (i.e. RGB 432) resulted in considerable spectral confusion, for example between water and mountain shadows. Following attempts at other RGB band combinations, the RGB combination of bands 3 (red, 0.63-0.69 μm), 4 (near infrared, 0.76-0.90 μm) and 7 (mid infrared, 2.08-2.35 μm) was found to be best at differentiating the different cover types. The main cover types in the study area at the time of year of study can broadly be grouped as healthy vegetation (crops, grass, trees), dry vegetation, water, bare soil and bare rocky surfaces (including gravel roads). Using these three bands covering the stated spectral regions can result in differentiation of these cover types as, in theory, illustrated in Figure 4.7. Built up (settlement) areas tended not to have unique spectral signatures, they were spectrally similar to sparsely vegetated areas (classes 3 and 4 in Table 4.4).

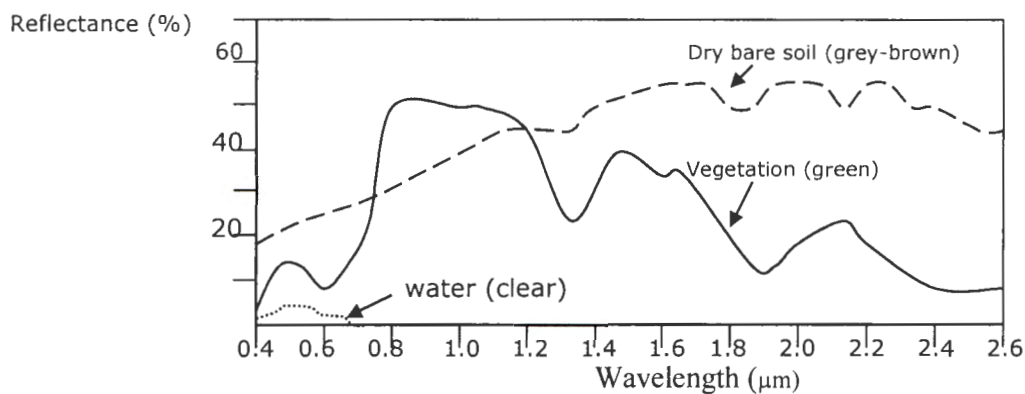


Figure 4.7 Generalised spectral reflectance curves for vegetation, soil and water (Source: Lillesand *et al*, 2004, Figure 1.10, p.17).

4.4.3 Classification Accuracy Assessment

The performance of the classification scheme was tested with respect to the January 2005 image, with particular emphasis on the rangelands. Communal grazing areas in Lehurutshe are basically well designated and maps of their location are available at the Premier's Office, in digital form as farm (block) boundaries. The digital maps of the location of these rangelands were obtained in order to enable the location of the rangelands on the geometrically rectified, classified images. A printout of an a vector overlay of the rangeland location map on the classified 2005 image (Figure 4.8) was printed on A3 paper and taken along for a field verification of the classification. Fifty randomly selected pixel locations classified as bare ground were visited in the field.

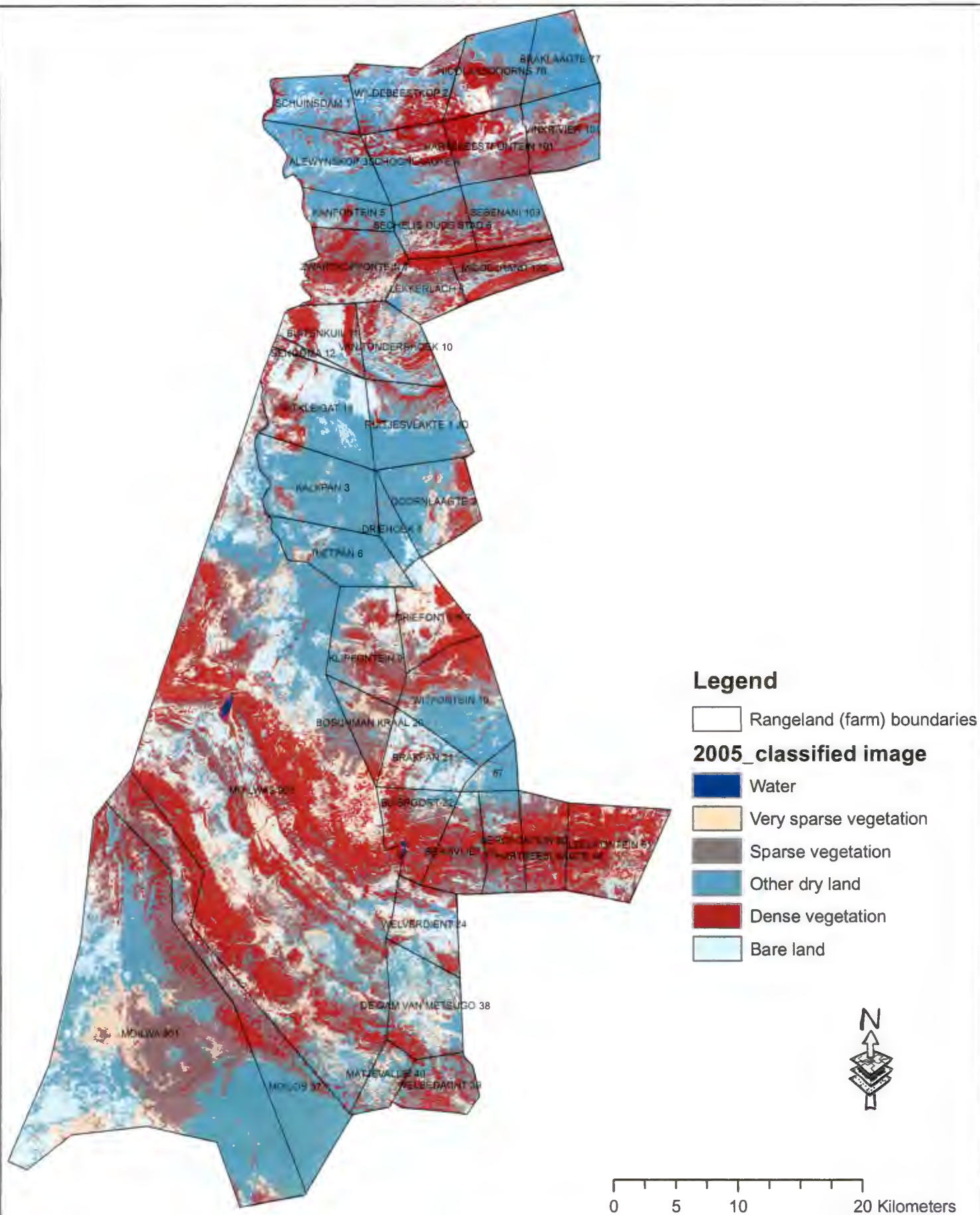


Figure 4.8 The classified 2005 image with rangeland polygons overlaid.

