A MULTI-DIMENSIONAL ASSESSMENT OF LAND DEGRADATION IN THE STERKSPRUIT RIVER CATCHMENT: THE NEXUS BETWEEN LANDSCAPE SENSITIVITY, LAND USE DYNAMICS AND LANDSCAPE RESILIENCE

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A thesis submitted in fulfillment of the Doctor of Philosophy degree in Geography and Environmental Science in the Department of Geography and Environmental Science at the University of Fort Hare

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DEDICATION

To my loving and very supportive wife, Lilian, and my children Tendai, Anesu, Nyasha and Tyne, for their patience and support

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ABSTRACT

This study sets out to assess the status and causes of land degradation in the Sterkspruit catchment of the Eastern Cape, and the extent to which this has affected the biophysical environment and rural livelihoods. The attributes of the biophysical and socio-economic environments that predispose the area to land degradation, the manifestations of land degradation and people's responses to the dynamics of their environmental circumstances are some of the key issues of enquiry.

This research pursued a multidimensional approach to land degradation assessment, looking at numerous criteria on multiple scales. The landscape-scale component of the study included detailed analysis of climatic data to provide a backdrop for land degradation. It also entailed developing and analyzing land use-land cover maps of Sterkspruit catchment, based on LANDSAT TM satellite imagery of medium resolution (30m x 30m). Ground-truthing, transect walks at several pre-selected locations, followed. Participatory rural appraisals [illegible] and questionnaire surveys on rural livelihoods, householders' experiences as well as their perceptions of land degradation, and their responses to it were conducted in the catchment's villages of Magwiji and Hinana.

Site-specific survey involved identifying sample sites at various stages of degradation, visually assessing them and generating degradation indices, adopting a multidimensional analysis technique using several soil- and vegetation-related variables. It also involved vegetation condition assessment through rangeland transect sampling, recording data for basal cover, species dominance, biomass productivity, and the presence of indicator species, such as decreasers and increasers. Estimates of soil loss at sites were done through measurements of gullies, rills, and pedestals, and

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calculation of volumes lost per unit area. *In situ* soil degradation was assessed through field measurement of infiltration capacity and soil penetration resistance. From the study sites, soil samples were collected and analyzed in the laboratory for soil bulk density and for the chemical indicators EC, pH, organic C, Na, K, Mg, Calcium, available P, and total P.

Study results showed manifestations of land degradation in various forms. The LU-LC analysis indicated that bare ground appeared in dry seasons and in drought years; vegetation recovered with the return of the rains. The land degradation index (LDI) showed eight out of 21 sites as extremely degraded, while the rest were, seriously to moderately, degraded. The largest amounts of soil loss were from sheet erosion, followed by heavy losses from gully erosion, especially in Hinana village. Another manifestation of degradation was the loss [illegible] land to gully encroachment. Soil bulk density tests showed serious compaction in four sites; the rest of the sites were either slightly compacted or not compacted. Vegetation transect surveys, showed an increase in unpalatable grass species (increaser II) and bush encroachment on grassland. Chemical indicators were as follows: EC indicated strongly saline soils; K levels were good, making plants drought-tolerant; excessive amounts of Ca and Na made the soils dispersive, predisposing them to erosion; Mg amounts were adequate; total P was high-to-medium on 13 sites, low on eight sites; organic C was low on all sites, indicating low fertility and deficiencies in N, P, and boron. Causes of degradation include sustained grazing pressure in a drought-prone environment. Residents' responses included rehabilitating degraded land, cutting down on arable agriculture as a risk avoidance strategy, and providing supplementary feed to livestock. Livelihood changes showed a trend towards the use of communal lands for residential purposes rather than for farming, while subsisting on government grants and pensions.

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LIST OF ACRONYMS

ICM	Integrated catchment management
IPCC	Intergovernmental Panel on Climate Change
LADA	Land degradation Assessment for Dryland Africa
LDI	Land Degradation Index
PRA	Participatory Rural Appraisal
RUSLE	Revised Universal Soil Loss Equation
SLEMSA	Soil Loss Equation Method for Southern Africa
UNEP	United Nations Environment Programme
UNUEP	United Nations University Environment Programme
VDIv	Veld Degradation Index (visually based)
VDIt	Veld Degradation Index (transect data based)
WCED	World Commission on Environment and Development
WHO	World Health Organisation
WOCAT	World Overview on Conservation Approaches and Technologies

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DEFINITIONS

The following key words and terms are used in this study; their definitions are given so as to provide the context in which they are used.

Catchment: a basin-like area from which rainfall runoff flows into a river, lake, or reservoir; it is bordered by a ridge of land separating waters flowing to different river systems.

Climatic variability: repeated significant departures from annual or seasonal mean temperature and annual or seasonal mean rainfall patterns – high enough to affect livestock or crop production.

Integrated Catchment Management Holistic approach to assessment of the physical, biological and hydraulic functions of rivers and their catchments (Brasington & Richards, 2007), participatory planning and management by various stakeholders, integrating environmental, social and economic systems as the basis for land management and decision making (Rhind, 1991; Clayton & Radcliffe, 1996).

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Land-Care An Australian initiated approach to protecting and repairing the environment. It involves partnership between the community, government and business in tackling land degradation at various scales nationally. In the South African context it is a community based and government supported approach to the sustainable management and use of agricultural natural resources.

Landscape: “Landscape to an ecologist is the vegetation and associated faunal populations draped over the geomorphology that give it most of its colour and texture” (Miles, et al, 2001). It is the landforms of a region and their associated flora and fauna.

Landscape sensitivity refers to the response of landscape systems to perturbation on different temporal and spatial scales (Thomas, 2001), or instability versus stability of a landscape (Miles, et al, 2001). Stable systems are those that resist change until threshold values of system parameters are exceeded (Thomas, 2001).

Landscape structure was viewed by Forman & Godron (1986) as referring to the spatial relationships between landscape patches as defined by patch descriptors such as shape, degree of isolation, accessibility, interaction and dispersion. This concept is applied in the study to the spatial patterning of topographical features on a landscape scale, and its effect on land use practices and their impacts.

Resilience was defined by Hill (1987) as the ability of an ecosystem to recover to its initial state after a disturbance. It also includes the ability of the ecosystem to adapt to perturbations.

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Sustainability (from an agroecosystem perspective): it is the capacity to remain productive while maintaining the resource base – being sustainable means being ecologically sound, economically viable, socially just, humane, and adaptable (Reintjes, et al, 1992); it is the "ability to maintain productivity in the face of shocks or stress. The most vulnerable...systems are those which are highly sensitive to shocks and which have low resilience" (Moorehead & Wolmer, 2001: 97), i.e find it hard to bounce back after perturbations. These definitions are in line with the Brundtland report which defines sustainable development as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED, 1987).

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CHAPTER ONE

1 INTRODUCTION

This introductory section examines the background to this particular research. It looks at the link between land degradation and food security as well as the rationale for the study. It outlines research objectives and introduces the study's location as well as its significance.

1.1 Background Information

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Land degradation is a decline in land quality or a loss of its biological and economic productivity due to natural or anthropogenic factors. It is a reduction in the quality of land resources such as soil, water, vegetation and ecosystem integrity.

Land degradation has been highlighted as one of the global challenges of our time. This is because of the negative impacts it has on natural vegetation, agricultural productivity and food security. According to one estimate made a few years back, only about 37% of the globally available land area is suitable for agriculture; a predicted additional 10^9 hectares of land will be required by 2050 to produce the projected 50% increase in production (Benton, 2007). The UNDP-GEF (2004) estimates that about 20% of the world's pastures and rangelands are degraded. Despite this, land degradation in different parts of the world has led to the abandonment of previously productive land. A study by Pimentel (2006) concluded that each year about 10 million ha of cropland are lost due to soil erosion, thereby exacerbating the shortage of agriculturally suitable land.

The world's population was estimated at 6, 555 millions in mid-2006. It is estimated to be at 6,790 million at the beginning of 2009 and is projected to reach 7, 940 million by 2025, as well as 9, 243 million by mid-2050 (Population Reference Bureau, 2006). An earlier study by Cohen (2003) also confirmed the same estimates. These figures point to serious problems, especially when viewed against the backdrop of the World Health Organization's assessment that more than 3.7 billion people in the world are malnourished (Pimentel, 2006). Added to this is the problem of a decreasing per capita world grain-harvested area. This is a matter of grave concern, especially in view of the increasing demand for food production for the world's ever-growing population. Moreover, the productive land area lost to degradation has had to be replaced by bringing new land under agriculture, in the process putting at risk ecologically-sensitive eco-regions such as tropical rainforests, steep lands and regions of aesthetic, cultural and historical significance.

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Central in these developments is climate change, a contemporary subject of much scientific research and intellectual discourse. While it is generally agreed that global warming is linked to the greenhouse effect resulting from industrial emissions disagreements are on how the projected temperature increases differ from past climate changes. Contemporary indications denote that while human-induced global warming will be similar in magnitude to some of the largest increases of the past, it will occur 20 to 50 times faster currently and in the future (McWilliams & Leafloor, 2005). Another source highlighted that the 1900s was the warmest century, “and 1990 to 2000 was the warmest decade” (Hardy, 2003: 40). The annual carbon dioxide concentration growth-rate was larger during the decade 1995 – 2005 (average: 1.9 ppm per year), than it had been since the beginning of continuous direct atmospheric measurements (1960 – 2005 average: 1.4 ppm per year) despite year-to-year variability in growth rates (IPCC, 2007). Such relatively rapid climatic changes affect biodiversity because “biota may migrate or adapt to slow climatic change, but rapid change could have far-reaching consequences” (Hardy, 2003: 36). Furthermore, global climate change over the past three decades has produced numerous shifts in the distributions and abundances of species and poses real risks of species extinction (Thomas, *et al*, 2004). In the long run, global climate change has already and will exacerbate the problems of rainfall variability, spells of droughts and land degradation in many parts of the world (Haarsma, et al, 2005; Salinger, 2005).

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While land degradation is a world-wide problem some regions are more at risk than others. Climate change may push completely out of production water-stressed and agriculturally marginal areas such as those in sub-Saharan Africa, northern Mexico, the Middle East, northeast Brazil and Australia (Hardy, 2003). Sources tend to emphasize that the situation in Africa is particularly dire. The UNDP-GEF (2004) classifies 43 per cent of the land as moderately to severely at risk from human-induced land degradation. The continent is especially vulnerable to factors that affect water supply and it has been noted that “per capita water availability has diminished by 75% during the past 50 years”

(Hardy, 2003: 81). South Africa in particular has a long history of land degradation. Some of the former homelands had been subjected to rehabilitation schemes throughout the second half of the 20th century. Their status quo has hardly improved and some have even deteriorated further, as illustrated in the national survey conducted by Hoffman, *et al* (1999).

1.2 Rationale for the study

In view of the environmental challenges posed by rapid population growth and global warming, research into several aspects of land degradation is necessary. An understanding of the biophysical processes involved and the resultant impacts is a pre-requisite to any formulation of human responses to the problem. While much has been done at global and regional scales in the assessment of spatial patterns and magnitude of degradation, a lot still needs to be done on the exploration of landscape-scale, biophysical and socio-economic dynamics of land degradation. Further research into sustainable, local-level approaches and technologies for natural resources management and rehabilitation of degraded lands needs to be carried out. Moreover, research has to be carried out on how various communities perceive land degradation and on how they have been able to adapt their production practices and livelihoods against that challenge. This thesis addresses these particular challenges in varied detail.

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1.2.1 Research Questions

The study sought to answer several research questions regarding the Sterkspruit river catchment area of South Africa in the Eastern Cape Province. The questions were as follows:

What attributes of the biophysical and socio-economic environments make local land resources vulnerable to land degradation?

- In what ways and to what extent does land degradation manifest itself in this study area?
- What have been the impacts of land degradation on the biophysical environment in the very same area?
- How has land degradation impacted on the rural livelihoods of the residents of the area and in what ways have the people responded to their circumstances?

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1.2.2 Research Aim

The aim of the study is to assess the status and causes of land degradation in this study area and the extent to which it has affected the biophysical environment and rural livelihoods.

1.2.3 Research objectives

The study had a number of specific objectives and they are as follows:

- develop a land use-land cover map of Sterkspruit river catchment based on satellite imagery for the period 2000-2007 and use this to assess the extent of land degradation on a landscape scale
- to generate land degradation indices using a multidimensional analysis technique based on several indicator variables and use them to assess the extent of land degradation in the Sterkspruit river catchment
- to assess the impacts of land degradation on the biophysical environment in the study area (rangeland condition, soil condition, potential for rehabilitation, etc)
- to assess the impacts of land degradation on the socio-economic environment (community residents' perceptions and their livelihood responses) in the study area.

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1.3 Thesis delineation

The subject of land degradation is broad and a single research project such as this can therefore only address certain aspects of it. This section of the thesis deals with the subject matter or focus areas of the research, it provides a summation of limitations of the research and the study.

1.3.1 Thesis statement

Landscape sensitivity and land use changes are the main drivers of land degradation in Sterkspruit catchment.

1.3.2 Delineation of thesis statement

This statement is made with reference to non-urban areas of Sterkspruit catchment only. Landscape sensitivity is examined in terms of landscape structure, climatic variability (specifically rainfall), locational attributes of the physical landscape (slope, aspect, soil characteristics) and vegetation condition and land use history. Aspects of land degradation such as soil and water pollution are not dealt with here. The study has confined itself to the presence or absence of bare patches, loss of vegetation and vegetation composition changes, herbaceous biomass productivity (grasses only), soil degradation and soil loss.

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1.3.3 Limitations of study

For a study of this nature to be fully comprehensive it would need to be carried out over an extended period consisting of several years. Moreover, it would involve detailed recording and analysis of climatic data, vegetation condition monitoring, soil quality measurements and analysis, as well as the monitoring of population dynamics for both humans and livestock. This is beyond the scope of research that underpins this study in terms of time-frame, associated costs, the technical and logistical challenges.

The constraints of carrying out this particular study included (1) the paucity of data on several attributes of the research area, (2) discontinuous or patchy climatic data (temperature and rainfall records), and socio-economic data (human and livestock population statistics, agricultural productivity statistics), and (3) the logistical challenges of doing site-specific surveys in several spread out sites. Nevertheless, the study endeavoured to strike a balance between achieving an academically sound assessment of land degradation dynamics in the research area and keeping the costs of the survey within manageable limits. It also ventures into breaking new ground with its analysis and attribution of multi-criteria definition to the concept of land degradation.

1.4 Research problem

Several studies, based on various methods have been carried out on the subject of land degradation in South Africa. With a few exceptions (e.g. Dube & Fatunbi, 2006; Giannecchini, et al, 2007), these have tended to concentrate on soil erosion assessment. Moreover, these studies have been concerned with spatial and temporal issues of land degradation at the expense of site-specific scientific investigations of factors, processes, and effects of land degradation. Their research reports tended to generalize and thus have been limited regarding the utility to land management policy makers, the natural resources management planners and managers as well as the affected communities. Many of these studies were conducted on such broad scales that they could not readily be incorporated into practical land use planning and/or land management units.

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This study responds to the shortcomings of earlier research on land degradation in several ways. It pursues a multidimensional approach (multiple criteria and multiple scales) to land degradation assessment. The study techniques encompass analysis of published data, remote sensing and GIS, ground truthing, soil quality assessments, vegetation sampling and analysis as well as interviews with community residents and other stakeholders. Starting from the catchment scale, through the landscape scale to the specific sampling site, the study endeavours to provide empirically derived details on land degradation that planners and natural resources managers at various scales could use. This approach is particularly appropriate in the context of integrated catchment management.

1.5 The study area

This study is located in the northern area of the Eastern Cape Province, in the Sterkspruit river catchment, a sub-catchment of the upper Orange river – approximately 391 km^2 on the borders of Lesotho. It is located within the Herschel magisterial district of the former Transkei homeland, and is currently part of the Ukhahlamba District Municipality. The area is bounded by the southern edge of the Drakensberg Mountains to its north and east (locally, the ridge of the Witteberge mountains), and the Orange river to the west. It is located between 30^0 29’ S and 30^0 43’ S and 27^0 17’ E and 27^0 32’ E. Figure 1 on the next page illustrates the location of the Sterkspruit river catchment with respect to the whole of South Africa.

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The location was chosen in the context of a wider, Kellogg-funded assessment of the effects of different range management strategies on conditions of communal rangelands in the Eastern Cape Province of South Africa. Land degradation and its impacts on rangeland resources was an important part of that research project. The study sites for the Kellogg project were in contrasting biomes; they included Sterkspruit, which is the focus of this thesis; Cala, in the Xhalanga district of the north western Transkei;

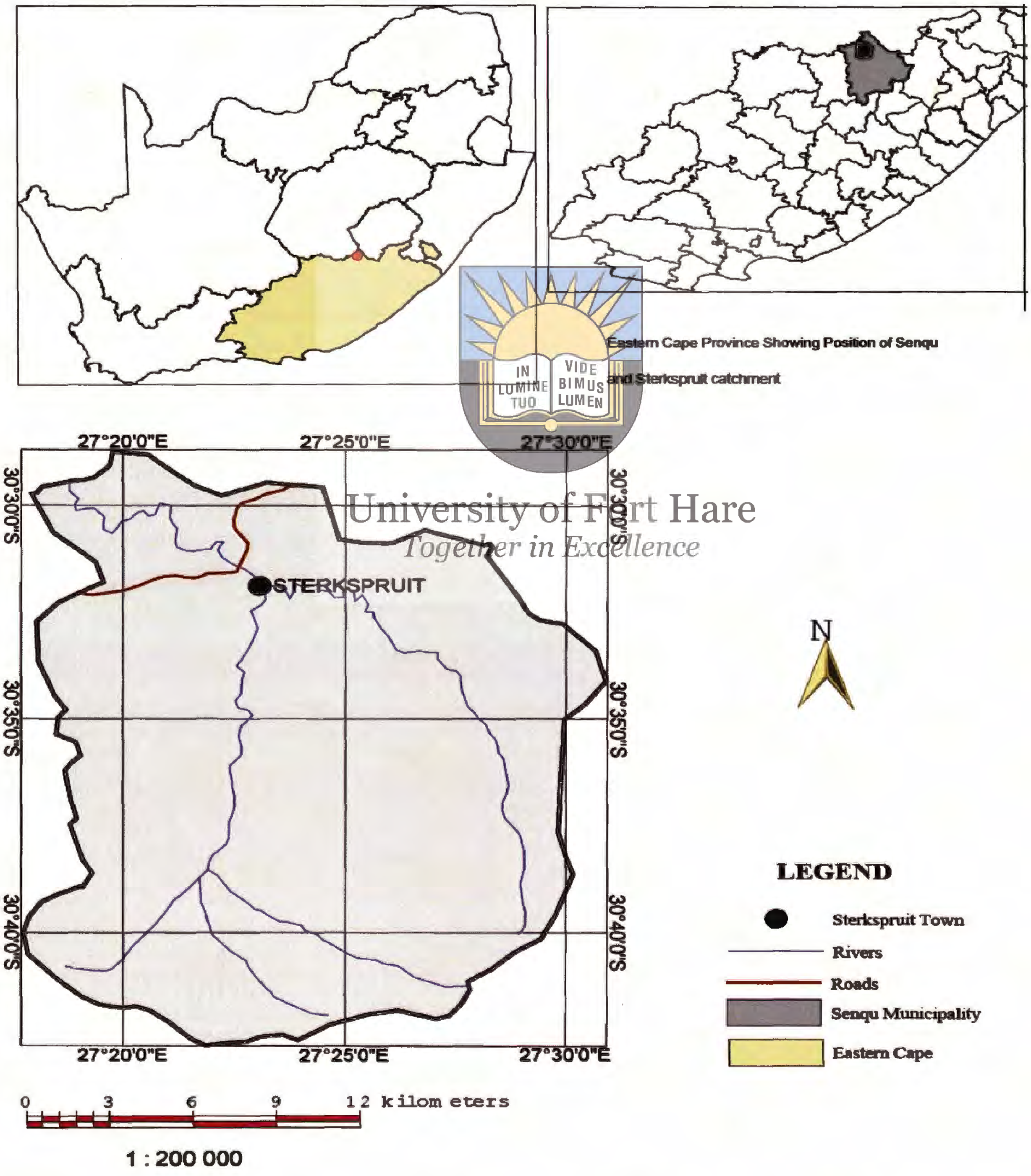

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Figure 1 The study area: Sterkspruit catchment, showing its position in the Eastern Cape province and in South Africa

Centani, south eastern Transkei coastal district; and Mgwali, of Stutterheim district, within the former Border's 'white corridor'.

Sterkspruit therefore constitutes a South African case study of communal rangeland degradation in an upland catchment. General land degradation constitutes a major component of the study as communal rangelands virtually include most lands not covered by built-up areas and cultivated fields.

1.6 Significance of the study

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This is a detailed multidimensional study that seeks to go a long way towards providing a more holistic picture of the nature of land degradation – necessary for sustainable rural livelihoods. It does so by examining the problem of degradation from the point of view of the various factors that contribute to the environmental deterioration of the whole landscape. The study deals not just with the loss of vegetation cover and the resultant soil erosion. From the livestock keeper's angle, it looks at changes to the species composition of the vegetation in response to grazing pressure. From the crop farmer's view it examines the biophysical and socio-economic challenges that farmers in the area have had to deal with over the years. The study also seeks to explore how residents of the area have coped with the consequences of degradation, especially in the context of the relatively frequent droughts that occur in the area. The research provides a case study of the status of landscape biodiversity in heavily grazed highland rangelands.

Responses to land degradation in South Africa may be influenced to go beyond the pre-occupation with the impacts of soil erosion, to a more comprehensive suite of responses such as Land-Care and World Overview of Conservation Approaches and Technologies (WOCAT). It provides an informed basis for communities, extension workers, natural resources managers, researchers and policy makers to plan and execute integrated catchment management (ICM) strategies, particularly in the area under examination.

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1.7 Chapter outlines

This section outlines in brief contents of this and subsequent chapters. Overall, the thesis consists of eight chapters and they are arranged as follows:

Chapter 1 provides the background to the study, indicating the objectives of the study, and the research problem. It also identifies the study area, and comments on the significance of the study conducted.

Chapter 2 deals with surveyed literature for the conduct of this study. The chapter includes definitions of concepts of land degradation, methods of land degradation assessment, and contemporary studies of land degradation aspects.

Chapter 3 is a detailed study of the Sterkspruit area and its river catchment which constitutes the location of the study area. It sets out the outline of the biophysical and socio-economic background to the study.

Chapter 4 details the research methodology used for the study. It first outlines the methodology in general and explains each method or approach adopted in detail. The chapter also outlines data formats resulting from the various methods.

Chapter 5 is the presentation and analysis relating to the landscape scale of the study. These include the results of the land cover-land use assessments, climatic data analysis, livestock inspection data, and questionnaire survey results.

Chapter 6 is the presentation and analysis of results of site-specific surveys of vegetation and soils.

Chapter 7 synthesizes the interlinkages of landscape sensitivity, land use history, and landscape resilience in the land degradation conundrum.

Chapter 8 outlines the findings of the study in terms of the extent of land degradation, its manifestations, possible responses to the problem, and recommendations for further research.

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CHAPTER TWO

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2 LITERATURE REVIEW

This literature review examines concepts and definitions of land degradation and manifestations of the problem at various scales as well as responses to it. It also reviews some previous literature on land degradation which serves as a background to the current studies.

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2.1 Introduction

Most definitions of land degradation incorporate concepts of the loss of ecosystem integrity and persistent decline in the productivity of the soil and vegetation. McKeon, et al (2004), adopted the view of degradation as the reduction in the character and quality of the soil, vegetation and landscapes in a major study of pasture degradation in Australia. One all-encompassing and frequently cited definition views land degradation as "the reduction or loss of the biological and economic productivity and complexity of terrestrial ecosystems, including soils, vegetation, other biota, and the ecological, biogeochemical and hydrological processes that operate therein, resulting from various factors including climatic variations and human activities" (UNCCD, 1994). Manifestations of degradation include deforestation, desertification, decline in rangeland condition, soil erosion, *in situ* soil degradation, land pollution and threats to, or loss of, biodiversity (Gisladottir & Stocking, 2005).

While scientists see land degradation in terms of physical and chemical processes in the environment and their measurable impacts, farmers and other land users in rural communities tend to view it from a livelihood perspective. There is a general awareness of the decline in productivity of land with agricultural use; however, the responses to the phenomenon are informed by various socio-economic factors. “Environmental impacts are functions not only of mere physical changes but also of the ability of an economy or culture to withstand those changes” (Agnew & Warren, 1996: 312). Farmers’ perceptions of the impacts of soil erosion may be influenced by the fact that while the soil loss of fertility is more dramatic on virgin soil. “As the soil progressively loses its quality, subsequent erosion has less proportional impact…” (Stocking, 2003: 1357).

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Instead of linking the poor condition of pastures to land degradation livestock keepers may make a direct link between the amount of rainfall and the condition of their livestock as a reflection of the impact of rain on forage availability (Allsop, *et al*, 2007). Of much concern to farmers dependent on rain-fed agriculture is the frequency and quantity of rains. Contrary to the popular belief that farmers, especially in the developing world, mismanage farmlands, there is much evidence that smallholder farmers have skills and social networks for managing soils sustainably and productively. They adopt technologies to their local needs while avoiding labour-demanding and expensive practices (Stocking, 2003). One strategy adopted by farmers for coping with land degradation is diversification of the household economy (Asmalu, *et al*, 2007).

2.2 Responses to land degradation

Over the years several international initiatives have been launched in response to the problem of land degradation. These have included United Nations-sponsored programmes, development initiatives financed by the more developed countries, and the activities of various environmentally-oriented non-governmental organizations. The United Nations Conference on Desertification which was held in Nairobi, Kenya, in 1977, drew up a global plan of action to deal with the problem of land degradation. Set up initially in 1991, and restructured after the 1992 Earth Summit in Rio de Janeiro, the Global Environmental Facility (GEF) was mandated to forge international cooperation and finance actions to address four critical threats to the global environment: biodiversity loss, climate change, degradation of international waters and ozone depletion.

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In the last decade of the 20th century, initiatives to address land degradation were stepped up world-wide. The United Nations Convention to Combat Desertification (UNCCD) was adopted and came into force in December 1996 after the requisite number of countries had ratified it. In December 2000 the United Nations Conference on Land Degradation was held in Bonn, Germany. Three years later two new focal areas were added to the GEF's original mandate: the mitigation and prevention of land degradation and persistent organic pollutants. In its first ten years of existence, GEF allocated a total of US$19 billion in grants and additional financing, for more than 1,300 projects in 140 developing countries and transitional economies, as well as more than 5,000 projects in 73 countries that participate in the GEF Small Grants Programme, managed by UNDP (UNDP-GEF, 2004).

2.3 Land degradation: Manifestations and previous studies

In this study "land" is perceived in broad terms to include many elements of the biophysical environment, such as the soil, the plants and the animals, the soil biota, the insects and the birds, the streams and groundwater. Land degradation is the result of an upset in the fragile balance between human actions and climate variables in different biomes of the earth. Degraded areas are characterized by combinations of any two or more of the following: rapid population growth, high rates of deforestation, recurrent episodes of drought, soil erosion and poverty.

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The root causes, and at the same time the consequences, of land degradation and desertification are often poverty and food insecurity, combined with harsh climatic events such as drought, leading to excessive pressures on often fragile ecosystems, the natural resource base, and the adoption of resource depleting survival strategies by the poor (UNDP- GEF, 2004). Land degradation is now acknowledged as a world-wide problem, deserving a multi-faceted international response (Gisladottir & Stocking, 2005). It manifests itself in several ways and various approaches have been used in assessing its different aspects. The following sub-section discusses many of the different aspects of land degradation.

2.3.1 Deforestation

The clearing of forests is often done in connection with land preparation for arable agriculture or the commercial exploitation of timber resources for furniture and building industries. Local rural (and urban) communities often clear forests or woodlands for household fuel wood and other uses.

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Two studies highlighted the role of accessibility to forests in the deforestation process. Ali, et al (2005) conducted a study on deforestation in the Basho Valley in the Western Himalayas of Pakistan using interviews and analysis of satellite imagery. They found that the forest had been reduced by at least 50% due to road construction in the area during 1968. Contrary to widely held theories that attributed continuing deforestation to rapid population growth, the main causes of deforestation in Basho Valley were found to be mismanagement and illegal commercial harvesting endorsed by officials of the Forest Department. This was a classical failure or mishap of an official natural resource management practice.

The second study examined forest alterations in a 2800ha alluvial ecosystem using aerial photographs (Madrinan, et al, 2007). Analysis of the aerial photography showed that in the period 1939-1997 high canopy forests decreased by 70.4%, while low canopy forests (below 15m) decreased by 51%, resulting in a highly fragmented landscape. The more accessible high canopy forests occurred on fertile soils more favourable to agriculture. The soils of the low canopy forest were less fertile and their inundation by water from river channel migration made the forest less accessible to humans.

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A continent-level study of forest-to-cropland and forest-to-pasture conversions was carried out using a land use change modeling framework (Wassenaar, et al, 2007). The model incorporated various elements of land use change such as interrelation of spatial and temporal dynamics, land use history, data on current land use and location factors. Significant statistical relations were established, describing sub-regional land use patterns, deforestation processes and their locational factors. Quantitative estimates of land use change "hot spots" of forest to pasture and crop land conversion were projected and mapped. While substantially different trends among countries were predicted, the results envisaged a predominant replacement of forest by pasture.

In South Africa, a longitudinal study on fuelwood use following electrification of rural villages in Bushbuckridge was conducted by Madubansi and Shackleton (2007). This revealed that over 90% of households were still using fuelwood as a source of energy, more than a decade after electrification. Importantly, they cited the cost of electricity as the major factor that has contributed to the perpetual use of firewood as an energy source. This was despite the increasing time and effort required to gather adequate stocks of fuelwood. The implications for sustainable woodland usage and land degradation arising from this situation are quite far reaching and they continue to be so especially around poor households of rural Southern Africa.

2.3.2 Landscape fragmentation

A form of deforestation often researched on is forest/woodland fragmentation or landscape fragmentation. In one such study, the dynamics of land use/land cover and land degradation as manifested through landscape fragmentation were examined through analysis of LANDSAT TM data for 1973 and 2000 for Bindura District, in Zimbabwe (Kamusoko & Aniya, 2007). Land use/land cover maps were generated and from these various class level landscape metrics were calculated using a GIS software module (FRAGSTATS) in order to analyse landscape fragmentation. The analysis showed that while agriculture, mixed rangeland, settlements, bare land and water increased, woodland areas decreased.

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The most documented widespread human-induced environmental transformation in world history has been the clearing of woodland for pasture, cultivation and settlement. In this particular case, the landscape had become more highly fragmented as indicated by an increase in the patch number and a decrease in the mean patch size (MPS) of the woodland and mixed rangelands classes. The researchers concluded that the study pointed to anthropogenic activities, driven by agricultural expansion, as the main causes of landscape fragmentation, leading to landscape degradation in the study area.

In a study on the relationship between herders and trees in northern Cameroon it was established that due to land clearance and wood harvesting, fodder resources were becoming scarcer and pasturelands more fragmented; fodder trees were emerging as a key resource, allowing herds to subsist up to the end of the dry season (Gautier, *et al*, 2005).

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2.3.3 Rangeland degradation

One definition of rangeland includes grasslands, shrublands, and savannas: it is any dry land of at least 0.5 ha in size and 20 m in width, having at least 10 percent vegetation cover for at least 2 months of the year and less than 10 percent tree cover and is not used for growing crops (Lund, 2007). A study on pastoralists' management practices and perceptions of rangeland degradation in southern Ethiopia found the causes of degradation to include recurrent and prolonged droughts, increased livestock populations, encroaching of cultivation on grazing land, a ban on the use of fire for controlling bush encroachment, and the development of water ponds in rangelands (Soloman, *et al*, 2007).

In an Australian context, degradation included soil erosion, loss of perennial vegetation (grasses and shrubs), pasture composition change, woody weed invasion and woodland thickening following the suppression of a regular and frequent burning regime. Severe and/or extended droughts as well as inappropriate grazing management practices were generally associated with pasture degradation. “Deteriorated and degraded pasture environments are characterized by a reduced capacity to absorb rainfall and increased runoff, greater surface disturbance and greater patchiness, loss of surface soil nutrients and overall poorer nutrient availability” (McKeon, *et al*, 2004: 33).

Elsewhere, experiments conducted on two types of Japanese mountain pastures to quantify the effects of cattle trampling, measured herbage growth, tiller density, soil loss in runoff water, hydraulic conductivity, soil hardness and soil surface roughness. The study found that trampling resulted in a significant decrease in herbage growth, greater soil loss with runoff water (especially on steep pastures), decreased hydraulic conductivity, increased soil hardness and soil surface runoff. A strong negative relationship was noticed between tiller density and soil surface roughness; the effect of treading on plants and soils increased with treading intensity (Pande & Yamamoto, 2006).

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In researching changing grazing systems in central north Namibia, Verlinden & Kruger (2007) mapped local rangeland units with Landsat TM imagery and analysed them with GIS. They also gathered and analysed information on farmers’ knowledge of historical livestock movements, rangeland potential, the vegetation conditions and plant indicators. The study concluded that good grazing had previously been maintained by low herbivore pressure and frequent fires in a management regime controlled by hunter-gatherers and limited permanent water supply. The advent of large-scale enclosures in the predominantly more fertile land units with the most palatable perennial grass species and water had led to conflicts between grazing and cropping, a decrease in grazing condition, and migration to new areas without adequate water supplies.

2.3.4 Desertification

Desertification was defined at the Earth Summit (1992) as 'land degradation in arid, semi-arid and dry subhumid areas resulting from various factors including climatic variations and human activities' (UNCED, 1992). The term implies the progressive transformation of non-desert areas into deserts.

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A recent study of desertification in semiarid China from the 1950s to the early 2000s aimed to evaluate the key contributors to desertification or rehabilitation in this region (Wang *et al*, 2006). Its methodology included an analysis of proxies for human activity, such as the area of arable land, number of livestock, and population size, and of variations in climatic indices, such as precipitation, evaporation, temperature, frequency of sand-driving winds, and drift potential. The researchers pointed out that while the area's vulnerability to desertification had been a function of both anthropogenic pressures and climate changes, human activities had not played the key role in environmental change in this region. They concluded that two climatic indices (drift potential and the frequency of sand-driving winds) had had a much stronger effect than had been appreciated in previous research.

The study also involved a dynamic simulation model of commercial livestock-grass-soil systems was developed to analyse the processes of desertification. After qualitative analysis of the model the researchers proposed some early warning indicators of the risk of long-term desertification due to overgrazing. Furthermore, the study illustrated the use of those indicators in three hypothetical, yet likely, extensive livestock farming scenarios in Spain (Ibáñez, *et al*, 2007).

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2.3.5 Soil erosion and soil degradation

This sub-section provides a detailed definition of soil erosion and soil degradation. Soil erosion is the detachment and removal of soil particles by raindrop impact or runoff. A distinction is usually made between geological or natural erosion and accelerated erosion which is due to anthropogenic activities. The two processes may occur simultaneously on the same piece of land, the distinction being only a matter of degree and rate. This study looks at the different but interrelated forms of examples.

2.3.5.1 Gully erosion

While gully erosion is commonly associated with agricultural landscapes where vegetation clearance and farming practices increase runoff, leading to fluvial incision, it can also occur in forests subjected to some major disturbances. Following a severe cyclone on the East Coast of New Zealand's North Island in 1988, with rainfall of 535mm, there were 21 active gully systems within an indigenous forest where prior to the event there had only been four (Parkner, *et al*, 2007).

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A South African study to examine the erosion processes leading to the development of badland and gully systems in the Sneeuberg uplands of the Great Karoo experimented with simulated rainfall on plots (Boardman, et al, 2003). Rill and gully erosion had accompanied the replacement of grassland by shrub vegetation from this area of semi-arid extensive stock farming. Species composition changes and ground cover reduction had led to a positive feedback loop which had exacerbated land degradation. The study concluded that badland areas had been active under high-frequency, low-magnitude rainfall events while major gullies are likely to have been the result of occasional, high-magnitude events. Overgrazing in the past had been the most likely cause of the degradation. This included continued movement of livestock on the same areas and kraaling of small stock such as sheep, which became a norm in parts of the Karoo from the nineteenth century (Beinart, 2003).

2.3.5.2 Sheet erosion by water

"The flow of water across sloping sections of the landscape and the cutting action of this flow lead to the formation of rills which join up down slope to increase velocity and cutting power, leading to shallow gullies 'which then work their way upslope'" (McKeon, *et al*, 2004: 75). Without the presence of substantial ground cover, the roots of trees and shrubs are ineffective at preventing these erosion processes.

Condon (2002), cited in McKeon, *et al* (2004: 75) identifies "scalding" - a process associated with duplex or texture-contrast soils (a loam or sandy loam surface on clay subsoil with a high proportion of exchangeable sodium). Removal of the top soil exposes the clay subsoil, producing a near-impenetrable surface which produces high runoff and soil loss. The texture-contrast soils are believed to be particularly susceptible to erosion because the sandy loam surface is easily pulverized by excessive trampling; livestock are attracted to these soils due to nutritional quality arising from the high sodium levels in soil and the rapid response of vegetation to light rains; the soils occur as elevated components of the landscape; and feed quality and soil conditions favour rabbits (Condon, 2002).

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2.3.5.3 Soil degradation

Soil degradation involves *in situ* deterioration in soil quality (i.e. without necessarily involving wholesale removal of soil). It is the "decline in soil quality as measured in terms of its biomass productivity and environment moderation capacity" (Lal, 2004:

106). While soil degradation may occur naturally, it is drastically accentuated by anthropogenic activities.

Physical soil degradation includes decrease in quantity and stability of aggregates, seal formation, crusting, compaction, reduction in infiltration rate, and detachment by water and wind. A study on farmland in southeastern Ethiopia was carried out to assess the effect of cultivation on soil aggregation, aggregate stability and on total soil organic matter (SOM) as well as on the quantity and quality of particulate organic matter (POM). Samples were collected from a cropland cultivated for 26 years as well as from an adjacent natural forest and after their laboratory analyses, several conclusions were arrived at (Ashagrie, *et al*, 2007). Amongst other things, the proportion of water-stable macroaggregates was found to be significantly reduced in the cultivated soil; cultivation had also induced significant losses of organic carbon (OC) and nitrogen (N) both in bulk soil and water-stable aggregates.

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In this process, two sealing mechanisms are involved: physical disintegration of surface soil aggregates by rain wetting and rain drop impacts (Fox, et al, 2004; Tang, et al, 2006) and a physico-chemical dispersion of soil clays, which are deposited within and clog the soil pore spaces immediately beneath the surface (Assouline, 2004; Fox, et al, 2004, Tang, *et al*, 2006). This creates a denser and less porous layer than the soil below it; this layer is known as a seal when wet and a crust when dry. Seal formation at the soil surface reduces rain infiltration and leads to runoff accumulation and erosion.

"An increase in soil sodicity increases soil susceptibility to crusting, runoff, and erosion" (Tang, et al, 2006). Soil compaction can result from activities such as several over-passes of heavy agricultural machinery (Zhang, *et al*, 2006) and livestock trampling (Pande & Yamamoto, 2006). Soil compaction controls the abundance, biomass and distribution of earthworms in soils (Chan & Barchia, 2007). The results of a study by Neave & Rayburg (2007) suggested that while the loss of vegetation cover over the study area had increased the extent of surface crust and seal development the crusts were playing an important role in mitigating erosion.

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Chemical degradation includes reduction in pH, acidification, accumulation of salts in the root zone by salinization, elemental imbalance leading to toxic concentration of some and deficiency of others (Lal, 2004). Soil and water degradation and contamination are treated together as it is often impractical to separate them, except in situations where a study is looking at water quality specifically. Hole and Zaitchik (2007) examined the impacts of irrigation in northeastern Syria. The impacts included soil and water salinization. These researchers used a historical review and satellite imagery analysis to study the structure and dynamics of land-use in this water-limited region. They concluded that a combination of declining water quality, a deepening water table and degradation-prone soils had led to the rapid abandonment of many steppe farms.

In a related research theme, the results of a study based on analysis of soil and water samples collected from several sites on the northern Indo-Gangetic alluvial plains showed that the soil and surface water of the region were contaminated with several persistent organic pesticides (Singh, *et al*, 2007). Again, in a study aimed at differentiating between natural metal sources and anthropogenic sources, surface sediments were collected at sites along a new gas pipeline near Port Harcourt, in the Niger Delta (Nigeria). Chemical procedures undertaken to test the levels of the metals present in the sediments established higher levels of zinc and cadmium than of the other metals (chromium, nickel, copper, zinc and cadmium). It was concluded that their anthropogenic source could be derived from urban and industrial sewage (Adami, *et al*, 2007).

Another study on the cost-benefit analysis of cleaning the Ganges river painted a bleak picture of the quality of its water. The river was heavily polluted with sewerage, industrial waste, runoff from millions of tons of fertilizers and thousands of tons of pesticide used in the river basin, “and thousands of animal carcasses and several hundred human corpses released into the river everyday for spiritual rebirth” (Markandya, et al, 2004: 82). Awofolu, *et al* (2005), collected and tested samples of water and sediment from the Tyume river, at sites near Alice, South Africa. Levels of trace metals (Cd, Pb, Co, Zn and Ni) were determined in the samples. Some of the metals were also determined in soil and vegetables cultivated on irrigated farmland in the area, indicating a possible contribution from the river.

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Biological degradation includes reduction in activity and species diversity of soil fauna and flora, depletion of SOC pool (Lal, 2004). These manifestations of degradation are often linked to soil physical degradation and/or soil management practices such as excessive irrigation and inadequate application of soil nutrients to compensate for losses resulting from continuous cultivation. This form of degradation is closely linked to vegetation degradation and threats to biological diversity can refer to below ground or above ground flora and fauna. Of particular concern to livestock farmers are vegetation species changes which occur in intensively grazed rangelands, with the more palatable species being replaced with less palatable ones.

2.3.5.4 Multifactor land degradation

Land degradation can result from the interaction of several factors. A study in the South African former homeland areas of Gazankulu and Lebowa, which became part of Bushbuckridge, in Mpumalanga, found that site-specific land degradation was due to the combined effect of interacting forces that included population growth, drought, shortages of land, grazing and wood resources, weakening institutional governance of natural resources, and the diversification of livelihood strategies, including the sale of fuel-wood, concurrent with declining employment security and cattle ownership (Giannecchini, *et al*, 2007).

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Niazi (2003) argued that land tenure, land use and land degradation in Pakistan were interlinked. Uneven access to land engendered intensification of its use by large and small holders, contributing to land degradation. Large landholders tended to over-irrigate cash crops, leading to waterlogging and salinity, thereby diminishing land productivity. Zhang, *et al* (2007) used land use survey data sets (1991-2001) in a study to assess the temporal and spatial dynamics of land degradation in China. Rates of land use conversions were calculated and distribution patterns were mapped out with the aid of GIS. The study concluded that the land use changes had affected the wider environment and accelerated land degradation. Six land degradation processes were identified, namely: desertification, secondary salinization, loss of agricultural use, deforestation, grassland degradation and loss of wetland.

2.3.5.5 Degradation impacts on biodiversity

One other highly noted aspect has been the impact of degradation on biodiversity. Rangel, et al (2007), found that natural grassland was being replaced by large-scale agro-pastoral activities in a study of conflicts between biodiversity conservation and socio-economic development across the Brazilian Cerrado. Research on the impacts of converting alpine pastures in the Himalayas of India to protected areas for the conservation of biodiversity established that the strategy was actually threatening diversity. Invasions of the areas by weeds and bushes negatively affected the dynamics of the alpine ecosystems; the invasive species replaced the habitat of many important herbs in the former pastures (Nautiyal & Kaechele, 2007).

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A study of the effects of grazing on the structure and functions of grasslands employed continuously grazed and ungrazed paired plots for comparison. This showed that absence of grazing in the Uruguayan Campos promoted shrub increase. It also highlighted the positive effect of grazing on plant diversity. “Our results partially support the hypothesis that grazing promotes species coexistence by reducing competitive exclusion and by increasing colonization through bare soil patches formation and reducing litter cover" (Altesor, *et al*, 2006: 329).