Based on visual verification in the field, 43 of the 50 sites were correctly classified as bare ground, giving a classification accuracy of 86%, the error largely due to confusion between bare ground and dry grass. Only bare ground could reliably be used in accuracy assessment due to the historic nature of the images. This approach to accuracy assessment, as opposed to the more conventional approach of constructing an error (confusion) matrix to calculate overall accuracy, commission and omission errors and the *K-hat* (Kappa coefficient) statistic, can be justified on the grounds that the research sought to identify and classify the rangelands as opposed to land cover classes in general in the study area. In addition, because of the historic nature of the images and the likelihood of change over time due to inherent non time-stability in cover types like water and vegetation, correct 'ground reference' data to compare the classification with can at best only be inferred using maps or aerial photographs prepared or acquired, respectively, at times of year that are different from the times of image acquisition. Had a January 2006 image been available at SAC (to coincide with the time of field work), an error matrix for the vegetation classes would have been accurate. Overall, though, the classification scheme was quite accurate as can be discerned from comparing Figures 4.8 and 4.9 with Figure 4.5. Although TM bands 3, 4 and 7 were used during the classification, the colour scheme used was specific to RGB 432, as is apparent in Figures 4.8 and 4.9; ERDAS allows such specifications.

4.5 Ancillary Data

For purposes of aiding in the explanation of any rangeland degradation trends noticed from the images, ancillary data on livestock numbers (livestock census) in Lehurutshe was obtained from the Veterinary Department in Mmabatho. The data available were for the years 1999, 2000, 2003 and 2004. Information about official policy on livestock numbers / management for the communal areas was also sought.

4.6 Rangeland Degradation Detection

Based on the fact that bare land is the ultimate stage in rangeland degradation (Tainton, 1999), this class was isolated on each of the classified images (Figures 4.8 and 4.9) by attribute recoding within ERDAS. Then the 1995 bare land image was coded as 1 and the 2005 bare land image as 2. Within ERDAS, overlay GIS analysis was then undertaken, specifying that the minimum value be on top in the overlay, so

that the 1995 bare land pixels would override the 2005 pixels (i.e. 1995 bare land to be 'on top' of the 2005 bare land). This way it was possible to map growth of bare land patches between 1995 and 2005. Additionally, the area covered by the other classes into which the images were classified was calculated for each grazing block on each of the classified images, in order to quantify the amount of degradation. The ERDAS software was used for the area calculation, which the software accomplished by counting the number of 30m x 30m pixels under each class, a GIS 'aggregation' operation. One after the other, each grazing block was isolated as an area of interest (AOI) to facilitate this calculation.

Ancillary data stated in Section 4.5 were then used in analysing possible causes of the change, supplemented by field visits in August 2006 to locations identified as undergoing degradation, during which interviews with cattle farmers were conducted to verify or refute suspected causes of the rangeland degradation. In Chapter 5, the results of all these quests are presented.

Chapter 5

PRESENTATION AND INTERPRETATION OF RESULTS

5.1 Introduction

The research set out with the objectives of locating areas of active and sustained rangeland degradation in the Bahurutshe communal grazing areas, quantifying the degradation and establishing a link between the observed degradation and perceived cultural causes. In this chapter, the results from the targeted methodological procedures in Chapter 4 are presented and briefly analysed to answer these objectives, leaving detailed discussion to Chapter 5.

5.2 Location of Rangeland Degradation in Lehurutshe

The results of the overlay analysis procedures in Section 4.6 are shown in Figure 5.1, which is a rangeland degradation map, using bare land as indicative of the severely degraded rangeland (the ultimate stage in degradation; Tainton, 1999). In Figure 5.1, green indicates locations with degraded rangeland in 1995, and red indicates degraded rangeland as it existed in 2005. Green, therefore, indicates degraded rangeland that had recovered and changed into vegetated land cover classes by 2005, but where there is green surrounded by red it is indicative of degraded rangeland that was small in extent in 1995 but had grown in 2005. Based on this interpretation, there is active and severe degradation in the south western portion of the Moilwa 901 block, north western portions of the Moilos 37 block, central Moilwas 900, Mat Jevallei 40, De Dam Van Meitsugo 38, Welverdient 24, as well as Schuinsdam 1 block (Figure 5.1). The areas appearing to have undergone little to no degradation are blocks 57 and Driefontein 7.

The southern grazing blocks of Molilwa 901, Moilwas 900, Welverdient 24 and De Dam van Metsugo 38 appear to be the most severely affected by this degradation trend, indicating that there is a regional rather than random distribution to degradation in the communal grazing lands of Lehurutshe. This could be because the southern zone has the largest settlements in Lehurutshe (see Figure 1.1). The northern grazing blocks little scattered patches of degradation in 2005, indicating either spuriousness in the degradation trend or the early inception stages of the degradation.

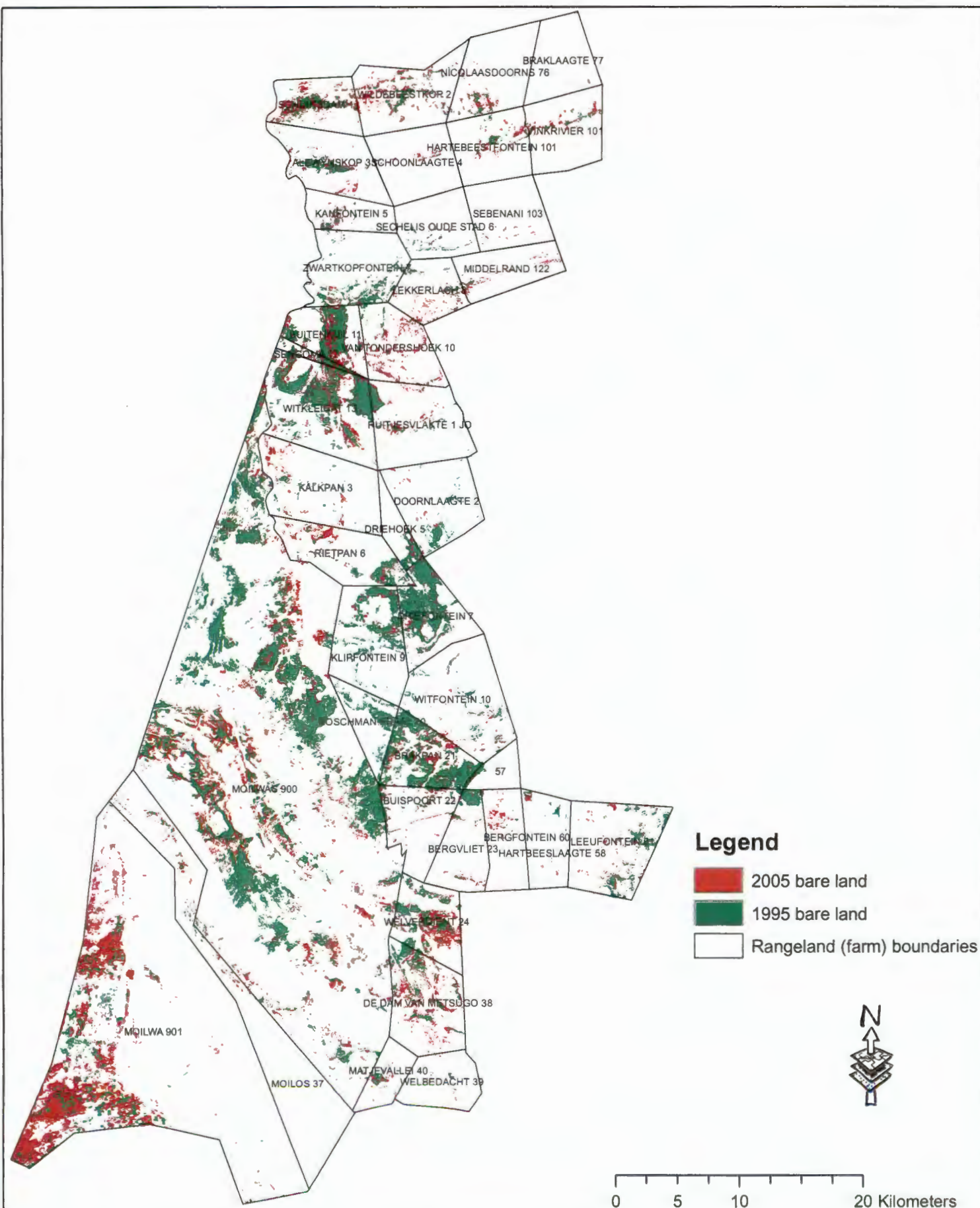


Figure 5.1 Degradation of rangelands in Lehurutshe indicated by bare land from 1995 and 2005 classified images.

5.3 Quantification of Rangeland Degradation in Lehurutshe

The Appendix shows the sizes of area covered by each of the land cover classes on the two image dates, from the classified images shown in Figures 4.8 and 4.9. Using the data in the Appendix, the amount of rangeland degradation can be quantified as shown in Table 5.1.

Table 5.1 Amount of Rangeland Degradation into Bare Land Between 1995 and 2005 in Lehurutshe

Camp / Block	Degradation (ha) (= 2005 bare land – 1995 bare land in the Appendix)	Degradation as % of total land	Camp / Block	Degradation (ha) (= 2005 bare land – 1995 bare land in the Appendix)	Degradation as % of total land
Braklaagte 77	2.07	0.02	Buispoort 22	2.7	0.04
Nicolaasdoorns 76	51.21	0.65	Bergvleit 23	-29.34	-0.52
Wildebeestkop 2	154.8	1.83	Bergfontein 60	59.31	1.12
Schuinsdam 1	214.11	3.83	Hartbeeslaagte 58	-8.28	-0.15
Alewynskop 3	40.32	0.52	Leeufontein 61	-78.39	-0.78
Schoonlagte 4	28.89	0.40	Welverdient 24	206.01	3.27
Hartbeestfontein 101	74.88	1.11	De dam van Metsugo 38	215.46	2.38
Vinkrivier 101	73.98	1.03	Matjevallei 40	22.23	0.71
Kanfontein 5	15.75	0.41	Welbedacht 39	5.31	0.10
Sechelis oude Stad 6	-11.61	-0.19	Moilwa 901	2803.77	4.13
Sebenani 103	10.98	0.17	Moilos 37	44.55	0.23
Zwartkopfontein 7	-141.57	-1.66	Moilwas 900	-1864.62	-1.49
Lekkerlach 8	85.05	1.76			
Middelrand 122	66.69	1.18			
Buitenkuil 11	217.71	4.13			
Van Tondershoek 10	207.99	3.05			
Sengoma 12	23.67	2.74			
Witkleigat 13	157.77	1.28			
Ruitjesvlakte 1 JO	68.85	0.72			
Kalkpan 3	81.81	0.75			
Driehoek 5	-43.65	-1.83			
Doorenlaagte 2	-130.14	-1.53			
Rietpaan	-65.61	-0.86			
Driefontein 7	-477.9	-7.13			
Klipfontein 9	-441.45	-4.58			
Witfontein 10	-112.77	-0.97			
Brakpan 21	-218.97	-3.29			
Boschman Kraal 20	-341.1	-6.22			
57	-8.46	-0.383			

For example, for some of the farm / rangeland blocks that exhibit the largest degradation in Figure 5.1, like Moilwa 901, Moilos 37, Mat Jevallei 40, De Dam Van Meitsugo 38, and Welverdient 24, the amounts of rangeland degradation are 2803.77ha, 44.55ha, 22.23ha, 215.46ha and 206.01ha, respectively, as shown in Table 5.1.

In terms of proportions of the total areas of these grazing blocks, these amounts of rangeland degradation represent 4.13%, 0.23%, 0.71%, 2.38% and 3.27%. The degradation expressed as a percentage of the total grazing block area indicates that the largest proportions of degradation were in Moilwa 901 and Buitenkuil 11, both with 4.13% degradation. This is followed by Schuinsdam 1 and Weverdient 24 grazing blocks, with degradations of 3.83% and 3.27%, respectively. However, as indicated by the negative numbers in Table 5.1, some grazing blocks actually show recovery in degraded rangeland. These include Moilwas 900, Boschman Kraal 20, Brakpan 21, Klipfontein 9, Driefontein 7, Doorenlaagte 2, Driehoek 5, and Zwartkopfontein 7.

There appears to be an inverse relationship between change in bare land and sparse vegetation categories on the rangelands, as illustrated in Figure 5.2. An increase in rangeland degradation, i.e. in amount of bare land, results in a reduction in sparse vegetation. Conversely, rangelands that exhibit a recovery from large amounts of bare land to less bare land, e.g. Moilwas 900, have increases in amounts of sparse and very sparse vegetation. In Figure 5.2, this trend is illustrated using a mixture of grazing blocks; those that experienced increase in degradation and those that recovered from the degraded state between 1995 and 2005. The inverse relationship between bare land and sparse vegetation categories can be discerned from Figure 5.2. What can be confirmed from the illustration and the data is the obvious relationship that rangeland degradation into bare land robs rangelands of grazing / browsing vegetation that was classified as sparse and very sparse vegetation in this study.