In another case, a study set out to describe variations in abundance, distribution and species richness of small mammals under 'no tillage cropping' in agroecosystems of the Rolling Pampas, in central Argentina. This served to assess the effects of these changes on the community structure of small mammals in the rural landscape (Bilenca *et al*, 2007). The study results showed no significant preferences by small mammals for particular crops under no tillage cropping system, suggesting that rodents were looking for finer scale microhabitat features within the habitat rather than selecting a macrohabitat type based on crop identity.

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2.3.6 Land degradation assessment approaches

Assessments of land degradation have been carried out at various scales. They have included an assessment of land cover changes on a global scale (UNEP, 1992) and an analysis of a mixed group of 103 high-income and low-income countries. Assessments also involved responses to deforestation, and realized that – as the countries became more developed, their rate of deforestation initially increases. Assessments also revealed that deforestation eventually decreases when a certain level of development and wealth has been reached (Ewers, *et al*, 2006). Examples of regional studies include a study of the impacts of pasture expansion into forest (Wassenaar, *et al*, 2007). National studies have also included an analysis of the relative roles of climatic and human factors in desertification in semi-arid China (Wang, *et al*, 2006) and a national review of the state of land degradation in South Africa (Hofmann & Todd, 2000). Local studies comprise an analysis of the impact on soil aggregation and total organic matter following conversion of natural forest to continuous cultivation in Ethiopia (Ashagrie, *et al*, 2007) and an investigation into land degradation at Tsolwana game reserve, north west of Whittlesea, in the Eastern Cape Province, South Africa (Dube & Fatunbi, 2007).

2.3.6.1 The methods of assessment

Methods of assessment of land degradation have varied depending on such issues as the accessibility and geographical extent of the area to be studied, the costs involved in the study, and the technological feasibility of the methods.

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Detailed field investigation, laboratory testing and statistical analysis

Some approaches entail detailed field investigation of the study area through sampling, combined with laboratory testing of samples collected in the field, and statistical analysis of the data so generated, as described in several studies (Adami, et al, 2007; Ashagrie, et al, 2007; Ibáñez, et al, 2007). One study on interill erosion, based on simultaneous field and laboratory investigations, allowed successful identification and quantification of the main erosion mechanisms and controlling factors of interrill erosion. It entailed installing one metre square micro-plots to quantify the soil material removed by either detachment of an entire soil aggregate or aggregate destruction and the detached material transported by thin sheet flow. In addition, laboratory tests were carried out to quantify the aggregate destruction in the process of water erosion by slaking, dispersion and mechanical breakdown (Chaplot, *et al*, 2007).

Use of Remote Sensing and Geographic Information Systems

In situations where the area to be studied is not easily accessible from the ground (e.g. regions too costly, too dangerous, too rugged, too remote, or too extensive for humans to assess directly) environmental hazard assessments tend to use remote sensing techniques. Remote sensing is the science, technology and art of obtaining information about objects from a distance (Aronoff, 2005). This involves the acquisition, processing, and interpretation of remotely sensed data in the form of aerial photography, digital satellite imagery and radar. The information is captured through equipment mounted on platforms in aircrafts, spacecrafts and ships. Remote sensing offers an overview that enables us to discern patterns and relationships not apparent from ground-based assessments. It enables researchers to monitor the weather on a global scale and to assess and monitor the condition of the earth's resources on a continuous basis. The information garnered from the aerial photography and digital imagery is used to produce maps of various features of the earth such as topography, natural resources and built-up areas. The integration of remote sensing and geographic information systems (GIS) has revolutionized procedures for the conduct of environmental hazard assessments.

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Geographical information systems (GIS) are essentially computer-based systems for the input, storage, manipulation, analysis and display of data which are referenced to the earth's surface (Walford, 2002). In a GIS environment, maps no longer just serve as passive sources and media for archival storage of spatial information; they have become active and dynamic tools for modeling spatial processes and undertaking analysis. The advent of global positioning systems (GPS), used for determining location on the earth's surface has revolutionized the gathering of georeferenced data in the field and its incorporation into digital maps (Aronoff, 2006; Walford, 2002). This is a resource that is also fully developed and is used in numerous planning processes and in various disciplinary studies in South Africa.

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A number of studies in various parts of the world have made use of remotely sensed data and GIS in carrying out environmental assessments in various contexts. One study on aridity and desertification in Jachal, Argentina, was based on the analysis of remotely sensed data (LANDSAT satellite images) using vegetation indices, image differentiation, change detection, and pattern metrics. The study concluded that net land degradation linked to irrigated farming, grazing, firewood gathering and settlement had occurred between 1973 and 2001 (Adamoa & Crews-Meyerb, 2006). Shalaby and Tateishi (2007) used Landsat images for the years 1987 and 2001 in a study to map land cover changes in the northwestern coast of Egypt. Processing of the images included classification, change detection, and ground truthing. The study concluded that severe land cover change had occurred due to agricultural and tourist development projects. It also revealed that vegetation degradation and water-logging had occurred in parts of the research site. In another related study of the western Brazilian Amazon, Lu, et al (2007) used multispectral Landsat TM/ETM+ images for identifying, mapping and monitoring land degradation risk. The procedure they adopted included developing a surface cover index (SCI), examining the relationship between land-use and land-cover (LULC) types and land degradation risks, as well as, assessing the impacts of LULC change on land degradation. Their findings concluded that perennial agriculture and pastures had higher risk potential for degradation than mature forest, advanced successional forest and agroforestry. Land degradation in their research site manifested itself through deforestation and associated soil erosion.

One study in Australia involved monitoring the health of arid and semiarid landscapes using remotely sensed vegetation cover and elevation data (Ludwig, *et al*, 2007).

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Combining scientific and indigenous knowledge systems (IKS) approaches

Within the field of Environmental Studies there has been a growing realization that the widely accepted western scientific approaches to land degradation assessment in developing countries are inadequate. There is now an acknowledgement of the important role played by the long-existing local environmental knowledge, ideas and practices. In recent times there have been growing attempts to reconcile these two approaches for an integrated and effective approach to tackling environmental problems.

As recent as 2007, Stringer & Reed investigated the potential for integrating scientific expertise with local knowledge(s) in assessing land degradation to enhance the accuracy, coverage and relevance of land degradation assessment. Potential land degradation indicators provided by communities in Botswana and Swaziland were assessed according to local and scientific understandings. The study found a significant overlap between scientific and local knowledge(s) about land degradation in most instances. In a review paper that was conducted a few years earlier, Reid (2004) looked at the epistemological utility of linking local knowledge and global science in multi-scale assessments. This was also done earlier by Warren et al (2003), who compared scientific evidence and local views of the measurements of soil erosion. Significantly the method was adopted even in later years as it was indicated with Jianchu, et al (2005) who reviewed IKS in China and advocated for their adoption in national conservation policy. This was also evident in a longitudinal study based mainly on structured interviews of households conducted by Madubansi & Shackleton (2007) that examined the fuelwood use habits of a local community and how they contributed to land degradation.

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2.3.7 Previous research on land degradation in South Africa: Is another study necessary?

Several studies on land degradation have been carried out in South Africa using a variety of methods. A national review of soil and veld degradation based on the perceptions of agricultural extension workers and resource conservation technicians was conducted in 1997 and 1998 (Hoffman & Todd, 2000). The maps generated from the study suggested that it was largely in the communal areas and especially the grazing lands, which are situated along the steep slopes of the escarpment in the eastern parts of South Africa, that degradation was the greatest. This study also included a multiple regression analysis, which showed that both biophysical and socio-economic factors were associated with high levels of soil and veld degradation.

Other studies have mostly been on regional or on local-level scales. Giannecchini, et al (2007) examined the many causes and effects of rural land degradation in Mpumalanga. The study of fuelwood use in a rural area by Madubansi & Shackleton (2007), which was noted earlier in the chapter, established that the rate of deforestation had increased in an area that had been provided with electricity over a decade before the mid-2000s. Another longitudinal study by McCusker & Ramudzuli (2007) also explored historical land use changes in the former bantustan of Lebowa, from 1963 to 2001 and revealed that changes in land use had arisen from the prevailing socio-economic dynamics as well as from historical precedent established by the apartheid regime. A different researcher, Mupakati (2005) used a combination of remotely sensed data and GIS to conduct a spatio-temporal study of land degradation in the upper Tyumie river, in the Eastern Cape Province of South Africa. A few years earlier, Boardman, *et al* (2003) had studied the development and morphology of badlands and gullies in a commercial farming area whilst Dzivhani (2000) examined rural communities' perceptions of land degradation in the Northern Province. These studies illustrate the variety of methods employed and the multifaceted nature of findings that were reached.

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Quite close to the University of Fort Hare, a recent study of land degradation at Tsolwana Game Reserve in the midlands of the Eastern Cape Province looked at three categories of assessment: soil assessment, vegetation assessment and landscape assessment (Dube & Fatunbi, 2006). Using various site-specific sampling procedures and statistical methods this study developed land degradation indices for vegetation, soil and landscape; these were then used to assess the status of land degradation in the game reserve.

Importantly, and with a few exceptions (e.g. Dube & Fatumbi, 2006; Giannecchini, *et al*, 2007), most of the previous studies on land degradation in South Africa tended to concentrate on soil erosion assessment. Studies have been concerned with spatial and temporal issues of land degradation at the expense of site-specific scientific investigations of the factors, processes, and effects of land degradation. Research reports tended to be too general and of limited utility to land management policy makers, natural resources management planners and managers, as well as to other affected communities. This is because the studies have been conducted on scales that could not readily be incorporated into practical planning and/or management units.

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Responses to land degradation in South Africa have, since the inception of rehabilitation schemes in the former reserves/homelands historically reflected the pre-occupation with soil erosion and its attendant problems. Activities to combat erosion typically involved gully reclamation, contour ploughing, the banning of the use of fire in veld management, and calls for the reduction in cattle numbers, especially in communal rangeland areas. Over the last two decades or so it has come to be generally appreciated that land degradation is a much wider problem than just soil erosion. It is now accepted that many previous efforts directed at dealing with the effects of land degradation, despite emanating from government departments (top-down), were merely dealing with the symptoms of land degradation, but not its causes. Two initiatives of the National Department of Agriculture launched in the 1990s hold the promise for successful interventions of land degradation. These are the World Overview of Conservation Approaches and Technologies (WOCAT) and the LandCare Initiative.

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WOCAT includes, among other technologies, the construction of terrace walls, ripping and over-sowing of pastures, water runoff control, wetland rehabilitation, control of invasive species and minimum tillage. LandCare, based on an Australian programme, is a community-based and government-supported land management programme, working in liaison with provincial Departments of Agriculture. It is intended to provide financial support and technical assistance to LandCare community groups who will identify, implement and monitor the conservation activities needed to deal with land degradation problems experienced in particular areas. Among the areas chosen to pioneer this approach to land degradation is Blikana village in Sterkspruit, in the vicinity of this particular research and the study area.

It is highlighted that a detailed multidimensional study such as the one undertaken in this research will go a long way in establishing the specific requirements of each LandCare project before it is launched. Observations already made pertaining to the trends and prospects of the LandCare approach suggest that it offers a practical and, in the long run, more sustainable response to the land degradation and rehabilitation problem in South Africa (Goqwana, *et al*, 2007; Rowntree, 2006; Constitutional Review Committee, 2005).

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CHAPTER THREE

3 STERKSPRUIT DISTRICT AND STERKSPRUIT RIVER CATCHMENT: THE BIOPHYSICAL SETTING AND RURAL LIVELIHOODS

The approach used is to initially describe the Sterkspruit district as the regional location of the study area. This is followed by a more detailed exposition of the biophysical and socio-economic aspects of the Sterkspruit catchment considered to be of relevance to the study.

3.1 Sterkspruit District

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From conquest, Sterkspruit became the magisterial seat for the district of Herschel under the Cape Colonial administration system. Following the creation of Union South African government and the expansion of ‘Native Affairs Department’ (NAD), Herschel became one of the magisterial districts of the Ciskeian territories from 1934 until 1975 when it was transferred to Transkei in return for this homeland’s acceptance of spurious independence. In the course of these years, the small town of Sterkspruit continued to serve as the administrative centre of Herschel to the extent that the area became synonymously known as the Sterkspruit magisterial area. In the re-demarcation and reorganization of administrative units in the post-1994 period Herschel has commonly been referred to as Sterkspruit area (Municipal Demarcation Board, 2001).

3.1.1 Geographical location

The Sterkspruit district of the Eastern Cape Province forms a triangular area bounded by Lesotho to its east, the Free State Province to its west, and by farm districts of Lady Grey and Barkly East to its south. This study is based on the Sterkspruit river catchment, a sub-catchment of the upper Orange river – approximately 391km^2 in extent. The area is located within the Sterkspruit magisterial district, which after the reconfiguration of new municipalities from the year 2000 became part of the Senqu local municipality, one of the six local municipalities of the Ukhahlamba District Municipality, in the northern parts of the Eastern Cape Province. Sterkspruit is bounded by the southern edge of the Drakensberg Mountains to its south and east (locally, the ridge of the Witteberge mountains), and the Orange river to the west. It is located between 30^0 29' S and 30^0 43' S and 27^0 17' E and 27^0 32' E as shown in figure 1.

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3.1.2 Climate

The relatively continental location of Sterkspruit district and its wide latitudinal (and altitudinal) range between localities influences both temperatures and rainfall. The climate of Sterkspruit is sub-tropical, with cool winters and warm summers. It ranges from humid/sub-humid with mild summers and very cold winters in the southeast to sub-arid with warm summers and cool winters in the north east (Loxton, Venn and Associates, 1988).

3.1.3 Temperature

The mean daily maximum temperature for January is 29.9^{0}C while the mean daily minimum temperature for July is around -1.5^{0}C, a difference of 31.4^{0}C. The January temperature may reach an extreme of 36.7^{0}C while July temperature has been known to reach a high of 23.5^{0}C (Els, 1971).

3.1.4 Rainfall

The mean annual rainfall figures reflect a gradient from the relatively dry Orange River valley in the west and northwest, at just above 500 mm to the Witteberge mountains, where figures above 1000 mm are not uncommon (Els, 1971). The rains are distributed seasonally throughout the year. In the spring season (September–November), most of Sterkspruit receives 150–200 mm, with the mountainous southeast receiving a bit more, which is approximately 200–250 mm. The summer season, from December to February, is the main rain season, with 250–300 mm falling in the northern half of the district (including the southwest). During this season the mountainous areas receive heavier amounts with 300–400 mm in the Witteberge to the south, and 400+ mm on the mountains of the southeast. The autumn months of March–May, record amounts of 200-250 mm. Not surprisingly, records for winter drop substantially during this season of the year and the area receives the smallest amounts of 25–50 mm in the greater part of the district, with the south and southeast mountains recording slightly higher at 50–75 mm.

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3.1.5 Geology and Soils

This section examines the geological formations of the Sterkspruit area in the context of the geology of the whole country. This is followed by an analysis linking the soils of the area to the underlying geology.

3.1.5.1 Geology

The Sterkspruit area lies in the Karroo Basin which extends some 1300km from the south-west to the north-east of South Africa (Furon, 1963). The area forms part of the Karroo sequence with distinct formations (see figure 3.1). The mountain peaks are of

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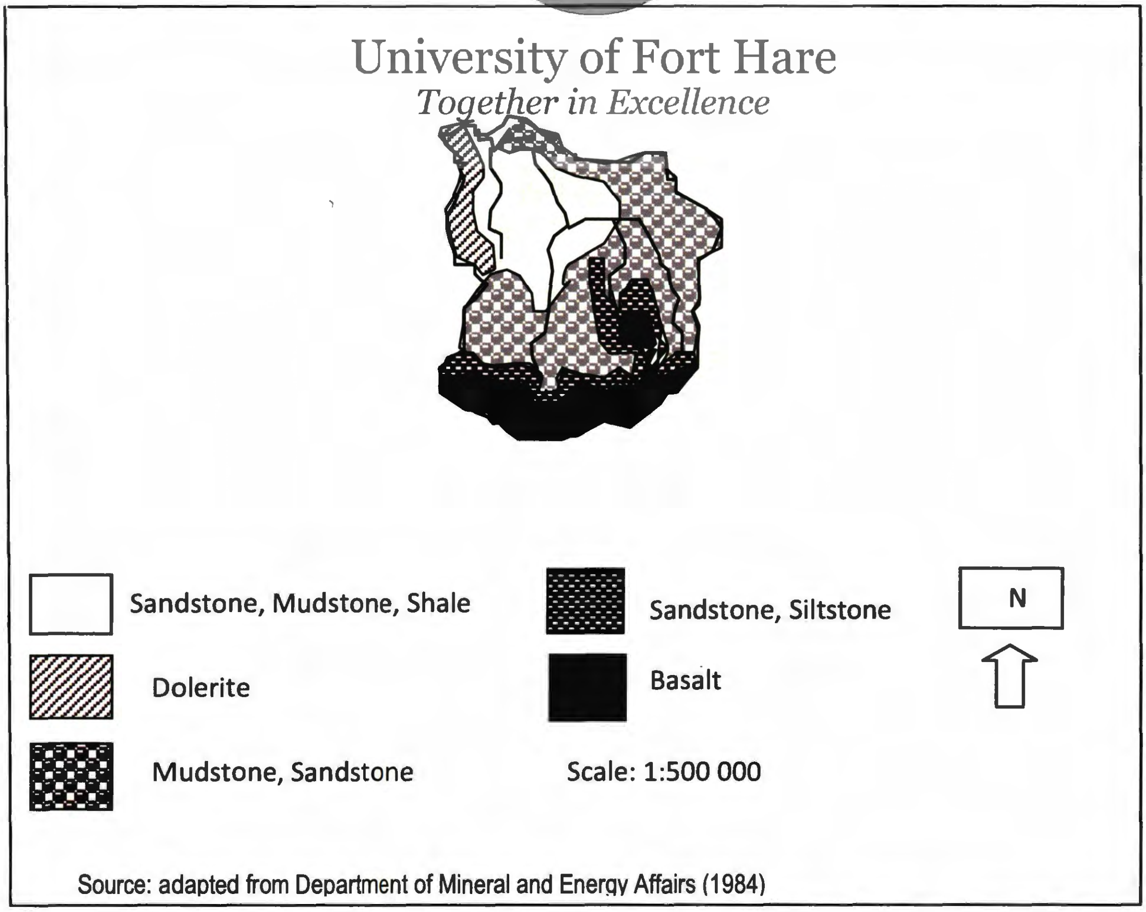

Source: adapted from Department of Mineral and Energy Affairs (1984)

Figure 3.1 Geological map of Sterkspruit River catchment

Drakensberg volcanic lavas. Between the peaks and the cave sandstones below lies a layer of Drakensberg basalts. The southwestern margin of the Drakensberg mountains, locally the Witteberg mountains are marked by massive lava flows and sandstones of the Clarens Formation (cave sandstone), which form prominent scarps (Moore, et al, 2006). The Clarens Formation overlies the Elliot Formation on the mountain slopes and is made up of yellow and white massive and cross bedded feldspathic sandstones and minor grey-green shales and silts. The Elliot Formation, which is underlain by the Molteno Formation, comprises laterally continuous floodplain mudstones and associated fluvial sandstones (Bordy, *et al*, 2004) These consist of grayish red and purple mudstones, with minor yellow and grey sandstones (Dingle, et al, 1983). The Molteno Formation occupies the relatively low lying area of 1300-1500m between the scarps and the Orange river to the west. It is composed of glittering sandstones, grits and conglomerates, with grey and black shale, mudstones and coals (Dingle, *et al*, 2003). Spread out over the low lying and flatter areas are some dolerite dykes.

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3.1.5.2 Soils

The geological basis of the soil forms are the sedimentary sandstones and shales and the igneous dolerite and lava which form the parent materials, combined with the influence of climate, high relief and steep slopes. The soils of the study area comprise sandy clay loams (60%) and clay loams (30%) and are of varying depths: 300-600 mm (60%) and 600-1000 mm (30%), (Schulze, 1997). Fine textured soils (high clay content) are slow draining while coarse-textured (sandy) soils are relatively fast draining. Several of the soil forms found in Sterkspruit are lithosols or duplex soils; they comprise B horizons with low permeability overlain by more permeable A horizons. These texture-contrast soils are exposed to scalding – the removal of heavily trampled soil by erosion which exposes the clay subsoil, producing a near-impenetrable surface which produces high runoff and soil loss rates (Condon , 2002; cited in McKeon, *et al*, 2004). The local soils consist predominantly of sandstone and mudstone, and their combination with the steep slopes of the mountainous terrain has produced a light grey loam soil of about 300 mm deep resting on a yellow grey sticky clay and limestone subsoil (Els, 1971). The calcareous subsoil is, consequently, highly susceptible to gully erosion.

A thin veneer of fine black turfy soil with a good crumbly structure derived from basaltic lava is found along the steep ridges. Dolerite extensions give the soils of the mountain slopes their characteristic chocolate colour (brownish red and grey mudstones). These are overlain by a layer of cave sandstone. The deeper and arable soils are found accumulated in the lower-lying and level areas (Els, 1971). Alluvial soils, of largely sandy loam to clay loam texture are found in the narrow floodplains of river valleys. In the low-lying areas soils exhibit the characteristics of the sedimentary parent rocks, namely gritty sandstone, grey mudstone and shale. Soil fertility rating based on clay content and the base status of the soil on a scale of 0-10 classifies the soils of Sterkspruit as “average” at 4-5 and “average +” at 5-6 in some localities (Schulze, 1997).

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3.1.5.3 Relief and Drainage

Three physiographic regions may be demarcated for the Sterkspruit area on the basis of zones used in an earlier study conducted about four decades ago (Els, 1971). A belt of relatively low lying, Hilly Plains cover the area along the southern banks of the Orange River from the southwest to the north and curves southeast along the border with Lesotho. This belt is followed in a general southeasterly direction by a rising Hilly-to-Mountainous region. On the south east border of Sterkspruit with Lesotho, and the southern border with Barkly East, is a Mountainous and Rugged region. The Witteberge rises quite high - from 1525m to 1525m above sea level, in a distance of less than 24km (Els, 1971); this illustrates just how mountainous and rugged the Sterkspruit area is.

The Sterkspruit area is drained by the Orange River and its tributaries, mainly the Sterkspruit River and its tributaries (figure 3.2). The rivers descend from the Witteberge in the south and southeast and run through the deeply dissected landscape to the Orange River.

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3.2 Sterkspruit River Catchment

This study is based on the Sterkspruit River catchment. As a follow-up of the description of aspects of Sterkspruit district as a whole a detailed description of some characteristics of the catchment is presented here.

3.2.1 Demarcation of the catchment

The Sterkspruit River catchment forms a pear-shaped basin contained by a mountainous rim to its southwest, south, southeast, east and north and by a crest of broken mountains and hilly terrain to the north and west of the basin. The mountainous rim runs from around Magadla village, south west of Sterkspruit, along the crest of the

Witteberge to the south and southeast then north, past Bongolethu to its west, past Mlamli to its west, to KwaNojiki mountain and then west to Spitzkop, which is northwest of Sterkspruit (sheet 3027 CB Sterkspruit). The catchment covers an area of about 391km^2 in extent.

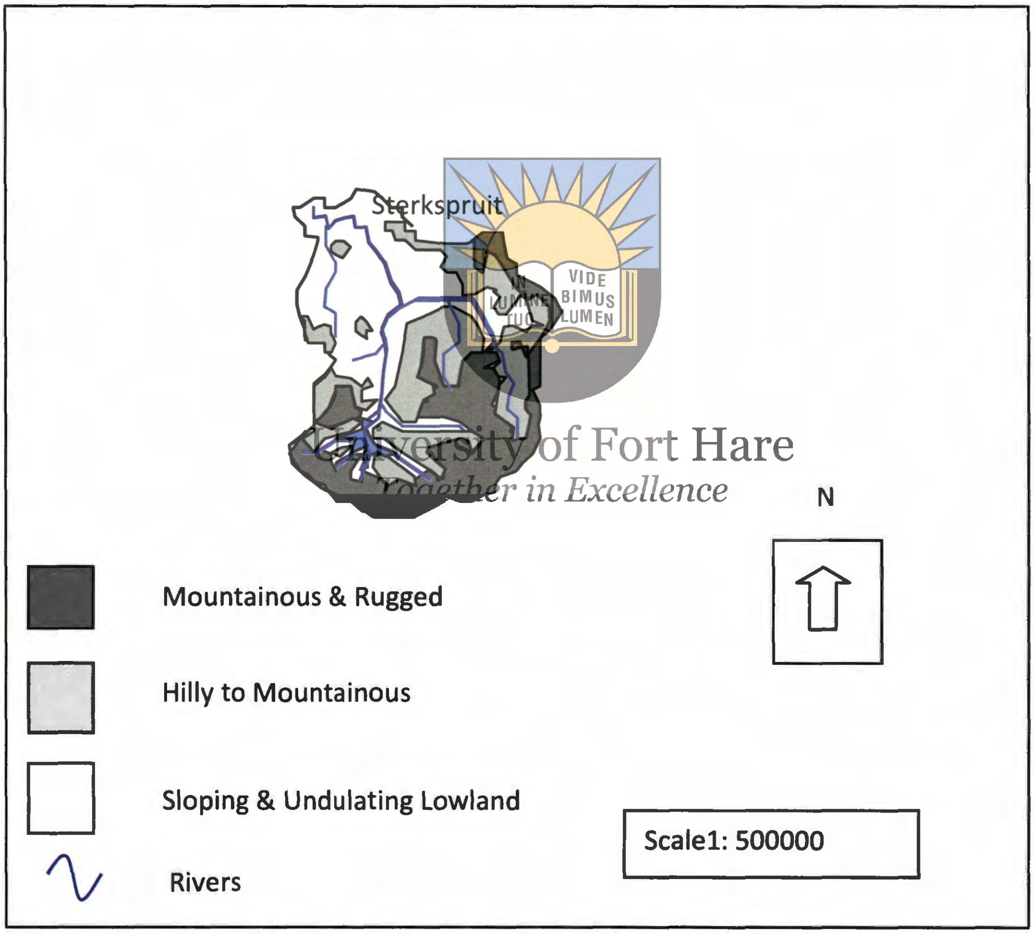

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Figure 3.2 Sterkspruit catchment: relief features

3.2.2 Relief and Drainage of catchment

Adopting the terrain morphology terminology used in an earlier study (Schulze, 1997, after Kruger, 1983) and adapting the relief zones used in the present study, three terrain morphology classes can be identified in Sterkspruit catchment. These are: high mountains with high relief in the southwest, south, southeast, and east; undulating plains with few hills in the central areas around Bensonvale and Sterkspruit, and lowlands with low relief in the narrow, northwest section of the catchment. The high mountains-high relief areas comprise steep slopes and high drainage density characterized by first order and second order streams. Several springs are evident in the mountain areas, with a number of these acting as sources of first order streams.

The catchment is drained by the Sterkspruit River, its main tributary, the Kromspruit, and a number of smaller tributaries such as Bensonvale Spruit, Bamboespruit and Mpongo River. The Kromspruit forms a substantial subcatchment of its own, especially in the mountains; the Bensonvale Spruit has a relatively narrow subcatchment. The altitude of the basin varies from an average of 2566 m above sea level on the crest of the Witteberge to around 1300m at the point where the Sterkspruit River enters the Orange River. From the source of the Sontyosi, the central headwater stream of the Sterkspruit, to the mouth of the Orange River there is a distance of about 28km. The average gradient of the stream is, therefore, (E1-E2/HD): (2566-1300)/28000 = 0.45214 This gradient means that the land rises 451.12m every 1km on the horizontal distance travelled along the Sterkspruit river from its confluence with the Orange river to its headwaters in the Witteberge mountains.

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3.2.3 Climate

The physiographic configuration of the catchment basin influences the local climate in several ways. There is a general temperature and moisture gradient between the lowlands-with-low -relief areas and the high mountain-high relief areas.

3.2.3.1 Temperature

According to figures taken from a study by Schulze (1997) the January mean daily minimum temperature for Sterkspruit catchment is 14^{0}C-16^{0}C for the low areas and 12°C-14^{0}C for the higher areas; the mean daily maximum temperature is 30-32^{0}C. For July mean daily minimum figures are 0°C-2^{0}C for the low areas and -2^{0}C to 0^{0}C. The daily mean temperatures for January were 22^{0}C-24^{0}C for the low area, 20°C-22^{0}C for the higher areas; for July the daily mean temperatures were 8^{0}C-10^{0}C for the lower area, and 6^{0}C-8^{0}C for the higher area. The average duration of frost period is 121-150 days in the lower areas and 151-180 days per year in the high altitude areas (Schulze, 1997). This has important implications for agriculture.

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3.2.3.2 Rainfall

The rainfall pattern of Sterkspruit River catchment follows the pattern of the rainfall of the whole of the Sterkspruit area. On the basis of figures cited in a study by Midgley, et al (1990) mean annual precipitation can be characterized as follows:

Sterkspruit, lower catchment: 600 – 700 mm
Hinana village, middle catchment: 700 – 800 mm
Magwiji village, upper catchment: 800 – 1000 mm.

These figures are comparable to those depicted on the graphs in figures 3.3 and 3.4.

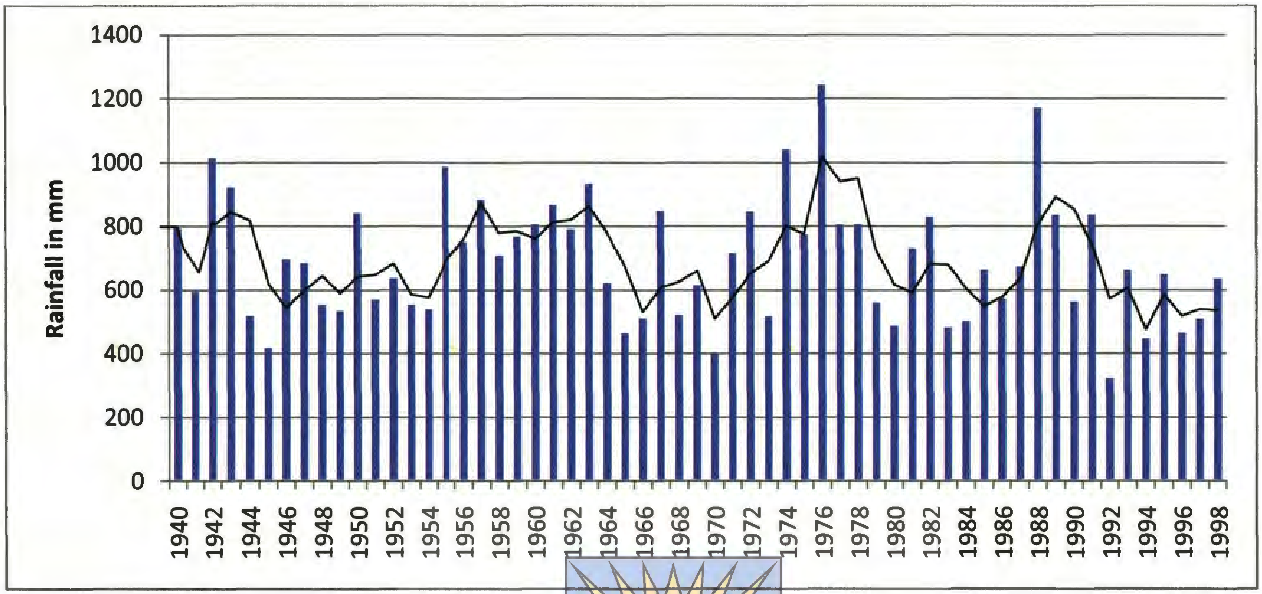

Figure 3.3 Annual rainfall (mm), 1940-1998: Sterkspruit TNK, Sterkspruit catchment, with 3-year average trend line

The graphs are based on rainfall records of recording stations within Sterkspruit catchment supplied by South Africa Weather Service (2008).

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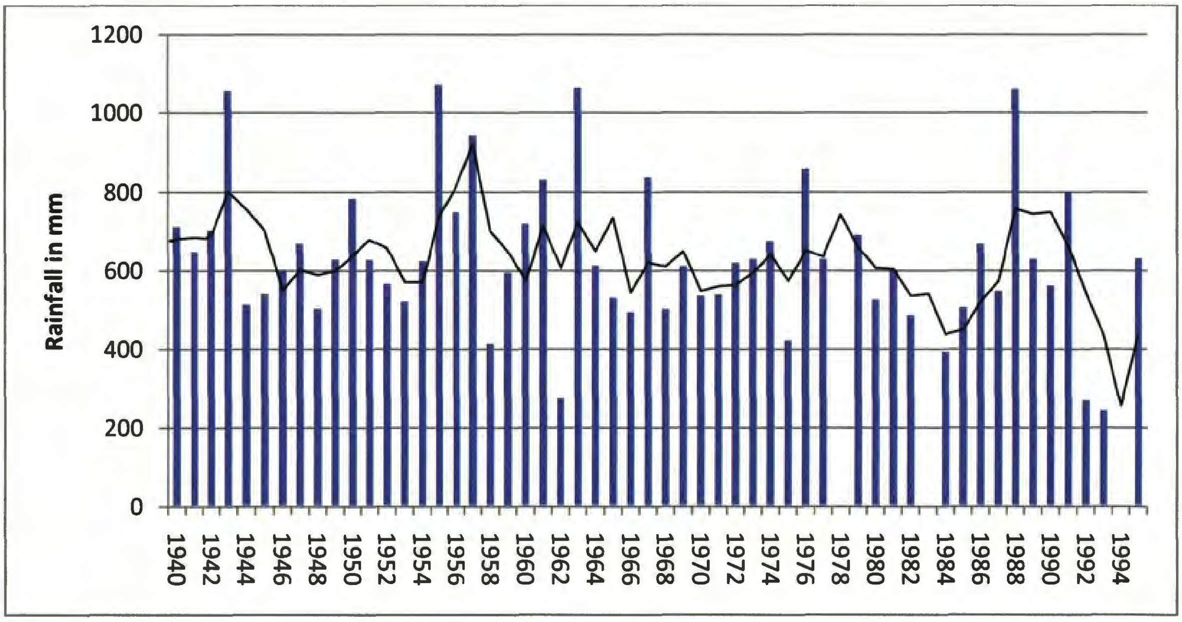

Figure 3.4 Annual rainfall (mm), 1940-1995: Bensonvale, Sterkspruit catchment, with 3-year average

In the late Spring or early Summer (around October-November) the rains may occur as hailstone-bearing thunderstorms, causing considerable damage. Figures 3.5 and 3.6 illustrate images from just such a storm witnessed at Magwiji village in October 2007.

Figure 3.5 Hail storm at Magwiji village, Sterkspruit

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The intense storms result in large amounts of runoff within short periods. When combined with the generally steep slopes of the area, this results in soil erosion,

Figure 3.6 Sheet wash erosion from intense rain storm at Magwiji village

especially where the soil is not adequately covered by vegetation.

3.2.4 Vegetation

The mountainous areas of Sterkspruit fall under the Afromontane vegetation region characterized by temperate conditions which receive a relatively high rainfall of up to 1000 mm per year (Cowling, *et al*, 1997). The generally black and turfy soils are derived from the Drakensberg basalt and are very erodible. The dominant vegetation is grassland and ericaceous shrubs. In areas above 1830 m and receiving rainfall of more than 575 mm the *Themeda-Festuca* Veld occurs (Els, 1971). The short dense grassland is dominated by the *Themeda triandra* and other tussock grasses, ericoid dwarf shrubs and creeping plants.

Fire is used as a pasture management tool in commercial farming establishments for the control of bush encroachment and the removal of "dead" grass to make way for new grass which livestock find more palatable. The use of fire as a management tool in a communal rangeland setting is not officially sanctioned by the authorities. On grasslands that have not been exposed to fire for some years shrubs and climbers form a dense thicket. The shrubs suppress the grass and the grassland is invaded by secondary forest trees (White, 1983). Scrub forest is found in sheltered creeks and on mesic, steep slopes with a southern aspect. The southern slopes are protected from the overhead position of the sun and this increases their soil moisture regime in the dry season (Granger and Schulze, 1977).

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Small pockets of *fynbos* occur throughout the grassland, especially on nutrient poor soils derived from Aeolian sands of the Clarens formation, and are confined to localized areas protected from fire by virtue of topography (Killick, 1963; du Preez, 1992, cited in O'Connor & Bredenkamp, 1997). The word fynbos means fine-leaved bush. The biome consists predominantly of an evergreen shrubland on sandy, infertile soils, characterized by the universal presence of restoids, a high cover of ericoid shrubs and the common presence of overstorey proteoid shrubs (Cowling, *et al*, 1997). As examples observed in the field *Stoebe vulgaris* was observed to be flourishing on steep, north facing, fire protected slopes to the north of Hinana village and healthy looking stands of an admixture of *Acacia mearnsii, Passerina Montana, Chrysocoma filifolis*, *Rhus erosa* and *Diosparos lycioides* were observed on steep slopes east of the Holohlahatse dam.

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The undulating landscape below the mountain Scarp consists of shallow, rocky soils often derived from dolerite (O'Connor & Bredenkamp, 1997). It comprises *Hyparrenhia hirta* tall grassland evident in areas that are not overgrazed. In heavily grazed localities such as the plains between Bensonvale and Sterkspruit grasses also include *Aristida congesta* and *Elionurus muticas.* The low-lying southwestern and northern sandy areas of Sterkspruit are grasslands dominated by *Cymbopogon-Themeda* species (Els, 1971).

With reference to livestock farming the mountain veld consists of sour grassveld, the plains and low-lying areas are sweet (Els, 1971). Sourveld is characterized by fast growth, an increase in fibre content with growth, a decrease in digestibility and less palatability than sweet or mixed veld. It is dominated by the palatable *Themeda triandra* species in conditions of frequent fire and low grazing pressure. When subjected to sustained grazing intensity the palatable species give way to grazing tolerant, unpalatable species such as *Eragrostis curvula, Eragrostis plana, Sporobolus africanus* and *Sporobolus pyramidalis* (Hardy, *et al*, 1999). The absence of intense fires arising from low fuel loads consequent upon heavy grazing promotes the growth of fynbos in certain areas. Selective grazing of sourveld leads to increased abundance of 'wire' grasses such as *Aristida junciformis, Elionurus muticas* and *Dibeteropogon filifolis*. Once degradation of the sourveld advances to such a state, there is little chance of reversing it. "Sour grassveld is therefore considered to have low resilience" (Hardy, et al, 1999: 282).

Sweet grassveld is typified by slow growth, retains most of its nutritive value throughout the year and the digestibility and tastefulness of mature grass does not differ from the green grass (Nel, 1971).The year-round palatability to grazing animals "has historically led to heavy grazing pressure and reduced fire frequency and intensity in these grasslands" (Hatch, 1999: 290). Degradation of sweet grassveld may involve, among other things, a reduction in basal cover, decreased infiltration, increases in runoff, increase in the abundance of less productive pioneer species, and an increase in woody species such as *Acacia, Chrysocoma, Pentzia and Felicia* (Hatch, 1999). "Sweet grassveld is less stable than mixed and sour grassveld but is highly resilient and recovers rapidly following disturbance (such as drought)" (Hatch, 1999:290).

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3.2.5 History of Settlement

The dense grass cover of the mountainous areas is testimony to the richness of the fine rich turf derived from basalt. In areas where the relief permits some cultivation can be carried out. This also applies to areas of crumbly black clayey soil found in relatively flat areas between the hills. The light grey loamy soils are suitable for dryland cultivation while the sandy soils of the cave sandstone are relatively poor and acidic (Els, 1971).

An economic and social survey conducted in 1925 (Macmillan, 1930) reported that the Herschel area had been settled rapidly from the 1830s and 1840s by various small offshoots of the Mfecane refugees and other immigrant groups. These included the Hlubi, Tlokwa and Sotho; as well as some Thembu and 'Mfengu' immigrants from the Eastern Cape. Though the upland locations had higher rainfall and better soils the people had settled more densely in the lower areas in sub-villages such as Tugela, Ndofela, Madakana and Bamboespruit. This had been because the lower areas were more suitable for cultivation and were near the major transport routes (Beinart, 1987). In later years settlements expanded towards the mountains coinciding with population growth. Livelihoods then included livestock production, in the form of moving livestock seasonally between the highlands and lowlands, and cultivation of arable plots in the valleys. Agricultural products largely included wool and grain. Labour migrancy was also a feature of rural life and had largely been so by the beginning of the twentieth century. Macmillan (1930) also observed that by mid- 1920s the district was overpopulated by both people and livestock. By this time there was an absence of firewood and crucially, soil erosion was spreading.

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3.2.6 Settlement pattern and population distribution

Herschel's residential settlements comprise a sizable service centre, Sterkspruit, and a number of clustered rural villages. Sterkspruit, originally known as Phooko, is a relatively compact settlement developed in colonial times as an administrative outpost (seat of Superintendent of Native Locations); it accommodated various groups, including some state employees, traders, labour agents, and craftsmen (Beinart, 1987). By 1998 it had an estimated population of about 13 000 (Statistics South Africa, 1998; Statistics South Africa, 2001) and offered services like district administration offices, police, shops, banks, schools, and health services. Other compact settlements comprised Bensonvale and Mlamli. Bensonvale developed initially as a Christian religious and educational centre, whilst Mlamli developed originally as a Christian mission hospital. The rest of the settlements can be described as clustered villages spread out in gently sloping or flat areas of the Sterkspruit catchment (see Figure 3.7). They include Esilindini and Madakana, west of Sterkspruit, just off the road to Herschel; Tapoleng, Bensonvale, Magadla, and Jozana's Nek, southwest of Sterkspruit, off the road to Jozana's Nek; Jozana's Hoek, Mangweni and Magwiji, south of Sterkspruit; Mlamli, east of Sterkspruit; and Voyizane, Kromspruit, Hinana and Bhongolethu, southeast of Sterkspruit. There are some smaller, scattered or outlying villages that tail off from the main villages. These settlements used to be scattered on the side of the mountains until they were re-organised under the betterment schemes which were implemented in the area in 1961-2.