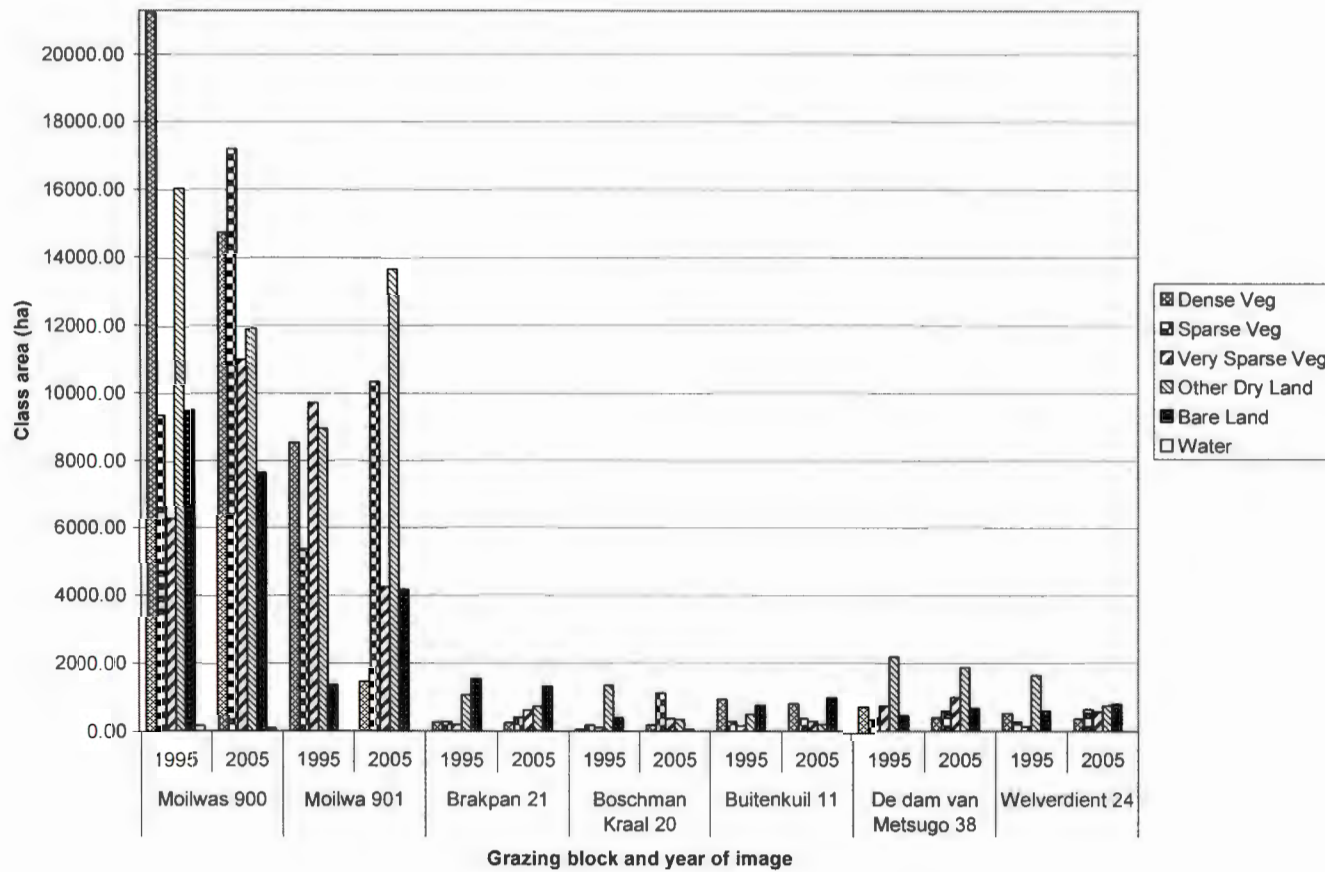


Figure 5.2 An illustration of changes in quantities of rangeland cover classes between 1995 and 2005 in selected grazing blocks in Lehurutshe.

5.4 Perceived Causes of Lehurutshe's Rangeland Degradation

At the beginning of the research project it was expected that an increase in livestock numbers, particularly cattle numbers, could have occurred in Lehurutshe to result in rangeland degradation. However, livestock data (Table 5.2) do not support this hypothesis because livestock populations, particularly cattle numbers, appear to be on the downward trend. One reason that was given by cattle farmers for this decline in cattle numbers is the high demand for cattle on the market, and the consequent high prices attracted, and some cattle thefts as a result. So farmers could have started selling rather than keeping cattle for prestige as has long been the custom in Tswana culture. However, it is quite possible that, although the overall trend for the entire Lehurutshe district is reduction in cattle numbers, there could have been localised increases in the grazing blocks that in Figure 5.1 are exhibiting a large amount of degradation. Grazing block specific data were, however, not available from the veterinary authorities in Mmabatho from whom the data in Table 5.2 were sourced.

Table 5.2 Census Data for Livestock in Lehurutshe

Year	Cattle	Sheep	Goats	Pigs	Poultry	Horses	Donkeys and Mules	Total
1999	67296	3109	32624	222	7817	53	1444	112565
2000	63138	2525	31030	391	12262	71	1816	111233
2003	57078	4610	*4041	948	no data	183	3933	**70793
2004	56150	3820	21598	451	17781	65	3830	103695

*Figure appears too low; error from source suspected.

**Incomplete data due to missing poultry data.

DATA: Veterinary Department, Mmabatho. Only data for grazing/browsing and vegetation consuming livestock is listed.

Donkeys and mules, however, appear to be increasing in number in the area but the grazing behaviour of donkeys and mules wouldn't be expected to result in making rangelands bare because these animals do not have a herding habit and appear to live isolated at the homesteads that keep them because they are largely draught animals. Increases in goat numbers would be expected to result in rangelands being stripped bare, because of the grazing and browsing habit of these animals.

The most likely cultural cause of the rangeland degradation detected is the management of the grazing in these rangelands. There is supposed to be rotational grazing in the farm blocks in 'camps' which is not adhered to, with some farmers moving their animals to other camps in defiance of the established communal rules. Field visits in August 2006 yielded this perceived cause of rangeland degradation. Visits were made to rangelands in the southern zone of Lehurutshe which in Figure 5.1 are indicated as having undergone degradation in terms of increase in bare ground. The visits were in the grazing blocks of Moilwa 901, Moilos 37, Moilwas 900, Mat Jevallei 40, De Dam Van Meitsugo 38, Welverdient 24, and Brakpan 21. During the visits, farmers were informally asked about their adherence to the rotational grazing system. Those that openly declared non adherence to the system gave wide ranging reasons as to why they engaged in the apathy, including the following:

- It is convenient for them to take their animals to any grazing land they want, any time.
- 'Conflicts and quarrels' are avoided when they don't have to go with the majority. As an example, one elderly cattle owner in the Moilwas 900 grazing block cited a meeting at which modalities of implementing the rotational grazing system was discussed. The meeting ended in 'disarray' due to non agreement on pertinent issues.
- Stock thefts are minimised because animals are taken to places that are close by and 'safe'.
- Diseases are avoided when farmers don't have to 'mix' their animals with diseased ones from other homesteads.