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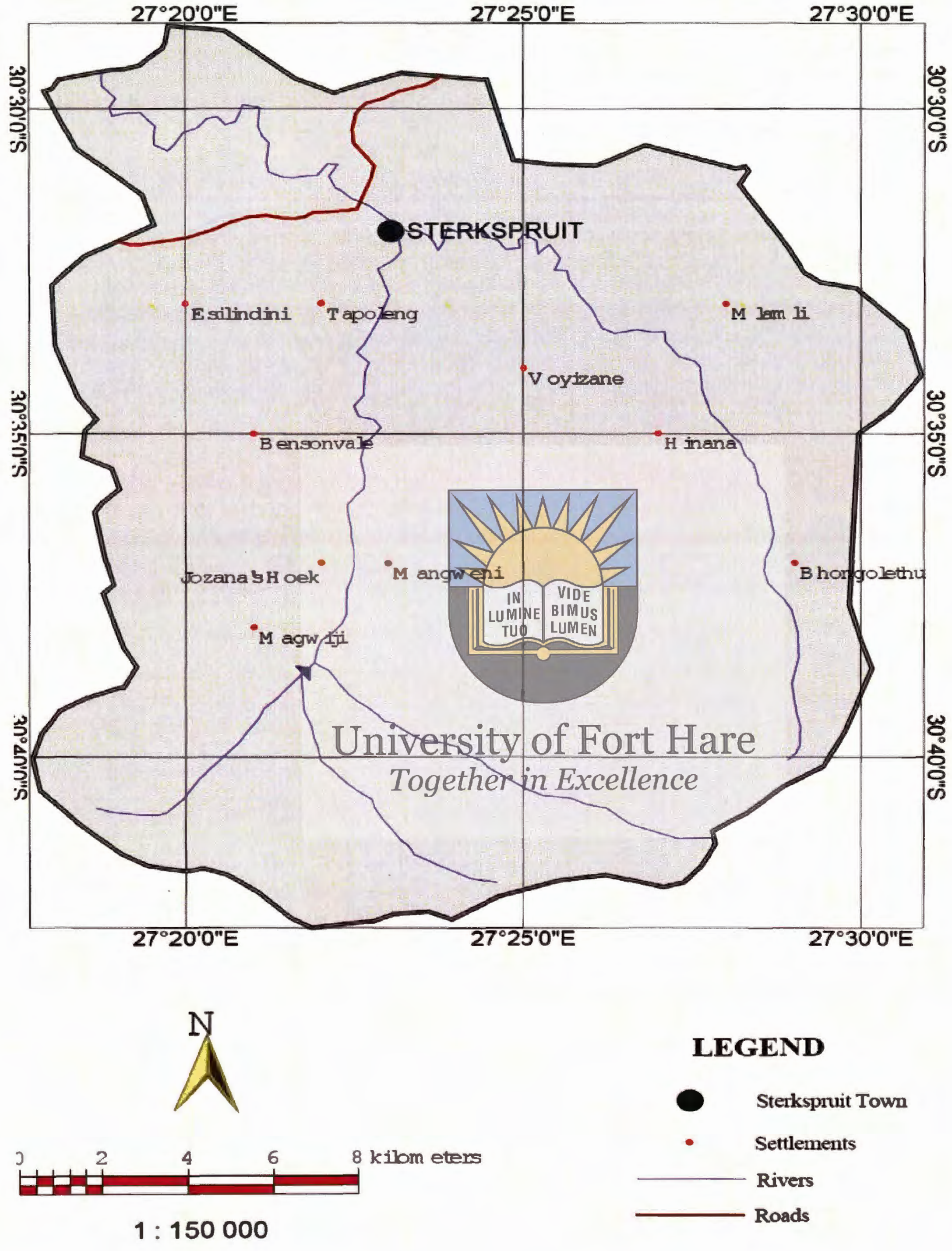

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Figure 3.7 Sterkspruit catchment: settlement patterns

Betterment consisted of “attempts started in the 1930s by successive South African governments to combat erosion, conserve the environment and improve agricultural production in the black reserves” (De Wet, 1995: 39). Herschel district was regarded as experiencing serious soil erosion which required urgent attention even before the 1920s (Beinart, 1989). The South African Drought Investigation Commission report of 1922-23 had, among other things, attributed the problem of soil erosion in pastoral farming areas to overstocking and the practice of kraaling sheep and cattle. The 1930s and 1940s saw the introduction by government of anti-erosion measures in affected areas and Herschel was one of the earliest African districts to which these measures were applied. There was some spirited opposition to these measures for a number of reasons. In a special issue on conservation edited by Beinart (1984) it was revealed that peasant farmers in Herschel blamed the government for gully erosion. The techniques involving the construction of large ridge terraces or bunds on hillsides were seen as wasteful of land and ineffective as the often carelessly constructed terraces were susceptible to bursting. Local farmers also pointed out to their own old system of small furrows and channels round the fields, their system of *spaarveld* which rested grazing lands, and their meticulous contour ploughing.

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After the publication of the Tomlinson Commission report in 1954 a large part of betterment was aimed at reorganizing black communal villages into planned settlements with separate residential, arable, and grazing areas for purposes of what planners deemed better land use. It must be emphasized however that the Tomlinson Commission, which at the time was the most comprehensive planning document ever produced on South Africa, had recommended a category of full-time farmers on substantial economic units, held under freehold tenure. The National Party government did not entertain the recommendation because it had committed itself by 1951 to "tribal land entities" held under re-introduced chieftaincies and associated tribal authorities. It therefore rejected most of the recommendations of the Tomlinson Commission and, believing that it could build revenue by taxing local Africans, it reduced the recommended Commission's development funds by more than two thirds, from £105 million to £36 million (Wotshela, 2001: 7-15).

Rural planning therefore was directed largely to villagisation or "betterment" as old African settlements had an added responsibility of absorbing families that were displaced from farms – a phenomenon that was in occurrence since the application of the 1913 Land Act. Under betterment then large numbers of families were moved and relocated into centralized settlements with their own locations and fencing-off residential, arable and grazing areas (Wotshela, 2001). In theory, this re-organization of locations would be accompanied by low-level agricultural interventions for the improvement of agricultural productivity. In practice there was hardly any improvement in productivity (De Wet, 1995). Land was allocated by headmen and councilors. In this scheme of things Herschel was divided into Trust villages comprising some 21 major residential areas and several smaller ones, with the amount of arable land allocated to each family varying from nothing to six acres (Desmond, 1971). Some villages ended up with land divided into grazing camps only, without any arable land; others were allocated arable land which was too far to be of any practical use. Though a number of dams were built there was no irrigation equipment to enable the farmers to make use of the water for agricultural purposes. These settlements were plagued by chronic

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unemployment and malnutrition and Desmond (1971: 100) characterized them thus, "Herschel Reserve is merely a labour-pool for contract and seasonal workers, since only the headmen and councilors can possibly make a living from the land".

As the National Party government's Bantu or Tribal Authorities administration was gaining momentum by the early 1960s, Herschel was then divided into six Tribal Authorities, namely, Basotho, Amaqwathi, Mnyemane, Amavundle, Abatlokwa and Hlubi (Jackson Survey Report, p 3, cited in Wotshela, 2001). The district population was estimated at 76 821 by 1974 (Jackson Survey Report, p 49); this agrees with another estimate of 75 000 (Desmond, 1971). The Herschel and Glen Grey districts were handed over to the Transkei homeland in 1975 when the Transkei was granted its "independence" by the South African government, in the context of a compromised territorial arrangement under Apartheid policy. Tensions developed between supporters of the Transkei tribal authorities and those who did not want to be part of an "independent Transkei". The South African government added to this as it committed itself to provide an alternative territory with resources and full compensation of losses to those who were prepared to relocate out of an "independent Transkei". This sparked an exodus from Herschel to newly released Queenstown farms that were intended for the consolidation of a fledgling Ciskei homeland. The first people to move out of Herschel were a group of residents from Voyisana. This was followed in September 1976 by the official relocation of Hershel chiefs Henry Hinana, Jonas Malefana and Larabaza Bebeza with several of their followers. Some followers of the other chiefs who did not move joined the emigrants (Wotshela, 2001). An estimated 32 000 people migrated from Herschel to a Northern Ciskei transit camp of farms Thornhill and Loudon some

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30km west of Queenstown (Surplus People Project, 1983; Wotshela, 2001). Other sources put the estimated number of the relocatees who had moved out of Herschel by 1977 at 41 420 (Wotshela, 2001: 206). The differences in estimated numbers may have arisen due to the fact that the official figures were based on the number of people assisted to move by government, whereas there were a number of people who organized and paid for their own relocation, without waiting for government assistance. Another source of confusion regarding numbers of migrants is the fact that one group of refugees went to Qwaqwa, an area adjacent to Lesotho's north-western border. This group is not included in the numbers cited as having left Herschel for Whittlesea (Wotshela, 2001).

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Some five years later, the construction of the Jozana dam in Herschel by 1981 led to the relocation of Magwiji village which had been located to the south of the new dam wall (Department of Land Affairs, 1998). The current village is located just south of Sunduza village, in what used to be part of the rangelands used by Sunduza people's livestock. Several of the homesteads, including graveyards, were drowned when the dam filled up. The homesteads that were not drowned reverted to rangeland. The choice of the site for the location of the dam wall was influenced by the existence of steep and rocky relief on both sides of the dam narrowing towards the dam wall site. Access to the rangelands upstream of the dam is restricted for both humans and livestock due to the steepness of the land on the eastern and western side of the dam.

3.2.7 Livelihoods

The area is occupied by communal land farmers engaged mostly in the rearing of cattle, goats and sheep. There is also some ownership of horses, donkeys, and pigs. Livestock keeping has always been the main source of livelihood in the area from the nineteenth century (Macmillan, 1930). A study on Herschel (Brown, 1971) indicated that the Herschel district had a total grazing area of 181 700 morgen, 59 058 mature large stock units, an estimated carrying capacity (MLU) of 51 914 measured at a grazing pressure of 3.08 MLU. This seemed to indicate a form of overstocking and in fact the Tomlinson Commission confirmed so about two decades earlier. However, according to later studies, use of carrying capacity concepts in non-equilibrium communal rangeland is now called into question (Behnke, *et al*, 1993; DeAngelis & Waterhouse, 1987; Scoones, 1993).

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There is much evidence that the growing of crops once played an important role in the residents' lives in much of the catchment. This is seen in the well demarcated previously ploughed fields laid across the slopes. However, most of the crop fields are now abandoned and/or have been turned into rangelands. While the majority of people keep livestock there is quite a sizable number who own neither livestock nor crop fields. These rely on declining wage labour remittences and welfare options, which include government pension payouts and other forms of grants. The only urban settlement in the catchment, Sterkspruit, employs people in mostly service industries such as government administration, banking, shops, hospitals, schools, etc. Some informal businesses can also be observed in the town, such as traders and food outlets. There are a number of schools and clinics which employ people in non-agricultural activities in several locations in the catchment (teaching, nursing, etc), e.g, at Bensonvale and Mlamli. Within the villages, a few people run spaza shops both formally and informally.

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CHAPTER FOUR

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4 RESEARCH METHODOLOGY

This chapter outlines the research methods used, the data generated and collected, as well as processing or data treatment undertaken. The analysis and interpretation of data is done under the relevant sections in chapters 5 and 6 respectively. It was seen as appropriate in the context of a multi-scale study to discuss the results of the landscape scale assessment separately from those of the site-specific surveys.

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4.1 Research Design

This section outlines the philosophical conceptualization of the study and the methodological framework informing the approaches adopted.

4.1.1 Conceptual Framework

The study took a hydrological catchment (watershed) approach to assessment of land degradation. An integrated approach, involving multiple criteria and multi-scale evaluation procedures was adopted, making use of various techniques to determine the spatial and temporal dynamics of land degradation in the area. The approach lends itself to integrated geographical analysis of the landscape and offers potential for tackling land degradation problems in the context of integrated catchment management (ICM) as adopted in earlier studies (Bartley, et al, 2006; Kgathi, et al, 2006). It is now widely accepted that environmental, ecological, social and economic systems require integrated assessments as the basis for land management and decision making on a landscape scale. River catchments are ideal as functional geographic units for integrating a variety of environmental processes and human impacts on landscape policy. Vezina, et al (2006) and Bellamy, et al (1999) give comprehensive examples of the use of the integrated approach in environmental assessment. The multidimensional analysis of the land degradation problem adopted for this study suits the catchment approach. It involves examining the problem at the lateral and temporal scales and, from the point of view of remote sensing "the remotely sensed landscape is multidimensional: horizontal, vertical, multispectral" (Quattrochi & Pelletier, 1991: 6).

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4.1.2 Methodological Framework

On one level the research project pursued *a* techno-positivist perspective (scientific method) – formulating a hypothesis or thesis statement (theory), collecting data on the studied phenomena, and using them to test the theory (Le Treut, et al, 2007). On another level, it adopted the postmodernist perspective of a multi-epistemological assessment conducted at multiple scales to facilitate the incorporation of multiple sources of knowledge (Millenium Ecosystem Assessment, 2003). The approach incorporated *triangulation* – using many individual assessments and examining general trends of several techniques and sources of information to see if they are in agreement (Stocking & Murnaghan, 2001).

In the multi-scale approach, "scale" is viewed as the physical dimensions, in either space or time, of phenomena or observation (Reid, 2004). The approach sought to make the study holistic in outlook, incorporating assessments taken at different scales – catchment level (to check for overall landscape fragmentation), landscape level (to examine rangeland condition around Magwiji and Hinana villages), specific landscape sample site (rangeland transect, gully, soil sampling site).

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4.2 Research Instruments

Research instruments employed in this study were quite varied, reflecting the nature of the multidimensional approach. They included acquisition, processing and interpretation of remotely sensed data, analysis of maps, climatic records, census data, livestock records, study of previous research reports on issues relating to the study area, questionnaire surveys and sampling of vegetation and soils to generate new data.

4.2.1 Remote sensing

In view of the relatively large aerial extent of the study area (391 km^2) and its rugged nature landscape level assessment of degradation employed remote sensing techniques, making use of satellite images and aerial photographs. This made it possible to have an overview of the whole study area at a small fraction of what it would have cost to actually travel around the whole catchment gathering data (Aronoff, 2005). The challenge of using this method is that one cannot always get the time series images or aerial photographs at the regular intervals that one might desire. However, with judicious selection of data and careful processing and analysis of the results, this is a relatively quick and fairly reliable method of assessment of land cover changes over a large area. To authenticate what was observed through remote sensing, ground truthing traverses were carried out in the form of transect walks along strategically pre-selected routes.

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4.2.2 Analysis of historical climatic and livestock data

In the absence of readily available baseline data on the climate, population, and livestock of the study area it was necessary to resort to whatever historical and anecdotal records were available. Historical climatic data, particularly rainfall figures, were analysed for evidence of climatic variability. Problems encountered with this data were the lack of temperature figures and gaps and discontinuities in the rainfall data. Despite this it was possible to combine this data and the other from proxy weather stations in the same general region to construct long term trends in rainfall patterns for the area. Historical data on livestock numbers for the study area, obtained from the Department of Agriculture in Sterkspruit, was available only for the period since 1998. This created problems as it made it difficult to compare long term fluctuations in livestock numbers with long term fluctuations in rainfall. However, recourse was had to relevant studies conducted in other parts of the Sterkspruit district, such as those by

Vetter (2003) and Goqwana, *et al* (2007). Vetter's study found that while cattle numbers had fluctuated over the years, on average they had remained stable for about a century (Vetter, 2003). This helped to give a fuller picture of the livestock situation in the area.

4.2.3 Analysis of available population data

Population data for Senqu district municipality, which encompasses Sterkpruit were taken from the national censuses (Statistics South Africa, 1998; Statistics South Africa, 2001). Since these data were aggregated for an area much larger than the study area, it was difficult to extract directly the exact figures for the population of the settlements in the Sterkspruit catchment. Nevertheless, this data, combined with the accompanying population density maps, gave a fairly useful basis for calculating the rate of population growth and the levels of population pressure on the resources of the area.

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4.2.4 Participatory rural appraisals and questionnaire surveys

Village level data on socio-economic aspects of the study were gathered through participatory rural appraisals (PRAs) and questionnaire surveys, which were conducted in Hinana and Magwiji villages in 2007 and 2008. The PRA techniques used included natural resources mapping by the villagers and identification of incidences of land degradation by the villagers on transect walks. These provided useful insights into area residents' land use practices, attitudes and perceptions to rangeland condition and land degradation in general.

4.2.5 Landscape inspection, vegetation and soil sample surveys

Site specific data on vegetation and soils were gathered through field work involving physical inspection of the rangelands, transect sampling, and soil sampling. The sample data from this were later processed and analysed, and the results were used to develop vegetation degradation and soil degradation indices. While generally one should be wary of upscaling results obtained from sampling small areas and applying them to larger regions, nothing beats empirically derived data when it comes to giving as accurate a picture as possible of the phenomena under study. In this study the empirical data were also useful in providing pointers as to what evidence of degradation to look for during ground truthing landscape traverses.

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4.3 Data Sources and Data Manipulation Procedures

Data for the study were collected from several sources using various methods. These included maps, official records, publications, research reports, aerial photographs, satellite images, sampling data, interviews, questionnaires, and observations. All these methods were all employed to various levels at different stages of the research.

4.3.1 Secondary Data

Information and data in this section were mainly to do with the biophysical and socio-economic setting of the study. The data pertained to the landscape scale of the study, i.e, of relevance to the whole catchment or substantial portions of it.

- 1: 50 000 contour map of study area (SHEET 3027CB STERKSPRUIT) (Department of Land Affairs, 1983), served as a useful basis for demarcating the Sterkspruit river catchment and for identifying settlement patterns. Comparing earlier (1960) and later (1983, 2007) versions of the map helped to piece together the history of land uses.
- Aerial photographs of study area (scale: 1: 10 000) were studied for any visible land cover changes. Analysis of these provided additional remotely sensed data regarding land cover changes over time (land use history, settlement morphology and size).
- Two sets of satellite imagery of study area (Landsat Thematic Mapper TM): spanning period 2000-2007 (resolution 30m x 30m) were acquired and were processed for analysis of land cover changes. Percentage changes in various land cover classes were analysed and interpreted.
- Data on climate were first processed (calculation of means, coefficients of variation, packaging into graphs and tables) and then analysed for climatic variability. Unfortunately, temperature figures were not readily available. Mean temperatures cited in various studies had to suffice (Elsl, 1971; Schulze, 1997).
- Geology, soils, water resources, and natural vegetation data for the study area were obtained from published sources (Acocks, 1988; Els, 1971; Mucina &

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Rutherford, 2005; Stekspruit map sheet 3027CB, 1983) and used for description and analysis of biophysical setting of study.

- Perusal of published reports of previous research on various aspects of land degradation in South Africa (Hofmann & Todd, 1999) and in the Herschel-Sterkspruit area (Beinart, 2003; Goqwana, et al, 2007; Vetter, 2003; Vetter, 2007); of settlement and livelihoods in Herschel-Sterkspruit (Goqwana, et al, 2008; Beinart, 1987; Lesodi, 2008; Moyo, et al, 2008); and of people displacement in Herschel (Wotshela, 2001; Wotshela, 2004).
- Government publications and records pertaining to the study area, e.g. censuses, development plans, annual reports (Statistics South Africa, 1998; Statistics South Africa, 2001; Govender, 1998; Department of Bantu Administration and Development, KWT Office, 1964).

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4.3.2 Primary Data

Data gathering procedures outlined in this section were for site-specific assessment of land degradation.

- Field survey: observation of soil characteristics and collection of soil samples from pre-selected sites
- Soil loss measurements (gullies, rills, pedestals)
- Soil infiltration capacity and soil penetrometer resistance measurements on sites
- Rangeland transect observation, recording of aspects of rangeland condition (basal cover, species dominance, species diversity, indicator species – decreasers, increasers, etc)

- Taking illustrative photographs of aspects of land degradation at each site
- Interviews with key informants (agricultural extension officers, environmental conservation technician, members of the community) on their perceptions of land degradation, its causes, manifestations, impacts and responses
- Questionnaire survey (& PRA) of community householders on socio-economic issues and practices with some relevance on land degradation
- Transect walks at selected localities to observe different aspects of land degradation – erosion, soil deposition, invasive plants, changes in grass species composition (and for ground truthing of phenomena observed by remote sensing)

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4.3.3 Laboratory and Office Work

- Drawing of study area maps (location map of study area, geology map, relief map, and settlement pattern map)
- Analysis of satellite imagery for land cover changes, assignment into land cover – land use classes and digitizing of the resulting maps
- Analysis of aerial photographs of study area for patterns of land cover changes between 2000 and 2007 and to check for other details not apparent from the satellite images
- Laboratory treatment and analysis of soil samples to determine chemical attributes (with help of soil science expert) – of the physical conditions only the test for soil bulk density was conducted
- Collation of soil chemical data (and soil bulk density) into tables and graphs

- Collation of soil infiltration capacity and penetrometer resistance field data into tables and calculation of relevant statistics
- Calculation of rangeland condition indicators from field data and generating tables and graphs
- Analysis and interpretation of survey data in different formats: tables, graphs, maps, and indices
- Thesis compilation, synthesis and construction of the findings – report writing

4.4 Landscape Scale Data Generation and Data Processing

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It was decided to use a remote sensing approach for the initial assessment of the status of land degradation in the whole Sterkspruit catchment. This was because it was the only practical approach for assessing the condition of the land at the landscape scale. The whole catchment assessment was then followed by field visits to selected areas and land marks for ground-truthing of phenomena initially observed from the satellite imagery.

4.4.1 Land Use-Land Cover Dynamics

Two Landsat TM satellite images of medium resolution (30mx30m) were acquired for processing and analysis in order to assess whether or not any land degradation had occurred between two cut-off dates. One image was taken in September 2000 (after the first spring rains in Sterkspruit) and the other was taken in February 2007 (during the summer rain season). Images are classified by automatic categorization of all pixels in the image into land cover classes or themes – using the spectral pattern present within the data for each pixel as the numerical basis for categorization (Lillesand & Keifer, 1987).

Before images can be classified they have to be preprocessed to remove distortions arising from the image acquisition procedures. The distortions include atmospheric haze, which reduces image contrast, and geometric distortions. The distortions stem from a diverse group of causes that ranges from variations in altitude and velocity of the sensor platform, to factors such as panoramic distortion, earth curvature, atmospheric refraction and relief displacement. The preprocessing of the images involved atmospheric correction for haze removal and geometric correction for edge matching. Geometric correction compensates for the distortions so that the corrected image will have the geometric integrity of a map (Lillesand & Kiefer, 1987).

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Processing entailed creating an NDVI of the three spectral bands (4, 6, 3) of false colour composites. Both supervised and unsupervised classification of images were employed. Supervised classification entailed defining the land cover categories, selecting features on the image and placing them into land cover categories based on their spectral separability. Unsupervised classification was adopted for areas of overlap between classes, using their spectral signatures to aggregate the pixels into special classes and assign them to different land cover types. Hierarchical classification was used to come up with four land cover classes, namely dense vegetation, grassland, bare ground, and water. The dense vegetation consisted of scrub forest and invasive bush species; grassland included all areas covered with grass, whether in the low lying areas or on the mountains. Bare ground included areas denuded of vegetation and any areas covered with bare rock; and water included the dam, stock dams, and rivers. The minimum mapping unit, based on the area represented by each pixel, was 30m x 30m. The implications of this are that any feature which is less than 30m x30m in areal extent will not appear as a separate entity on the map. The total areas covered by the classified land cover types were calculated and expressed as percentages of the area covered by the catchment. Two maps reflecting the four classes of land cover were produced, one for the year 2000, the other for 2007. These are shown as Figures 5.1 and 5.2 in Chapter 5 where they are analysed and interpreted. Two tables (5.1 and 5.2) summarising the land cover percentages for the two satellite images were also constructed. These are also discussed in chapter 5 (section 5.1.3).

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4.4.2 Landscape Geometric Configuration

Using information from the land use-land cover maps and ground truthing transects an analysis was made of the geometric configuration of the landscape and the effect this had on socio-economic activities in the area. This was related to previous studies of the impact of physical barriers on habitat characteristics of various life forms. This is done in section 5.1.3

4.4.3 Climatic variability

Several studies have portrayed Sterkspruit (Herschel) as an area with serious land degradation (Hofmann & Todd, 1999; Vetter, 2003; National Land Cover Map, 1996). The objective of this part of the study was to examine the role played by climatic factors (particularly rainfall), vegetation dynamics and socio-economic factors in the land degradation process.

4.4.3.1 Temperature data

Historical and current temperature data are not available for the area. However, mean temperatures for various periods were provided in several studies (Els, 1971; Schulze, 1997). The figures in Tables 4.1 and 4.2 were analyzed and their medians were taken as

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Table 4.1 Mean daily minimum temperatures and mean daily maximum temperatures in Sterkspruit catchment. Source: Schulze (1997)

Mean daily minimum temperature		**Month**	**Mean daily maximum temperature**	
Low altitude	High altitude		Low altitude	High altitude
14-16°C	12-14°C	January	30-32°C	30-32°C
14-16°C	12-14°C	February	26-28°C	26-28°C
12-14°C	10-12°C	March	24-26°C	24-26°C
8-10°C	6-8°C	April	20-22°C	20-22°C
4-6°C	2-4°C	May	18-20°C	18-20°C
0-2°C	0-2°C	June	16-18°C	14-16°C
0-2°C	-2 to 0°C	July	16-18°C	14-16°C
2-4°C	0-2°C	August	18-20°C	16-18°C
4-6°C	4-6°C	September	22-24°C	20-22°C
8-10°C	6-8°C	October	24-26°C	22-24°C
10-12°C	8-10°C	November	26-28°C	24-26°C
12-14	10-12	December	30-32°C	28-30°C

mean monthly minima and maxima; these were then used to construct the graphs presented as Figures 5.4, 5.5, and 5.6 in Chapter 5.

Table 4.2 Mean monthly temperatures for Sterkspruit catchment

Low altitude	**Month**	**High altitude**
22-24°C	January	20-22°C
22-24°C	February	20°C
18-20°C	March	16-18°C
14-16°C	April	12-14°C
10-12°C	May	10-12
8-10°C	June	6-8°C
8-10°C	July	6-8°C
10-12°C	August	8-10°C
12-14°C	September	12-14
16-18°C	October	14-16°C
18-20°C	November	16-18°C
20-22°C	December	18-20°C

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4.4.3.2 Rainfall data

Historical rainfall data for the Sterkspruit catchment and environs was supplied by Weather SA. Mean annual rainfall for Sterkspruit catchment ranges from just over 500mm in the Orange River valley in the west to over 1000mm in the Witteberge mountains to the south and south-east. Recording stations, Sterkspruit TNK, Sterkspruit and Bensonvale were located in the Sterkspruit catchment; stations Herschel, Helvellyn and Lady Grey were outside the catchment but were used in the study as proxies to provide comparable data as they are in the same general region.

Mean annual rainfall was calculated for each station, together with the standard deviation in order to show variability in the rainfall amounts. To compare the relative variability in the data from the different recording stations a coefficient of variation (CV) was computed for each station. Table 5.3 and Table 5.4 summarize the rainfall patterns for the various stations. The rainfall data were also put into graph format for further analysis. The graphs in Figures 5.7-5.12 show the rainfall patterns with a wavy 3-year running average and a linear trend-line for each recording station. Figures 5.13-5.18 are graphs illustrating percentage deviations from mean annual rainfall for the various stations, with three-year running mean deviations and linear trends over the entire period of record. Deviations from mean monthly rainfall amounts for several months were analyzed. The variations in monthly rainfall amounts were represented in Tables 5.5 and 5.6. These variations in monthly rainfall amounts were also captured in graph format, Figures 5.19 to 5.26.

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4.4.4 Landscape Scale Vegetation Data Analysis

In an area which has been settled for as long a time as Sterkspruit has been it can be difficult to identify the nature and state of the 'original' climatic climax vegetation. Recourse to historical literature on the vegetation expected to be in the area in terms of the geology, soils, climate, and characteristic biomes of the area is necessary. Perusal of sources (Mucina & Rutherford, 2005; Acocks, 1988; and Tainton, 1999), and study of NDVI maps prepared for land cover change analysis (see section 5.1), were followed by transect walks in a number of localities. During the walks, vegetation types of the

Sterkspruit catchment area were observed and recorded; vegetation species identification was also carried out.

On the mountain immediately to the east of the Holohlahatsi dam and at the bottom of mountain slopes southwest of Hinana village the vegetation consisted of grassland surrounded by thickets of scrub forest. The lowlands and mountain valleys east of Magwiji village were mostly grassland with the occasional shrub. In the lowlands and valleys upstream and to the south of the dam the vegetation consisted of grassland interspaced with high fynbos. There were thickets of scrub forest on either side of streams and on south facing slopes. The river valley north and northeast of Hinana village consisted of grassland dominated by *Hyperrhania hirta, Eragrostis chloromelas* and *Aristida congesta*. *Hyperrhania hirta, Cynodon dactylon*, and *Aristida congesta* were common on slopes south-west and north of Hinana village. The Kromspruit valley from the confluence of the Kromspruit and the Sterkspruit rivers to Mlamli was made up mostly of grassland, with a few trees along the river. The hills and mountains overlooking the valley consisted of scrub forest; this was especially noticeable on the south facing slopes.

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In the lowland areas on either side of the road linking Bensonvale and Sterkspruit, the vegetation consisted of *Hyperrhania hirta, Aristida congesta* and *Eragrostis chloromelas*, among other grasses. *Hyperrhania hirta, Cynodon dactylon*, and *Aristida congesta* were observed just south-east of Tapoleng; and just south of Voyizane. At sites about five kilometers north-west of Sterkspruit along the road to the Lesotho border some *Eragrostis chloromeles, Aristida congesta*, and remnants of *Hyperrhania hirta* were observed. Details of the observed vegetation and an analysis of its contribution to landscape sensitivity are presented in section 5.2 in chapter 5. Later, specific sites were selected for detailed study.

4.4.5 Soil erodibility and estimation of catchment scale sediment loss

The erodibility of a soil is its susceptibility to erosion; hence it depends on its physical and chemical characteristics and its management (Hudson, 1986). Soil texture, soil bulk density, and soil aggregation are some of the physical properties that contribute to soil erodibility (Hofmann & Ries, 1991). Due to intensive grazing and trampling, the study area has much loose surface soil. The high intensity of the rain and the kinetic energy exerted by the large drops of the intense rain storms characteristic of the area disperse the finer particles of the soil. These fill up pore spaces between the larger particles, causing soil capping. The overall effect is to reduce the soil's infiltration rate, thereby contributing to rapid accumulation of overland flow and erosion.

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Rainfall erosivity refers to the potential of rain to cause soil detachment and transport (Lal & Elliot, 1994). Rainfall amount and intensity contribute to erosivity as they determine the kinetic energy expended in soil erosion processes. Processes requiring the use of energy include the breaking down of aggregates, splashing them in the air, scouring and carrying away soil particles. Several soil loss prediction models have included the calculation of the erosivity index (R) (Wischmeir & Smith, 1976) and of the kinetic energy (KE) index (Hudson, 1986). The applicability of these empirically developed models to different climatic conditions and geographical locations is problematic.

Notwithstanding its limitations, the revised universal soil loss equation (RUSLE) was applied to Sterkspruit catchment in an effort to estimate amounts of soil lost through erosion processes. The equation is set out thus: A = RKLSCP

Where:

A is the predicted soil loss, which is the product of

R=rainfall erosivity

K=soil erodibility

L=slope length

S=slope gradient or steepness

C=cover and management

P=erosion-control practices (land management factors).

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Using these factors as outlined in Brady & Weil (2008), and an adaptation of a soil erodibility table by Mitchell & Bubenzer (1980) – which derives the erodibility factor through analysis of a soil's texture and percentage organic matter - the equation can be solved thus: A=RKLSCP

Table 4.3 Soil loss estimates based on the revised universal soil loss equation (RUSLE)

A	R	K	L	S	C	P
		Lithosols	200m	160	Range grasses & low shrubs	Contour factor 3-16%
	350	0.061*	5.4		0.17	0.7

*mean % organic matter at surveyed sites (0.94) / (2% organic matter) x (K factor 0.13): (adapted from table by Mitchell & Bubenzer, 1980)

A=(350)(0.061)(5.4)(0.17)(0.70)

A=13.72t/ha/a

The estimated soil loss for the catchment is 13.72 tonnes per hectare per year. This result is presented in section 5.2.3 in chapter 5 for discussion and comparison with other estimates.

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4.4.6 The state of surface and groundwater resources in the catchment

A survey of the nature and state of the surface water and groundwater resources of Sterkspruit catchment was made using maps, census data, remotely sensored imagery analysis and ground truthing. This was done in the context of the role of the water resources in land degradation and landscape resilience in the catchment.

4.4.6.1 Sources and uses of water

The survey looked at the natural availability of water in the area, the history of water provision by authorities and the uses to which water was put by the residents. Details of the results of the assessment and the attendant ramifications are dealt with in section 5.2.4.1 of chapter 5.

4.4.6.2 Sources of household water

Using census data for the 2001 national census and questionnaire survey data, graphs were constructed on household water sources in the study area. Figures 5.29 and 5.30 in chapter 5 summarise these data; the analysis is done in section 5.2.4.2.

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4.4.6.3 Water pollution

While no direct measurement of water pollution was undertaken for logistical reasons, the roles of sedimentation, manure from confined livestock, and faecal matter in water pollution were considered. Census data on household toilet facilities in Senqu municipality were used to construct a graph (figure 5.32) to assist in the analysis of possible sources of water pollution. This is dealt with in section 5.2.4.3 of chapter 5.

4.4.7 Human population pressure and livestock carrying capacity

Due to the fact that the outer perimeter of the catchment area did not coincide with those of the administrative boundaries such as those of the municipality and the ward it was necessary to make certain numerical computations so as to arrive at a reasonable estimate of the size of the population of the study area. Moreover, some changes to the administrative boundaries were made by the Municipal Demarcation Board between the 1996 census and the 2001 census, making direct comparison of population figures for parts of the district and municipality difficult.

The population of Senqu municipality, in which Sterkspruit district is situated, is given as 118 174 people living in an area 7330k[illegible]ge; this gives a population density of 16.12 per km^2 (http:/senqumunicipality.co.za/Downloads/Doc_231.pdf). An earlier study of the four villages making up Magwiji ward (Jozana's Nek, Jozana's Hoek, Sunduza, and Magwiji) gave their population as 5330 living in an area 1354 morgen (Govender, 1998); the area is actually more than 14029 morgen according to another source (Department of Bantu Administration, 1964). The population figure was based on the 1996 census; if this figure is adjusted by the national percentage increase between 1996 and the 2001 census (Statistics South Africa, 2001) ((5330x0.0213) + 5330) the population for the four villages was around 5443.5 by 2001. Using the same percentage increase (2.13% in five years, we multiply 5443.5 by 1.0213); this figure is estimated to have risen to 5559.47 by 2006 and 5607 by the end of 2008). The questionnaire survey carried out in Hinana village as part of the current study found its population to be made up of 651 households with an average size of 5, giving an estimated total of 3255 people for the village. These five villages are located within the Sterkspruit catchment;

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together they had an estimated population (5607+3255) of 8862 in 2008. This gives an average of 1772 people per village. When this number is multiplied by the number of villages located in the catchment area (14x1772=24808) and added to the 12623 (Statistics South Africa, 1998, Statistics South Africa, 2001) people resident in Sterkspruit town, the Sterkspruit catchment has an estimated population of 37431. The population figures are captured in Table 5.8 in chapter 5 where they are discussed under section 5.3.

As a measure of population pressure on land resources it is useful to assess the extent to which residents of an area own or have access to arable land. Household access to land was examined using figures obtained from the study by Govender (1998) and questionnaire data from the current study. The data was put into graphs and compared. Figures 5.33 and 5.34 in chapter 5 are the relevant graphs and the analysis is done in section 5.3.1.2.

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Livestock carrying capacity assessment was estimated on the basis of figures cited in a previous study (Govender, 1998) and livestock census figures supplied by the Department of Agriculture in Sterkspruit. An estimate of livestock in the catchment is made using average figures calculated from data on five villages. The data on cattle, goats, and sheep is converted to cattle units; these units are then employed to determine whether the assessed carrying capacity for the area has been exceeded. A data table (5.9) is used to summarise the calculations. This table is presented and analysed in section 5.2 of chapter 5.

4.4.8 **Historical livestock data**

The Department of Agriculture at Sterkspruit provided livestock census records for Hinana and Magwiji villages for the ten-year period from 1998 to 2007. Processing of these data entailed calculating for each category of animals, the ten-year mean, the standard deviation, and coeffient of variation. These figures are shown in Table 5.10. To illustrate the nature of the changes in livestock numbers it was decided to compare the figures for each year with the means for the ten-year period. This was presented in the form of graphs, Figure 5.35 for Magwiji village, and Figure 5.36 for Hinana village. The net changes in livestock numbers were captured in another graph, figure 5.37. The graphs and accompanying analyses are in Chapter 5.

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4.4.7 Socio-Economic Survey

This section reports on the methods used to gather data on socio-economic factors of some relevance to land degradation issues. The methods included participatory rural appraisal (PRA) and questionnaire survey. It also outlines the data processing involved and the outputs thereof.

4.4.9.1 Participatory rural appraisal (PRA): residents' perceptions of land degradation and suggested solutions

A participatory rural appraisal preceded a questionnaire survey in both Magwji and Hinana villages. Raw data for a survey done in Magwiji in January 2008 (Lesodi, 2008) was kindly made available for use with the data for the Hinana survey.

Several PRA methods have been used for evaluating the state of natural resources and/or land uses and their impacts in rural areas. The method considered appropriate to use in a particular situation will depend on the context of the study and, perhaps, on socio-cultural considerations. The critical considerations for successful and sustainable engagement with the community are: the respect and attention given to the opinions, ideas and perspectives of locals (Mog, 2004). The participatory process can be viewed as involving three steps (Fagerstro¨ma, et al, 2003). The first step is the initial contacts with researchers learning about local conditions; in this study this was learning about the status of land degradation. The second step was analysis of land degradation by the local farmers themselves. The third step was farmer-researcher feedback on the different land degradation scenarios and their impacts on rural livelihoods.

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The PRA meeting for Magwiji was conducted in January 2007. The PRA in Hinana village was conducted in May, 2008. A total of 67 people attended the Hinana gathering. A whole group session discussed the quality of life in the area generally regarding livelihood trends and changes, health and food security and the state of the land as described by proponents of this method such as Chambers (1994). After this initial session the group was divided into three focus groups. The methods used in both Magwiji village and Hinana village included semi-structured interviews, focus group discussions (whole group, male elders group - age above 25, female elders group – age above 25, and younger males and females group – under age 25), with the points being summarized on a flip chart. Natural resources mapping, was done by a diverse group of residents, using a ground sketch initially and then on a large sheet provided by the researcher for the purpose. This was followed by a transect walk by groups of residents during which field identification of different land degradation features was undertaken. The results of the PRAs are summarized in Table 5.11.

To avoid repetition the results of the interviews regarding rangeland use patterns in both Magwiji and Hinana are discussed in section 5.4.2 of Chapter 5.

4.4.7.2 Questionnaire Surveys

Questionnaire surveys were conducted in Magwiji (January 2007) and Hinana (May 2008) villages. The surveys were aimed at gathering empirical data on household demographic characteristics and livestock rearing practices of the people of the two villages and analysing them to see what effect they might have on residents' perceptions and attitudes to land degradation in their area. Figures for cattle ownership in Magwiji were summarized in Table 5.12 and those for Hinana in table 5.13. Table 10 provides a comparative picture of cattle ownership in the two villages. Ownership of cattle, sheep, and goats in Magwiji is captured in figure 5.39 while ownership of cattle, sheep and goats in Hinana is illustrated in figure 5.40.

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Changes in livestock numbers in Hinana by type of animal and by reason is illustrated in figure 5.41. Changes in livestock numbers in Magwiji village by type of animal are shown in figure 5.42. The question of provision of supplementary feed to livestock was investigated; the idea was to gauge the adequacy of rangeland forage resources in sustaining livestock of the area. Figure 5.43 illustrates the household patterns with regard to provision of supplementary feed.

Responses on the diversity of wild life found in the rangelands and the usefulness of rangelands to villagers are depicted in graph format in figure 5.44 and figure 5.45, respectively. Responses to questions on patterns of household energy use and on application of manure to the land were presented as graphs, figure 5.46 and figure 5.49, respectively. Energy source for cooking in the whole of Senqu municipality using data from the 2001 census is captured in figure 5.48. The application of manure to arable land was examined in the context of land degrading from lack of replenishment of soil nutrients by farmers. Figure 5.44 represents househoders' response to the question.

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4.5 Sample Site Data Generation and Data Processing

This section looks at the data gathering methods employed at the level of the sample site and the subsequent data processes and outputs. Data was gathered on the physical condition of the landscape at close range, vegetation condition, species identity, and soils.

4.5.1 The Physical Condition of the Landscape

The study examined the condition of communal rangeland in the upper Sterkspruit catchment using a multidimensional assessment approach. The area has been grazed for over a century by livestock consisting mainly of cattle, goats and sheep. The study was carried out between May 2007 and August 2009. After visual inspection to assess the physical condition of the landscape several potential study sites were identified on the basis of visible signs of land degradation such as gullies, animal tracks and loose soil. Out of the potential sites 21 sites were chosen for detailed study; 10 were in rangelands around Magwiji village and 11 were in rangelands around Hinana village.

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4.5.2 Land Degradation Index

Sample sites were visually assessed for physical manifestations of land degradation using variables identified in a participatory selection process for indicators of rangeland conditipon (Reed & Dougill, 2002) and used in the study by Dube and Fatunbi (2007). These variables included: erosion severity as borne out by the presence of pedestals, sand deposition on roads or paths, incidence of livestock tracks, soil looseness, presence of gullies and degree of landscape slope. The variables were scored on a scale of 1-5 at each site, with 5 indicating the highest manifestation of the variable and 1 the least. The author and a soil scientist each made an independent assessment and these were later reconciled into a final score for each variable per site.

The scores were later employed to develop a (soil) land degradation index (LDI) using the multidimensional analysis technique already explained in section 5.2 and reported in studies by Sharma, *et al* (2007) and Guillin, *et al* (2007). The six variables listed above were used to generate the LDI. Total factor loading of each parameter in this statistic-based method for identifying a minimum data set for land degradation assessment enables maximal representation of all the assessed parameters with minimal data redundancy. Table 4.5 illustrates the LDI and the parameters used to derive it. To obtain the degradation index for each variable: divide the score figure in the first column by 5;

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Table 4.5 Calculation of land degradation index (LDI) from weighted parameter values of six indices for land degradation

Site	Soil looseness			Sand deposition			Animal tracks			Erosion severity		Degree of landscape slope			Presence of gully		Deg Index	Degrd class
		4			4			3			5		4		5			
1	2	0.4	1.6	2	0.4	1.6	1	0.2	0.6	4	4	4	0.8	3.2	4	4	**15.0**	**2**
2	3	0.6	2.4	2	0.4	1.6	3	0.6	1.8	2	2	2	0.4	1.6	4	4	**13.4**	**1**
3	4	0.8	3.2	3	0.6	2.4	3	0.6	1.8	4	4	3	0.6	2.4	3	3	**16.8**	**2**
4	2	0.4	1.6	2	0.4	1.6	3	0.6	1.8	3	3	3	0.6	2.4	2	2	**12.4**	**1**
5	4	0.8	3.2	4	0.8	3.2	3	0.6	1.8	5	5	4	0.8	3.2	5	5	**21.4**	**4**
6	2	0.4	1.6	2	0.4	1.6	2	0.4	1.2	2	2	3	0.6	2.4	2	2	**10.8**	**1**
7	5	1.0	4.0	5	1.0	4.0	4	0.8	2.4	5	5	4	0.8	3.2	5	5	**23.6**	**4**
8	5	1.0	4.0	5	1.0	4.0	2	0.4	1.2	5	5	3	0.6	2.4	5	5	**21.6**	**4**
9	5	1.0	4.0	5	1.0	4.0	3	0.6	1.8	5	5	4	0.8	3.2	5	5	**23.0**	**4**
10	5	1.0	4.0	5	1.0	4.0	4	0.8	2.4	5	5	2	0.4	1.6	3	3	**20.0**	**3**
11	4	0.8	3.2	4	0.8	3.2	2	0.4	1.2	4	4	3	0.6	2.4	4	4	**18.0**	**3**
12	4	0.8	3.2	4	0.8	3.2	2	0.4	1.2	4	4	3	0.6	2.4	3	3	**17.0**	**2**
13	5	1.0	4.0	4	0.8	3.2	3	0.6	1.8	4	4	2	0.4	1.6	1	1	**15.6**	**2**
14	5	1.0	4.0	5	1.0	4.0	4	0.8	2.4	5	5	4	0.8	3.2	2	2	**20.6**	**4**
15	4	0.8	3.2	5	1.0	4.0	2	0.4	1.2	4	4	3	0.6	2.4	3	3	**17.8**	**3**
16	5	1.0	4.0	5	1.0	4.0	2	0.4	1.2	4	4	3	0.6	2.4	2	2	**17.6**	**3**
17	5	1.0	4.0	5	1.0	4.0	2	0.4	1.2	5	5	3	0.6	2.4	4	4	**20.6**	**4**
18	5	1.0	4.0	5	1.0	4.0	3	0.6	1.8	5	5	4	0.8	3.2	3	3	**21.0**	**4**
19	4	0.8	3.2	5	1.0	4.0	4	0.8	2.4	5	5	4	0.8	3.2	2	2	**19.8**	**3**
20	4	0.8	3.2	4	0.8	3.2	2	0.4	1.2	5	5	2	0.4	1.6	3	3	**17.2**	**2**
21	2	0.4	1.6	2	0.4	1.6	2	0.4	1.2	2	2	3	0.6	2.4	2	2	**10.8**	**1**
			28			32			32		27			23		38	20	38.1

Note: Figure in box is the value for weight of importance for the specific variable

Degradation lasses: 1: Nondegraded 2: Moderately degraded 3: Seriously degraded 4: Extremely degraded multiply the resulting figure entered into the middle column by the value for weight of importance for the variable in the box at the top; enter the index in the right hand column. The composite index for the whole site is obtained by summing all the individual indices for the variables; these are recorded in the column headed "degradation index". The index was finally categorized further into four degradation classes as follows: 1: hardly degraded, 2: moderately degraded, 3: seriously degraded, 4: extremely degraded. The LDI is presented in summarized format as figure 6.1 in Chapter 6, where it is interpreted in detail for each sample site.

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4.5.3 Soil Degradation and Soil Loss

Data gathering on soils at the study sites included measurement of gullies, rills, and pedestals to help in soil loss estimates. Soil samples were collected for laboratory analysis to determine some of the physical and chemical qualities of the soils and how these related to soil degradation processes. Field measurements of soil infiltration rates and soil penetration resistance were carried out to generate data for assessing the soil's physical predisposition to degradation. Soil samples were also collected for the measurement of soil bulk density as an indicator of the level of compaction of the soils. Soil textural class was determined in the field by the method of running a handful of soil through the fingers and feeling it; this was done with the assistance of a trained and experienced soil scientist.

4.5.3.1 Soil Physical Degradation

Soil physical condition, among other things, relates to soil strength, particle size distribution, infiltration capacity, bulk density, and aggregate stability. For the purposes of this study it was necessary to carry out certain measurements to determine the physical condition of the soils on the study sites.

4.5.3.1.1 Penetration resistance

Soil resistance to stress or deformation is measured with a penetrometer. The general shape of the penetrometer is of a metal rod (<0.5cm diameter) with a narrow tip. The penetrometer is pushed into the ground and measurement can be either penetration depth per given weight or depth stress depletions which have to be overcome by the penetrating body (Horn & Baumgartl, 2002). The T171 model pocket penetrometer used in this study was made from hard anonized aluminium and consisted of two telescopic cylinders containing a compression spring. The inner spring ends with a tip of 6.35mm diameter that is pushed into the soil sample; when taking a reading the penetration tip of 6.35mm length should be buried completely into the ground. A value of the unconfined compressive strength can be directly read from the instrument, expressed in kg/cm^{-2}, derived from the force required to penetrate the soil (Controls Testing Equipment, Ltd, Hertfordshire, UK. Instruction manual). Penetration resistance was measured at each site and the data were put in table format, Table 4.6. They were presented in graph format in Chapter 6 as Figure 6.1.

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4.5.3.1.2 Infiltration capacity

Soil infiltration rates were measured at all the 21 sites. The infiltrometer measurements indicate the time it takes to infiltrate a given volume of water (eg 15 ml) into the ground. The infiltration rates were recorded at each site and these are presented in graph format and discussed in Chapter 6 (Figure 6.2).

4.5.3.1.3 Bulk density

The bulk density of sampled soil is calculated as follows:

SBD = M/V expressed as g cm^{-3}

where M = oven-dry weight of soil removed from hole (g)

V = volume of hole (cm^3)

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The method of sampling for bulk density measurement involved taking a core sample using a coring cylinder of known volume (in this case 5 cm high x 5 cm diametre. The core is driven into the ground and then dug out, scraped off to level the base and the top of the cylinder. The cylinder is tightly capped at both ends for transporting purposes, taking care not to lose any of the soil in the core. Three samples were taken per site, each from a different location on the site. The method requires that at least three samples per site should be taken and their bulk densities averaged out to produce a mean bulk density (Landon, 1992). This method should be used only with homogenized or structureless sandy soils as no relationship exists between strength and bulk density in aggregated soil (Horn & Baumgartl, 2002). The soil samples were oven dried, weighed and their volumes measured; their masses and volumes were then used to calculate the soil bulk densities for the sites. It was difficult to find relatively undisturbed sample spots to use as controls for comparison with the degraded sample spots: recourse was had to spots protected by relatively impenetrable canopies and fences. The soil bulk density measurements are presented and discussed as Table 6.2 in Chapter 6.

4.5.3.1.4 Soil Loss Estimation

Soil loss estimates were based on measurements of gullies, rills, and pedestals at sample sites using methods described in previous studies (UNUEP, 2002; Dube & Fatunbi, 2007). The measurements taken and the calculations made in order to arrive at the soil loss estimates are explained in the three examples shown in the tables in Appendices B.1, B.2, and B.3. The soil losses are summarized in the table in Appendix C. The data on the different types of soil losses presented in these tables were put into graphs presented in Chapter 6, first separately for gully erosion, rill erosion and sheet erosion (figures 6.3, 6.4, and 6.5) and then as percentages of total loss at each site (Figure 6.7). The actual computations are shown in Appendices B.1, B.2, and B.3. A t-test was conducted on them to see if there were any statistically significant differences between losses in Magwiji and Hinana (Table 6.3).

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4.5.3.1.5 Loss of Grazing Area to Erosion

Apart from soil loss that occurs as a result of gully erosion thre is also loss of grazing area. Locally this can be quite substantial. To estimate the amount of grazing lost to gullies use was made of data already collected as part of gully width measurement. The surface area of the gully at its top was used; lost areas were expressed as percentage of the total area of the catchment area of the gully.

4.5.3.2 Soil Chemical Degradation

Soil samples were collected from the 21 sample sites; the sample at each site comprised ten sub-samples combined into one composite sample. This was done in order to get a sample that was as representative of the whole site as possible. Various chemical tests were carried out on the soil samples to establish the quality of the soils in terms of their chemical attributes. The levels of these attributes in the soil were of relevance in so far as they were indicative of the soil's state of degradation or the soil's predisposition to degradation. Tests were done for soil pH, electrical conductivity (EC), potassium, calcium, magnesium, sodium, phosphorus (available P, total P), and organic carbon.

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The methods used were as follows: soil pH: soil/ water ratio 1: 2.5; electrical conductivity: 1: 2.5 soil/water ratio; organic carbon: Walkely – Black method; exchanges bases: extraction using 1M ammonium acetate (pH 7); available P: Bray – 1. The analytical methods used and the interpretation regarding critical levels of the nutrients for plants are discussed in various sources (Landon, 1992; Brady & Weil, 2002; Soil and Plant Analysis Council, 1992; Tan, 1998; Tan, 1994; Jones, 2001; Mayland, 1989). The results of the tests are summarized in table 6.2 in Chapter 6 where the analysis and interpretation of the results is done.

4.5.3.3 Soil Chemical Degradation and the Land Degradation Index

In order to show a link between soil chemical attributes and levels of land degradation mean levels of the various cation exchange capacities of the sampled soils were calculated. These were grouped into four categories to correspond to the four classes of land degradation in the land degradation index (LDI) as shown in table 4.6. The data (mean values for pH, EC, organic C, K, Na, Ca, Mg, available P, and total P) were put into a Table (6.3) and discussed in Chapter 6.

4.5.4 Vegetation Degradation Assessment

This section deals with vegetation condition assessment at sample site level. It involved choosing representative sites for detailed study which included species identification, grass height, and distances between grass swards. This data were later processed and produced graphs and tables for analysis.

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Table 4.6 Results of chemical tests carried out on soil samples (incorporating land degradation classes) from sites at Magwiji and Hinana villages

Site	Soil pH (water)	Electrical Conductivity (µS/cm)	Potassium (mg/kg)	Calcium (mg/kg)	Magnesium (mg/kg)	Sodium (mg/kg)	Avail P (mg/kg)	Total P (g/kg)	% Organic carbon	LDI	Derdtn Class
1	5.81	76.7	231.32	5349.6	269.88	101.64	2.59	0.91	1.98	15	2
2	5.82	31.3	180.64	2441	327.92	167.88	1.77	0.31	0.68	13.4	1
3	5.81	37.3	228	5612.2	509.68	396.84	2.19	0.83	1.62	16.8	2
4	5.87	39.8	205.08	2593.4	211.76	125.88	3.51	1.36	1.76	12.4	1
5	5.47	69.3	378.16	2504.4	382.48	225.8	3.55	0.9	1.66	21.4	4
6	5.78	23.3	167.96	3940.4	131.44	186.8	3.95	1.09	1.69	10.8	1
7	5.66	32.6	3963.92	1560.7	210.68	465.08	2.88	0.27	0.58	23.6	4
8	5.83	16.72	3264.76	2898.8	234.24	936.92	3.1	0.17	0.59	21.6	4
9	5.61	56	4526.2	7932	464.88	2577.8	3.39	0.28	0.59	23	4
10	5.41	53.7	138.24	3063.9	236.28	84.64	3.91	0.26	0.56	20	3
11	5.28	65.4	326.92	12295	1497.72	2271.1	2.88	0.13	0.61	18	3
12	5.35	68.9	150.6	4660.4	301.2	592.68	2.64	0.22	0.54	17	2
13	5.36	67.3	109.84	4231.6	219.96	260.24	2.55	0.18	0.86	15.6	2
14	5.7	59.3	212.6	10698	576.36	186.92	4.27	0.23	1.27	20.6	4
15	5.5	93.8	153.68	5064.8	299.52	81.88	2.66	0.02	0.68	17.8	3
16	5.79	129	94.92	1658.8	101.52	102.64	2.21	0.06	0.79	17.6	3
17	5.55	62.6	108.72	2364.8	148.32	349	1.93	0.44	0.81	20.6	4
18	5.8	62.8	85.48	985.32	53.32	169.6	1.91	0.02	0.42	21	4
19	4.55	396	102.96	822.76	40.76	96.16	2.09	0.12	0.59	19.8	3
20	5.26	129.7	109.56	1638.5	65.92	86.52	4.79	0.04	0.61	17.2	2
21	5.21	161.8	149.24	4239.8	115.24	147.28	2.86	0.79	1.59	10.8	1

Class 1: non-degraded, 2: moderately degraded; 3: seriously degraded and 4: extremely degraded

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4.5.4.1 Site selection and objectives of study

After a reconnaissance survey of the physical landscape of the catchment for visible signs of land degradation such as loose soil, livestock pathways and soil deposition, rangelands used by two villages were chosen for more detailed field study. These were Magwiji village (30^0 39'S; 27^0 21'E) near the Holohlahatse dam in the southern part of the catchment, and Hinana village (30^0 34'S; 27^0 26'E) in the southeastern upper catchment. The main occupation of the residents of these villages is livestock-rearing in a communal rangelands set-up. The area has been reportedly heavily grazed over an extended period by livestock consisting mainly of cattle, goats and sheep. The survey of the condition of vegetation in the rangelands was carried out to study the effects of livestock grazing on the natural vegetation of the catchment. The objectives were to develop through on-site investigations: an initial vegetation degradation index for each site based on visual assessment, and subsequently a transect data-based vegetation degradation index incorporating details on the dominant vegetation species (especially grasses), basal cover, biomass productivity, and grazing area lost to gully erosion. These would then be used in assessing the extent of vegetation degradation and their relative contribution to total land degradation when compared to the observed landscape scale manifestations of land degradation covered in different sections of Chapter 5. Table 4.7 gives details of the location and other attributes of each of the sites.

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4.5.4.2 Vegetation condition assessment procedure

Data were collected from 10 sites in rangelands around Magwiji village, and 11 sites in rangelands around Hinana village (see Appendix A). The central position of each site was marked by a portable global positioning system (GPS) to enable consistency of location on later visits and remote sensing-related procedures. Sites were inspected for visible signs of vegetation degradation using variables described in a participatory selection process for indicators of rangeland condition (Reed & Dougill, 2002) and used

Table 4.7 Study sites in Sterkspruit catchment: Locational attributes

	Coordinates X	 Y	Aspect	Slope %	Soil texture	Basal (%)	Remarks/land use history
MAGWIJI							
1	30.66219	27.38338	NE	13.33	Loamy sand	38	formerly arable, livestock route
2	30.65972	27.37861	NE	8.889	Sandy loam	50	formerly arable, livestock route, frequently grazed
3	30.65044	27.36853	NE	8.889	sandy silt	28	former homestead site, livestock route
4	30.65033	27.35856	NW	8.889	sandy	64	former homestead site, frequently grazed
5	30.65278	27.35994	NE	8.889	sandy loam	48	formerly arable, frequently grazed
6	30.64569	27.35689	NW	8.889	sandy	58	formerly arable, regularly grazed
7	30.63319	27.35836	NW	17.78	sandy silt	26	livestock route, near homesteads
8	30.63394	27.37611	NE	8.889	sandy loam	10	livestock route passes at top, partly fenced
9	30.62828	27.37002	E	8.889	sandy	24	frequently grazed, partly fenced, near homesteads
10	30.63081	27.36975	NE	17.78	sandy	26	near homesteads, frequently grazed
HINANA							
11	30.58203	27.44347	NW	17.78	sand	21	formerly arable, near homesteads, frequently grazed
12	30.58333	27.44217	NW	17.78	sand	44	formerly arable, near homesteads, frequently grazed
13	30.58408	27.44094	NW	17.78	sandy	34	formerly arable, near homesteads, frequently grazed
14	30.58581	27.44244	NW	17.78	sandy	30	formerly arable, regularly grazed
15	30.58633	27.43869	NW	17.78	sandy	38	formerly arable, regularly grazed
16	30.57211	27.44797	NE	17.78	sandy	56	formerly arable, regularly grazed
17	30.57194	27.44811	NE	17.78	sandy	53	formerly arable, regularly grazed
18	30.56978	27.44753	NE	17.78	sandy	26	formerly arable, regularly grazed
19	30.56806	27.44769	NE	8.889	sandy	46	formerly arable, regularly grazed
20	30.57403	27.45594	SE	8.889	Sandy loam	40	formerly arable, regularly grazed, livestock route
21	30.576	27.46103	NW	13.33	Clayey loam	52	formerly arable, regularly grazed

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in a study by Dube and Fatunbi (2007). The variables used in the assessment included grass cover, abundance of palatable species, plant species richness, and abundance of trees and/or shrubs. A fifth variable, percentage of grazing area lost to gully erosion, was added to the original variables of the participatory approach.

4.5.4.3 Vegetation degradation index (VDI$_v$): visual assessment

The variables used in the assessment included grass cover, abundance of palatable species, plant species richness, grass height, and percentage of grazing area lost to gully. These variables were scored on a scale of 1-5, with 1 indicating the least manifestation of the variable (i.e. highly degraded) and 5 denoting the greatest incidence of the variable. The scores were later used to develop a vegetation degradation index (VDI) using the multidimensional analysis technique reported by Sharma, et al (2007), and Guillin, et al (2007). The approach involves (i) defining the goal of the analysis, (ii) selecting a minimum data set (MDS) of indicators that best characterize the land degradation function, (iii) scoring the MDS indicators on the basis of their importance to the soil degradation function, and (iv), integrating the indicator scores into a comparative index of vegetation degradation. Calculation procedure for the VDIv is shown in Table 4.8. Table 6.3 in Chapter 6 is the VDIv based mainly on visual assessment; it is derived from the calculations in figure 4.13. Figure 6.10 in chapter 6 captures the same vegetation degradation index in graph format.

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Table 4.8 Vegetation degradation index (visual assessment)

Site No.	Grass cover			Abundance of palatable species			Plant species richness			Grass height			Grazing area lost to gully %			VDIv	Vegetation Degradation Class
	5			4			3			4			3				(1-4)
1	4	1	4	3	0.6	2	3	1	2	3	1	2	3	1	2	2.7	1
2	4	1	4	3	0.6	2	3	1	2	3	1	2	4	1	2	2.7	1
3	3	1	3	3	0.6	2	3	1	2	2	0	2	2	0	1	2.2	2
4	4	1	4	3	0.6	2	3	1	2	3	1	2	4	1	2	2.7	1
5	3	1	3	3	0.6	2	2	0	1	3	1	2	4	1	2	2.3	2
6	4	1	4	2	0.4	2	2	0	1	3	1	2	2	0	1	2.3	2
7	2	0	2	2	0.4	2	2	0	1	2	0	2	1	0	1	1.6	4
8	3	1	3	3	0.6	2	2	0	1	2	0	2	4	1	2	2.1	3
9	3	1	3	2	0.4	2	2	0	1	2	0	2	4	1	2	1.9	3
10	3	1	3	2	0.4	2	2	0	1	2	0	2	4	1	2	1.9	3
11	3	1	3	2	0.4	2	2	0	1	3	1	2	2	0	1	2.1	3
12	3	1	3	2	0.4	2	2	0	1	4	1	3	4	1	2	2.3	3
13	3	1	3	2	0.4	2	2	0	1	4	1	3	2	0	1	2.3	2
14	2	0	2	2	0.4	2	2	0	1	5	1	4	4	1	2	2.2	2
15	3	1	3	2	0.4	2	2	0	1	4	1	3	1	0	1	2.3	2
16	2	0	2	3	0.6	2	3	1	2	3	1	2	4	1	2	2.2	2
17	2	0	2	2	0.4	2	3	1	2	3	1	2	1	0	1	2	2
18	2	0	2	2	0.4	2	2	0	1	2	0	2	1	0	1	1.6	4
19	2	0	2	1	0.2	1	2	0	1	2	0	2	4	1	2	1.4	4
20	3	1	3	2	0.4	2	3	1	2	4	1	3	1	0	1	2.4	1
21	4	1	4	4	0.8	3	3	1	2	3	1	2	1	0	1	2.9	1

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4.5.4.4 Vegetation analysis data gathering by transect sampling

Adopting a technique described in Beckerling, et al (1995) a sample site measuring 50m x 100m was selected at each degraded study site. At each site vegetation condition assessment was carried out along two parallel 100m line transects set 25m apart along the 100m length of the site using the step point method. Walking along the 100m tape, a point is marked with a sharp rod (or front of shoe) every two steps on the two transects (two rows of fifty points). The distance from point to base or root of a living plant is measured in centimeters and the plant species is recorded. These data were later used to calculate the basal cover and percentage frequency of the various species compositions for each site.

The height of a standing crop of grass in the rangeland was estimated by means of a disc pasture meter. The device was originally developed by Bransby & Tainton (1977) and later calibrated by Trollope (1984) for use in the Eastern Cape Province of South Africa. It measures the settling height of an aluminum disc on the standing grass holding it above ground (Trollope, 1992). Data were collected on the disc height of each grass tuft along a transect and later used for calculation of biomass productivity for each site.

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4.5.4.4.1 Vegetation degradation index (VDI_t): transect-based measurements

Data were collected from 10 sites in rangelands around Magwiji village, and 11 sites in rangelands around Hinana village. Details of the locations of the vegetation sample sites in Magwiji and Hinana villages in the Sterkspruit catchment are listed in Appendix A.

The variables used in the assessment included basal cover, percentage of increaser II SPP, plant species richness, grass biomass productivity, and percentage of grazing area lost to gully. The variables were scored on a scale of 1-5, with 1 indicating the least manifestation of the variable (i.e, highly degraded) and 5 denoting the greatest incidence of the variable. The scores were later used to develop a vegetation degradation index (VDI_t) using the multidimensional analysis technique reported by Sharma, et al (2007), and Guillin, et al (2007). The approach involves (i) defining the goal of the analysis, (ii) selecting a minimum data set (MDS) of indicators that best characterize the land degradation function, (iii) scoring the MDS indicators on the basis of their importance to the soil degradation function, and (iv), integrating the indicator scores into a comparative index of land degradation. The computation of the figures for the degradation index is illustrated in table 4.9. The analysis and interpretation of the index is done in Chapter 6 with the help of table 6.4 and the graph in figure 6.11.

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4.5.4.4.2 Vegetation condition data processing

This section looks at the field data gathered in connection with vegetation transect sampling. It describes the preparation of the data and its packaging into formats that lend themselves to analysis. The issues examined in this section include basal cover, grass biomass productivity, grass species dominance, and woody species prevalence at sites.

Table 4.9 Vegetation degradation index computations based on transect data (VDIt)

	Basal cover (cm)			Increaser II species %			Invasives (karoo) %			Grass biomass Kg.ha-1			Grazing area lost to gully %			Plant species richness (number)			VDIt
	5			4			3			4			3			3			
1	3	0.6	3	5	1	4	1	0.2	0.6	3	0.6	2.4	2	0.4	1.2	5	1	3	2.37
2	4	0.8	4	5	1	4	1	0.2	0.6	3	0.6	2.4	1	0.2	0.6	5	1	3	2.27
3	2	0.4	2	3	0.6	2.4	3	0.6	1.8	2	0.4	1.6	3	0.6	1.8	4	0.8	2.4	2.33
4	5	1	5	5	1	4	1	0.2	0.6	3	0.6	2.4	1	0.2	0.6	5	1	3	2.1
5	4	0.8	4	5	1	4	1	0.2	0.6	3	0.6	2.4	1	0.2	0.6	3	0.6	1.8	2.4
6	2	0.4	2	3	0.6	2.4	3	0.6	1.8	3	0.6	2.4	3	0.6	1.8	1	0.2	0.6	2.17
7	1	0.2	1	2	0.4	1.6	3	0.6	1.8	2	0.4	1.6	4	0.8	2.4	4	0.8	2.4	1.97
8	1	0.2	1	2	0.4	1.6	4	0.8	2.4	2	0.4	1.6	1	0.2	0.6	2	0.4	1.2	1.4
9	1	0.2	1	4	0.8	3.2	2	0.4	1.2	2	0.4	1.6	1	0.2	0.6	2	0.4	1.2	1.47
10	1	0.2	1	1	0.2	0.8	5	1	3	2	0.4	1.6	1	0.2	0.6	2	0.4	1.2	1.37
11	2	0.4	2	4	0.8	3.2	2	0.4	1.2	3	0.6	2.4	3	0.6	1.8	3	0.6	1.8	1.9
12	4	0.8	4	5	1	4	1	0.2	0.6	4	0.8	3.2	1	0.2	0.6	2	0.4	1.2	1.93
13	4	0.8	4	4	0.8	3.2	2	0.4	1.2	4	0.8	3.2	3	0.6	1.8	4	0.8	2.4	2.63
14	2	0.4	2	4	0.8	3.2	2	0.4	1.2	5	1	4	1	0.2	0.6	2	0.6	1.8	2.47
15	3	0.6	3	5	1	4	1	0.2	0.6	4	0.8	3.2	5	1	3	3	0.6	1.8	2.43
16	5	1	5	5	1	4	1	0.2	0.6	3	0.6	2.4	1	0.2	0.6	4	0.8	2.4	2.17
17	4	0.8	4	5	1	4	1	0.2	0.6	3	0.6	2.4	5	1	3	3	0.6	1.8	2.8
18	3	0.6	3	5	1	4	1	0.2	0.6	2	0.4	1.6	4	0.8	2.4	3	0.6	1.8	2.4
19	3	0.6	3	4	0.8	3.2	2	0.4	1.2	2	0.4	1.6	1	0.2	0.6	2	0.4	1.2	1.8
20	3	0.6	3	5	1	4	1	0.2	0.6	4	0.8	3.2	4	0.8	2.4	1	0.2	0.6	2.3
21	4	0.8	4	5	1	4	1	0.2	0.6	4	0.8	3.2	4	0.8	2.4	2	0.4	1.2	2.4

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4.5.4.4.2.1 Basal cover

Basal cover status for each site was obtained by adding up all the 100 point-to-plant distances and dividing by 100 to obtain the mean distance. The mean point-to-plant distance for each site is related to the type of basal cover on a scale of 0 - 6+ cm, with less than 3 cm being high basal cover, 3 – 6 cm moderate-to-low basal cover, and greater than 6 cm very low basal cover (Beckerling, *et al*, 1995). Alternatively, use can be made of the data collected during the step-point procedure for recording the presence or absence of herbaceous plants along the transect. Each hit at the base of the plant was recorded as a strike and hits between plants were recorded as bare ground or rock as the case may be. The number of strikes was expressed as a percentage of the total number of hits and was then used as percentage basal cover. This procedure is described in a study by Lesoli (2008). Use of percentage basal cover eliminates areas of overlap between classes of basal cover. A composite table in chapter 6 (table 6.5) shows the basal cover, ecological status of vegetation in response to grazing, and grass biomass productivity at each of the 21 sites. Figure 6.12 illustrates the basal cover and point-to-plant distances for each of the 21 study sites in Sterkspruit catchment.

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4.5.4.4.2.2 Biomass productivity

The mean grass height for each site was based on the average disc height. Calculation for biomass productivity was based on Trollope's (1984) calibration relating the mean disc height of 100 readings to biomass productivity in kg/ha. The figures for the biomass productivity of the 21 study sites are captured in the composite table also showing basal cover, and ecological status with response to grazing pressure (table 6.5).

4.5.4.4.2.3 Grass species composition and dominance

Using data from the vegetation condition assessment field procedures plant species identified in the field were classified according to the relevant terminology into decreasers, increasers, and invaders; they were put into tables and/or graphs for analysis. The classification used in this study was taken from Trollope, *et al* (1990: 60). Forage factors were taken from Trollope (1986). Table 6.6 represents grass species identified according to ecological status with response to grazing, percentage composition, and life cycle characteristics. Table 6.10 shows grass species identified at each site, species grazing value, number of sites where identified, and species average on all sites (dominance).

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4.5.4.4.2.4 Woody species at study sites

Apart from the transect measurements, a visual and physical inspection of the sites was done in order to identify their woody species composition. These were listed and an estimate made of percentage coverage of the site.

Bush/tree cover assessment at each site included the following: estimation of percentage bush cover of the total area of the site, identification of the species on the site, an estimation of the average height of each species, and percentage species composition. Table 6.11 in chapter 6 summarizes the woody species identified at the different sites.

4.5.4.4.2.5 Rangeland condition

Rangeland condition in Magwiji and Hinana rangelands is further categorized according to grass species response to grazing, Figure 6.13. This involved classifying each site into categories of overgrazing or undergrazing (%) as represented by the percentage of grasses at each site that represented the particular grazing status.

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CHAPTER FIVE

5 PRESENTATION AND ANALYSIS OF RESULTS: LANDSCAPE SCALE ANALYSIS

This chapter examines the extent of land degradation at the landscape scale, the factors contributing to degradation and the consequences of land degradation at that scale. The data acquisition and processing are reported in Chapter 4.

5.1 Land degradation assessment at landscape scale

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This section deals with the assessment of land degradation at the landscape scale using the remote sensing approach

5.1.1 Land Cover Changes, 2000-2007

The satellite image processing and classification described in Chapter 4 produced the maps in figure 5.1 and 5.2. As can be seen in the map figure 5.1, representing conditions in September 2000, dense vegetation is represented mostly by elongated strips of dark green colour along rivers and in a number of other locations on mountain slopes (Figure 3.2). This land cover class constitutes only 2.45% of the catchment (table 5.1). Grassland, shown in pale green, constitutes the biggest class at 77.06%. Bare ground, shown in brown, makes up 20.04% and water, shown in blue, makes up 0.45%.

Figure 5.2 represents land cover categories in February 2007. Dense vegetation increased to 4.14% from 2000 (table 5.1). Grassland decreased to 51.94% from 2000. Bare ground had increased to 43.74%, and water decreased to 0.18%.

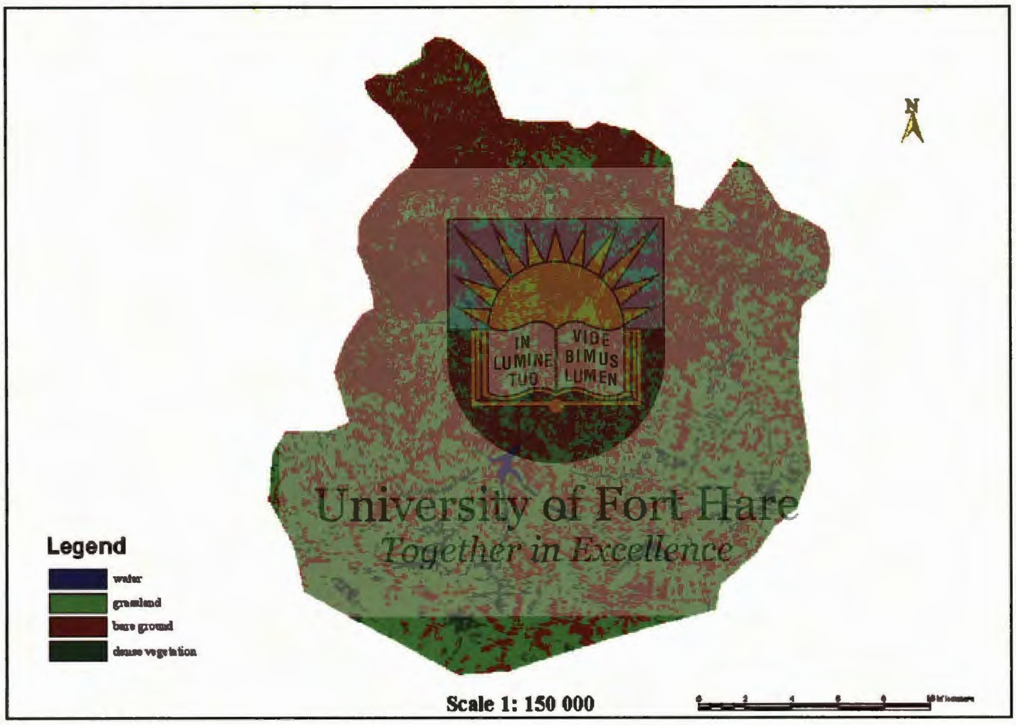

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Figure 5.1 Land cover pattern in Sterkspruit catchment (2000)

To put these differences into context rainfall figures for Lady Gray can be used to explain the setting for the land cover changes (see figure 5.8b). The study area had

Table 5.1 Distribution of land cover types by percentage in Sterkspruit catchment (2000)

Type of cover	**% Cover**
Dense vegetation	2.45
Grassland	77.06
Bare ground	20.04
Water	0.45

fairly heavy rains in the years 2000, 2001, 2002, 2004, and 2006; it had below average rainfall in 2003, 2005, and 2007. What these figures show is that woody species were not as badly affected by drought or by grazing pressure. Between 2000 and 2007 they had increased from 2.45% to 4.14%. Much of the increase was due to bush encroachment on grassland; this was verified by detailed examination of the vegetation to the south east and east of the dam during transect walks. The decline in percentage bare ground between 2000 and 2007 can be explained by the fact that the spring rains of 2000 had revived the grass ahead of the satellite image's capture. The cover was quite good at 77.04%. Though the image for 2007 was captured during the rain season, this was one of the drought years. The grassland which had been denuded by grazing pressure in the dry season had not been able to recover. Instead, grazing pressure had continued, making larger areas of the land bare. This explains why bare ground

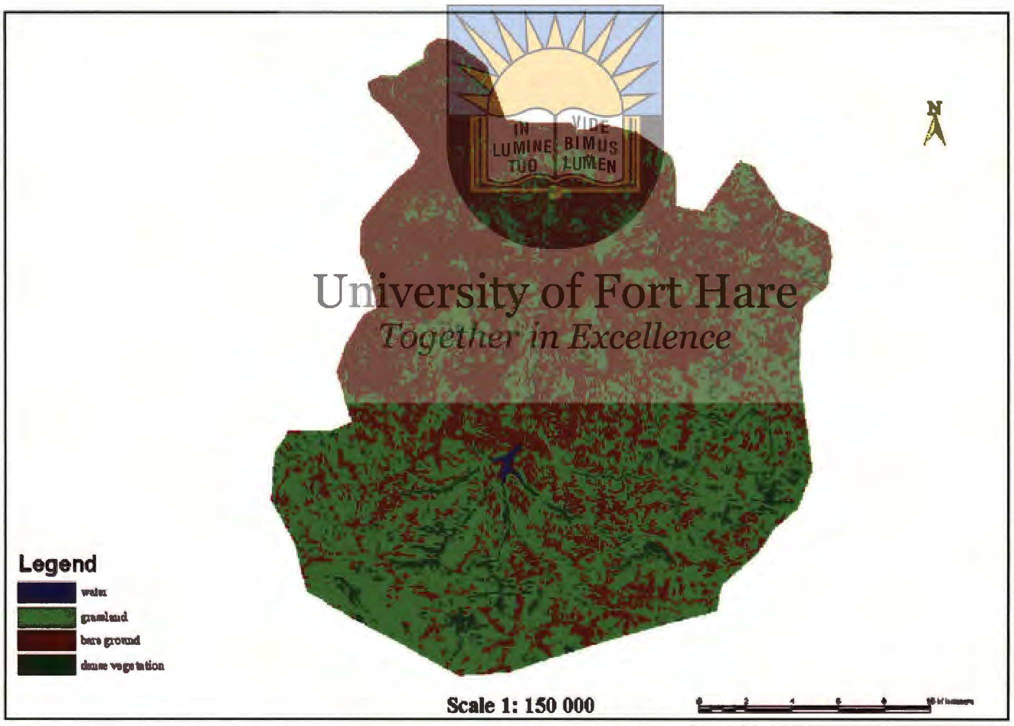

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Figure 5.2 Land cover pattern in Sterkspruit catchment (2007)

Table 5.2 Distribution of land cover types in Sterkspruit catchment by percentage (2007)

Land cover type	% Cover
Dense vegetation	4.14
Grassland	51.94
Bare ground	43.74
Water	0.18

increased more than two-fold from 20.04% in 2000 to 43.74% in 2007. The reduction in the percentage of water from 0.45% in 2000 to 0.18% in 2007 also confirms the reduction in surface water coverage in drought.

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5.1.2 Cover Change Dynamics

Vegetation cover in Sterkspruit catchment fluctuates in response to rainfall patterns. Scrub forest and invasive fynbos are perennial in nature and have longer roots than the grasses; they do not succumb to moisture stress over short-duration droughts. They are found on wetter south facing slopes and along rivers. Grasses tend to respond to seasonal and annual moisture fluctuations more directly than do trees. Because of the heavy grazing in the area if the rains are poor in a particular year the grass does not grow vigorously. In a good season it will recover. What appears as bare ground from satellite images is in most cases grassland with grass grazed close to the ground during the dry season or in times of drought. The apparently dead grass suddenly comes back to life when the rains come. Several visits to the area in 2008 and 2009 confirmed this. The field visits bore testimony to the transformation of the bare ground into grassland with a fairly good basal cover. Figure 5.3 shows the state of a mountain rangeland in the dry season. The rangeland is located on the mountain immediately above the

Figure 5.3 Mountain grassland condition in the dry season (just east of the Holohlahatse dam)

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Holohlahatse dam, on its eastern side. The short grass recovers with the return of the rains. The trampling of the ground softens the soil making it receptive to seeding during the spring rain, thereby promoting rapid recovery of the grassland.

5.1.3 Landscape Geometrical Aspects

The Sterkspruit catchment can be divided into two relief types: the highly dissected highlands and the low-lying areas with isolated hilly areas. Livestock movement in the low-lying areas is not generally physically restricted. Although there are assigned grazing camps for each village going back to the days of the betterment programme in the early 1960s, enforcing adherence to these artificial boundaries is difficult. This is especially so in the absence of the fences which were long removed or vandalized. As a consequence of this apparent lack of control of livestock movement the rangelands in the lowlands tend to be denuded of grass during the dry season or during droughts. This is apparent from an examination of the maps in Figures 5.1 and 5.2.

The highland areas are generally dissected by steep sided valleys which provide natural physical barriers to livestock movement across the rims of these valleys. This makes it relatively easy for villagers to restrict use of grazing camps to livestock of residents of their villages. As a result rangelands in the mountainous areas do not get to be denuded of grass cover as much as those in the low-lying areas. This can be seen from the two maps (Figures 5.1 and 5.2).

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5.2 Landscape Biophysical Setting

The landscape scale analysis of land degradation involved analysis of catchment scale data on climate, soils, surface water resources, land cover / land use changes, and socio-economic factors.

5.2.1 Climate

The climate of Sterkspruit catchment plays an important role in providing the environmental setting in which land degradation processes can be analysed. The role played by rainfall and temperature are examined in this section.

5.2.1.1 Temperatures

Historical or current temperature records were not available for the area at the time of the study. However, mean temperature figures for various periods were given by several sources as outlined in Chapter 4. These were used to compile the graphs in figures 5.4, 5.5 and 5.6

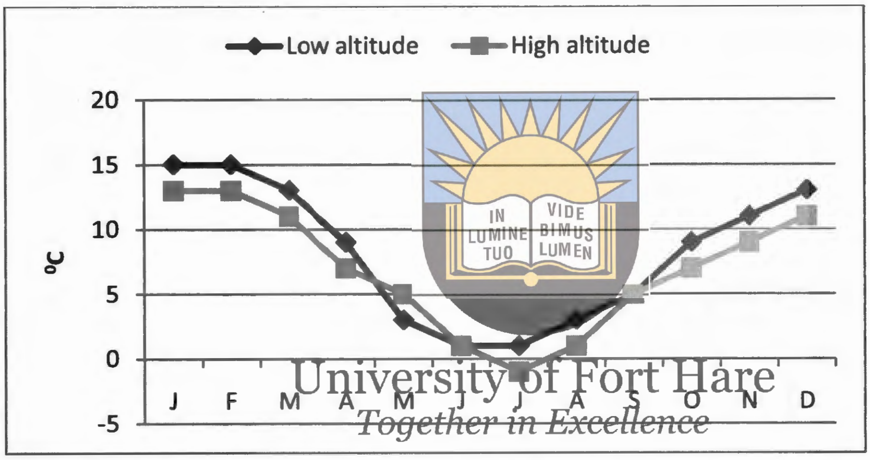

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Figure 5.4 Mean monthly minimum temperatures in Sterkspruit catchment

Such low temperatures may help to explain why the area's natural vegetation is Afro - montane grassland. Cultivated plants with little or no freezing tolerance such as maize, cucurbits, and beans will experience some frost damage since they cannot survive external temperature lower than -1 to -3 (Hale & Arcutt, 1987). Those crops with some limited tolerance (hardiness) can withstand some ice formation, for example, spring wheat, peas, potatoes, and cabbage. Trees generally appear in the form of scrub forest on slopes and along rivers, and as invasive fynbos in wooded grasslands.

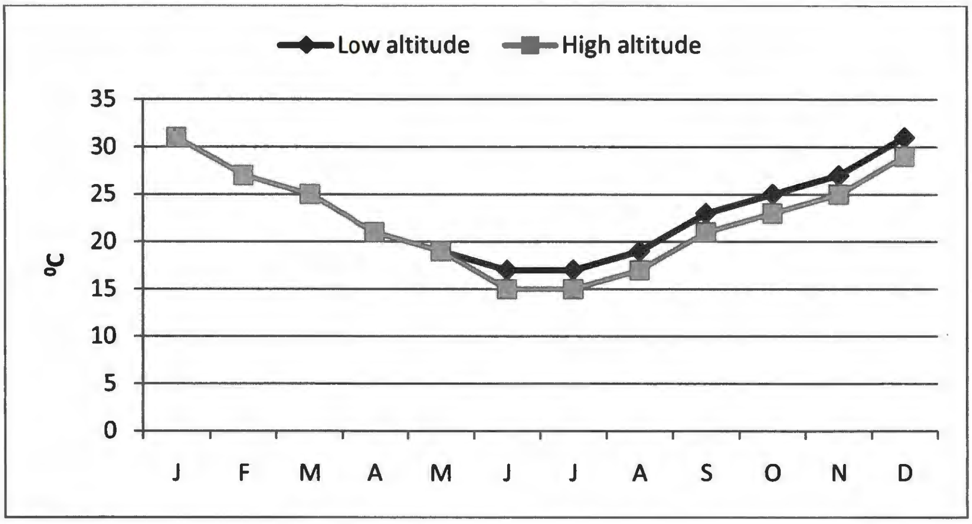

Figure 5.5 Mean monthly maximum temperatures for Sterkspruit catchment

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Schulze (1997) also provides other useful statistics on the climate of the study area. Mean annual temperature is 14-16°C. The average first date of heavy frost occurs between May 1 and May 15, while the average last date of heavy frost in the low areas falls in September, and in the mountains it falls in October. The average duration of frost is 121-150 days in the lower areas and 150-180 days in the mountain areas. The average number of days with heavy frost is 31-60 in the low areas and 61-90 days in the mountains. The standard deviation of number of days with frost falls in the range 10-15. While the winter temperatures for the area are quite low the summer temperatures are relatively high, especially for the months of December, January and February. A previous study recorded the mean daily maximum temperature for January as 29.9^{0}C and the mean daily minimum temperature for July as around -1.5^{0}C, a difference of 31.4^{0}C (Els, 1971). Moreover, according to Els (1971) the January temperature for the area may reach an extreme of 36.7^{0}C while July temperature has been known to reach a high of 23.5^{0}C. This is of significance with respect to evapotranspiration rates and

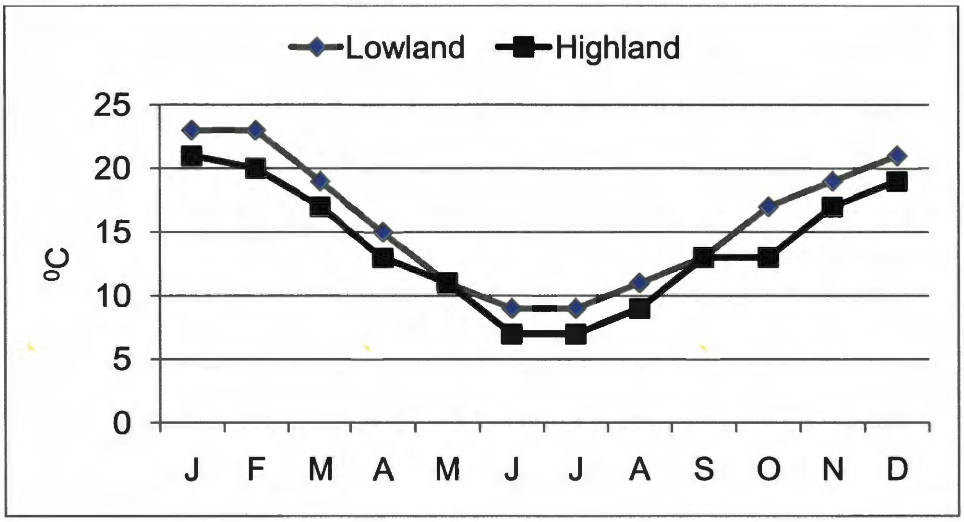

Figure 5.6 Mean monthly temperatures for Sterkspruit catchment

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plant growth. Mean annual evaporation for the area according to one study is 1500-1600 mm (Midgley, et al, 1990). This can result in moisture stress for cultivated crops in years when the rains are erratic and may lead to crop failure. Indeed, local farmers have reported the occurrence of many mid-season dry spells during the rain season. When this is considered in conjunction with the problem of stray livestock invading unfenced cultivated fields, crop farming in the area is fraught with risks and many farmers just gave up.

5.2.1.2 Rainfall variability

Mean annual rainfall for Sterkspruit TNK for the period 1940-1998 was calculated at 688.38 mm, with a standard deviation of 192.71 mm. In the period 1959-1974 Sterkspruit station had a mean annual rainfall of 642.68 mm, with a standard deviation of 133.46 mm. Bensonvale had a mean annual rainfall of 630.125 mm, with a standard deviation of 189.68 mm in the period 1940-1993. The proxy stations show a similar pattern: Herschel (mean 638.20 mm, sd 159.64 mm), Helvellyn (mean 948.76 mm, sd 296.66 mm) and Lady Grey (643.93 mm, sd 207.78 mm). Table 5.3 summarizes the rainfall patterns for the various stations. To compare the relative variability in the data from the different recording stations a coefficient of variation (CV) was computed for each station (Table 5.3). The CVs are as follows: Herschel 25%, Sterkspruit 20.8%, Helvellyn 31%, Bensonvale 30.1%, Sterkspruit TNK 27.9% and Lady Grey 32.3%. The generally high CVs clearly illustrate the relatively large fluctuations in rainfall amounts from year to year at all the stations in the region.

Table 5.3 Mean annual rainfall and rainfall variability in Sterkspruit catchment and environs. (Source: Computed from official records of the South African Weather Service)

Station	Period	Annual Mean(mm)	Std Deviation (mm)	Coefficient of Variation (%)
Sterkspruit TNK	1940-1998	688.38	192.71	27.90
Sterkspruit	1959-1974	642.68	133.46	20.80
Bensonvale	1940-1993	630.12	189.68	30.10
Herschel	1900-1951	638.20	159.64	25.00
Helvellyn	1959-2007	948.76	296.66	31.00
Lady Grey	1950-2006	643.93	207.78	32.30

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Table 5.4 shows the pattern of rainfall variability at recording stations in the study area in terms of aridity or humidity of the climate. It is worth noting that the three stations located within the Sterkspruit catchment recorded rainfall amounts which fell into the sub-humid categories for the majority of the years of record: SterkspruitTNK (39 out of 59 years), Bensonvale (40 out of 52 years), and Sterkspruit (14 out of 16 years). With the exception of Helvellyn (16 out of 49 years) the other stations in the region show a similar pattern: Lady Grey (42 out of 58 years), and Hershel (40 out of 52 years). This points to a pattern of rainfall variability, and particularly, a tendency for annual rains to be between 400mm and 800mm.