One difficulty of the rotational grazing system cited by the farmers is the need for demarcations to use in the rotation. Some farmers interviewed expressed their opposition to this, calling it an 'alien' concept which they oppose. An example was cited for the Moilwas 900 block, in which demarcations that had been installed were secretly removed by saboteurs from within the community, in opposition to the system. In the Brakpan 21 block (called 'Ngwate' by the locals), when asked whether the farmers were noticing that the rangeland was getting barren, responses were given

that the real problem in the block was lack of water, which caused the livestock to wander around in search of water, thereby opening up the grassed rangeland with their trampling hooves. One dimension to the increase in barren land in these rangelands, therefore, appears to be rainfall. It is quite possible that the rains have been getting less and less, or starting later than normal. Rainfall analysis was, however, not conducted as part of this research but is one avenue that seems important in any future similar research.

DISCUSSION

6.1 Introduction

Chapter 5 showed that remote sensing techniques can identify locations with active and sustained rangeland degradation in the Bahurutshe communal grazing lands. It was also shown in Chapter 5 that such degradation can be mapped and quantified using remote sensing techniques, and that such remote sensing procedures can form part of the processes of finding reasons behind rangeland degradation in the area. The rangeland degradation was quantified to be up to 4% in some grazing blocks, with some blocks registering recovery in degradation between 1995 and 2005. In this chapter, the usefulness of such techniques is discussed in the context of possible sources of error.

6.2 Usefulness of the Study's Remote Sensing Methodological Procedures

The study demonstrates the usefulness of remote sensing techniques in the rapid appraisal of environmental degradation over time, as well as quantification of spatial phenomena in general, in the South African context. With the launch of South Africa's own environmental satellite, *SumbandilaSat*, it should be possible to more frequently use such spatial appraisals using remote sensing techniques in a GIS framework because satellite images will be available more frequently. According to the specifications of *SumbandilaSat* on the Department of Science and Technology website (<http://www.space.gov.za/za002.php>), the sensor will have a spatial resolution of 6.25m, with a revisit time (temporal resolution) of 5 days, and 6 bands ranging from the visible region (0.44 – 0.51 μ m, blue) to the near infrared (0.845 – 0.89 μ m). This spatial resolution is far superior to the 30m resolution of the images used in this study so more spatial change detail will be detectable using *SumbandilaSat* images. The temporal resolution will be far superior too, compared to the 16 days of Landsats 5 & 7 from which the data used in this study were acquired. This higher temporal resolution will almost enable the monitoring of phenomena using anniversary date images (i.e. on the same date of

the year, weather permitting), to negate the effects of seasonal and sun angle / sun azimuth differences on change detection accuracy that are stated in Section 3.3.

There are a number of examples of change detection and environmental degradation appraisals that can use remote sensing methodology such as the one utilized in this research. In the Department of Agriculture, Conservation and Tourism, North West Province, the GIS Units can rapidly appraise the change in the state of rangelands following a policy change or new rangeland management practices, including in determining the optimal stocking rates in the rangelands based on the amount of degradation in rangeland per given stock density. Ground surveying of the rangelands to detect and monitor the rangeland change would be impractical given the historical nature of some of the data required.

Another potential application of the methodological procedures used in this study is in evaluating the impact of drought. Being a transitional zone towards the desert environment, droughts are common in the North West Province. The impacts of such drought episodes on vegetation and crops can potentially be rapidly mapped and quantified by using high spatial resolution satellite images of the area before and after the episode, geometrically registering them, classifying them into classes that make it possible to map the impact in question, and undertake change detection by overlaying in a GIS framework.

6.3 Causes of Rangeland Degradation in the Bahurutshe Communal Lands

As pointed out in Section 5.4, livestock numbers alone do not seem to account for rangeland degradation in the Bahurutshe communal lands. What is the more plausible cause is the management of the grazing. Cattle farmers seem to graze their animals repeatedly in the same grazing lands year after year. It is quite possible that the carrying capacities of these grazing lands are not adhered to. Therefore, it is likely that the process of degradation is slow and gradual so that the farmers are unaware of it happening. This could explain why the farmers interviewed in the field are adamant that there has been no reduction in the amount of forage available for the animals over the years. Either this is the reason or the farmers are dishonestly hiding the fact that they have noticed the

degradation, fearing that if they do acknowledge the degradation then they will be persuaded by the authorities to adopt the much disliked rotational grazing system.

It is quite possible that the degradation of the rangelands into bare land patches in the Bahurutshe communal grazing lands is being caused by reduction in rainfall between 1995 and 2005. In order to analyse this factor, rainfall data for the months of September, October, November and December 1994 and 2004, prior to the acquisition dates of the images in January 1995 and 2005, respectively, were acquired from the records for the weather at the Mafikeng Campus of North West University.

Prior to the acquisition date of the 1995 image, the total monthly rainfall figures were 15.7mm, 79.6mm, 116.5mm and 125.8mm, respectively, for September, October, November and December 1994. Therefore, a total of at least 337.6mm of rainfall had fallen before the acquisition of the 1995 image. Prior to the acquisition of the 2005 image, the corresponding monthly rainfall figures were 0mm, 22.5mm, 27.1mm and 88.50mm, for a total of at least 138.1mm. Therefore, it could be argued that the reason the rangelands appear more degraded in 2005 compared to 1995 (see Figure 5.1) is that there was less rainfall prior to the acquisition of the 2005 image (nearly half the amount prior to the 1995 image), enabling the emergence of more fresh grass prior to the acquisition of the 1995 image. However, if this difference in rainfall amounts was the reason for the relatively larger amounts of area under bare ground in 2005 (indicative of rangeland degradation), then all rangelands would have more bare ground in 2005 than in 1995. However, some of the grazing blocks actually have less bare land, i.e. exhibit rangeland recovery from degraded state as indicated by the negative degradation numbers in Table 5.1. This disqualifies the argument that less rainfall prior to the 2005 image resulted in more degraded rangeland being detected on the 2005 than on the 1995 image. Therefore, the rangeland degradation figures in Table 5.1 and the degradation mapping in Figure 5.1 appear to reflect genuine change in rangeland quality.

A possible cause of the differences in rangeland cover classes detected could be the timing and amount of burning of the dry grasses. However, this seems to be a

negligible source of the changes detected, primarily because, as shown in the Appendix, there is a lot of un burnt grassland, classified as 'other dry land' (see Table 4.4). Fire in the period prior to the image acquisition dates would surely have burnt this grass as well.

6.4 Possible Sources of Inaccuracy

A number of factors could have affected the accuracy of this study. These are discussed in the sections that follow.

6.4.1 Sensor Factors

The bands of the Landsat sensor used for the change detection work have a spatial resolution of 30m. It is quite possible that spatial changes in rangeland of magnitude less than 30m were not detected and, therefore, are not reflected in the results of this study. Use of higher spatial resolution imagery, such as the 20m resolution of the SPOT HRV sensor, would have partly overcome this source of inaccuracy. There are higher spatial resolution sensors available these days, such as those on board the OrbView, EROS, IKONOS, Quickbird and SPOT- 4 & 5 satellites. However, these high spatial resolution sensors were only launched after the year 2000 and do not go far enough back in history to be useful for long term rangeland degradation analysis, going back into the 1990s. South Africa's satellite *SumbandilaSat*, which will have a spatial resolution of 6.25m, will be more useful in this regard than the Landsat images used in this study.

The spectral resolution of the TM bands used (bands 3, 4 and 7; see Section 4.4.2) was also relatively coarse given contemporary advances in spectral resolution by other sensors. They bands cover the following spectral ranges: band 3 (red): 0.63-0.69 μm), band 4 (near infrared): 0.76-0.90 μm and band 7 (mid infrared): 2.08-2.35 μm). Within these broad spectral ranges, the reflectance from rangeland features was grouped. Had the spectral resolution been higher, it would have been possible to detect spectral signatures from individual plant species and gravel (mineral content). This should have been complemented by field work using a spectroradiometer to determine the spectral signatures. Unfortunately a spectroradiometer was not available for this study. Fine spectral resolution is available in hyperspectral scanners. Using hyperspectral scanners would have

resulted in higher accuracy in feature spectral reflectance differentiation, as has been found by a number of researchers (e.g. Bork *et al*, 1999 a & b; Everitt *et al*, 2004; Koger *et al*, 2004; Lass *et al*, 2005; Lawrence *et al*, 2006; Mutanga *et al*, 2004; Parker Williams and Raymond Hunt, 2004). Unfortunately, hyperspectral scanners are relatively new technology compared to the broad band sensors like Landsat and SPOT (Lillesand *et al*, 2004) and were unavailable for the rangeland change detection involving comparing with the 1990's scenario but they will be useful in future such rangeland degradation studies in the Bahurutshe communal grazing lands.

6.4.2 Image Classification

As was established in Section 3.3, change detection using the method of classification comparison will only be accurate if the classification scheme and the actual classification of the multi temporal images is accurate. In this study, classification accuracy assessment for the images, being historical and involving vegetation, was difficult. As pointed out by Lillesand *et al* (2004), for phenomena like vegetation that are not time stable, ground truthing is difficult to time. Hence accuracy assessment for this study was only with respect to bare land which is more time stable. The accuracy was of the order 86%, which is quite satisfactory (Treitz *et al*, 1992) and was within the ranges generally reported by researchers in the literature (e.g. Reese *et al*, 2002; Lawrence *et al*, 2006).

The classes used (Table 4.4) are adequate for purposes of classifying rangeland because rangelands are either covered by healthy or sparse vegetation and water on one end or dry vegetation and bare ground on the other. That road surfaces and built up land are not explicitly catered for in the classification scheme is considered not to be a significant source of error because these land cover categories are not important for the overall goal of the image classification, which was to differentiate among the different rangeland cover classes. A literature review established that it is common for researchers in the literature to use land cover classes that satisfy their research goals at hand (see Section 3.6). As pointed out in Section 4.4.2, built up areas (settlements) were classified into the various vegetation classes in the classification scheme used in this study (dense, sparse, very sparse vegetation). Gravel roads were classified either as bare land or as

other dry land. Assuming both gravel roads and built up areas (settlements) have changed little between 1995 and 2005, the errors of commission introduced by the inclusion of these ‘alien’ pixels into the rangeland classes were negligible and can safely be ignored without introducing large error to the rangeland degradation results detected in the results of this research.

6.4.3 Spectral Signatures

One source of error in the rangeland degradation results could have been the lack of separability in the spectral signatures. The indicator of rangeland degradation used in this study was bare land and as stated in Section 4.4.2, there was spectral confusion between this class and the ‘other dry land’ class so their spectral signature statistics on the two images will be analysed for separability in the TM bands used (TM bands 3, 4, 7; see Section 4.4.2). The spectral signature statistics are shown in Table 6.1 and as shown in the table, on the 2005 image the spectral signature for bare land had a range from 33 – 255 (mean 57.6) in TM band 3 (red), 49 – 246 (mean 79.4) in TM band 4 (near infrared) and 54 – 243 (mean 82.4) in TM band 7 (mid infrared). The ‘other dry land’ class had ranges of 25- 89 (mean 42.7), 33 – 102 (mean 63.9) and 37 – 94 (mean 60.5), respectively.

There was, therefore, overlap in spectral signature DN ranges with respect to the red and near infrared bands (the same can be noticed on the 1995 statistics in Table 6.1), which could account for the confusion between the two although the Gaussian maximum likelihood classifier was used, not the parallelepiped classifier which is prone to error due to this range overlap problem in class statistics. This could have been avoided by using any other visible band instead of band 3, but bands 1 and 2 are unreliable due to their greater susceptibility to haze, particularly band 1 (Lillesand *et al*, 2004). What is comforting to note from the statistics in Table 6.1 is the fact that for these two classes, their class means in TM bands 3, 4 and 7 are quite similar between the 1995 and 2005 images, which points to the consistency in the method of classification of the two images, further pointing to the reliability of the methodology and the results obtained.