Table 5.4 Long-term rainfall variability at recording stations in Sterkspruit catchment and environs. (Source: Computed from official records of the South African Weather Service).

			Climatic distribution					
Station	Length of record		Super humid	Humid	Moist sub-humid	Dry sub-humid	Semi arid	Arid
		rainfall in mm	1000+	800-1000	600-800	400-600	200-400	0-200
	Years		Years	Years	Years	Years	Years	Years
SterkspruitTNK	59		4	14	18	21	2	0
Bensonvale	52		4	4	20	20	4	0
Sterkspruit	16		0	2	7	7	0	0
Helvellyn	49		19	13	13	3	1	0
Lady Grey	58		4		20	22	3	1
Herschel	52		1	7	25	15	4	0

Source: Table format adapted from Thornthwaite, 1941 (cited in Swindale & Bidinger, 1981)

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Sterkspruit has been described as drought-prone by several residents and agricultural extension workers. If drought is defined in the meteorological sense of annual rainfall below the mean for the area for the period of record (Glantz, 1994), then numerous droughts have occurred in the area. The graphs in Figures 5.7-5.12 (based on records provided by South African Weather Services) show the rainfall patterns with a wavy 3-year running average and a linear trend-line for each recording station. The three-year average line shows how erratic the rainfall pattern was and the trend line shows the long-term overall trend despite the inter-annual fluctuations in rainfall amounts. The term 'rainfall variability' on the graphs refers to differences between the annual amount and the mean annual amount of rainfall for the area. Sterkspruit TNK experienced 31 years of below average rainfall in the period 1940-1998

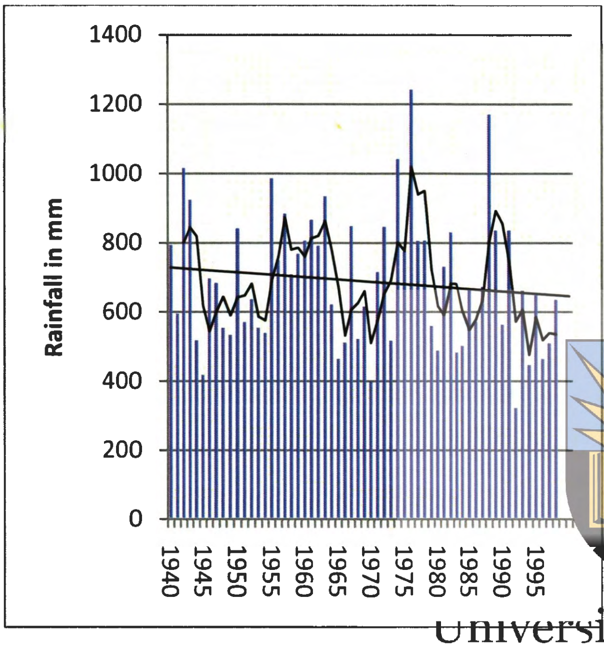

Figure 5.7a Mean annual rainfall at SterkspruitTNK: 1940-1998

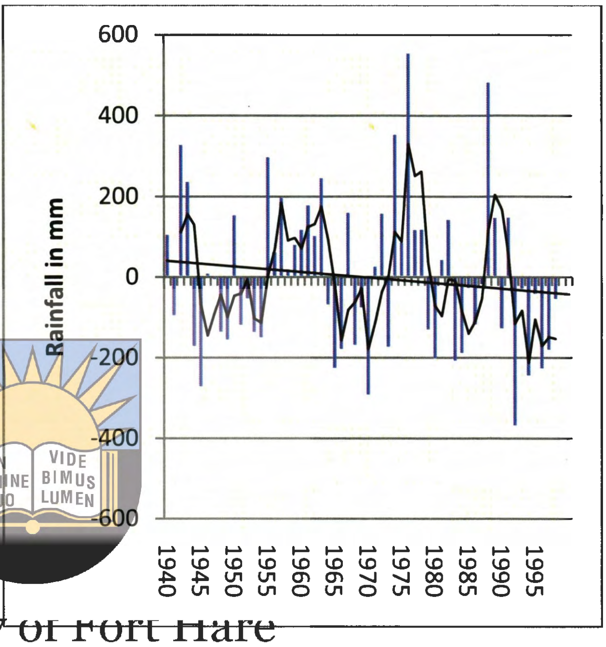

Figure 5.7b Rainfall variability for Sterkspruit TNK: 1940-1998

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(figure 5.7b), Sterkspruit, seven years in the period 1959-1974 (5.8b) Herschel, 22 years between 1900 and 1951 (5.9b), Bensonvale, 29 years between 1940 and 1992 (5.10b), Lady Grey, 28 years in the period 1950-2007 (5.11b) and Helvellyn, 26 years in the period 1959-2007 (5.12b). Some of the droughts lasted for several years at a time; for example as shown on the graphs for Bensonvale between the years 1980-1985, Sterkspruit TNK, 1992-1997, and Lady Grey from 2003 to 2007. Such droughts have devastating effects on vegetation (including crops) and livestock.

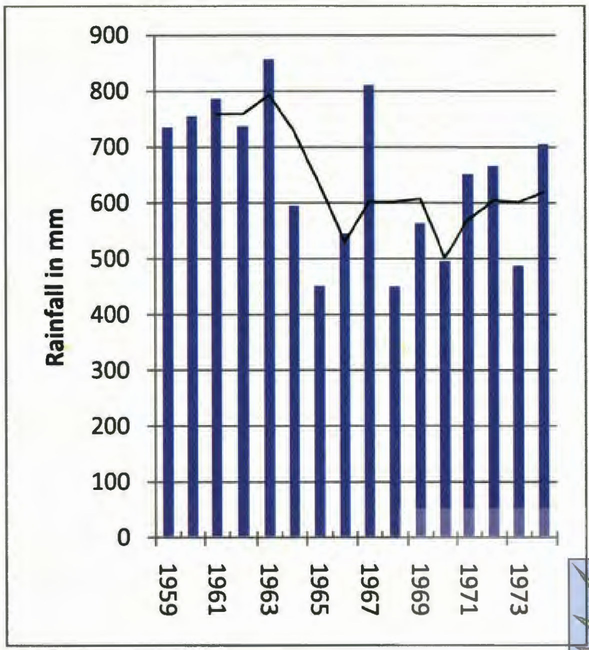

Figure 5.8a Mean annual rainfall at Sterkspruit, 1959-1974

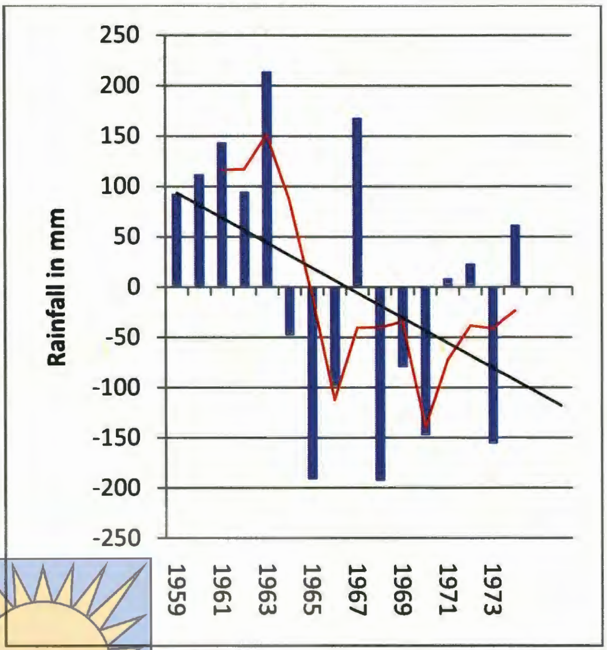

Figure 5.8b Annual rainfall variability, Sterkspruit: 1959-1974

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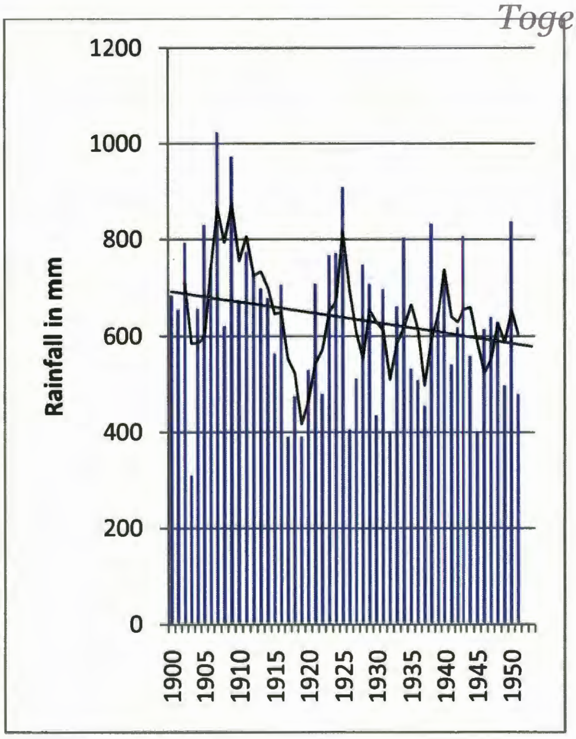

Figure 5.9a Mean annual rainfall at Herschel, 1900-1951

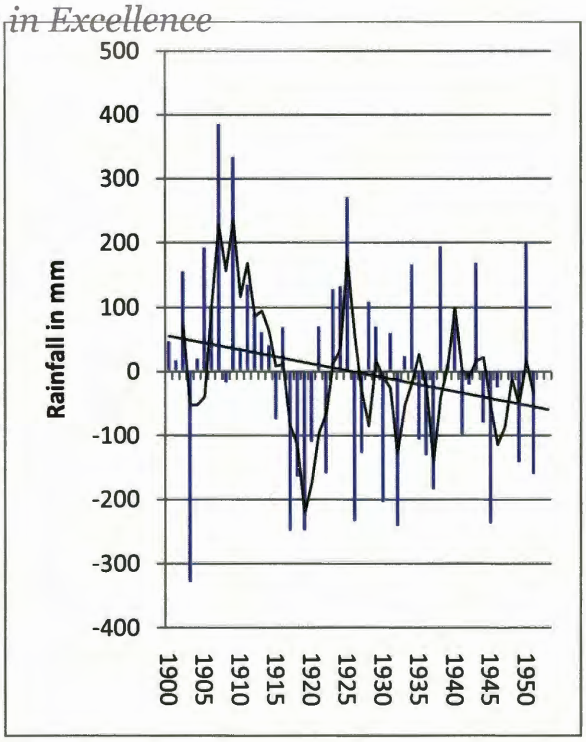

Figure 5.9b Rainfall variability Herschel: 1900-1951

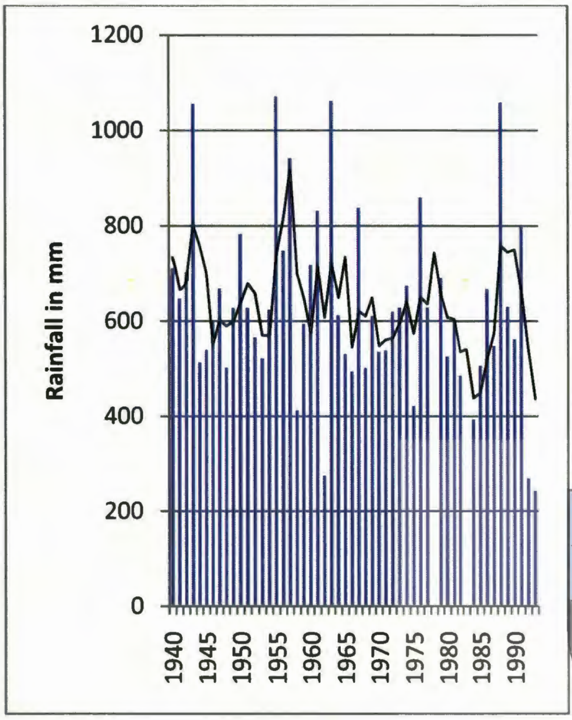

Figure 5.10a Mean annual rainfall at Bensonvale, 1940-1993

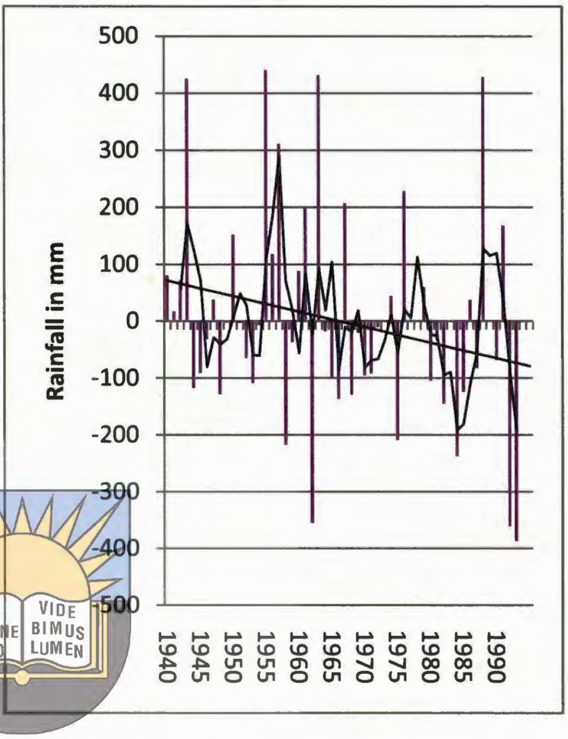

Figure 5.10b Rainfall variability at Bensonvale, 1940-1993

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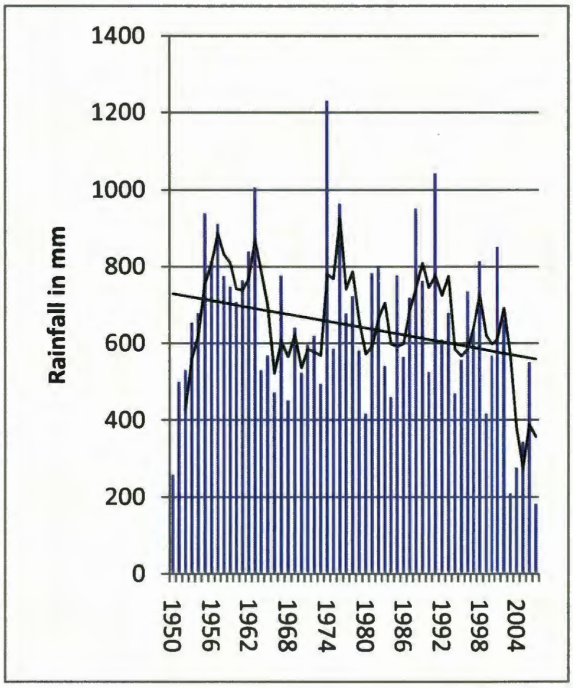

Figure 5.11a Mean annual rainfall, Lady Grey: 1950-2006

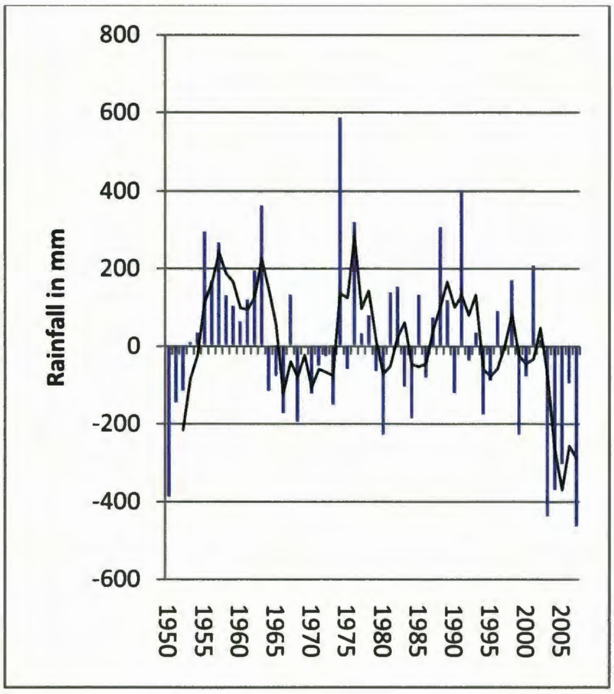

Figure 5.11b Rainfall variability, Lady Grey: 1950-2006

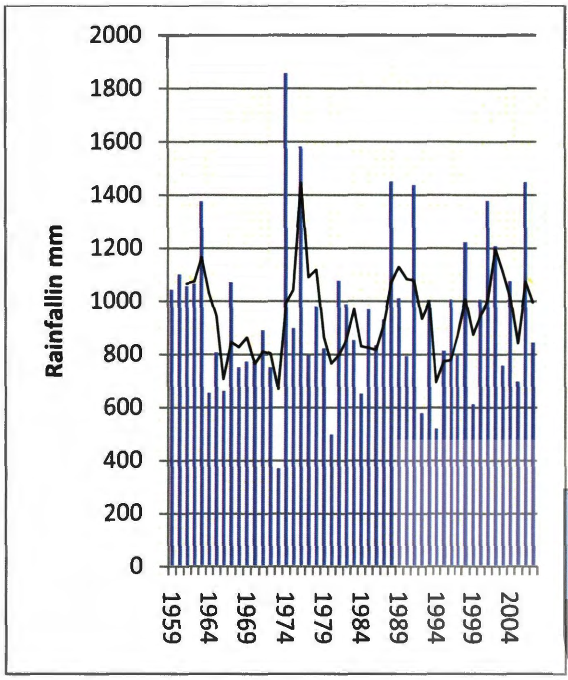

Figure 5.12a Mean annual rainfall at Helvellyn: 1959-2007

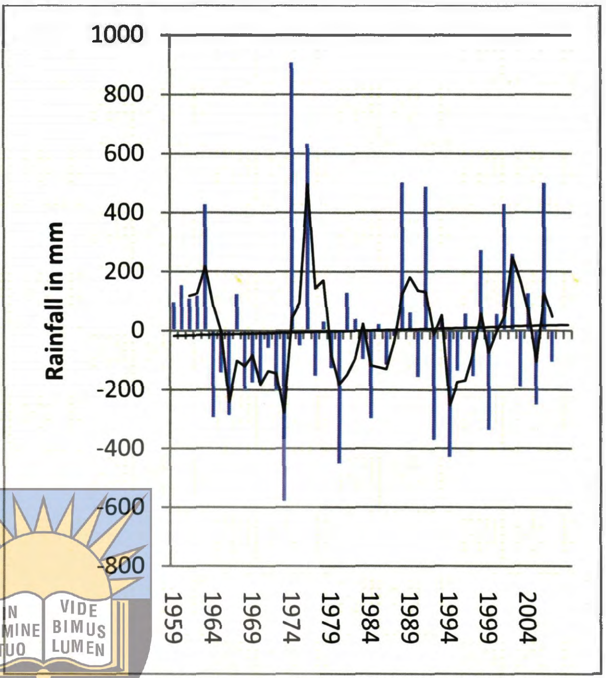

Figure 5.12b Rainfall variability in Helvellyn, 1959-2007

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Figures 5.13-5.18 are graphs illustrating percentage deviations from mean annual rainfall for the various stations, with three-year running mean deviations and linear trends over the entire period of record. For Sterkspruit TNK (figure 5.17) deviations were up to 69% of normal, while at Bensonvale (figure 5.16) they went up to 100% of normal. For Helvellyn (figure 5.15) and Lady Grey (figure 5.13) the deviations from the mean rainfall amounts were 87% and 83%, respectively. A linear trend line drawn on each of the graphs indicates a general trend in rainfall amounts over the years. With the exception of Helvellyn, all the station trends indicate a net decline in rainfall amounts over time. For Herschel the net rainfall trend fell below the long-term average in 1930 and continued to steadily decline up to the end of the period of record; for Sterkspruit

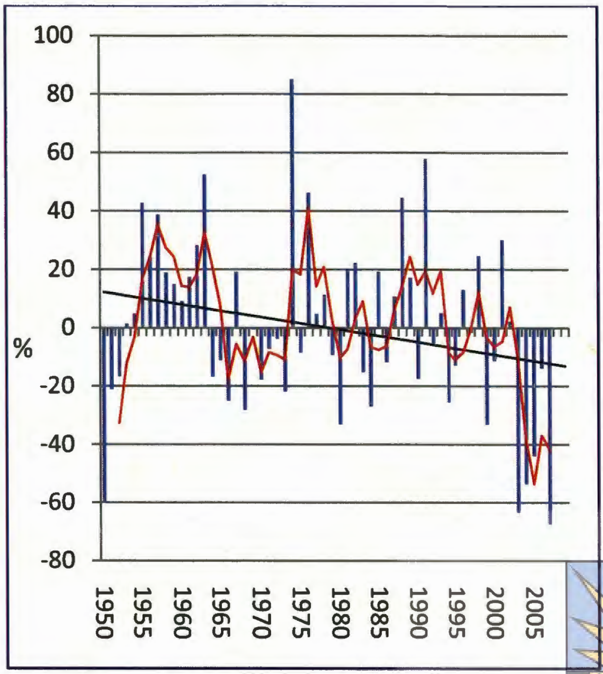

Figure 5.13 Deviations from mean annual rainfall at Lady Grey, 1950-2007

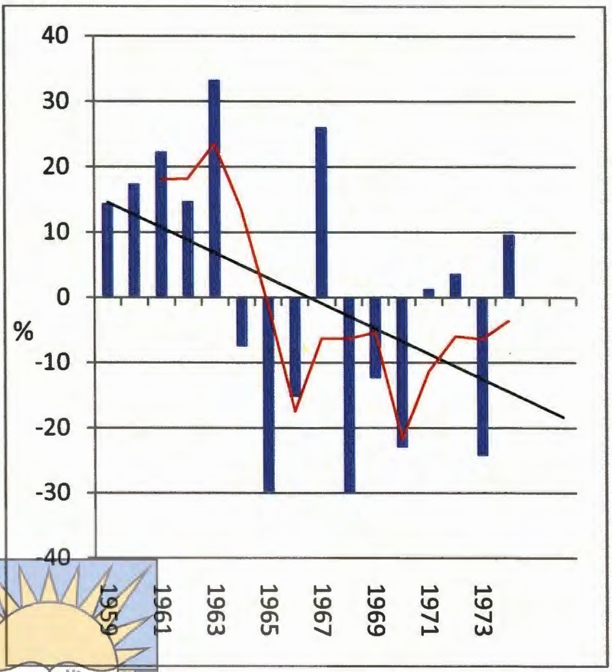

Figure 5.14 Deviations from mean annual rainfall, Sterkspruit: 1959-1974.

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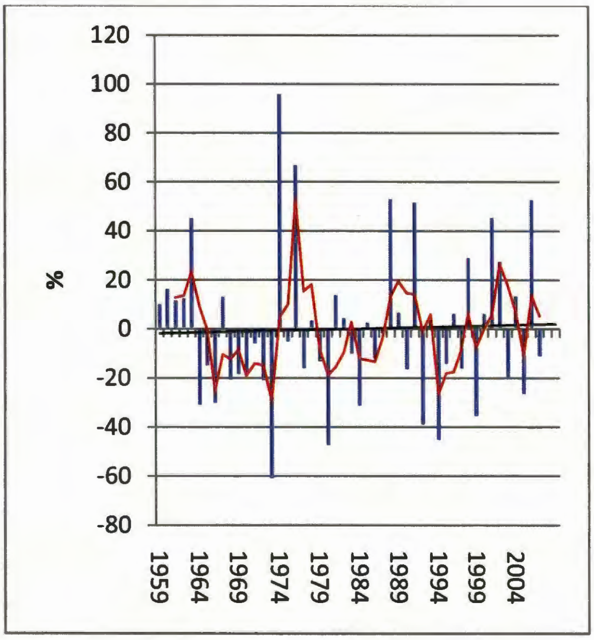

Figure 5.15 Deviations from mean annual rainfall, Helvellyn: 1959-2007

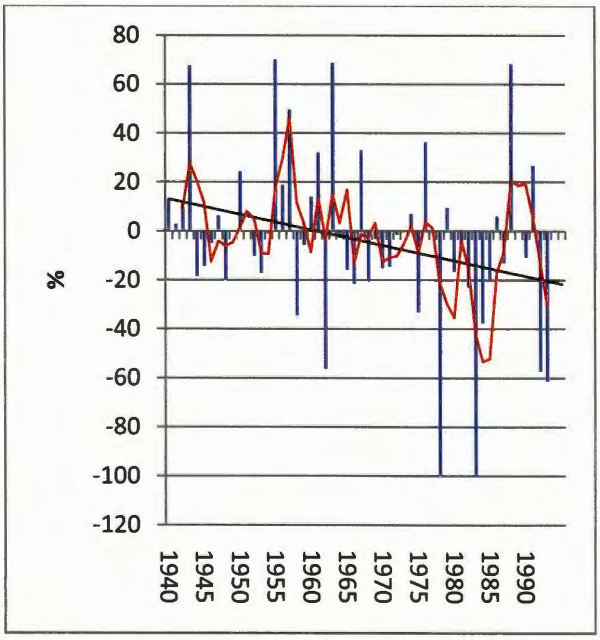

Figure 5.16 Deviations from mean annual rainfall, Bensonvale: 1940-1993

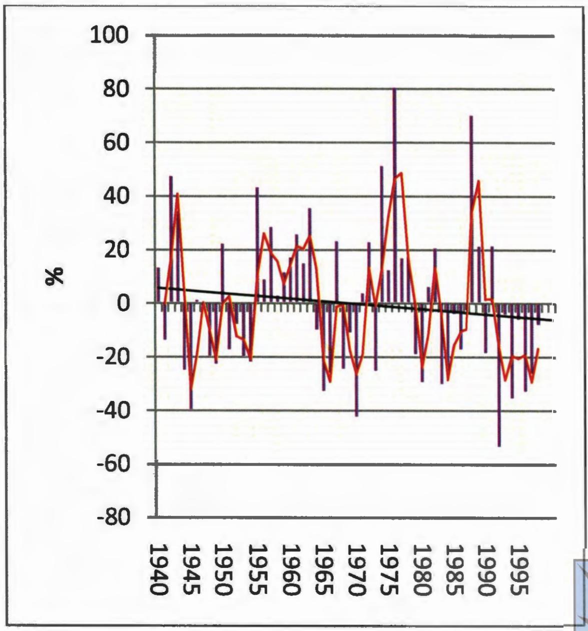

Figure 5.17 Deviations from mean annual rainfall, SterkspruitTNK: 1940-1998

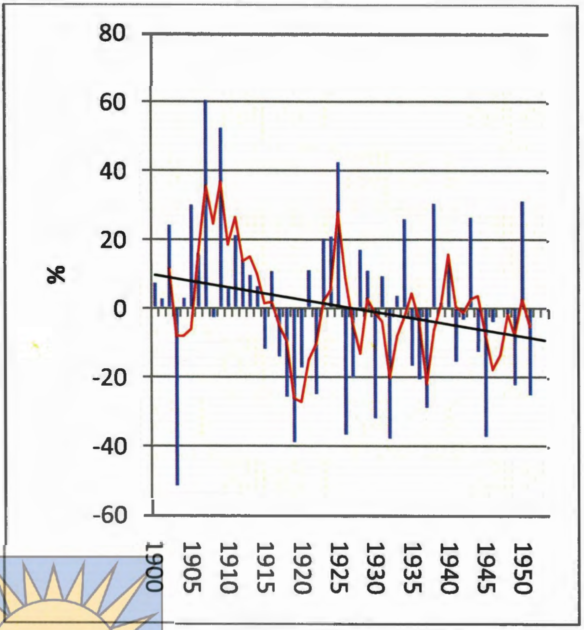

Figure 5.18 Deviations from mean annual rainfall, Herschel: 1900-1950

TNK, from 1974; Sterkspruit, from 1967; Lady Grey, from 1983; and Bensonvale, from 1962. Bensonvale's annual rainfall had declined by over 20% below the annual mean by 1993, Sterkspruit TNK by about 6% by 1998, and Landy Grey by 14% by 2007. For Helvellyn, the deviations from the mean had maintained a general trend around the mean annual rainfall by 2007. If these trends are calculated over shorter periods the rainfall figures would show a much steeper decline as is shown by the pattern for Sterkspruit (1959-1974) and by the three-year running means shown on all the graphs.

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5.2.1.3 Sterkspruit catchment, a climatically sensitive landscape

The variable nature of Sterkspruit catchment's climate weakens its potential for recovery after environmental perturbation. The area constitutes a brittle environment, i.e. one where precipitation is unreliable and humidity is poorly distributed throughout the year, regardless of its amount (Butterfield, et al, 2006; Savory, 1988). The historical climatic data attests to the fact that the rainfall of the area is inter-annually variable and frequently leads to meteorological droughts. In addition to this the pattern of rainfall with respect to seasonal distribution is also variable. The mean annual rainfall figures as computed from an earlier study of the area (Nel, 1971) when averaged for the mountain areas and the lower areas, are as follows: Spring (September – November), 225mm; Summer (December- February), 340 mm; Autumn (March – May), 225mm; and Winter (June, July, August), 50 mm. Although detailed records are somewhat patchy, the rainfall data for a selection of months over various periods show several changes in seasonal rainfall patterns as indicated by monthly figures. Tables 5.5 and 5.6 illustrate the monthly mean rainfall amounts for certain months at Sterkspruit and Sterkspruit TNK over long periods. The figures in table 5.5 show a highly variable rainfall pattern with coefficients of variation (CVs) ranging from 57.83% to 116.6%. The variability for the month of September in particular (116.6%) means spring rains can be very early or very late at Sterkspruit station. Table 5.6 shows rainfall variabilities for seven months of the year at Sterkspruit TNK; the CVs range between 567.72% and 111.92%. Again the month of September stands out. Figures 5.19-5.26 depict rainfall trends for certain months over extended periods at the same two stations. Long-term declines in rainfall

Table 5.5 Rainfall variability for selected months at Sterkspruit

Station: **Sterkspruit**		Period **1900-1951**	
Month	**Monthly Mean (mm)**	**Standard Deviation (mm)**	**CV (%)**
January	88.9173	57.08	64.19
March	107.0451	61.90	57.83
May	38.7020	31.04	80.21
September	30.996	36.16	116.6
December	78.7020	53.6	68.1

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Table 5.6 Rainfall variability for selected months at Sterkspruit TNK

Station: **Sterkspruit TNK**		Period: **1940-1998**	
Month	**Monthly Mean (mm)**	**Standard Deviation (mm)**	CV (%)
January (1940-1998)	95.493	65.127	68.20
March (1940-1995)	98.464	55.849	56.72
May (1940-1998)	33.617	30.974	92.14
Dec (1940-97)	89.374	53.360	59.70
Sept (1940-1983)	30.360	33.980	111.92
October (1940-89)	63.078	42.318	67.08
Nov (1940-80)	69.658	47.494	68.18

have occurred over the months of September (Figure 5.19), December (Figure 5.22) and May (Figure 5.26). This effectively means the rains came progressively later in September than they had done before, the mid-season rainfall amounts for December

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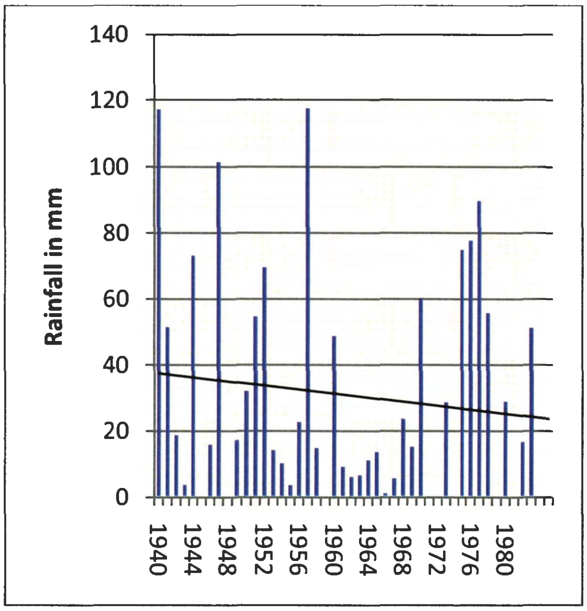

Figure 5.19 SterkspruitTNK, September rainfall: 1940-1983

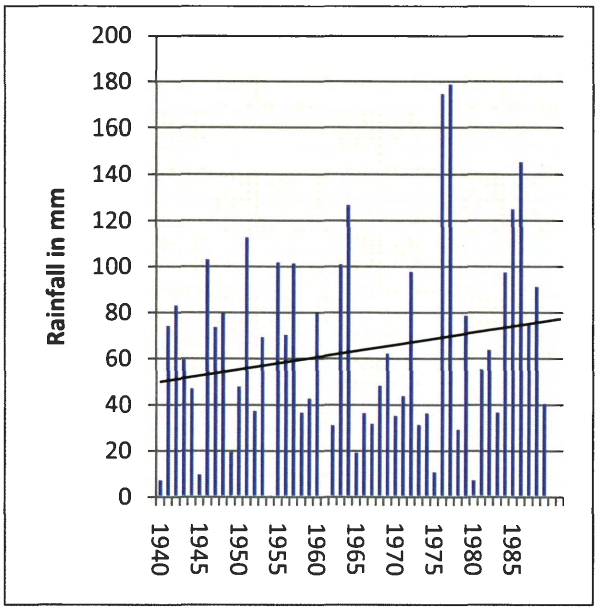

Figure 5.20 SterkspruitTNK, October rainfall: 1940-1989

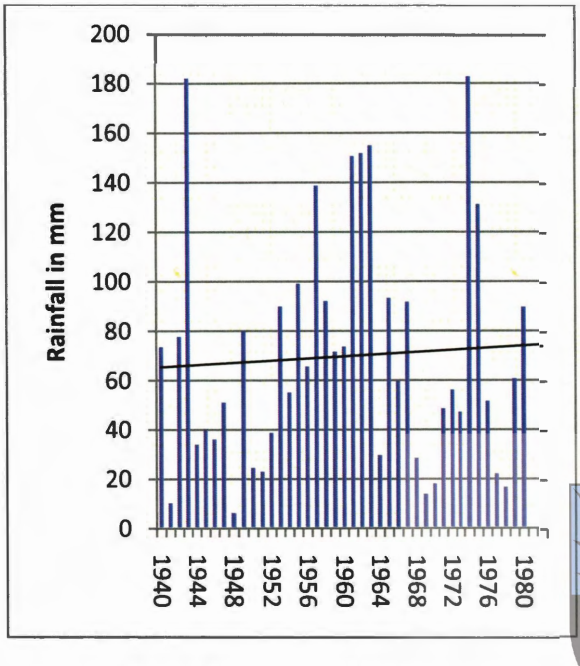

Figure 5.21 Sterkspruit TNK,
November rainfall: 1940-1980

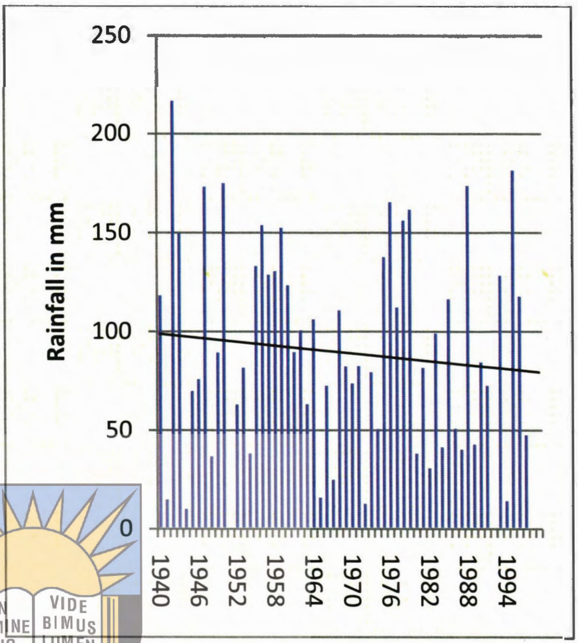

Figure 5.22 Sterkspruit TNK ,
December rainfall: 1940-1997

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were reduced, and the lower rains for May were due to the agricultural season ending sooner than in earlier years. In a late rainfall year livestock farmers who normally rely on the spring rains to revive the natural pastures have to find ways to keep their livestock going until the rains finally arrive. Crop farmers who may have prepared their fields for early planting have to wait longer while weeds germinate before their crops. Long-term increases occurred in the months of October (Figure 5.20), November (Figure 5.21), and February (Figure 5.24). The net effect was to shorten the agricultural season and to make the rains more erratic. Such changes in seasonal rainfall patterns have implications for plant germination, growth, and maturity; availability of grazing and browse for livestock have become less reliable.

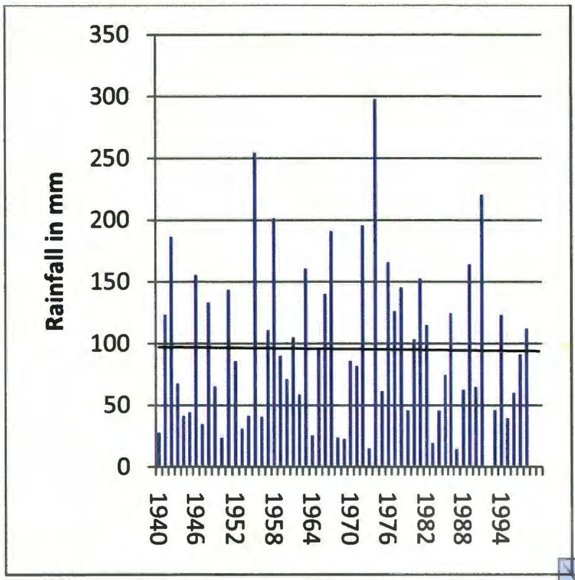

Figure 5.23 Sterkspruit TNK, January rainfall: 1940-1998

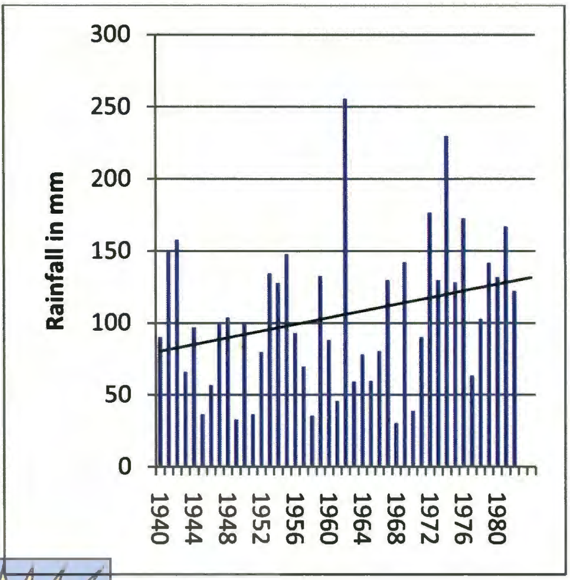

Figure 5.24 SterkspruitTNK, February rainfall: 1940-1982

All in all, this analysis does point to the fact that rainfall variability is a major aspect of the biophysical setting for land degradation in Sterkspruit catchment. Both inter-annual and intra-annual (seasonal) variability is involved. This has implications for the growth and development of the flora and fauna of the area as well as the generation and sustenance of livelihoods.

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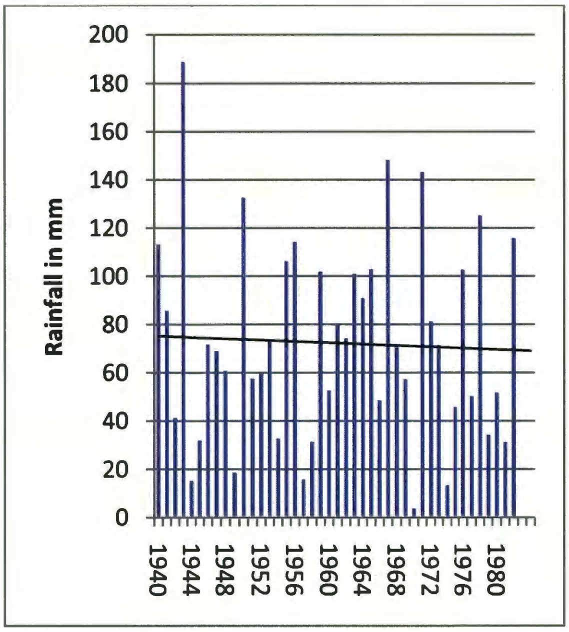

Figure 5. 25 Sterkspruit TNK, April rainfall 1940-1982

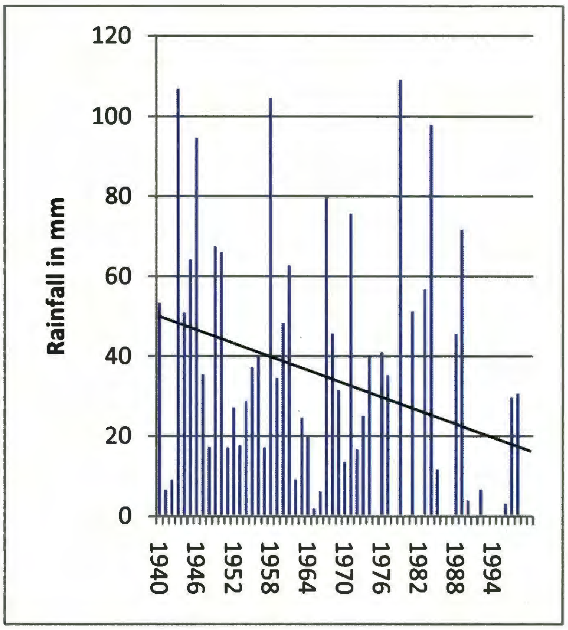

Figure 5.26 Sterkspruit TNK , May rainfall: 1940-1998

5.2.2 Vegetation-related landscape sensitivity

The landscape scale vegetation types observed and recorded as described in section 4.5.3.3 of chapter 4 are presented more systematically in this section for analysis – following the pattern of descriptions by Acocks (1988) and Tainton (1999).

5.2.2.1 Characteristics of Vegetation of Catchment

The natural vegetation of the Sterkspruit catchment can be characterized into two distinct types: the wetter mountain areas (annual rainfall 700-1000+ mm) comprise the Afromontane Grassland, and the lowland areas below 1500 m.a.s.l consist of what one writer calls Moist Cold Highveld Grassland (Vetter, 2008). The Afromontane grasslands are generally short and dense and include a subtropical element. Species include *Themeda triandra, Elionorus muticas, Heteropogon contortus, Hyperrhania hirta, Eragrostis* species (*E. chloromelas, E. racemosa, E. capensis and E. curvula), Andropogon appendiculatus,* and *Merxmuellera disticum*). More moisture-loving grass species such as *T. spicatus, D. filifolius* and *Cymbopogon marginatus* do better here than in the drier low-lying areas. The temperate species, much more important in the mountain areas than in the low-lying areas (Tainton, 1999), include: species of *Festuca (F. costata, F. scabra*, and *F. caprina), Merxmuellera (M. disticha, M. caprina* and *M. macowanii*), as well as *Pentachistis microphylla, Helictotrichon hirtulum, Tetrachne dregei, koeleria cristata* and *Bromus firmior.*

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Scrub forest is found on the more moist south-facing slopes and in sheltered valleys. Ribbons of full grown *Acacia mearnsii* are to be found along a five kilometre stretch of the Watervalspruit stream which enters the Holohlahatsi dam from the south-east direction. Trees and shrubs are found along all streams in the mountainous parts of the Sterkspruit catchment. Dense thickets of shrubs and trees comprising *Leucosidea sericea, Passerina Montana, Dysparos lycioides, Acacia mearnsii, Raminus prinodis* and *Rhus erosa* are to be found on the steep slopes on the eastern side of the Holohlahatsi dam. Similar vegetation is to be found on south-facing slopes in several localities in the Sterkspruit catchment. Areas near the villages which may have had any trees have been cleared either for agriculture or for firewood.