Table 6.1 Spectral Signature Statistics for the Classes Used in Image Classification

2005 image spectral signature class statistics																					
Class	TM Band 1			TM Band 2			TM Band 3			TM Band 4			TM Band 5			TM Band 6			TM Band 7		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Class 1	63.0	80.0	68.6	34.0	46.0	37.6	27.0	52.0	34.2	16.0	44.0	35.4	6.0	53.0	21.7	132.0	139.0	134.5	3.0	30.0	10.2
Class 2	58.0	255.0	74.7	22.0	255.0	40.6	33.0	255.0	57.6	49.0	246.0	79.4	111.0	255.0	155.7	0.0	177.0	160.0	54.0	243.0	82.4
Class 3	57.0	126.0	69.7	26.0	79.0	35.7	32.0	95.0	46.0	58.0	140.0	75.5	97.0	166.0	128.3	0.0	169.0	153.4	42.0	90.0	62.1
Class 4	53.0	105.0	64.7	15.0	70.0	30.6	22.0	99.0	36.3	28.0	117.0	68.0	57.0	138.0	103.4	0.0	171.0	151.1	25.0	71.0	47.5
Class 5	0.0	107.0	62.4	0.0	71.0	28.9	0.0	100.0	32.3	8.0	139.0	70.6	0.0	137.0	93.2	0.0	171.0	148.2	0.0	62.0	40.0
Class 6	54.0	126.0	69.1	15.0	67.0	33.6	25.0	89.0	42.7	33.0	102.0	63.9	74.0	159.0	119.8	139.0	176.0	158.9	37.0	94.0	60.5

1995 image spectral signature class statistics																					
Class	TM Band 1			TM Band 2			TM Band 3			TM Band 4			TM Band 5			TM Band 6			TM Band 7		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Class 1	54.0	65.0	60.9	27.0	36.0	32.6	21.0	37.0	28.7	8.0	15.0	10.6	3.0	14.0	6.3	127.0	136.0	128.2	1.0	7.0	4.2
Class 2	55.0	147.0	71.2	27.0	88.0	40.9	38.0	121.0	59.6	47.0	130.0	75.9	97.0	212.0	144.2	72.0	157.0	146.7	52.0	219.0	83.8
Class 3	29.0	79.0	60.6	14.0	42.0	29.4	17.0	57.0	35.9	31.0	81.0	63.2	84.0	127.0	98.2	70.0	154.0	143.4	36.0	70.0	50.1
Class 4	53.0	97.0	63.6	25.0	74.0	32.7	25.0	103.0	40.8	55.0	138.0	71.9	64.0	128.0	106.1	70.0	153.0	143.2	32.0	67.0	53.6
Class 5	29.0	91.0	58.8	13.0	70.0	27.4	15.0	98.0	30.5	27.0	142.0	63.9	46.0	105.0	82.9	69.0	156.0	140.6	18.0	76.0	38.2
Class 6	28.0	121.0	64.5	13.0	76.0	32.5	17.0	92.0	42.2	25.0	107.0	61.5	58.0	148.0	108.5	70.0	157.0	145.5	27.0	93.0	59.1

Class 1 = Water. Class 2 = Bare land. Class 3 = Very sparse vegetation. Class 4 = Sparse vegetation. Class 5 = Dense vegetation. Class 6 = Other dry land. Where Min = Minimum DN, Max = Maximum DN, Mean = Mean DN value.

6.4.4 Temporal Factors

The rangeland degradation assessment in this study assumes a linear trend in rangeland degradation. In other words, it is assumed that the rangelands were degraded gradually and continuously between the image dates in 1995 and 2005. It is quite possible that the rangelands were actually much healthier at some point between 1995 and 2005, and perhaps suddenly deteriorated just before 2005. Using more images in between the two dates could have helped rule this possibility out, to establish whether the rangelands have continuously degraded in the grazing blocks where degradation was detected between 1995 and 2005. Conversely, a longer time period could have established whether the degradation is indeed linear. Unfortunately, the archive of Landsat TM images at the Satellite Applications Centre did not go back farther than 1989, which limited the time frame in which the degradation assessment was undertaken (see Section 4.3).

CONCLUSIONS AND RECOMMENDATIONS

7.0 Introduction

In this chapter, the conclusions emerging from the study are stated, together with suggestions on how to remedy the situation of rangeland degradation in the Bahurutshe communal grazing lands, and how remote sensing techniques can more effectively be used in future rangeland degradation studies in the area.

7.1 Conclusions

The aim of the study was to map and quantify rangeland degradation that has taken place in the Bahurutshe tribal lands during the past two decades, using remote sensing techniques. The objectives were to identify the location of active and sustained rangeland degradation in the Bahurutshe communal grazing areas, to establish the amount of rangeland degradation that has taken place in the Bahurutshe communal grazing areas in the recent past and to establish the link between the observed rangeland degradation and perceived cultural causes.

The methodological procedures and results from this study lead to the following conclusions against the aim and objectives:

1. Only moderate amounts of rangeland degradation have taken place in the Bahurutshe communal grazing lands, mostly in the southern parts of the district where the largest settlements are located.
2. Although the amount of rangeland degradation in the Bahurutshe communal grazing lands has been low, only up to 4% in some grazing blocks, the degradation is likely to increase in the future.
3. The main cause of the observed rangeland degradation in the Bahurutshe communal grazing lands is the Tswana culture of keeping cattle but exacerbated by the less sustainable grazing management practice of sedentary grazing as opposed to the more recommended practice of rotational grazing.

7.2 Recommendations

The following recommendations can be made, emerging from the results of this study:

1. Remote sensing should be made an integral component of GIS units in government Departments in the North West Province that deal with spatial analyses like those pertaining to agriculture, forests, water, settlements and wildlife. Currently, it is more common in these units to use GIS for database creation and maintenance using software like ArcView and ArcGIS. With the launch of South Africa's own satellite *SumbandilaSat* in 2007, satellite images will more readily be available. This opportunity for rapid appraisal of spatial phenomena in South Africa should be taken advantage of.
2. Grazing management practices in the Bahurutshe communal grazing lands should be more stringent to avoid 'the tragedy of the commons' scenario in the area. The ultimate end in this scenario will be total degradation of the rangelands. Adherence to recommended stock densities in line with the carrying capacities of the grazing blocks is one avenue of avoiding this total degradation.
3. Future similar research should consider the following in order to make the results more accurate:
 - Use of higher spatial resolution images than the 30m resolution Landsat TM images could enable detection of rangeland changes of spatial magnitude less than 30m.
 - Use of multitemporal hyperspectral scanner images will enable the detection of rangeland degradation involving change from more palatable to less palatable rangeland species. This should be accomplished by undertaking field work using spectroradiometers to collect spectral signatures of the palatable species concurrently with the image acquisition time of at least one of the hyperspectral images to make the ground truthing more accurate. Such hyperspectral image rangeland degradation assessment can be undertaken at

any time of year, as opposed to this study that used images from the early part of the rain season to detect rangeland degradation as indicated by the amount of bare land on the rangelands.

- Long term rainfall analysis should be included as part of future similar work. This will enable verification of whether the rains are getting less and less, which can be one of the causes of rangeland degradation.
- Use of more images over a longer period of time could yield an extra dimension in the rangeland degradation process in the Bahurutshe communal grazing lands. This study used only two image dates, ten years apart.