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The Moist Cold Highveld Grasslands are found in the semi-arid lowlands with annual rainfall amounts of 400-500 mm. Grasses include tropical and subtropical species: *Themeda triandra, H. contortus, Microchloa caffra, Elionorus muticas, Setaria sphacelata, T. leucothrix,* several *Eragrostis* species (*E. chloromelas, E. racemosa, E. capensis and E. curvula*), *Brachiaria serrata* and *Cymbopogon plurinodis*. In contrast to the mountain areas the grass in the low-lying areas should be fairly tall (0.75m to 2m), and form uniform stands (Tainton, 1999). In reality, due to sustained grazing pressure over a long period, these grasses, identified in a number of localities (e.g. just north of Bensonvale and around Tapoleng), rarely attain their customary climatic climax heights.

5.2.2.2 Landscape sensitivity of grassland subjected to sustained grazing ressure

According to Acocks (1988), mismanagement of mountain grassland vegetation type may result in an increase in *Merxmuellera disitcum*, conversion of grassland to Karroo False Fynbos (e.g. *Passerina montana* and *Erica caffra*) and invasion by Karroid bush species such as *Chrysocoma ciliata*, *Felicia filifolia*, *Stoebie vulgari,* and forbs such as the *Helichrysum spp*. Evidence from field surveys has confirmed that the Afromontane grassland vegetation in Sterkspruit catchment has been subjected to sustained grazing pressure. The response of the vegetation to this pressure has included changes to species composition (e.g, increase in mountain wire grass, i.e. *M. disticum*) and bush encroachment. The invasion of the highland grasslands by Karroid bush species, especially on the slopes, has meant that these areas have less grass cover protection than in a climatic climax grassland.

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In the low-lying areas the climatic climax vegetation dominated by *Hyperrania hirta* and *Themeda triandra*, had undergone species changes to include an increase in grazing-tolerant species (Increaser II) such as *Eragrostis chloromelas*, *Aristida congesta*, and *Eragrostis carpensis*. While most of these species tend to be perennial in nature and more suited to the variable nature of the rains in the area than ephemeral species they do not provide adequate basal cover. They tend to have less leaf area than the annual species and so provide less protection for the soil, thereby increasing the risk of erosion.

Most of the rangelands used as grazing lands in the catchment are former arable lands or abandoned former homestead sites. Their re-vegetation has undergone various stages of plant succession, beginning with the initial stage of weed infestation. Excessive defoliation due to sustained grazing pressure in these former arable lands has put them at risk of degradation. Studies elsewhere have shown that such lands are at greater risk of soil erosion than lands that were not previously ploughed (Rowntree, *et al*, 2003, Sonneveld, *et al*, 2007).

5.2.3 Soil erodibility, rainfall erosivity, and estimation of catchment scale sediment loss

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The soils, comprised predominantly of sandstones and mudstones, are sandy by nature and highly erodible - as described in section 3.1.5.2. The intense thunder storms common to the area (see section 3.2.3.2) make the nature of the rainfall highly erosive. Application of the revised universal soil loss equation (RUSLE) to the catchment area produced a sediment loss estimate of 13.72 tons.ha^{-1}.year^{-1} as explained in section 4.4.3.4. When this figure is extrapolated over the whole catchment (391 km^{2}), which is 39 100 hectares, the soil loss amounts to a substantial fraction of the theoretically possible amount of 536452 tons.ha^{-1}.year^{-1}. A previous study estimated sediment yield for the catchment at 129 t/a (Midgley, et al, 1994) and erodibility index as medium. Soil loss estimates based on measurements at sites 1-6 which had been subjected to erosion over a 25-year period (1982-2007) yielded an average of 1.38 tons.ha^{-1}.year^{-1} (Table 5.7): when this figure is multiplied by the size of the catchment the estimated soil loss over the whole catchment is 53 958 tons.ha^{-1}.year^{-1}. These major variations in the soil loss estimates are a reflection of the differences in the methods used in the calculations; what is certain is that large amounts of soil are involved. Land degradation as represented by soil loss from erosion is a major problem in the catchment.

Table 5.7 Whole catchment soil loss estimate based on measurements of gullies, rills and pedestals

Site	Soil loss (tons) 1982-2007	Gully catchment (m^2)	Gully catchment (ha)
1	433.18	91 000	9.1
2	254.37	150 400	15.04
3	35.45	4 560	0.46
4	42.33	18 000	1.8
5	173.28	40 940	4.09
6	186.73	20 625	2.06
Totals	1125.34	325 525	32.55

Annual loss from 32.55ha: 1125.34/25yrs = 45.01 tons.ha^{-1}.year^{-1}
Annual loss from 1ha: 45.01/32.55 = 1.38 tons.ha^{-1}.year^{-1}
Annual whole catchment soil loss: 1.38 x 39 100 ha* = 53 958 tons.ha^{-1}.year^{-1}.
* Size of Sterkspruit catchment: 391km^2 (39 100ha)

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The potential sedimentation of water sources from the "lost soil" is also a serious problem. When considering the effects of sedimentation of dams and streams it is pertinent to bear in mind that not all the lost soil ends up in the water. Much of it is re-deposited at sites on the landscape within the catchment. "As the area for assessment increases, there is a greater likelihood of storage of sediment within the bounded area … In real field conditions as much as 90-95 per cent of eroded soil is re-deposited elsewhere within the landscape" (Stocking, 1995: 231). The penetrometer resistance measurements recorded for sites 10 and 20 were the lowest out of the 21 sites (chapter

6); this was because the two sites were areas of re-deposition of sediment transported from areas upslope on the landscape.

5.2.4 Surface and groundwater resources (rivers, dams, and springs)

In an area that frequently experiences drought such as Sterkspruit, surface and ground water storage is crucial for the survival of both humans and livestock. The area is relatively well endowed with both sources of water.

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5.2.4.1 Sources and uses of water in the context of landscape resilience

The Sterkspruit is a perennial river and, despite the numerous droughts common to the study area, there is no record of the river ever drying out completely. The impoundment of the river above Magwiji village for the construction of the Holohlahatsi dam around 1981-2 resulted in a much reduced river volume downstream of the dam. Despite this, the river continues to flow regularly as it is replenished by a tributary which flows in about kilometer below the dam wall. The Kromspruit River, a major tributary, joins the Sterkspruit River just before it reaches Sterkspruit town. The Kromspruit dries up in several sections during the dry seasons and in years of drought.

The catchment has several natural springs, particularly in the hills and the mountains. Several of the springs are prolific and are a perennial source of drinking water for people and livestock. The area immediately down slope of each spring is usually kept moist by water continually seeping from the spring and provides some green grass in the dry season and in years of drought. This helps the livestock's ability to survive droughts and to bounce back once the drought has ended. The only drawback is that the area around the springs is heavily trampled upon by livestock during the dry season and during droughts (see Figure 5.27). However, on the return of the rains the trampled area recovers as the attention of the livestock refocuses elsewhere.

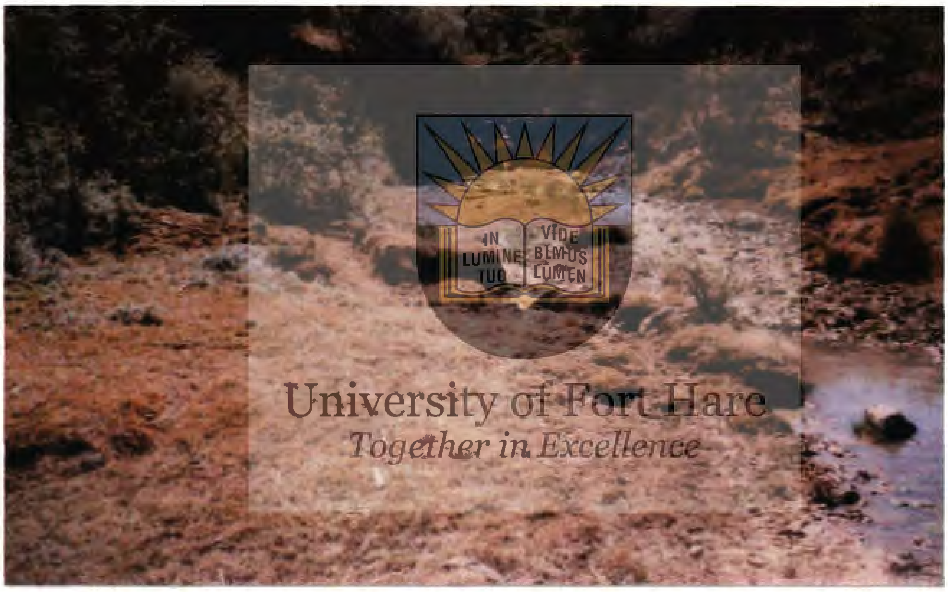
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Figure 5.27 Spring in mountain grazing camp, showing evidence of trampling around it

The Holohlahatsi dam was constructed in the early 1980s (Figure 5.28). Though its level flactuates with the seasons, the dam acts as a reliable source of water for the residents of the catchment. Water is piped from the dam to several parts of the catchment, including Sterkspruit town. The movement of the water is by force of gravity as the dam is in the highland area and most of the settlements are at altitudes below that of the dam.

Previously the dam has even been used to irrigate some crops (Fisana, personal communication, 2008). Livestock grazing in the camps situated immediately to the south of the dam use it as a source of drinking water. On the whole, the dam helps to enhance the resilience of the catchment in terms of availability of surface water. Sedimentation from the massive soil erosion upstream of the dam is a source of concern though for the future resilience of the catchment.

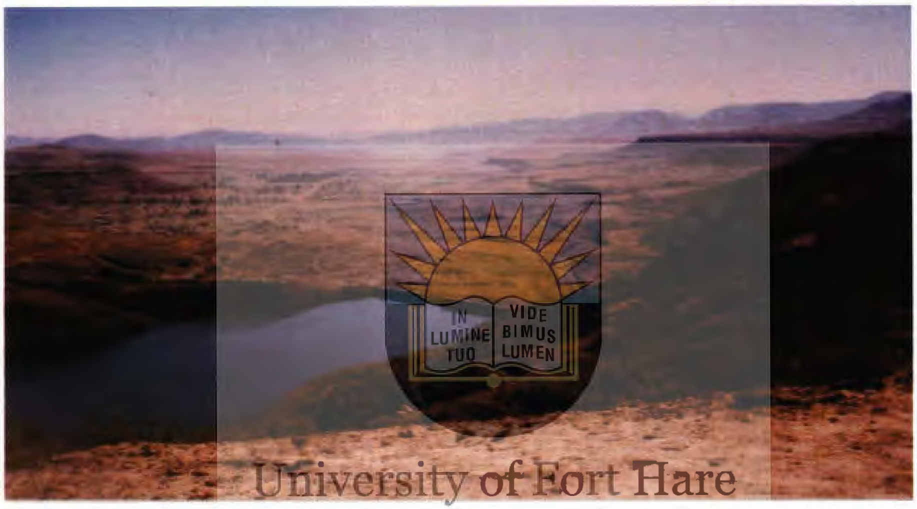

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Figure 5.28 The Halahlahatsi dam, situated just south of Magwiji village (September, 2007)

During the rehabilitation schemes of the 1940s t0 early 1960s, numerous stock dams were constructed at strategic locations throughout the rangelands of the Sterkspruit catchment. Over the years, many of the dams were subjected to sedimentation and dried up or burst their walls; however, several of them can still be seen at various points in the landscape. These dams play an important role in the water supply for animals, especially in areas further away from the rivers and the springs. A few boreholes in certain localities (e.g. Voyizane) provide water for use by residents.

5.2.4.2 Main sources of household water

The main sources of water for Senqu municipality households according to the national census of 2001 are as shown in figure 5.29. As seen from the graph the majority of the households (41%) get their water from a communal tap some distance from the house or within their yard (18%). A substantial number (18%) get their water from a spring, a river (8%), a borehole (5%), and various other sources. Figure 5.27 shows the main sources of water for household use at Hinana in 2008. The pattern of piped water at communal outlets conforms to that of the Senqu municipality as a whole. The other source is a communal borehole. While there are numerous springs in the catchment, this village does not have access to prolific springs. The variety of sources of water indicates how well endowed the Sterkspruit area is with water resources, despite the frequent droughts. This enables the local people to withstand droughts for long periods, in as far as water supplies are concerned.

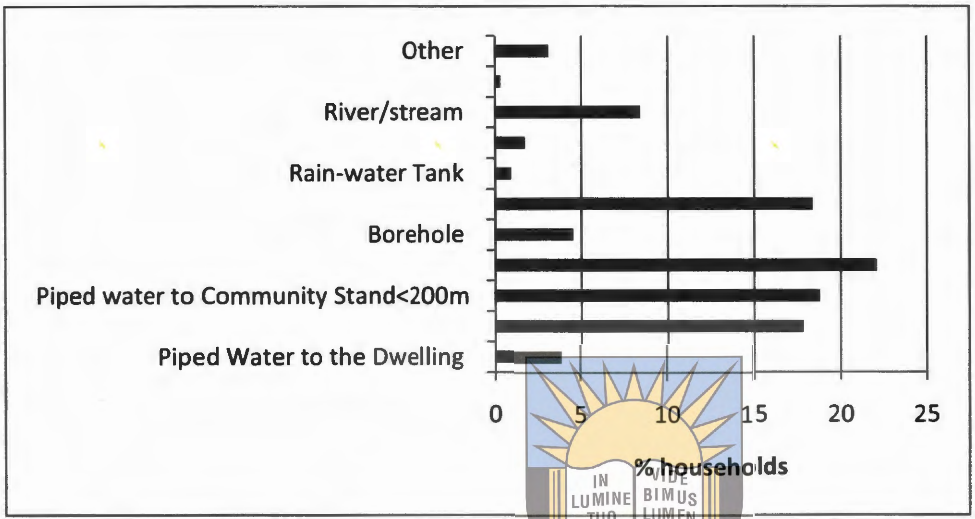

Figure 5.29 Main Water Supply in Senqu Municipality, 2001

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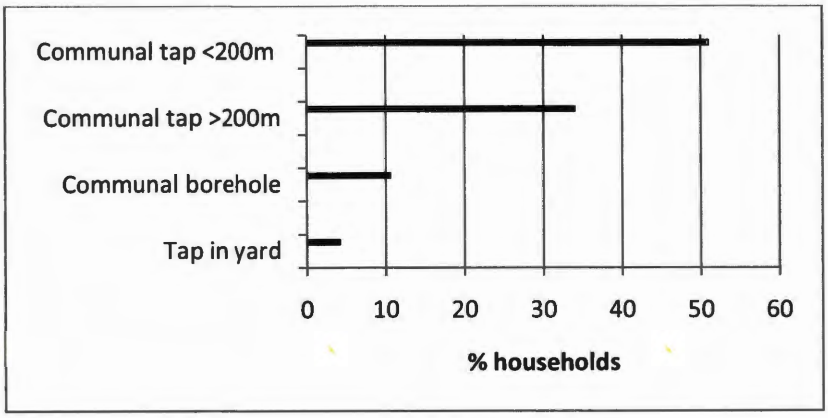

Figure 5.30 Main sources of water for houseold use at Hinana village, 2008 (source: questionnaire survey)

5.2.4.3 Water pollution

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Though no tests for water quality were conducted for the catchment two evident sources of water pollution were identified; these were sedimentation of surface water and contamination of surface water by faecal matter and coliforms arising from it, and by nitrates and phosphorus the main minerals in livestock manure. Sediment is made up of mineral or organic solid matter eroded from the landscape and deposited into the water sources. Sediment can clog piped water systems, smother aquatic life and increase water turbidity. Turbidity can cause thermal pollution as cloudy water absorbs more solar radiation than clear water. Figure 5.32 shows that over 35% of residents of Senqu municipality did not have toilet facilities and while on field visits the researcher observed a high number of homesteads in the study area without toilets. Use of the 'bush' toilet system exposed surface water sources to faecal matter. Kraals built around homesteads are used for confining livestock overnight and manure accumulates in them. Most of these kraals are on sloping ground and when rain storms come much of the confined livestock manure is swept away towards the rivers (see Figure 5.31).

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Figure 5.31 Livestock manure washed away from kraal by overland flow ends up in the river

Figure 5.32 shows distribution of toilet facilities by household percentage. Over 36% of households are shown as having no toilet facilities of any kind. This means that these

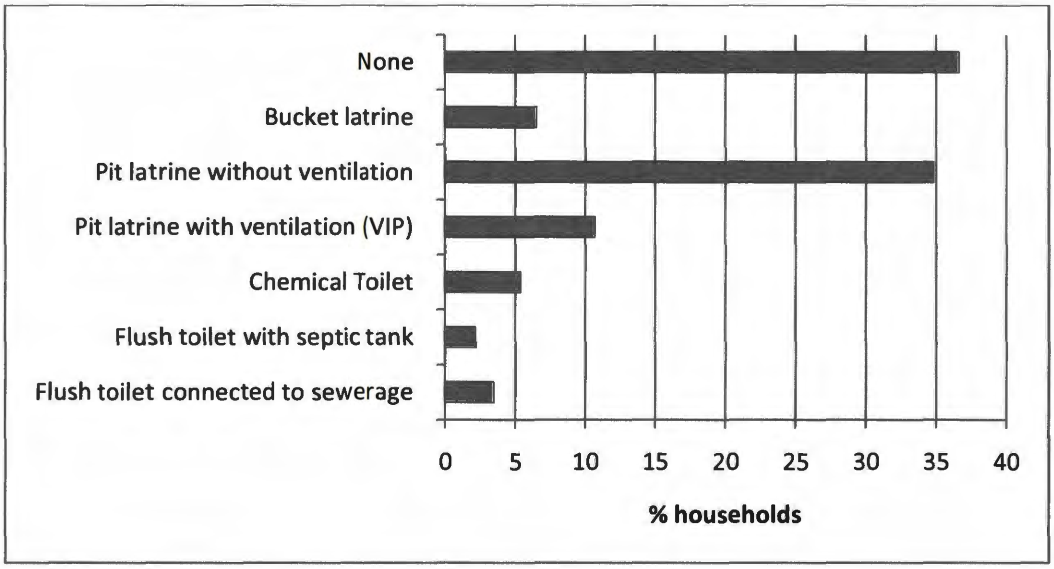

Figure 5.32 Toilet facilities in Senqu municipality, 2001

residents resort to the "bush" toilet. When the rains fall and generate runoff, faecal matter and the resulting pathogens are transported by running water to the streams and to any other open surface water sources. The figure of 32% "no toilets" is out of the total number of households in Senqu municipality, including urban households. When rural households are considered on their own, the percentage for households without toilet facilities is even much higher! Fortunately, the Holohlahatse dam is situated upstream of almost all the settlements. This ensures that faecal matter is not directly channeled towards the water in the dam. The water piped downstream to the settlements is treated at the storage tanks before it is distributed broadly for consumption.

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5.3 Landscape Socio-Economic Background

This section examines the socio-economic context within which land degradation issues in the catchment are explored.

5.3.1 Population pressure, access to land, and livestock carrying capacity

Population figures were calculated on the basis of the 1996 census as changes to administrative boundaries and aggregation of data made it difficult to compare the 1996 and 2001 census figures for the study area.

5.3.1.1 Population of catchment

Table 5.8 is a summary of population statistics for the Sterkspruit catchment. When the estimated population of 37431 is divided by the size of the catchment (37431/391km^2) it gives a population density of 96 people per km^2. These figures represent considerable pressure on the land resources of the area, especially in view of the largely subsistent nature of the land-based rural economy. While Sterkspruit can be classified as a small town, it lacks an industrial base, and the only jobs available are mostly in the tertiary services sector and government departments.

Table 5.8 Population estimates for Sterkspruit catchment

Village	1996	2001	2006	2008
Magwiji ward	5330	5443.5	5559.47	5607
Hinana				3255
Total for Hinana and 4 Magwiji ward villages				8862
Average population per village (8862/5)				1772
Estimated population of 14 villages in catchment				**24808**
Sterkspruit	12000	12996	14074.67	**12623**
Estimated population of Sterkspruit catchment				**37431**

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NB: Population estimates for Magwiji ward and Sterkspruit town were based on the 1996 national census Figures multiplied by a five-yearly increase rate of 8.3% (multiply 1996, 2001, and 2006 by 1.0213; the increment for 2008 is only 0.4 of the increment based on 2006 figure as it falls short of the five-year period by three years).

5.3.1.2 Access to land

The graph in figure 5.33 was constructed from data provided by Govender (1998). As will be seen from the graph more than half the households do not have access to arable

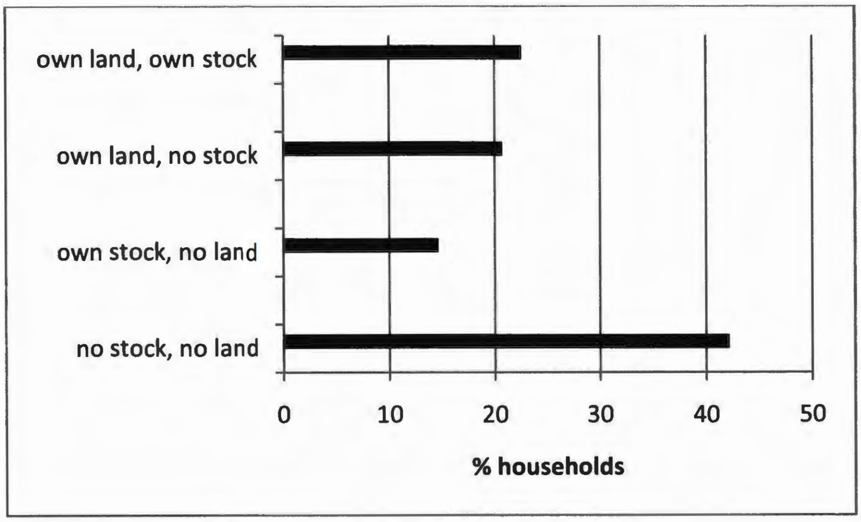

Figure 5.33 Household access to arable land in Magwji ward (Jozana's Hoek, Jozana's Nek, Magwiji, Sunduza), 1998

land (42.16% + 14.62%). Of the remainder [illegible] had access to this category of land 20.68% did not have livestock. Importantly only 22.54% of households had both land rights and livestock. Figure 5.34 shows the pattern of household access to land in Hinana village based on data collected in a questionnaire survey conducted in 2008. While the majority of households owned home gardens a surprisingly high percentage (18.75%) did not have access to land for home gardens even though they had homes in the village! Arable land was equally not plentiful as 43.75% of households did not have access to it. The situation of the five villages portrayed in the graphs shows there is a shortage of land in the Sterkspruit catchment. The figures from both graphs point to a situation where quite a large number of households are using the villages as residential areas only, and not for farming activities. This has some significance to how members of those households may perceive the problem of land degradation and how it should be dealt with. Perhaps it is also pertinent to mention that during the days of the betterment land demarcations some households had not been allocated arable land at

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all (Desmond, 1971).

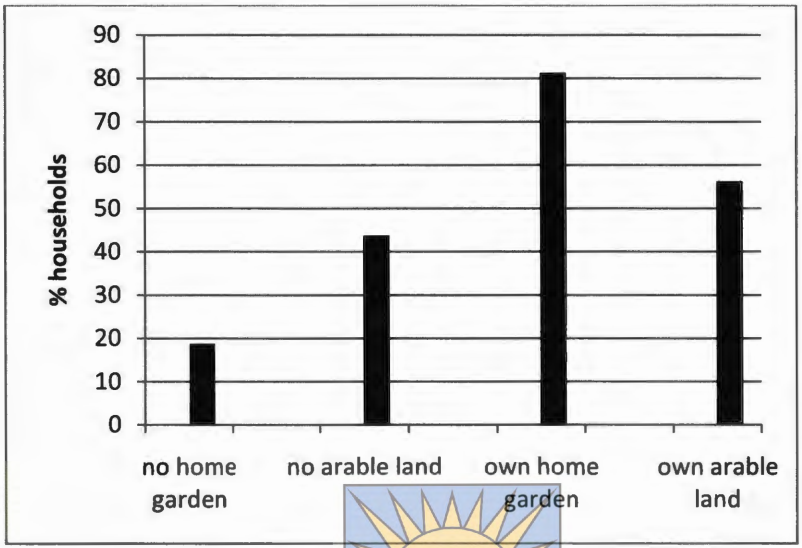

Figure 5.34 Household access to land in Hinana village, 2008

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5.3.1.3 Livestock carrying capacity

Figures for the calculation of livestock carrying capacity for the catchment were not readily available. However, using a combination of figures cited in a previous study (Govender, 1998) and figures provided by the Department of Agriculture in Sterkspruit, it was possible to get a reasonable estimate of carrying capacity. Table 5.8 shows the relevant calculations for the livestock numbers and livestock carrying capacity. The study by Govender (1998) gave the assessed carrying capacity for the area as 3 morgen (2.57 ha) per one cattle unit. Using that measure on the livestock statistics in Table 5.9 it shows the study area as being capable of supporting 15 214 cattle units.

Table 5.9 Estimates of livestock numbers and livestock carrying capacity in Sterkspruit catchment

Villages	**Cattle**	**Goats**	**Sheep**
Hinana	746	397	1808
Magwiji	628	598	502
J'Hoek, J'Nek,Sunduza	1435	3458	1832
Basis of computations			
Totals	2809	4453	4142
Average per village	561.8	890.6	828.4
Catchment total (14xAve)	7865.2	12468.4	11598
Number of cattle units (6 goats/sheep=1 cattle unit)	7865.2	2078.07	1932.9
Total cattle units (CUs)	11876		
Areal extent of catchment	391km^2 (39 100 ha)		
Carrying capacity at 2.57 ha (3 morg)/CU	39 100 ha/2.57 ha = **15 214 cattle units**		
Cattle units/Catchment carrying capacity	11876/15214 = 0.780 (78%)		
In theory the number of cattle units in the catchment is at 78% of its potential capacity			

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The number of cattle units in the catchment in 2009 works out at 11876. When this is put against the catchment's full capacity of 15214 cattle units it suggests that the catchment is carrying only 78% of its potential capacity. These figures suggest that there is no overstocking in the catchment. However, it must be taken into account that not all land is available for grazing. Some of it is built on (including urban and road construction) and some is used for arable purposes. The boundaries of the catchment area are also "flexible" in that they do not physically prevent both people and their livestock from accessing natural resources beyond the rim of the catchment. In theory this extends the carrying capacity of the catchment. However, people and livestock from beyond the catchment do also access resources in the outer edges of the catchment, cancelling this apparent advantage. One notable thing about the Sterkspruit area, though, is that people generally acknowledge and respect the notion of specific grazing camps belonging to specific villages. It is worth noting that some studies have questioned the validity of using carrying capacity concepts in non-equilibrium communal rangeland (Behnke, et al, 1993). The citing of overstocking as a cause of soil erosion has also been challenged on the basis of empirical evidence from some studies (Rowntree, et al. 2003). Nevertheless, when one takes into account the frequent droughts in the area and the poor state of the grass cover during these droughts the catchment's capacity to provide adequate grazing to livestock is often under strain.

5.3.2 Historical Livestock Data

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The livestock census data for Hinana and Magwiji village supplied by the Department of Agriculture at Sterkspruit is captured in table 5.10. As seen from the standard deviation (SD) for each data sub-set the largest variation in the livestock data is for Hinana sheep with an SD of 565.36, followed by that of Magwiji goats at SD 288.37, and then Hinana goats at SD 207.26. The coefficient of variation (CV) for each category of livestock shows changes in livestock numbers as follows (in descending order): Hinana sheep 47.6%, Hinana goats at 38.3%, Magwiji goats at 30.34%, Magwiji sheep at 24.4%, Magwiji cattle at 10.7% and Hinana cattle at 9,6%.

To illustrate the nature of the changes in livestock numbers the average figures for each animal category were calculated for the ten-year period (1998-2007). The numbers for each year were then compared with the mean for the period to see whether the changes were positive or negative.

Table 5.10 Livestock numbers for Hinana and Magwiji villages for the period 1998-2007

Year	CATTLE		GOATS		SHEEP	
	Hinana	**Magwiji**	**Hinana**	**Magwiji**	**Hinana**	**Magwiji**
1998	746	628	397	598	1808	502
1999	728	639	389	600	1843	518
2000	603	689	503	640	1877	497
2001	797	798	345	828	1560	526
2002	828	628	310	1003	1437	588
2003	766	745	414	935	860	616
2004	755	700	803	1098	650	720
2005	679	664	860	1128	580	795
2006	683	784	785	1230	592	841
2007	650	838	600	1456	672	940
Total	7235	7113	5406	9516	11879	6543
Mean	723.5	711.3	540.6	951.6	1187.9	654.3
StdDev	69.27	75.981	207.26	288.37	565.36	159.66
CV %	9.6	10.7	38.3	30.304	47.6	24.4

Source: Figures provided by Department of Agriculture, Sterkspruit

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5.3.2.1 Magwiji livestock dynamics (1998-2007)

Fig 5.35 shows how annual livestock census figures at Magwiji village differed from the mean livestock numbers for the ten-year period 1998-2007. The numbers of cattle declined in 1998, 1999, 2002, and 2005; they picked up in 2000, 2001, 2003, 2006, and 2007; 2004 was at par with the ten-year average. Goats recorded below average figures from 1998 to 2001 and recorded increases from 2002 to 2007. Sheep numbers remained below the mean figure from 1998 to 2003; then they continually increased from 2004 to 2007.

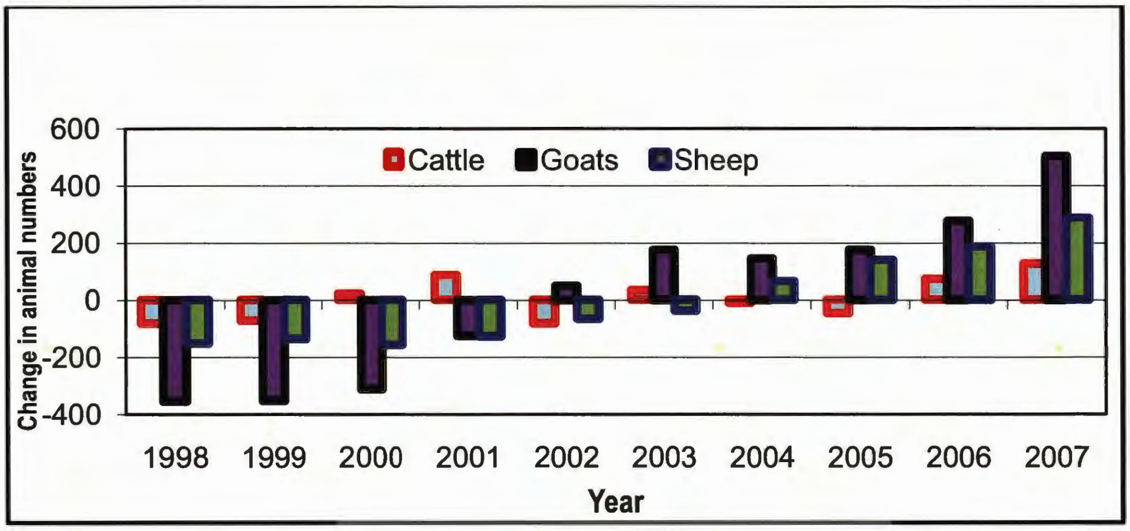

Figure 5.35 Annual departures from mean livestock numbers at Magwiji (mean for 1998-2007). Source: Computed from data provided by the Department of Agriculture, Sterkspruit

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5.3.2.2 Hinana livestock dynamics (1998-2007)

Figure 5.36 compares annual livestock numbers at Hinana village to the ten-year mean (1998-2007). The figures for sheep show a steady increase from 1998 to 2000; they fell dramatically in 2001/ 2; from 2003 they fell below average, and continued to fall in larger numbers before improving slightly in 2007. Cattle numbers hovered around the

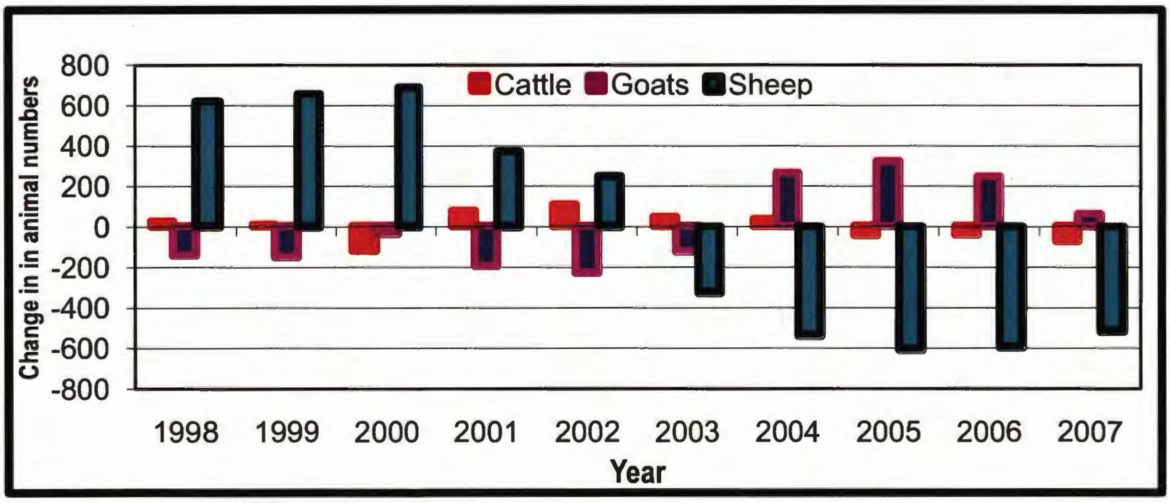

Figure 5.36 Annual departures from mean livestock numbers at Hinana (mean for 1998-2007). Computed from data at Department of Agriculture, Sterkspruit.

average figure throughout the period, showing noticeable drops in 2000 and 2007; the years 2001 and 2002 showed notable increases. Goats declined from 1998 to 2003 and then picked up in 2004 and continued above the mean before again sharply dropping to just above the mean in 2007.

5.3.2.3 Net changes to livestock numbers (1998-2007)

Figure 5.37 is a summary of the net livestock figures recorded at Magwiji and Hinana villages in the period 1998-2007. While Magwiji recorded net gains in all three categories of livestock, Hinana recorded net gain in goats and net losses in cattle and sheep. The reasons for declines in livestock numbers are varied. They included death from drought and diseases, sales, slaughter by owners, and general theft. Growth in numbers was due to natural increase (calving), purchase of replacement stock and inheritance from family.

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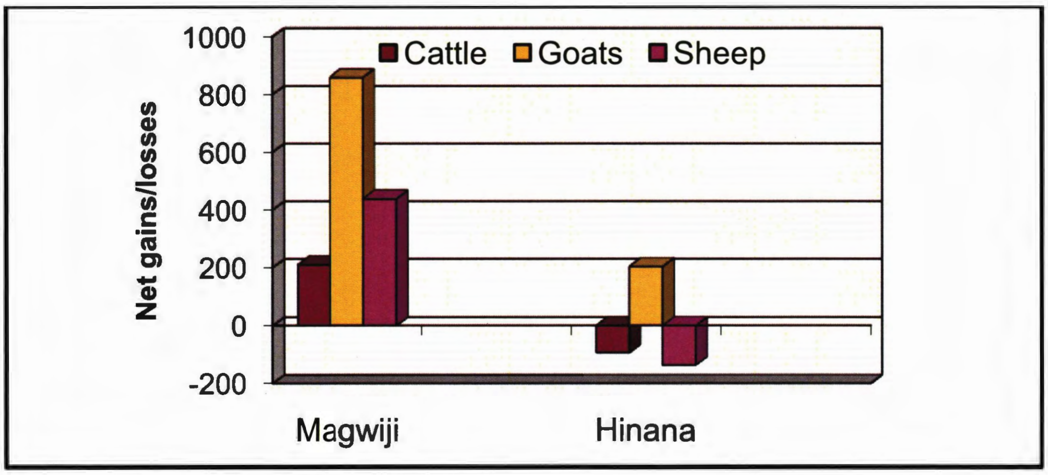

Figure 5.37 Net livestock gains / losses in Magwiji and Hinana villages

What these figures show is that while long-term trends may give a picture of stability in livestock numbers as shown in a previous study (Vetter, 2003), the short-term trends may have negative consequences for the farmer and for the condition of the rangelands. These patterns of decline and/or increase in numbers are revisited in section 5.4.5 which deals with questionnaire data analysis.

5.4 Landscape Socio-Economic Survey

This section reports on results of the interaction with members of the communities in both Hinana and Magwiji villages.

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5.4.1 Results of participatory rural appraisal (PRA)

The responses from the communities to questions on various aspects of land degradation are presented in table 5.11. Some common threads run through the responses from both villages. The causes of land degradation were seen as landscape sensitivity (steep terrain and rain storms generating large quantities of overland flow), "abandoned" arable land not protected from erosion, removal of fences formerly protecting rotational grazing camps, too many cattle on the grazing land (marketing

Table 5.11 Results of PRA interviews in Magwiji and Hinana villages

Magwiji PRA	**Hinana PRA**
Evidence of land degradation	**Evidence of land degradation**
Gullies at roadsides, in crop fields, in rangelands	Gullies cutting across fields – deep enough for livestock to fall in and fail to come out
Rocks exposed by running water – covering soil washed away	Gullies wide enough and deep enough to impede movement across the landscape
Bare patches of soil	Previously buried water pipelines and rocks exposed
Soil deposits on road sides and slope bottoms	“Poor quality” grasses and grass cover inadequate to protect the soil during the rain season
Invader woody species – e.g. *Acacia Mearnsii*	Invasion of rangelands by unpalatable shrub “blue bush” *Stoebie vulgaris*
Changes in grass species composition	Some farmers had to supply supplementary feed to their livestock
Livestock deaths during droughts	Livestock deaths during droughts
Reasons advanced for degradation	**Reasons advanced for degradation**
Steep nature of terrain – high volumes of swift and powerful overland flow erode the land	Swift flowing water passing through the fields – absence of grass to reduce the speed of the water
Most arable land no longer ploughed – left unprotected	Most arable lands left uncultivated – unprotected from animals
	Lands left uncultivated as cattle were “hungry and thin” and could not pull the plough
Removal of fences erected during Betterment days – unregulated use, rehabilitation structures unprotected	No fencing to protect the land – grazing camps as well as arable lands
Animals kept too long on rangelands (no local markets) - thereby depleting rangeland quality	“Outsiders” bringing their livestock to Hinana grazing areas making the grazing inadequate – rules no longer being observed
Suggestions for countering land degradation	**Suggestions for countering land degradation**
Fencing off rangelands into different grazing camps for rotational grazing	Fencing the arable lands and the rangelands – with the authorities supplying the fence, resting grazing camps
Closing off gullies using gabions and stone packing	Unemployed youths could be used to repair eroded lands (use of their labour)
Planting trees and certain grasses in eroded and/or vulnerable areas	Planting of trees and grasses in certain places to protect the soil
Making diversion furrows for channeling overland flow towards the bottom of the slope	Making furrows at the base of the slopes (using Govt supplied graders) for channeling water away from the fields
Setting up marketing infrastructure: cattle-holding and cattle-loading facilities	
Authorities to arrange for ploughing of farmers’ fields for a “reasonable” fee	Authorities should be asked to assist with ploughing communal farmers’ fields
Land husbandry rules to be revived and enforced – community leaders, land management committee, the municipality and Dept of Agric to be involved	Land management rules to be enforced

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problems, “outsiders’ cattle brought in”). It was generally agreed that the impacts of degradation included gullies, soil loss, invasion of rangelands by unpalatable plants, and necessitated provision of supplementary livestock feed.

5.4.2 Rangeland use patterns

In the pre-Betterment period clusters of households were always close to their arable lands and grazing was quite open and largely unfenced. Betterment introduced villagisation, with closer and more concentrated residential sites, in many instances located further away from their arable lands; rangelands were subdivided into fenced rotationally grazed camps.

5.4.2.1 Grazing camps

Following the introduction of Betterment, Magwiji village had 8 grazing camps situated in the mountains and valleys around and mo[illegible]ove Holohlahatsi dam (Magwiji dam). The relatively inaccessible nature of Magwiji's grazing camps makes it possible for the people of this village to maintain these grazing camps virtually exclusively for their own livestock. The grazing camps at Hinana village are more accessible and open to use by livestock from other villages. At the time of the study the fences had been removed from the camps and most of the arable lands were no longer cultivated. This has now blurred the picture of the land-use pattern as rangelands now encompass grazing lands and abandoned fields.

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Livestock movement patterns and overnight kraaling of animals has much relevance to land degradation issues, a factor that has been noted in the Karroo, especially in the late 19th and early 20th century (Beinart, 2003). In Magwiji cattle are left in grazing camps most of the time and only brought to the village for dipping purposes (once or twice every two weeks). This occasion is also used for counting the cattle and inspecting them for symptoms of ill health. The mountain rangelands are often covered with snow in the winter season and are abandoned for the warmer lowland rangelands. Left to their own devices, many cattle remain in the lowlands for most of the year rather than go up the rangelands on the very steep slopes and the mountain tops. As a result, the mountain rangelands tend to be selectively grazed when compared to lowland rangelands. Grazing pressure tends to be more on these rangelands than on the ones in the mountains and the steep slopes. Livestock traffic is also high in lowland rangelands, as animals move through them on their way to rangelands further away, or on their way to the village for kraaling or for dipping. Sheep and goats are also often taken to the grazing camps for the day and brought back for overnight kraaling (see Figure 5.38). Some goat and sheep owners arranged for herd boys (men) to camp in mountain rangelands for extended periods at certain times of the year, keeping the animals in stone-built kraals. Livestock tracks were observed along the regular routes of the animal movements. In Hinana the practice of kraaling the cattle was more prevalent

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Figure 5.38 Sheep on a regular route to and from distant rangelands, predisposing the soil to erosion

than in Magwiji; this resulted in numerous livestock tracks around the village. Llivestock owners complained of people from neighbouring communities bringing their livestock into their grazing camps. This put their camps under serious grazing pressure and also increased the risk of livestock thefts. This has motivated Hinana livestock owners to kraal their cattle on a daily basis.

The abandoned fields and rangelands around homesteads were used mostly for grazing bulls, sheep, goats, horses and donkeys. Several instances of tethered grazing involving horses, goats and sheep were observed, especially in Magwji. The rangelands close to the homesteads showed obvious signs of grazing pressure such as poor basal cover, short grass, and livestock tracks. Perhaps as evidence of the poor state of rangelands around homesteads, goats and sheep foraged for browse and for grass on steep slopes overlooking the villages some considerable distance from the homesteads.

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5.4.2.2 Mixed grazing regime, grazing pressure and bush encroachment

Livestock keepers in Sterkspruit catchment tended to practice common use of rangeland by mixing cattle, goats and sheep (horses and donkeys on a minor scale). Unlike cattle or sheep, goats are natural browsers rather than grazers. They eat plants such as brambles, hawthorn, ivy, thistles and nettles, and their diet includes tree leaves, flowers, and seed pods (Hetherington, 1987; Peacock, 1996). Goats are quite comfortable eating woody stems of trees and bushes; they can eat nearly all available vegetation. Because of the goat's versatility its inclusion in a grazing regime involving cattle and sheep makes for more efficient use of rangeland resources. According to Merrill and Taylor (1981) grass, forbs and browse are utilized much more uniformly than they would with any one animal species. In common use, cattle complement the feeding habits of sheep and goats; they graze coarse grasses, leaving them shorter and less course, thus making them more palatable to sheep and goats. Because of its preference for browse the goat is used in biological brush control as a rangeland management strategy.

Several studies have explored the question of bush encroachment as a form of rangeland degradation resulting from overgrazing. There is some debate over whether or not change in species composition constitutes degradation; any substantial increase in grazing pressure over previously ungrazed natural grassland leads to some change in species composition. According to one viewpoint, to constitute degradation the change must be irreversible. "Changes in species composition, shrub or ground cover are usually, not always, reversible" (Abel, 1997: 115).

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In a longitudinal study of a Chihuahuan Desert grassland by Yanoff and Muldavin (2008), the results of increased shrublands over time and in a grazed site suggested that vegetation change was due to grazing; however, despite higher invasion in grazed lands there were generally increased shrublands in that whole region. This suggested that climatic factors, rather than grazing alone were implicated in the vegetation changes. Abel (1997), in a study of communal rangelands in Botswana, pointed out that due to the highly variable nature of the rainfall of the region, there was no stable equilibrium represented by a single species composition. Rather there were several possible compositions, each characteristic of a particular rainfall regime and grazing history. Citing a study by O'Connor (1985), he pointed out that compositional change was determined more by rainfall than by grazing pressure.

The implications of all this for the present study are, if one accepts the argument by O'Connor (1985) and Abel (1997) on changes to the herbaceous layer composition being due to rainfall, bush encroachment in Sterkspruit catchment should have been due to an increase in rainfall. The analysis of rainfall data for the area in section 5.1.1 shows a decrease in the long-term average annual rainfall trends in Sterkspruit catchment. This would seem to suggest that deep rooted plants, namely trees and shrubs, over the years established themselves at the expense of the more vulnerable grasses. The increase in shrubs in certain areas of the rangeland also aided by grazing pressure which reduced competition from grasses, allowing the establishment of shrubs in places previously dominated by grasses. This development would support bush encroachment as a manifestation of rangeland degradation. One study suggests that once bushes have encroached on rangelands and established a scrub cover browsing alone is unlikely to reduce scrub cover, though it can control further expansion (Hester, et al, 2006). A combination of fire and browsing is considered to be the fastest and most effective in reducing or removing scrub cover completely.

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5.4.3 Questionnaire Surveys

Questionnaire surveys were conducted in Magwiji (January 2008) and Hinana (May 2008) villages. They included questions on livestock ownership patterns, changes in livestock numbers, diversity of wildlife in the rangeland, usefulness of rangelands to villagers, patterns of household energy use, and application of manure to the land (see Appendix F). Forty-eight households were interviewed in Hinana and forty-nine households were interviewed in Magwiji.

5.3.3.1 Cattle ownership patterns

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The pattern of cattle ownership in Magwiji villages is shown in Table 5.12. The figures show that 12 households or only 26% of the sample in Magwiji owned 67.95% of the cattle. More than a quarter of the households (28.3%) owned no cattle at all; 32.6% of households owned only 10.44% of the cattle. These figures show great disparities in cattle ownership patterns. Table 5.13 shows the cattle ownership patterns for Hinana

Table 5.12 Cattle ownership patterns in Magwiji (2008)

Size Herd	No. households	% Households	Number of cattle	% tot. cattle
Over 20	7	15.22	175	42.47
16-20	5	10.87	105	25.48
11-15	4	8.69	41	9.95
6-10	5	10.87	48	11.65
1-5	15	32.6	43	10.44
0	13	28.3	0	0

village. A single household owned 22.5% of the cattle in the sample (n=48), 52.2% of households owned no cattle at all, 39.9% of households owned 34.5% of the cattle, and 6.52% of households owned 28.17% of the total number of cattle. As in the case of Magwiji, these figures show great disparities in cattle ownership. A comparison of the two villages shows that the households in Hinana generally owned fewer cattle per household than the households in Magwiji.

Table 5.13 Cattle ownership patterns, Hinana (2008)

Size Herd	No. households	% Households	Number of cattle	% tot. cattle
Over 20	1	2.17	32	22.53
16-20	0	0	0	0
11-15	3	6.52	40	28.17
6-10	1	2.17	21	14.78
1-5	17	39.9	49	34.51
0	24	52.2	0	0

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5.4.3.2 Overall livestock ownership patterns

As illustrated in figure 5.39 more than 50% of households in Magwiji did not own any goats while over 60% of households did not own any sheep. While goat ownership was fairly widespread across the numbers of households sheep ownership was confined to fewer households.

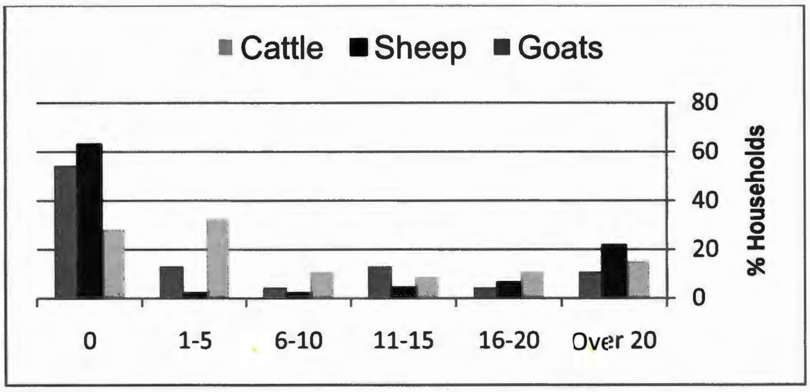

Figure 5.39 Livestock ownership patterns in Magwiji

In Hinana village 85% of households did not own any sheep while 58% of households did not own any goats (figure 5.40). When livestock ownership patterns for the two villages were compared it was apparent that more households in Hinana village than in Magwiji village did not own any cattle, sheep, or goats (Figure 5.40). The total numbers of households which did not own any livestock in all the three main categories are higher in Hinana, suggesting higher levels of poverty in Hinana than in Magwiji, i.e. in as far as livestock ownership represented socio-economic status.

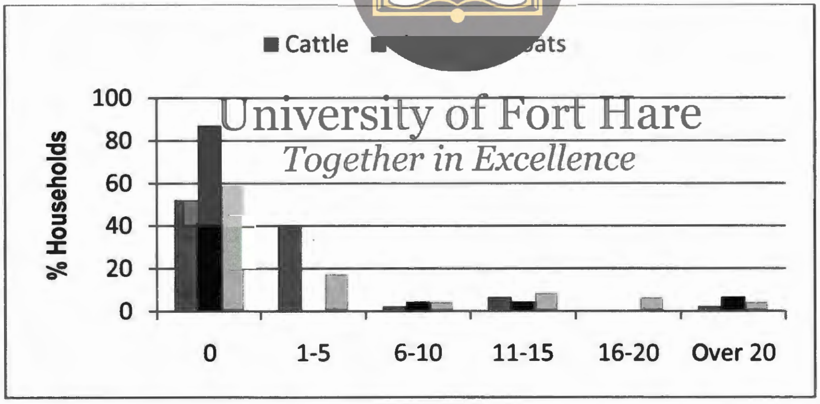

Figure 5.40 Livestock ownership patterns in Hinana

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5.4.3.3 Changes to livestock numbers and climatic variability

The question of changes to livestock numbers over time was examined with a view to account for causes of those changes. In Hinana village 30% of the decrease in cattle numbers in the period 1998-2007 was attributed to theft while 70% was attributed to "unexplained causes" which could be due to disease outbreaks or poor forage in drought years (Figure 5.41). Decreases in sheep and goats were all due to unexplained deaths, i.e. disease or starvation.

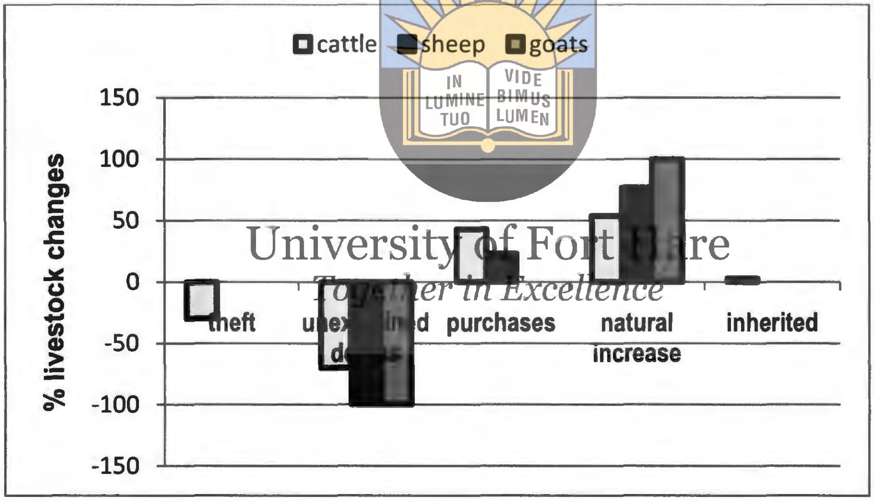

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Figure 5.41 Changes to livestock numbers and reasons thereof in Hinana village, 2002-2007

Increases in livestock numbers in the same period in Hinana were due to purchases of replacement stock (46% cattle, 20% sheep), natural increase (births): 51% cattle, 75% sheep, and 99.99% goats. A negligible percentage of goats (0.01%) were inherited from family. The purchase of replacement stock which is not matched by regular sales or slaughter suggests a practice whereby livestock are kept as a store of wealth (investment) which is liquidated into cash as and when required.

It is worth noting that none of the decreases in numbers were attributed to sales or slaughter. This implies that the priority for local farmers in livestock rearing was not regular income generation or meat provision. The question of acquisition and disposal of cattle in the communal areas has been examined by earlier writers researching into cattle ownership and production in the Eastern Cape. While many communal farmers may not appear to be active on the formal market "most of the selling and buying takes place within the villages" (Kepe, 2002: 70). Ainslie (2002: 5), discussing the issue of the perceived low off-take rates for cattle in the communal sector, pointed out that cattle sales figures often cited were based on 'formal' sales. In general, these figures did not record the out of hand sales to speculators and neighbours; they also did not capture the numbers of cattle 'slaughtered for home use' whose meat is sold locally.

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Changes to livestock numbers in Magwiji in the period 2002-2007 were as illustrated in figure 5.42. These figures show that more cattle were gained than were lost; in the case of sheep and goats more animals were lost in that period than were gained. The figures paint a different picture to that of the period 1998-2007 (Figure 5.37) which show a net gain for the three animal categories in Magwiji village. The implication from this apparent discrepancy in livestock number changes is that longer term trends mask the short term changes in livestock numbers.

While it was not possible to get recent rainfall figures for stations in the Sterkspruit catchment use was made of figures from Lady Grey and Helvellyn which are in the same region of the country. Lady Grey received below average rainfall in the following

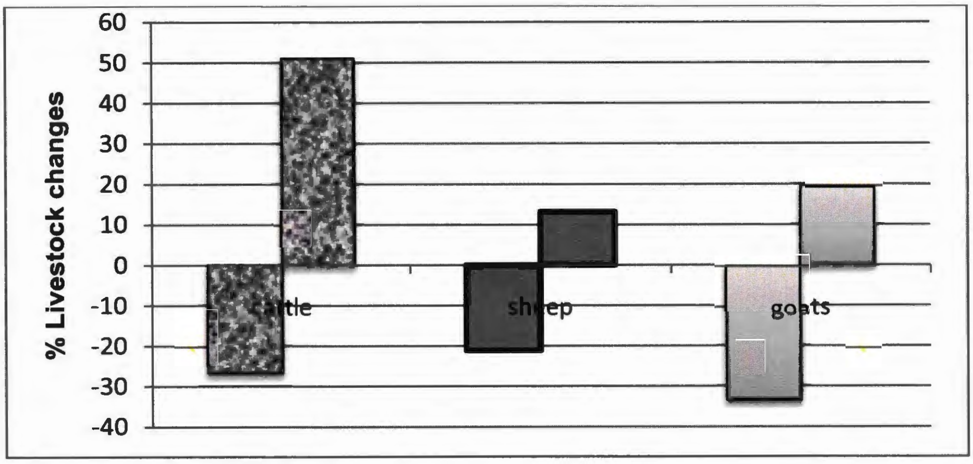

Figure 5.42 Pattern of livestock changes in Magwiji village, 2002-2007

years by the indicated CV: 2003 (-60%), 2004 (-57%), 2005 (-42%), and 2007 (-64%). Helvellyn received below average rainfall in 2003, 2005, and 2007, though the rainfall deficiencies were not as low as in Lady Grey. These figures confirm that several droughts occurred in the region in the period 2002-2007. Substantial livestock losses were incurred by farmers as illustrated in the two graphs (Figures 5.41 and 5.42) Those farmers who could do so purchased replacement stock as reflected in the graph for Hinana livestock changes.

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5.4.3.4 Supplementary feeds provision

Farmers provided supplementary feeds to their livestock. Figure 5.43 is a summary of the responses to the question on supplementary feeds provision practices of households in Hinana village. 59.6% of households responded that they did not or could not afford to provide supplementary feeds to their livestock. The rest of the households

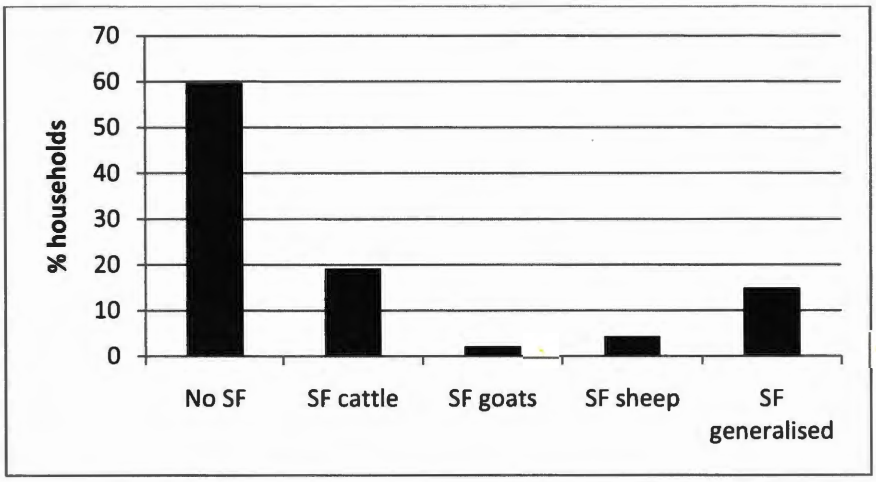

Figure 5.43 Supplementary feed (SF) provision in dry season and in drought in Hinana

stated that they provided supplementary feeds according to type of animal as follows: 19.1% provided feeds for cattle, 2.1 % for goats, 4.3% for sheep, and 14.9% said they provided feeds for their livestock in general. While it is evident the majority of farmers do not provide supplementary feeds, it was nevertheless apparent that a substantial number still did. This is an indication that farmers regarded as inadequate the amount of forage and browse available to their animals in the dry season and during drought years. This is a form of land degradation where the land cannot provide adequate grazing and browse at certain times of the year and in certain years.

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5.4.3.5 Wildlife diversity in rangelands and rangeland uses by villagers

Figure 5.44 represents householders' responses to the question on recently sighted rangeland wildlife. The presence of a variety of wildlife in the rangelands is an indication

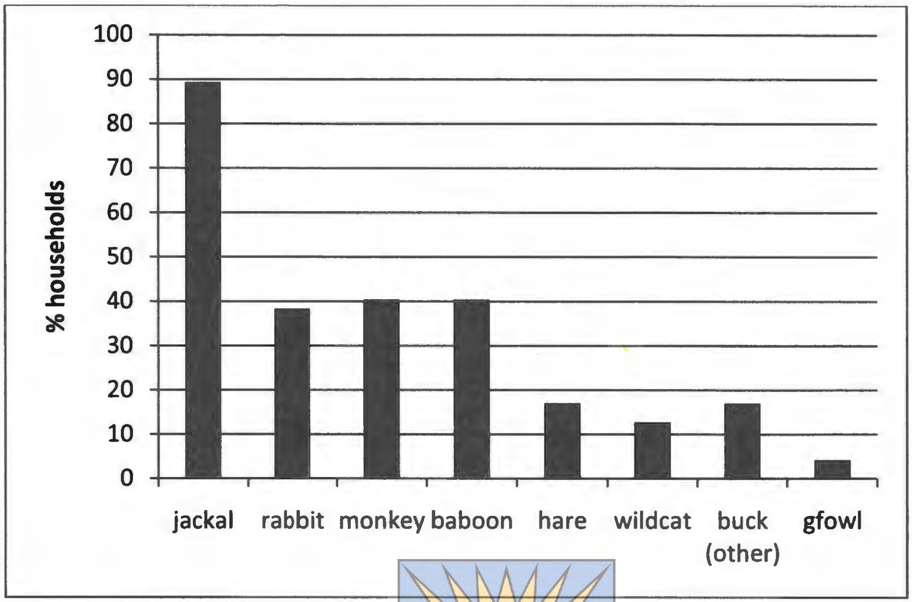

Figure 5.44 Wild life diversity in rangelands as identified by Hinana villagers

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of ecosystem biodiversity. It shows the rangelands' ability to provide different types of habitats which meet the unique requirements of each species of wildlife. It is a measure of landscape biodiversity that shows the potential for the rehabilitation of degraded land in Sterkspruit.

A related question attended to is the usefulness of the rangelands to residents of the area for non-pastoral purposes. Figure 5.45 shows the responses of householders to the question.

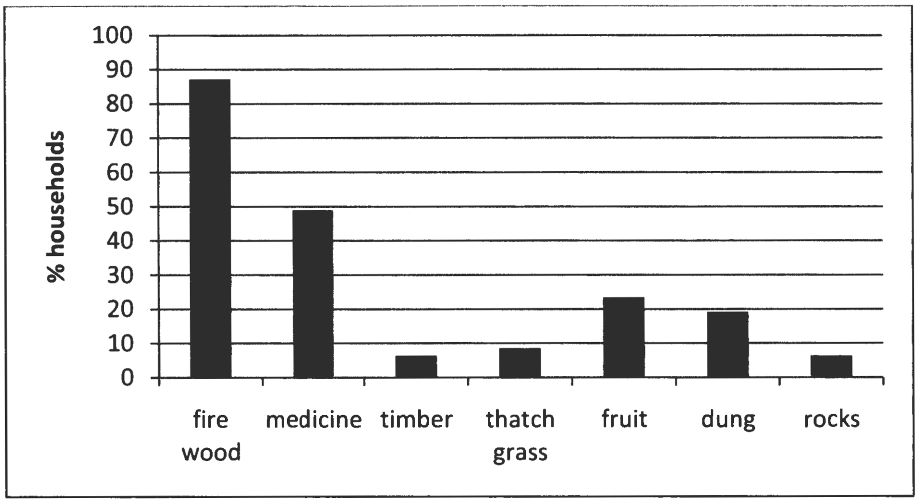

Figure 5.45 Rangelands uses for non-pastoral purposes as identified by Hinana villagers

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The value of the rangelands as a source of different resources was in the following order: firewood, medicine, fruit, dung, thatch grass, rocks and timber. On this basis it can be concluded that residents have a motivation to conserve the rangelands and biodiversity.

5.4.3.6 Sources of household energy

Household sources of energy were investigated with a view to assessing the extent to which their exploitation affected land degradation. Figure 5.46 is a summary of patterns of household sources of energy for cooking. There were cases of households which stated that they used single sources of energy as follows: paraffin (12.5%), firewood (8.3%), and electricity (6.25%). It was also very commonly found that most households used combinations of different sources of energy. These combinations can be ranked in

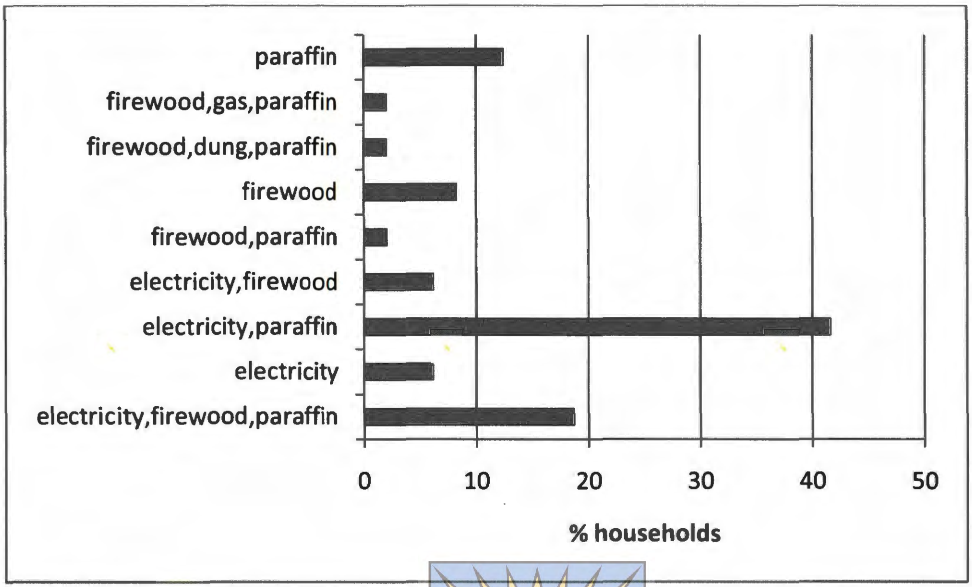

Figure 5.46 Patterns of household energy use in Hinana village

descending order as follows: electricity and paraffin (41.67%), electricity, firewood, and paraffin (18.75%), electricity and firewood (6.25%), firewood, gas, paraffin (2.08%), firewood, dung, and paraffin (2.08%), firewood and paraffin (2.08%). If the total number of households making use of each source of energy is aggregated by type of energy used the results will be as shown in figure 5.47. As shown, 79.2% of households

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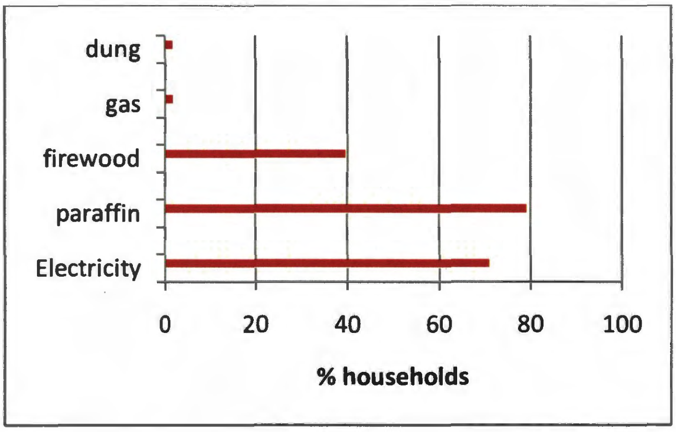

Figure 5.47 Source of energy use by households (total for exclusive use and combined use) in Hinana, 2008

use paraffin, 70.8% used electricity, 39.6% used firewood, while 2.08% used gas, and another 2.08% used cow dung. Most of the households use electricity for lighting and charging cellular phones. They say the electricity costs too much to use for cooking. Figure 5.48 shows energy source for cooking in Senqu municipality in 2001. The pattern of energy source use for cooking reflects the same pattern as for Hinana village. Paraffin was the main source at 53% of households, followed by wood at 27%, electricity at 13%, dung and gas, each at 4%, and coal, solar and other sources at minor percentages.

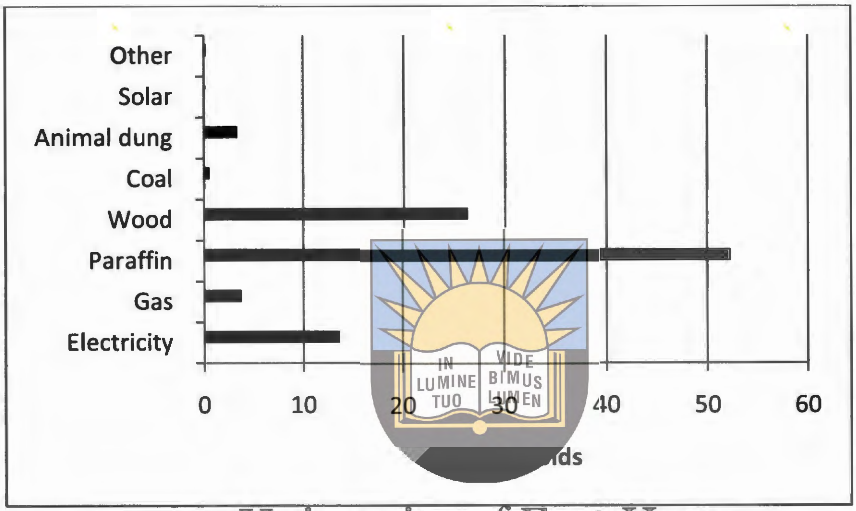

Figure 5.48 Energy source for cooking in Senqu municipality, 2001

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The implications of all this in the context of land degradation are that a substantial number of households use fuel wood as a source of energy for cooking; 8.3% use wood exclusively and other groups use wood in combination with other sources. Altogether 39.6% of households use wood. This places demands on the available scrub forests to supply the much needed fuel wood. If the deforestation for fuel wood purposes is not carefully managed, it becomes an increasing contributor to land degradation. Some

2.08% of households use animal dung as a source of energy. The collection of dung from the rangelands for fuel purposes means that in certain localities the land is deprived of this much needed source of phosphorus and nitrates. This contributes to the chemical degradation of the rangelands manifested through deficiencies in these minerals.

5.4.3.7 Application of manure to the land

Thirty-six percent of the householders responded that they applied manure to their lands (Figure 5.49). This response was interesting as most of the arable lands had not recently been ploughed. On further probing it emerged that residents were referring to the last time they had tilled their lands; in many cases several years had passed since then. One group (27.34%) indicated that they did not own any livestock and therefore did not apply manure to the field. Another group (24.62%) said they had no land on which to apply manure. A fourth group (12.46%) said that they owned livestock but did not apply manure to the land. With the exception of a few home gardens in

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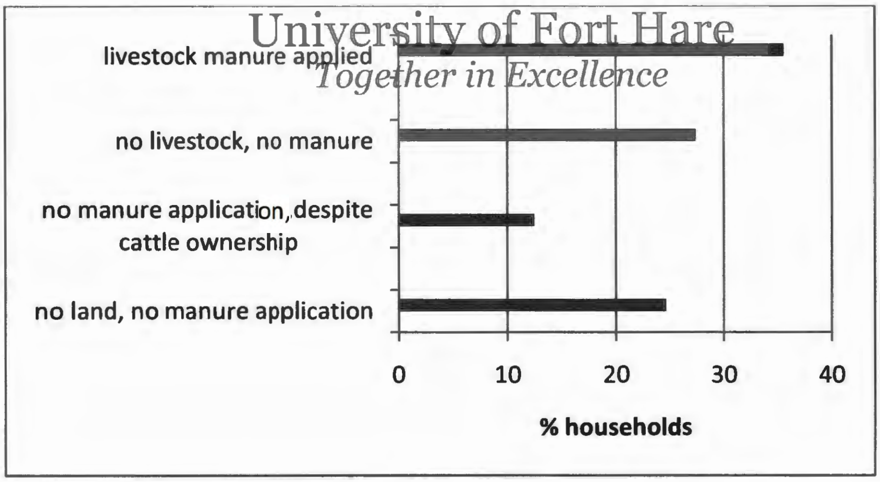

Figure 5.49 Application of manure to the land by % households in Hinana village

Hinana (and also in Magwiji) there was not much evidence of application of manure to the fields in recent times. The non-application of manure to the fields to replace depleted nutrients means that gradually the arable lands became more and more deficient in phosphorus and nitrogen.

5.4.3.8 A case of tragedy of the commons?

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About 32% of households in Hinana and 22% of households in Magwiji did not own any livestock (Figure 5.32 and Figure 5.33). The patterns of livestock ownership in these two villages raise a number of issues in the context of communal rangeland use. It is obvious that a few fairly well off families have access to more than their fair share of grazing land – they use their own share and the share of the people who do not own any livestock. They do so at no cost to themselves. Goats and sheep tend to be grazed on rangelands near the homesteads, leaving the rangelands further afield for the use of the cattle owners. In terms of the conservation of the rangelands what is the stake of the households who own no livestock? Indeed, what is the interest of the small livestock owners in preserving the rangelands further away from the homesteads?

The phrase 'tragedy of the commons' was coined by Garreth Hardin in 1968. While trying to make a case for legislated control of human population growth rather than encouraging voluntary family planning and birth control, Hardin used the analogy of a group of shepherds with access to a common field for grazing their sheep (Deese, 2008). Since it would cost the shepherd virtually nothing in the short-term, the rational course of action for him is to keep adding more sheep to his flock (Hardin, 1968). If all the shepherds did this, a situation would arise where the common grazing field would be so degraded as to be unable to support the sheep. In the case of the communal livestock keepers of Sterkspruit catchment, are they concerned about the sustainable utilization of the communal rangelands?

5.5 Landscape sensitivity and predisposition to degradation

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On a regional scale Sterkspruit catchment is a sensitive landscape prone to environmental degradation. It falls under Savory's "brittle environments" in terms of both inter-annual and intra-annual rainfall variability (Savory, 1988). This has an effect on vegetation growth both seasonally and in the long term. The intensity of the rain storms common to the area has the capacity to cause soil erosion. The rugged nature and general steepness of the land combine to generate large quantities of swift overland flow concentrated into incisive torrents capable of detaching and carrying away any inadequately protected soil. The appearance of apparently large bare areas in the catchment creates the impression of widespread vegetation denudation; the basal cover fluctuates with the annual rainfall patterns. Degradation as representated by bare ground is not a permanent feature – it follows rainfall patterns in terms of how they affect vegetation growth.

CHAPTER SIX

6 PRESENTATION AND ANALYSIS OF RESULTS: SITE-SPECIFIC SURVEYS

The results of the data gathering and data processing for site specific data described in Chapter 4 are presented, analysed, and interpreted in this Chapter. It is considered appropriate for site-specific data to be reported on and analysed separately from landscape-scale data.

6.1 The Physical Condition of the Landscape

The data presented in this section pertains to surveys done at the 21 sample sites used in the study. These include data on the following: the physical condition of the sites, vegetation condition, physical attributes of the soil, chemical attributes of the soil, and soil loss measurements. The data processing involved was described in Chapter 4.

6.1.1 Introduction

Table 6.1 shows the essential aspects of the land degradation index (LDI). Details of its construction are described in Chapter 4. The LDI is the result of multidimensional assessment involving the variables soil looseness, sand deposition, animal tracks, erosion severity, degree of landscape slope, and presence of gully.

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6.1.2 Land Degradation Index

The LDI was used to classify each site according to the extent of its degradation. On that basis the most degraded or extremely degraded sites were 5, 7, 8, 9, 10, 14, 17 and 18. Sites 11, 15, 16, and 19 were classified as seriously degraded. Sites 1, 3, 12, 13, and 20 fell into the moderately degraded category, while sites 4, 6, and 21 fell into the hardly degraded or non-degraded class. As can be seen from the scores for each variable on each site erosion severity and presence of gully are the two variables which contributed the most to the soil degradation index for most of the sites.

Table 6.1 Land degradation index and degradation class derived from weighted parameter values of six indices for land degradation

Site	Soil looseness	Sand deposition	Animal tracks	Erosion severity	Degree of landscape slope	Presence of gully	Degrad. Index	Degrad. class
	4	4	3	5	4	5		
1	1.6	1.6	1	4	3.2	4	**15.0**	**2**
2	2.4	1.6	2	2	1.6	4	**13.4**	**1**
3	3.2	2.4	2	4	2.4	3	**16.8**	**2**
4	1.6	1.6	2	3	2.4	2	**12.4**	**1**
5	3.2	3.2	2	5	3.2	5	**21.4**	**4**
6	1.6	1.6	1	2	2.4	2	**10.8**	**1**
7	4.0	4.0	2	5	3.2	5	**23.6**	**4**
8	4.0	4.0	1	5	2.4	5	**21.6**	**4**
9	4.0	4.0	2	5	3.2	5	**23.0**	**4**
10	4.0	4.0	2	5	1.6	3	**20.0**	**4**
11	3.2	3.2	1	4	2.4	4	**18.0**	**3**
12	3.2	3.2	1	4	2.4	3	**17.0**	**2**
13	4.0	3.2	2	4	1.6	1	**15.6**	**2**
14	4.0	4.0	2	5	3.2	2	**20.6**	**4**
15	3.2	4.0	1	4	2.4	3	**17.8**	**3**
16	4.0	4.0	1	4	2.4	2	**17.6**	**3**
17	4.0	4.0	1	5	2.4	4	**20.6**	**4**
18	4.0	4.0	2	5	3.2	3	**21.0**	**4**
19	3.2	4.0	2	5	3.2	2	**19.8**	**3**
20	3.2	3.2	1	5	1.6	3	**17.2**	**2**
21	1.6	1.6	1	2	2.4	2	**10.8**	**1**

Note: Figure in box is the value for weight of importance for the specific variable
Degradation classes: 1: Nondegraded 2: Moderately degraded 3: Seriously degraded 4: Extremely degraded

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6.2 Soil Degradation and Soil Loss

While soil erosion is the most evident form of soil degradation, *in situ* degradation of soil often predisposes the soil to erosion. This involves changes to the biological, chemical, and physical condition of the soil that adversely affect its sustainability as a medium for the growth of plant and animal life. This section examines some of these changes as they pertain to the study area.

6.2.1 Soil Physical Degradation

Physical degradation of soil is concerned with the *in situ* deterioration of the soil's physical condition. This condition of the soil is indicated by, among other things, soil penetration resistance, soil infiltration capacity, soil bulk density, and aggregate stability.

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6.2.1.1 Soil penetration resistance

The soil penetrometer resistance measurements taken at the 21 sample sites are presented in the graph in figure 6.1. The more the force (kg-cm^2) required to push the tip of the penetrometer into the soil the more resistant the soil was. Site 1 recorded the most resistance, followed by site 16 and sites 2, 11, and 15. Sites 10 and 20 were the least resistant; site 10 due to soil deposition from massive overland flow, and site 20 apparently due to limited livestock activity as it was dominated by the hardly palatable *Aristida congesta*, and therefore infrequently visited by the animals. The sites had generally been trampled by livestock while grazing, and especially while passing through the site. Penetration resistance is correlated with root growth, earthworm activity and tillage effects. These figures suggest that because of the tough nature of the soil at most of these sites new plants would not be able to easily establish themselves.

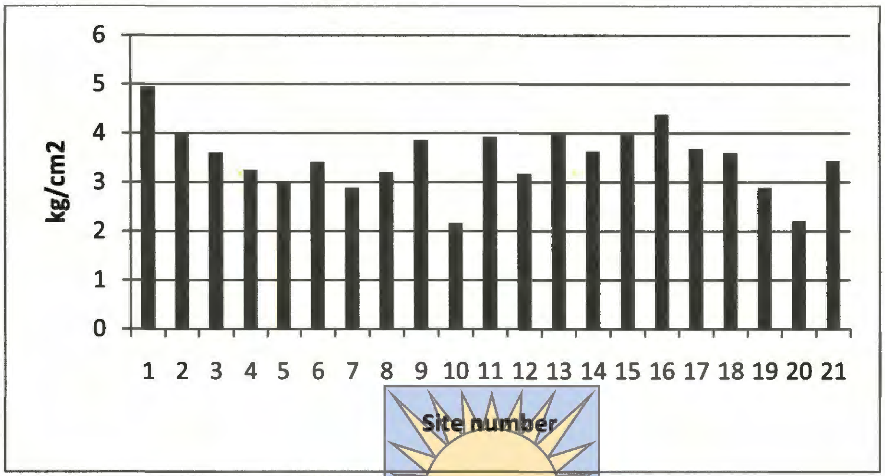

Figure 6.1 Soil penetration resistance at rangeland sites in upper Sterkspruit catchment

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6.2.1.2 Soil infiltration capacity

In general, the longer the time taken to infiltrate a given volume of water into the soil, the weaker the infiltration capacity of that soil. In the natural environment, water which does not immediately infiltrate into the soil and is not confined to some hollow will flow down the slope and become run-off lost to the soil. Soil infiltration capacity was poor at sites 12, 4, 11, 2, and 7 while it was high at sites 8, 14, 13, 15, and 16 (Figure 6.2), This was due to the fact that in a situation where testing was done before pre-wetting the soil, initial “infiltration” goes through cracks in the soil. On the whole, the infiltration capacities of the soils are generally low, setting the scene for the fast build-up of overland flow once the crevices have been filled up. The reasons for this are that the soils were once ploughed, left to lie fallow while being grazed and over the years were heavily trampled. Site 2 was heavily grazed because of the presence of a couple of springs which kept the grass greener than at other sites; it also lies in the way of the main livestock route for animals going to rangelands further afield and/or returning to Magwiji village. Site 4 used to be the location of homesteads and was not ploughed on; after Magwiji village was moved further north it became grazing land frequented by cattle and horses. Site 7 lies in the way of a livestock route just across from Magwiji village, in the proximity of an old bridge which is now broken and whose embankments lie devoid of soil cover after excavation by the strong currents of the Sterkspruit river. Sites 11 and 12 lie just south-west of Hinana village and were frequently used by herders who needed to graze their livestock near the homesteads. Sites 17, 18, 19, and 20 lie to the north of Hinana village and were frequently used by day herders who needed to be near homesteads and near a water source for their livestock. The Kromspruit River lies just to the north and east of these sites.

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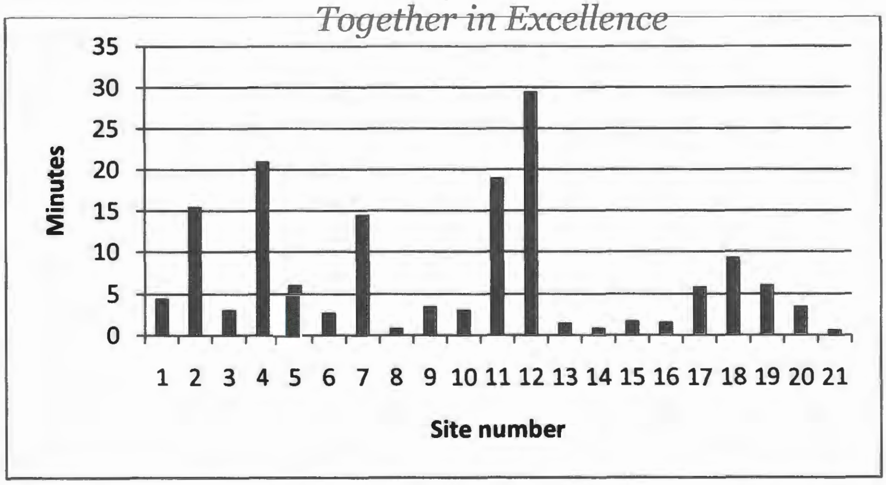

Figure 6.2 Infiltration rate (time taken to infiltrate 15 ml of water into the soil)

6.2.1.3 Soil Bulk Density

Interpretation of the measured soil bulk density (SBD) data in table 6.2 was done using the typical bulk density ranges provided by Taylor, et al (1966) as cited in Landon (1992). These ranges are as follows: 0.9-1.2 g cm^{-3} is the range for recently cultivated soils; surface mineral soils, not recently cultivated, but not compacted fall into the range 1.1-1.4g cm^{-3}; soils showing root restrictions are in the following ranges: sands and loams <1.6-1.8g cm^{-3}; silts <1.4-1.6g cm^{-3}; clays: extremely variable,

The SBDs on all the measured sites were in the range 1.38-1.78 g cm^{-3}. Sites 1, 2, 4, 5, 14, and 21 fell into the range of surface mineral soils, not recently cultivated, but not compacted (1.1 – 1.4 kg cm^{-3}). Sites 3 and 7 fell into the range of compacted silts, showing signs of root restriction (<1.4 – 1.6 g cm^{-3}). Sands and loams in the range <1.6-1.8 g cm^{-3} also experience root restriction; sites 8 and 9 were in this group. The rest of the sites fell into a category just above the "not compacted" and just below the "compacted". These sites (6, 10, 11, 12, 13, 15, 16, 17, 18, 19, and 20) were classified as "slightly compacted".

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In order to compare compaction levels between heavily used sites and lightly used sites, it was decided to identify locations which were enclosed by fairly impenetrable canopies, clumps, or fences from heavy use by livestock – as control sites for comparison with the open sites. Twelve such locations were picked in some of the sites already sampled for the SBD tests. The results showed that at sites 8 and 9 the level of compaction on the protected locations had improved from "compacted" to "slightly compacted". On sites 7, 10, 11, 12, 13, 17, 19, and 20 compaction levels had improved from "slightly compacted" to "not compacted" on the enclosed sites. The significance of these changes lies in the potential for rehabilitating compacted soils by enclosing them for pre-determined periods of time.

Table 6.2 Soil bulk density levels at sites in Magwiji and Hinana villages

Site No.	Soil texture	Open Sites		Control Sites	
		SBD	Compaction Status	SBD	Compaction Status
1	loamy sand	1.38	NC		
2	sandy loam	1.39	NC		
3	sandy silt	1.41	C		
4	sandy	1.40	NC		
5	sandy loam	1.4[illegible]	NC		
6	sandy	1.53	SC	1.51	SC
7	Sandy silt	1.55	C	1.38	NC
8	Sandy loam	1.62	C	1.53	SC
9	sandy	1.78	C	1.54	SC
10	sandy	1.56	SC	1.23	NC
11	sand	1.55	SC	1.19	NC
12	sand	1.56	SC	1.34	NC
13	sandy	1.51	SC	1.45	NC
14	sandy	1.45	NC		
15	sandy	1.53	SC		
16	sandy	1.52	SC		
17	sandy	1.51	SC	1.39	NC
18	sandy	1.58	SC		
19	sandy	1.55	SC	1.18	NC
20	Sandy loam	1.55	SC	1.26	NC
21	Clayey loam	1.42	NC	1.32	NC

Key: C: compacted SC: slightly compacted NC: not compacted

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These results are somewhat surprising as they do not paint a picture of serious overstocking in the area, as one would expect given the various reports of land degradation in Herschel-Sterkspruit (Beinart, 1987, Hofmann & Todd, 2000). Six sites did not show any signs of trampling at all, while ten sites were slightly compacted. Only four sites were compacted to the extent of resulting in root restriction. What this means is that despite apparently heavy usage communal rangelands are resilient as long as the rains are adequate.

6.2.2 Soil Loss Estimates: site measurement based

Using the measurements taken from table 4.6 soil loss estimates from gullies, rills and soil pedestals were put into graphs, figures 6.5, 6.6, and 6.7. Each type of soil loss is first examined separately, and then in terms of total soil loss.

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6.2.2.1 Soil loss from gully erosion

Figure 6.3 shows soil loss estimates based on gully measurements. Major soil losses from gully erosion were recorded for sites 14, 8, 7, 2, and 1. While losses from gullies at other sites were comparatively less, they were still quite substantial. If correction for outlier effect is applied to the mean gully soil loss value for all the sites by subtracting the highest (1435.5 tons for site 14) and the lowest (10.97 tons for site 20) values and dividing the resultant total loss (2100.95 tons) with the remaining 15 sites the mean soil loss is 140.06 tons.ha^{-1}. These are staggering amounts of soil loss by any standard. A combination of steep slopes, increased anthropogenic pressure and high magnitude storm events were responsible for the initiation and maintenance of gully erosion in Sterkspruit.

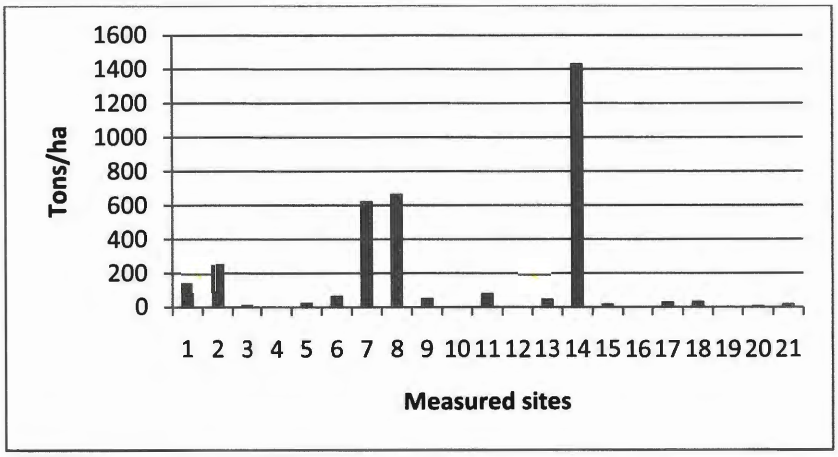

Figure 6.3 Soil loss from gully erosion at Magwiji and Hinana sample sites

An interesting feature of soil erosion in the area was that at several of the gullies (1, 2, 3, 6, 9, 10, 13, 15, 17, and 21) active erosion had slowed down or virtually stopped. A balance had been reached between erosion and deposition processes. This had happened where down-cutting had reached solid rock or the slope angle between the gully bottom and the top of the gully sides had reduced considerably with the widening of the gully. Slope angle ranged between 58^0 and 32^0. Vegetation was growing on soil deposited at the base of these inactive gullies or on gentle slopes (see Appendix H).