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APPENDIX

**LAND COVER CLASS AREAS FROM THE 1995 AND 2005
CLASSIFIED IMAGES IN FIGURES 4.8 AND 4.9.**

APPENDIX: Land Cover Class Areas from the 1995 and 2005 Classified Images in Figures 4.8 and 4.9.

Camp / Block	Dense Veg		Sparse Veg		Very Sparse Veg		Other dry land		Bare land		Water	
	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005
Braklaagte 77	2376.09	2376.09	95.04	446.76	73.89	30.87	507.87	2544.57	1.89	3.96	0.00	0.00
Nicolaasdoorns 76	2468.43	594.81	274.86	1122.48	295.47	349.11	789.30	1712.43	95.67	146.88	0.00	0.00
Wildebeestkop 2	1887.75	673.74	821.43	1249.29	621.54	320.85	687.24	1598.04	222.66	377.46	0.00	0.00
Schuinsdam 1	857.52	174.33	411.39	338.94	373.05	72.81	831.33	1665.00	317.25	531.36	1.53	15.66
Alewynskop 3	1414.53	187.56	627.57	463.50	677.79	127.98	964.98	2839.23	216.45	256.77	0.00	0.00
Schoonlagte 4	2062.53	690.39	221.22	1112.13	1107.27	253.53	188.91	1501.65	12.69	41.58	0.00	0.00
Hartbeestfontein 101	1485.72	945.45	278.46	1572.57	899.73	324.09	612.18	354.69	86.22	161.10	0.00	0.00
Vinkrivier 101	1921.23	346.50	235.17	1805.04	776.43	148.59	581.76	1160.19	71.82	145.80	0.00	0.00
Kanfontein 5	588.60	106.20	121.14	412.65	404.82	83.79	724.32	1248.66	72.45	88.20	0.00	0.00
Sechelis oude Stad 6	1511.19	569.88	240.48	1206.00	789.66	234.54	397.89	953.37	64.17	52.56	0.00	0.00
Sebenani 103	1713.15	407.52	124.83	1290.51	1176.21	113.58	200.16	1384.38	7.47	18.45	0.00	0.00
Zwartkopfontein 7	1134.00	1198.44	440.46	1981.08	994.23	546.57	1321.29	296.10	380.07	238.50	0.00	0.00
Lekkerlach 8	1092.78	540.63	331.92	803.88	283.32	418.05	642.06	487.8	79.29	164.34	0.00	0.00
Middelrand 122	2089.35	1405.98	108.00	829.8	287.91	234.09	305.82	263.61	31.86	98.55	0.00	0.00
Buitenkuil 11	936.45	800.91	281.70	370.80	160.65	284.94	492.48	194.85	763.20	980.91	0.00	0.00
Van Tondershoek 10	1258.47	493.65	607.41	1012.77	486.36	630.99	947.43	970.65	99.90	307.89	0.00	0.00
Sengoma 12	67.59	45.45	71.28	78.21	25.02	92.25	113.04	52.29	147.87	171.54	0.00	0.00
Witkleigat 13	439.02	480.06	631.17	765.54	317.34	649.62	3127.59	2463.39	1638.90	1796.67	9.27	3.06
Ruitjesvlakte 1 JO	1317.69	271.26	392.40	955.80	528.48	228.24	2330.19	3048.03	221.22	290.07	0.00	0.00
Kalkpan 3	309.06	56.34	254.70	348.84	381.33	231.57	4424.40	4607.64	92.52	174.33	0.00	0.00
Driehoek 5	217.89	0.09	18.90	32.58	22.41	20.07	739.80	988.83	192.96	149.31	0.00	0.00
Doorenlaagte 2	578.52	475.56	387.99	909.54	434.97	475.56	2616.84	2312.10	220.77	90.63	0.00	0.00
Rietpaan	721.53	11.52	221.31	205.11	268.38	327.60	2242.08	2974.77	344.97	279.36	0.00	0.00
Driefontein 7	1056.24	989.10	217.62	630.00	202.86	777.33	578.34	155.88	1286.28	808.38	0.00	0.00
Klipfontein 9	719.55	624.06	669.51	1842.84	583.74	825.39	2040.12	1130.40	819.09	377.64	0.00	0.00
Witfontein 10	1368.99	1170.09	513.45	1359.99	925.83	341.28	2550.69	2907.72	278.28	165.51	0.00	0.00
Brakpan 21	251.73	247.32	277.83	405.72	189.81	622.17	1067.67	726.57	1539.90	1320.93	0.00	0.00
Boschman Kraal 20	49.59	181.71	173.16	1116.99	106.02	376.74	1343.61	346.68	398.34	57.24	0.00	0.00

APPENDIX (continued) Land Class Areas from the 1995 and 2005 Classified Images in Figures 4.8 and 4.9.

Camp / Block	Dense veg		Sparse veg		Very sparse veg		Other dry land		Bare land		Water	
	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005
57	31.05	8.37	4.59	14.13	24.21	61.74	995.04	983.52	46.89	38.43	0.00	0.00
Buispoort 22	1470.51	1288.98	204.75	1071.90	585.63	307.08	805.59	372.87	170.28	172.98	24.57	32.67
Bergvleit 23	1541.25	884.52	56.61	1366.11	467.01	168.30	568.89	250.38	201.24	171.90	0.00	0.00
Bergfontein 60	1468.26	796.77	45.36	1037.34	429.66	138.69	676.71	579.60	25.47	84.78	0.00	0.00
Hartbeeslaagte 58	1840.86	1345.41	36.27	1178.73	249.66	107.91	544.77	50.31	47.79	39.51	0.00	0.00
Leeufontein 61	1944.09	2527.11	404.10	1190.07	928.62	841.50	1372.14	188.73	375.03	296.64	0.00	0.00
Welverdient 24	519.21	361.71	269.55	642.96	136.71	576.09	1632.51	762.30	592.20	798.21	0.00	0.00
De dam van Metsugo 38	760.32	404.37	387.72	595.35	736.92	996.75	2178.18	1872.00	458.10	673.56	0.00	0.00
Matjevallei 40	268.83	99.27	188.19	378.81	229.50	338.76	822.51	669.06	62.10	84.33	0.00	0.00
Welbedacht 39	506.07	504.63	104.22	1238.85	330.39	220.86	1593.81	528.03	14.94	20.25	0.00	0.00
Moiwa 901	8531.28	1496.70	5378.67	10337.85	9715.95	4243.32	8951.76	13692.60	1362.96	4166.73	0.00	0.00
Moiilos 37	3700.98	1493.55	463.86	3065.94	1974.87	552.15	3404.97	4376.07	101.61	146.16	0.00	0.00
Moiilas 900	21237.39	14730.57	9359.82	17201.43	6266.16	11028.69	16040.25	11914.02	9500.49	7635.87	164.52	83.34