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6.2.2.2 Soil loss from rill erosion

Figure 6.4 shows amounts of soil lost from rill erosion on sites in Magwiji and Hinana rangelands. An enormous amount of soil (1109.38 tons.ha^{-1}) was lost through rill erosion at site 3. A huge tree on this site provides shade for several livestock and on a number of visits to the area it was observed that livestock tended to graze and linger in the vicinity of the tree and to lie in its shade while resting. The resulting soil trampling from these animals loosens the soil; this predisposes the soil to rill erosion. Other sites subjected to this type of erosion include sites 17, 8, 12, 10, 15, 1, 7, and 19.

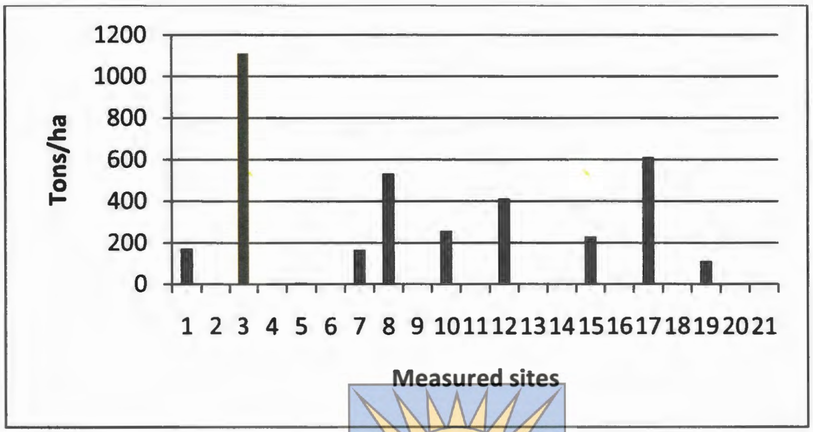

Figure 6.4 Soil loss estimates from rill erosion at sites in Magwiji and Hinana villages

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6.2.2.3 Sheet erosion

While sheet erosion had occurred virtually on all the sites, it was more pronounced in some localities as indicated by the heights of the pedestals. As can be seen from figure 6.5 soil losses through this method were quite dramatic at sites 9, 5, 10, 4, 12, 7, 3 and 20. Other sites with substantial soil losses were 17, 16, 6, 2, and 15. These sites, which had once been arable fields or homestead sites, had been converted to grazing lands and subjected to livestock trampling. The generally sandy texture of the soils predisposed them to sheet erosion once the initial soil loosening occurred.

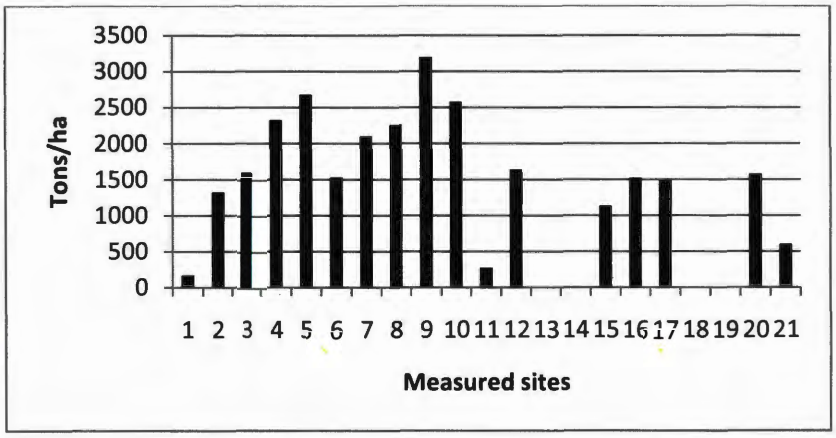

Figure 6.5 Soil loss estimates from sheet erosion at sites in Magwiji and Hinana villages

6.2.2.4 Mean soil loss estimates

A t-test was performed on the mean soil loss for the 21 sample sites to determine whether the mean soil loss values for Magwiji sites (10) and Hinana sites (10) were significantly different (Table 6.3). The means (M) and the standard deviations (SD) for the two sets of figures are taken from Table b in Appendix C. The formula and computations are based on the example in Appendix G. Critical t value at $\alpha = .05$, d.f. (10+11-2)=19=-1.729. For soil loss from gullies the obtained t is smaller than the critical t $(-0.0328 < -1.729)$. The decision is to accept the null hypothesis that there is no difference between the two means. This means that soil losses from gullies are similar in both Magwiji and Hinana. For soil losses from sheet erosion the obtained t is greater than the critical t $(-2.98 > -1.729)$, the decision is to reject the null hypothesis. The average soil loss from sheet erosion is significantly higher at $p < .05$ in Magwiji than in Hinana. For rill erosion soil losses the obtained t is smaller than the critical t $(-0.051 < -1.729)$, the decision is to accept the null hypothesis of no significant difference

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Table 6.3 Mean soil loss by type from sites in Magwiji and Hinana villages

	Magwiji		Hinana		
Soil loss method	M	SD	M	SD	t
Gully	201.07	261.51	210.20	495.59	-0.0328
Sheet	1975.44	854.89	917.12	693.75	-2.98
Rill	373.97	399.39	341.29	218.61	-0.051

t test: significant at $\alpha = p < .05$

Critical t value at $\alpha = .05$, d.f.(10+11-2)=19: -1.729

between the mean for Magwiji and the mean for Hinana. Mean soil loss from rill erosion at Magwiji is similar to mean soil loss from rill erosion at Hinana.

6.2.2.5 Soil loss distribution by method at all sites

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Comparison of soil loss by method of loss is illustrated in Figure 6.7. Soil loss from sheet erosion was prominent in rangelands of Magwiji village at sites 4, 5, 6, 9, and 10; it was also particularly manifest at sites 21, 20, 16, 15, 12, and 11 in Hinana. Gully erosion was predominant in Hinana at sites 13, 14, 18, and 11; it was also quite substantial in Magwiji at sites 1, 2, 7, 8 and 6. Rill erosion was the major contributor at site 19 in Hinana. Sites 17, 15 and 12 also in Hinana had significant losses from rill erosion. In Magwiji the effects of rill erosion were quite substantial at sites 1, 3, 7, 8, and 10.

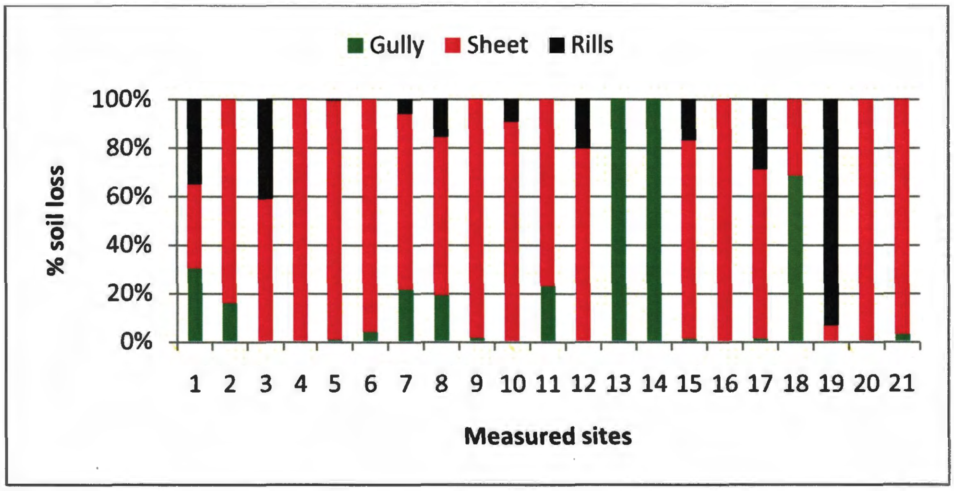

Figure 6.7 Distribution of soil loss from rangeland sites in Sterkspruit by method of loss at each site

6.2.2.6 Physical Loss of Arable/Grazing Land

On a local scale the reduction of grazing area as a result of the physical removal of part of the land mass by erosion can be quite substantial. Figure 6.8 shows the percentages of the land area lost to grazing at each site either through gully erosion alone or through gully erosion and denudation of previously ploughed land by sheet erosion, creating an

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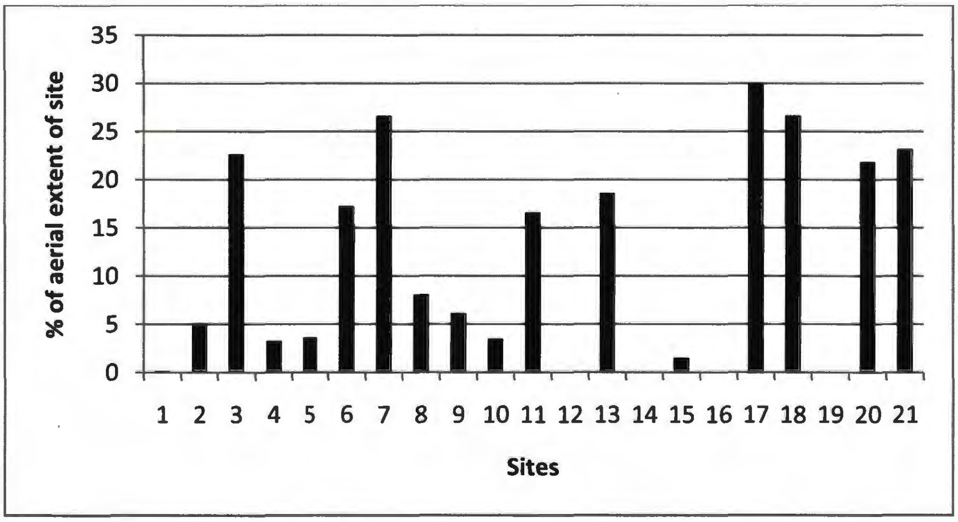

Figure 6.8 Grazing area lost to gully or bare rock-hard patches in Magwiji and Hinana

iron-hard, bare surface. These plough pan surfaces will not be of any further use for grazing as they have been denuded of all top soil and are too hard for any grass seeding to take place. They will have to be rehabilitated if they are to be used for arable or grazing purposes.

6.3 Soil Chemical Degradation

The results of the various chemical tests performed on the soil samples from Magwiji and Hinana rangelands are summarized in Table 6.4. Analysis of the results of each test is done in the sections that follow.

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6.3.1 Soil pH

Soil pH ranges between 0 and 14. Values below 7 are increasingly acidic while values above 7 are increasingly alkaline. Tests on soils sampled from the study sites recorded pH values in the range 4.55-5.87. Using criteria reported in Landon (1992) the pH values were grouped into moderately acidic soils (5.5-5.87) and strongly acidic soils (4.55-5.47). While most plants grow well in soils with a slightly acid reaction, excessive soil acidity constitutes a major chemical manifestation of land degradation as it leads to poor nutritional status of the soil, restricts root growth and is directly or indirectly conducive to other forms of land degradation. In the pH range 6.0 to 7.0 most plant nutrients are available in optimal amounts. At pH ranges below 6.0 soils will be more

Table 6.4 Results of soil chemical tests carried out on soil samples from study sites

Site	Soil pH (water)	Electrical Conductivity (µS/cm)	Potassium (mg/kg)	Calcium (mg/kg)	Magnesium (mg/kg)	Sodium (mg/kg)	Avail P (mg/kg)	Total P (g/kg)	% Organic carbon
1	5.81	76.7	231.32	5349.6	269.88	101.64	2.59	0.91	1.98
2	5.82	31.3	180.64	2441	327.92	167.88	1.77	0.31	0.68
3	5.81	37.3	228	5612.2	509.68	396.84	2.19	0.83	1.62
4	5.87	39.8	205.08	2593.4	211.76	125.88	3.51	1.36	1.76
5	5.47	69.3	378.16	2504.4	382.48	225.8	3.55	0.9	1.66
6	5.78	23.3	167.96	3940.4	131.44	186.8	3.95	1.09	1.69
7	5.66	32.6	3963.92	1560.7	210.68	465.08	2.88	0.27	0.58
8	5.83	16.72	3264.76	2898.8	234.24	936.92	3.1	0.17	0.59
9	5.61	56	4526.2	7932	464.88	2577.8	3.39	0.28	0.59
10	5.41	53.7	138.24	3063.9	236.28	84.64	3.91	0.26	0.56
11	5.28	65.4	326.92	12295	1497.72	2271.1	2.88	0.13	0.61
12	5.35	68.9	150.6	4660.4	301.2	592.68	2.64	0.22	0.54
13	5.36	67.3	109.84	4231.6	219.96	260.24	2.55	0.18	0.86
14	5.7	59.3	212.6	10698	576.36	186.92	4.27	0.23	1.27
15	5.5	93.8	153.68	5064.8	299.52	31.88	2.66	0.02	0.68
16	5.79	129	94.92	1658.8	191.52	102.64	2.21	0.06	0.79
17	5.55	62.6	108.72	2364.8	148.32	349	1.93	0.44	0.81
18	5.8	62.8	85.48	985.32	53.32	169.6	1.91	0.02	0.42
19	4.55	396	102.96	822.76	40.76	96.16	2.09	0.12	0.59
20	5.26	129.7	109.56	1638.5	65.92	86.52	4.79	0.04	0.61
21	5.21	161.8	149.24	4239.8	115.24	147.28	2.86	0.79	1.59

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likely deficient in some of the available nutrients for optimal plant growth. Calcium, magnesium, and potassium are especially low in acid soils. The high pH in many of the soils also reduces availability of many micronutrients, frequently causing deficiencies in Fe, Cu, Zn, and Mn (Tan, 1998). On the basis of the soil pH levels measured for soils in rangelands of Magwiji and Hinana villages the soils at sites 1-9, and 14-18 are moderately acidic; those at sites 10-13, and sites 19-21 are strongly acidic. This means that the soils at all the sites are degraded in terms of acidity, the only differences being in degrees of acidity.

16.3.2 Electrical conductivity (EC)

Tests conducted on soils from the 21 sites yielded results in the range 31.3-396 µs/cm Table 6.4). Critical levels are: strongly saline (>15), and moderately saline (8-15). These levels produce stunted growth in salt tolerant crops only and they have a detrimental effect on osmosis from the point of view of plant nutrition. Variations in tolerance levels may differ according to soil types: >16.1 for all soils, >9.0 for loamy sands, >9.5 for loamy fine sand to loam, and >11.5 for silty clay loam to clay (Jones Jr, 2001). The soils at all the sampled sites were found to be very strongly saline as they all had an EC way above the limits of tolerance. From the point of view of plant growth for those plants that are not salt tolerant the soils were seriously degraded.

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6.3.3 Potassium (K)

The levels of potassium found in soils sampled from study sites were in the range: 85.48-4526.2 mg/kg (Table 6.4). Potassium is the third most likely essential element to limit productivity, after nitrogen and phosphorus. In absolute levels, soils in the silt loam to clay textural range are considered sufficient in K with exchangeable K levels between 90 and 140 mg/kg (202 and 314 kg/ha), sandy soils 30+mg/kg (67+ kg/ha), and low CEC soils 50mg/kg (112+ kg/ha) (Jones, 2001). Soils in sites 2, 3, 5, 7, 8, 20, and 21 fall into the first category with K levels between 109.56 and 4526.2 mg/kg; this is well above the adequate level. Site 1, with a K level of 231.32 mg/kg is well catered for. The rest of the sites (4, 6, 9-19) fell into the sandy category and had K levels in the range 85.48-4526.2 mg/kg, which is more than adequate for this type of soil texture. Good potassium nutrition is linked to improved drought tolerance (Brady & Weil, 2002).The vegetation at all the sites is therefore provided with excellent potassium nutrition, which makes it generally drought tolerant.

6.3.4 Calcium (Ca)

The levels of calcium found in soils sampled from study sites fell in the range: 822.76-10698 mg/kg. Primary sources of calcium are calcite, aragonite, dolomite, and gypsum (Tan, 2001). Calcium is a macronutrient essential for all plants and plants use Ca in amounts second only to N and K. (Brady & Weil, 2002). The ability of a soil to supply calcium is linked to soil acidity. Depending on the test methods used, critical values indicating calcium deficiencies in soil range from <1.75 mg/kg to <18 mg/kg. For excess amounts of calcium in soil, the critical values range from >3.25 mg/kg to >45+ mg/kg, again depending on test methods (Jones, 2001: 78; note: original values converted from lb/acre to mg/kg). The results of the tests indicate excessive amounts of Ca in the soils at all the sites; critical values are exceeded in all cases, regardless of the test used. High calcium content gives the soils a more dispersive characteristic, making them more prone to erosion.

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6.3.5 Magnesium (Mg)

Tests for levels of magnesium in the soils produced a wide range: 40.76-1597.72 mg/kg. Dolomite is the most common source of Mg in soils. Mg is also contained in Mg silicates, Mg phosphates, Mg sulfides, and Mg molybdates (Tan, 2001). Like Ca, magnesium is a macronutrient essential for plant growth. While plants take up comparatively smaller amounts of Mg than of Ca, deficiencies may be detrimental to animal health. "Forages with low contents of Mg compared to Ca and K can cause grazing animals to suffer from a sometimes fatal Mg deficiency known as grass tetany (Brady & Weil, 2002). Soil moisture is a factor affecting Mg plant availability. Other factors affecting the availability and uptake of Mg by plants and animals include decreased availability with decreasing pH, low uptake by grasses, and low uptake with decreased temperature (Mayland & Wilkinson (1989), cited in Jones, (2001). Soils in the silt loam textural range are considered sufficient in Mg with exchangeable Mg levels between 150 and 350 mg/kg and sandy soils with 15+ mg/kg, being regarded as adequately catered for (Jones, 2001). The sampled soils are considered to have sufficient Mg levels in the range 40.76-1597.72 mg/kg; the uptake of Mg by grasses is hampered by the low pH levels at several sites (10-13, and 19-21) and the temperatures which are frequently quite low.

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6.3.6 Sodium (Na)

Sodium levels found in the soil samples were in the range 81.88-2577.8 mg/kg. Figures for electrical conductivity tests also showed the soils of the study area to be strongly saline. Salinity results from the presence of high amounts of chlorides and sulphates of sodium, calcium, magnesium, and potassium. Strong salinity in soils results in the decrease of the quality of soil and water and only salt-tolerant grasses, herbaceous plants, and certain shrubs and trees will grow in such an environment. The high Na amounts in the soils give them a dispersive character which predisposes them to erosion.

6.3.7 Phosphorus

Phosphorus found in mineral forms is divided almost equally between that in soil organic matter and that in various forms of inorganic matter. The inorganic P forms are primarily mixtures of aluminum, iron, and calcium phosphates; the availability of phosphorus varies with soil pH, being highest between pH6 and pH7 (Soil and Plant Analysis Council, 1992).

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6.3.7.1 Total P

Total phosphorus ranged between 0.02 and 1.36 g/kg (20mg/kg-1360 mg/kg) (Table 6.3). The interpretation is that <200 mg/kg is regarded as low; 200-1000 mg/kg as medium; >1000 mg/kg as high. The figures in Table 6.3 were converted from g/kg to mg/kg for ease of interpretation. Sites 4 (1360 mg/kg) and 6 (1090 mg/kg) had high levels of total P and were not degraded in terms of this parameter. Sites 1, 2, 3, 5, 7, 9, 10, 12, 14, 17, and 21 had medium levels of total P, while sites 8, 11, 13, 15, 16, 18, 19, and 20 fell into the low level category. During field visits it was observed that sites 2, 4, 5, and 6 were frequently grazed by livestock (site 4 by horses in particular). This might have had something to do with the relative abundance of phosphorus, an essential nutrient for livestock productivity. These sites were also near sources of water; the combination of water and phosphorus at these sites would have made them more attractive than other sites which had an abundance of one or the other.

6.3.7.2 Available P (mg/kg)

Measurement results were in the range 1.77-4.79 mg/kg. By the resin extraction method <3 mg/kg and by other methods, <4 mg/kg is regarded as extremely deficient-to-deficient; 3-6.5 mg/kg is regarded as deficient for grass and cereals. Maximum availability of phosphate ions for plant growth occurs within the pH range 5.5-6.5.

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Neither plants nor animals would grow without phosphorus (Brady & Weil, 2002). Adequate phosphorus nutrition enhances plant physiological functions such as photosynthesis, nitrogen fixation, root growth, flowering, fruiting and maturation. In relatively undisturbed natural ecosystems there is enough phosphorus in the biomass and soil organic matter to maintain a substantial amount of vegetation. In lands that have been disturbed or degraded through clearing, harvesting and other anthropogenic activities substantial losses of phosphorus occur in eroded soil particles, in runoff water and in biomass removals. The capacity of the soil to supply phosphorus becomes so depleted that re-growth of natural vegetation is patchy and crops on agricultural land fail to produce useful yields.

Phosphorus deficiency is particularly critical in leguminous plants (expected to replenish soil nitrogen) as it inhibits effective nodulation, thereby retarding the biological nitrogen-fixation process. Deficient in both phosphorus and nitrogen, these plants cannot provide sufficient vegetative cover to prevent heavy rains from washing away the surface soil. The resultant erosion will further reduce soil fertility and water holding capacity.

The appearance of the 'abandoned fields' turned into rangelands in many parts of Sterkspruit catchment can be put down to phosphorus deficiencies. The common practice of not kraaling cattle overnight means that while under cultivation the old fields were not adequately manured as there was insufficient manure to apply to the majority offields. Many are covered with short grass and sparsely distributed trees and shrubs. All sites fell into the low category for total P (- < 200 mg/kg), and into the deficient–to-extremely deficient category for available P (- <4 mg/kg). Available P is especially deficient for cereals and grass species; this makes natural vegetation recovery particularly difficult, and is compounded by the seasonal defoliation due to grazing. Continuous grazing throughout spring and summer means that vegetation hardly has sufficient time for maturing and seeding before being grazed.

6.3.8 Organic C

Organic C ranged between 0.42 and 1.98%; <2% is regarded as very low, 2-4% as low, 4-10% as medium. The element carbon, which is the foundation of all life, is contained in all organic substances. SCM exists in the form of crop and microbial residues and humus; crop and microbial residues upon decomposition, are the source for a number of essential plant nutrient elements such as, nitrogen (N), phosphorus (P), and boron (B) (Soil and Plant Analysis Council, Inc, 1999). In this sense, SOM acts as a slowrelease nutrient reserve for large amounts of plant nutrients, especially for nitrogen. SOM contributes to soil structural stability and the water-holding and cation-exchange capacities of the surface soil. The formation and stabilization of soil aggregates are largely due to certain components of soil organic matter (Brady & Weil, 2002). As can be seen from the % range of organic C on all sampled sites, the level of SOM in the soil is very low. Low levels of SOM also means deficiencies of nitrogen and phosphorus in the soil. Such low levels of soil organic C in the soil indicate that while soil nutrients were taken out of the soil through agricultural activities they were not replaced. This constitutes serious soil degradation in terms of its loss of fertility and deficiencies in a number of soil nutrients.

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6.4 Soil Quality and Land Degradation

Soil chemical degradation was considered in the context of the land degradation index (LDI) calculated for the study area. The idea was to see if there was any relationship between chemical land degradation and general land degradation.

6.2.4.1 Soil pH, EC, and organic C as manifestations of land degradation

The mean values for the soil variables pH, EC, organic C, K, Na, Ca, Mg, available P, and total P were computed on the basis of the four degradation classes as shown in table 4.8. They were arranged according to the level of degradation of the sites in terms of the land degradation index (LDI) (Table 6.5).

Though the differences between the categories were not substantial, the soil pH level decreased generally with increasing land degradation. It fell into the range 4.55-5.87; this is the category of acidic to strongly acidic soils. Soil acidity was a problem of the soils of the sample sites on the whole; it increased with increasing levels of land degradation. Except for the uncharacteristically high level of electrical conductivity (EC) for site 19, which pushed up the average considerably in the seriously degraded class, the EC levels did not show a trend with increasing land degradation. All the values were noticeably higher than 15, which is the threshold for strongly saline soils. This means that levels of soil salinity at all sites constitute acute land degradation. The organic C levels of the sampled soils were generally low, falling into the range 0.42-1.98%; in terms of the mean values they were generally declining with increasing levels of land degradation.

Table 6.5 Effects of soil pH, EC, K, Na, Ca, Mg, available P, total P, and organic C on land degradation at sites in Sterkspruit catchment

Degradation category	pH (water)	EC	K	Na	Ca	Mg	Avail P	Total P	Org C
	0-14	µs/cm	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
Non-degraded	5.67	64.05	175.73	156.96	3303.64	196.59	3.02	0.89	1.43
Moderately degraded	5.52	75.98	165.86	287.58	4298.46	273.33	2.95	0.44	1.12
Seriously degraded	5.31	147.60	163.34	527.28	4581.00	435.16	2.75	0.12	0.65
Extremely degraded	4.95	51.33	1791.41	701.59	4134.87	295.75	3.00	0.33	0.85
SED (0.05)	0.02	3.91	1.60	0.32	140.34	23.43	0.014	0.16	0.65

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6.4.2 Influence of K, Na, Ca, Mg, total P, and available P on land degradation

The mean levels of K, Na, Ca, Mg, total P, and available P on the sample sites were also examined in the context of the land degradation index, as shown in Table 6.4.

The levels of potassium (K) decline gradually between the first three classes of land degradation (non-degraded at 175.73 mg/kg to seriously degraded at 163.34 mg/kg); however, they rise sharply for the extremely degraded sites. The average for these sites rises abruptly to 1791.41mg/kg. The levels of K at all sites are well above the critical levels for plant nutrition. This means the vegetation on all the sites was generally adequately supplied with K, which it needs to cope with the drought-prone climate of the study area. The sodium (Na) levels found in the soil samples fell in the range 81.88-2577.8 mg/kg. The mean levels of Na increased with increasing land degradation and their greatest manifestation was at sites 11, 13, 14, 15, and 16 which fall into the most degraded category. The levels of calcium (Ca) in the soil samples fell in the range 822.76-10698 mg/kg. As the table shows mean Ca levels were found to increase with increasing land degradation. However, the seriously degraded sites had a higher mean Ca level than the extremely degraded sites.

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The levels of magnesium (Mg) in the soil samples fell in the range 0.76-1597.72 mg/kg. Mean levels show an increase with increasing levels of land degradation. In terms of Mg requirements for vegetation and livestock nutrition these levels do not indicate any deficiencies.

Levels of available phosphorus (P) in sampled soils fell in the range 1.77-4.79 mg/kg. Their mean values did not differ much between non-degraded and degraded sites.

Levels of total phosphorus (P) on all sites fell in the range 0.02-1.36 g/kg. The mean values showed a progressive decline from the non-degraded to the extremely degraded sites. The generally low levels of phosphorus on all sites and the falling levels of P with increased levels of land degradation are a serious indication of land degradation. Plants need phosphorus for their growth and other physiological functions such as rooting, shooting, flowering and fruiting. Any plans to rehabilitate the degraded land will have to consider replenishment of phosphorus levels in the soil.

6.5 Vegetation Condition Assessment

An examination of the condition of the vegetation in a landscape can be a fairly good indication of whether or not land degradation has occurred in the area. A preliminary assessment can be made on the basis of a visual inspection; this can then be followed by a more detailed assessment based on vegetation transect data.

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6.5 .1 Vegetation Degradation Indices

The variables used in the computation of the visually based vegetation degradation index (VDIv) were grass cover, palatable species abundance, plant species richness, grass height and grazing area lost to gully.

6.5.1.1 The VDIv

The five variables were used to generate the VDIv which was finally categorized into four degradation classes. These were: 1: non-degraded (moderately degraded), 2: badly degraded, 3: seriously degraded, and 4: extremely degraded. The VDI classes were then used to assess the degradation status of each of the 21 sites, as illustrated in Table 6.6. From the table it can be seen that sites 7, 18, and 19 are the most degraded in terms of vegetation condition; sites 1, 2, 4, 20, and 21 are the least degraded. The rest of the sites fell either in class 3, denoting that they were extremely degraded (sites 8-12), or they fell in class 2, that was badly degraded (sites 3, 5, 6, and 13-17). It is worth noting that sites 7, 9, and 10 are the nearest to Magwiji village and sites 11 and 12 are the nearest to Hinana village, and are therefore subject to intense grazing

Table 6.6 Vegetation degradation index based on visual assessment (VDIv)

Site No.	Grass cover	Abundance of palatable species	Plant species richness	Grass height	Grazing area lost to gully	VDIv	Vegetation Degradation Class
	(5)	(4)	(3)	(4)	(3)		(1-4)
1	4	2.4	2	2	2	2.7	1
2	4	2.4	2	2	2	2.7	1
3	3	2.4	2	2	1	2.2	2
4	4	2.4	2	2	2	2.7	1
5	3	2.4	1	2	2	2.3	2
6	4	1.6	1	2	1	2.3	2
7	2	1.6	1	2	1	1.6	4
8	3	2.4	1	2	2	2.1	3
9	3	1.6	1	2	2	1.9	3
10	3	1.6	1	2	2	1.9	3
11	3	1.6	1	2	1	2.1	3
12	3	1.6	1	3	2	2.3	2
13	3	1.6	1	3	1	2.3	2
14	2	1.6	1	4	2	2.2	2
15	3	1.6	1	3	1	2.3	2
16	2	2.4	2	2	2	2.2	2
17	2	1.6	2	2	1	2	3
18	2	1.6	1	2	1	1.6	1
19	2	0.8	1	2	2	1.4	1
20	3	1.6	2	3	1	2.4	4
21	4	3.2	2	2	1	2.9	4

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pressure from animals which graze within sight of their owners or herders working for them.

This relationship between the VDI class and the degradation status is also captured in the histogram in Figure 6.9 which shows an inverse relationship between bar height and overall degradation status. It shows at a glance the comparative degradation levels at the various sample sites.

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Figure 6.9 The vegetation degradation index: the shortest bar indicates most degradation and the tallest bar indicates least degradation.

6.5.1.2 The VDIt

The data from the transect-based survey was used in the computation of the VDIt (Table 6.7). Increaser II species was substituted for palatable species abundance as there exists an inverse relationship between them. Basal cover was substituted for grass cover. The category for abundance of trees and shrubs was left out as several sites had neither trees nor shrubs. It was substituted for by the category on karoo invasives. From the table it can be seen that sites 10, 9, and 8 are the most degraded; sites 13, 14, 15, 21, 1, 3, and 20 are the least degraded. The rest of the sites fell either in class 3, extremely degraded, or class 2, badly degraded. This relationship is also captured in the histogram in figure 6.10 which depicts an inverse relationship between bar height and degradation status. The histogram will be used in the construction of a composite degradation index based on both transect-based data and visually-based assessment data.

Table 6.7 Vegetation degradation index based on transect data (VDIt)

Site No	**Basal cover cm**	**Inc II SPP %**	**Invasives (karoo) %**	**Grass biomass Kg ha^{-1}**	**Grazing area lost to gully %**	**Plant SPP Richness Total SPP**	**Vegetation Degradation Index**
	(5)	**(4)**	**(3)**	**(4)**	**(3)**	(3)	
1	3	4	0.6	2.4	1.2	3	2.37
2	4	4	0.6	2.4	0.6	3	2.27
3	2	2.4	1.8	1.6	1.8	2.4	2.33
4	5	4	0.6	2.4	0.6	3	2.1
5	4	4	0.6	2.4	0.6	1.8	2.4
6	2	2.4	1.8	2.4	1.8	0.6	2.17
7	1	1.6	1.8	1.6	2.4	2.4	1.97
8	1	1.6	2.4	1.6	0.6	1.2	1.4
9	1	3.2	1.2	1.6	0.6	1.2	1.47
10	1	0.8	3	1.6	0.6	1.2	1.37
11	2	3.2	1.2	2.4	1.8	1.8	1.9
12	4	4	0.6	3.2	0.6	1.2	1.93
13	4	3.2	1.2	3.2	1.8	2.4	2.63
14	2	3.2	1.2	4	0.6	1.8	2.47
15	3	4	0.6	3.2	3	1.8	2.43
16	5	4	0.6	2.4	0.6	2.4	2.17
17	4	4	0.6	2.4	3	1.8	2.8
18	3	4	0.6	1.6	2.4	1.8	2.4
19	3	3.2	1.2	1.6	0.6	1.2	1.8
20	3	4	0.6	3.2	2.4	0.6	2.3
21	4	4	0.6	3.2	2.4	1.2	2.4

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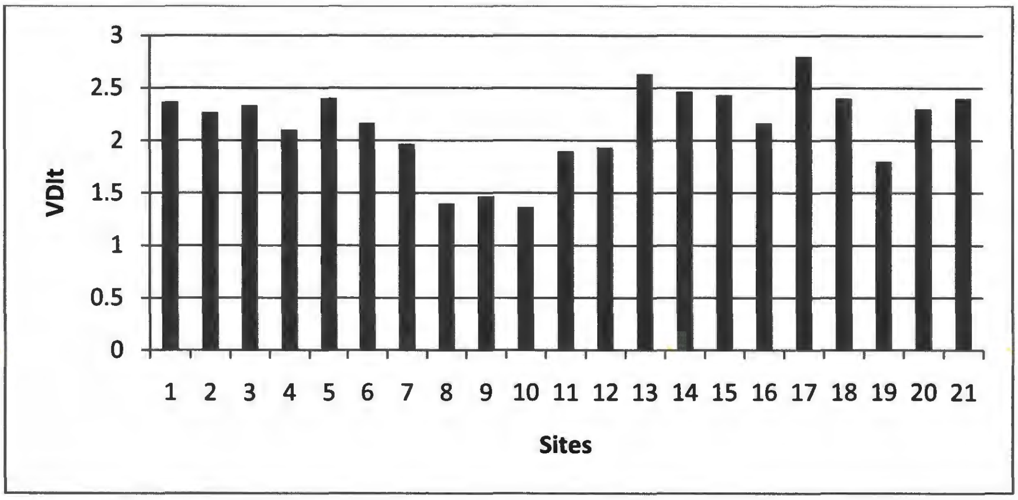

Figure 6.10 Vegetation degradation index based mainly on transect survey.

6.5.2 Vegetation data analysis

Aspects of vegetation considered relevant to land degradation assessment include the amount of basal cover provided by the herbaceous layer, biomass productivity of the herbaceous layer, and grass species composition changes in response to grazing pressure. Table 6.8 shows vegetation analysis data for each of the 21 sites, namely grass basal cover, percentage grass species composition by ecological status, grass height, and grass biomass productivity.

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6.5.2.1 Grass basal cover

Grass basal cover on the basis of point-to-plant distance was high on nine sites (2, 4, 5 in Magwiji; 12, 13, 16, 17, 20, 21 in Hinana), moderate-to-low on six sites (1 and 6 in Magwiji; 14, 15, 18, and 19 in Hinana), and very low in five sites (3, 7, 8, 9, and 10, all in

Table 6.8 Vegetation analysis data showing basal cover, ecological status in terms of vegetation response to grazing, and grass biomass productivity

Site No	Basal cover cm	Invasives (karoo) %	Decreasers %	Increaser I %	Increaser II %	Grass biomass Kg ha^{-1}	Grass height cm
1	3.58	2	0	0	98	1106	2.04
2	1.62	4	6	0	90	1125	2.07
3	6.14	18	0	0	82	1034	1.90
4	1.22	2	0	0	98	936.5	1.72
5	2.24	0	12	4	84	989	1.82
6	4.46	16	0	0	84	963	1.77
7	8.86	16	0	10	74	865	1.59
8	45.56	22	0	18	60	1008	1.86
9	6.6	12	2	7	78	1034	2.12
10	8.36	36	0	4	52	988	1.99
11	5.46	10	1	16	72	922	1.5
12	1.51	2	0	7	90	1137.4	2.07
13	1.9	12	1	10	54	1156	2.13
14	4.77	8	0	[illegible]	39	1548.4	3.13
15	3.19	5	4	10	70	1161.4	2.14
16	1.17	3	18	23	50	832	1.28
17	0.99	2	0	33	31	760.5	1.17
18	4.68	5	6	11	53	728	1.12
19	3.1	8	0	0	71	676	1.04
20	2.49	2	2	19	61	1265.2	2.36
21	1.41	4	14	28	54	902.94	1.43

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Magwiji) (Table 6.7). If percentage grass basal cover is used as a measure (Figure 6.12), high basal cover (50% +) was recorded at sites 2, 4, and 6 in Magwiji and sites 16, 17, and 21 in Hinana. Moderate basal cover (30-49.99%) was recorded at sites 1 and 5 in Magwiji, and sites 12, 13, 14, 15, 19, and 20 in Hinana. Low basal cover (0-29.99%) was recorded at sites 3, 7, 8, 9 and 10 in Magwiji, and sites 11 and 18 in Hinana.

6.5.2.2 Basal cover and soil protection

Earlier studies have shown that reduced basal cover due to grazing pressure has contributed to soil loss from erosion (Du Toit & Aucamp, 1985; Snyman, *et al*, 1985). However, there have been instances where basal cover has responded negatively to protection from grazing and fire (Angassa & Baars, 2001; Jacobs & Schloeder, 2002). In the latter case the dominant perennial grasses were resilient under grazing but defoliated when not grazed or subjected to a burning regime.

Figure 6.11 illustrates the basal cover and point-to-plant distances for each of the 21 study sites in Sterkspruit catchment. The seven sites with low basal cover (0-29.99%) and the eight sites with moderate basal cover (30-49.99%) provided evidence that the landscape was exposed to considerable soil erosion by running water as they all fell into the two highest categories for soil erosion severity (3, 4) on the soil degradation index.

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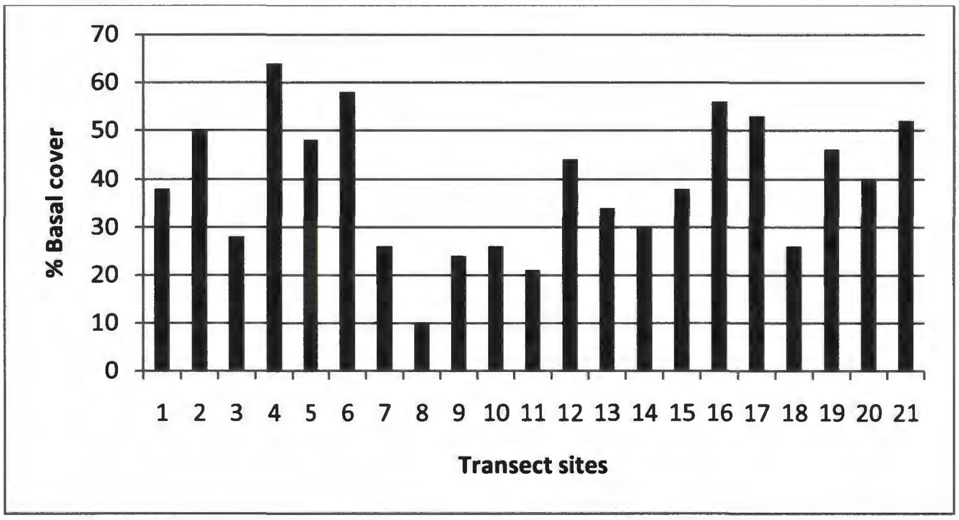

Figure 6.11 Basal cover at rangeland sites in Sterkspruit catchment

This was especially true in the context of the generally steep slopes and intense rain storms that are common in the area. In addition, fairly large bare patches comprising an "iron hard" plough pan on north-facing upper slopes in former-fields-turned-rangelands were observed. The bare patches appear to have resulted from swift flowing overland flow descending from the mountains detaching and sweeping along any loose soil from the fallow fields - slope wash (Larsen, et al, 1999). Because of the hardness of the surface and the lack of top soil, pioneer weed species and other species which normally follow in the succession sequence have not been able to colonize these bare patches. While they were observed on several of the sites the most evident in terms of aerial extent were on sites 1, 3, 4, 8, and 17; they were devoid of any top soil and contributed to the build-up of massive amounts of run-off during rainfall events. A variation of this is a plough pan with some vegetation which nevertheless can barely protect the soil (Figure6.12). Gully erosion, rill erosion and sheet erosion occur in the area as a consequence of inadequate soil protection from vegetation in many localities of the catchment; these have been dealt with in section 6.3.

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Figure 6.12 Sparse vegetation on a plough pan on a slope north of Hinana village

6.5.2.3 Grass biomass productivity

A t-test was applied on the mean grass biomass productivity for the 21 study sites to determine whether there was any statistically significant difference between the mean for the 10 sites in Magwiji and the mean for the 11 sites in Hinana. Table 6.8 shows the means (M) and the standard deviations (SD) for the two sets of figures taken from table 6.9. The formula and relevant computations are as shown in Appendix G. Because the obtained t is smaller than the critical t (-0.035 < -1.729), the decision is to accept the null hypothesis that there are no significant differences between the means of the two data sets at the chosen confidence level. So the mean biomass productivity for Magwiji and Hinana villages were not significantly different.

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Table 6.9 Mean grass biomass productivity from sites in Magwiji and Hinana villages

	Magwiji		Hinana		
	M	SD	M	SD	t
Grass biomass	10048.5	1004.85	11089.77	1008.161	-0.035

t - test: significant at α = p < .05
Critical t value at α = .05, d.f.(10+11-2)=19: -1.729

6.5.2.4 Grass species composition

The predominance of increaser II species at the expense of other species is evident (Table 6.10). Categorizing plants into decreasers, increasers, forbs, and invaders indicates, to some extent, the ecological status of the rangeland, whether it has been optimally, heavily, lightly or selectively grazed (Trollope, 1992). Grass species are further categorized according to their life cycle attributes into perennials, annuals and forbs. The life cycle of a species has some significance to its ecological status. While annual and other ephemeral species are of relatively high value in terms of protein and digestibility, they are short-lived and tend to decompose rapidly in moist environments (McKeon, *et al*, 2004). Perennial grasses and palatable shrubs are suited to variable climates as they provide a continuous supply of forage through the inter-annual and intra-annual climatic oscillations.

Sterkspruit catchment has a variable climate and perennial species are ideal for coping with the prevailing plant growth and maintenance moisture regime. They produce and

Table 6.10 Grass species characteristics at [illegible]tes in Sterkspruit catchment

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Site No.	Increaser II (%)			Increaser I (%)		Other species (%)			Life Cycle		
	Inc IIc	Inc IIb	Inc IIa	Inc 1b	Inc 1a	Decreasers	Invasives	Other	Perennials	Annuals	Other
1	52	42	4				2		6	1	2
2	50	36	4			6	4		6	1	2
3	48	32	2				18		6	1	2
4	50	36	4			6	4		6	1	2
5	30	32	16		4	12		6	5		2
6	34	42	8				16		6		2
7	24	48	2		10		10		6		2
8	26	20	14		18		22		5		2
9	46	24	14			2	12	2	7		3
10	32	20	8		4		36		7		3
11	55	15			16	4	10		8		2
12	66	26			7		1		7		3
13	42	26	18		10		4	2	8		3
14	39	8			18		8	27	8		3
15	62	10	5		11	4	5	3	9		3
16	38	11	8		2	18	3	20	9		4
17	22	10	11		33		24		11		2
18	30	22	16		9	6	15	2	12		3
19	27	42	3		4		13	11	9		3
20	39	22	16		23	2	2	6	8		5
21	27	40	1		14	14	4		8		3

store reserve nutrients and their leaves and stems are long-lived, enabling them to survive droughts which may last over two years (Van Oudtshoorn, 1992; McKeon, *et al*, 2004). Perennial grasses also seem resilient to overgrazing (Savory, 1988) and because of their longer roots they make better use of rainfall than annual grasses. They provide nutritive value through rapid response to rainfall events that are inadequate for germination and establishment of annual and ephemeral species (McKeon, *et al*, 2004), and they stabilize the surface soil, thereby protecting it from erosion by wind and water. As can be seen from the table the grass species on all the study sites were made up mostly of perennials, which appear to have adjusted well to grazing pressure and frequent droughts. From the point of view of grazing value and soil protection the loss of these perennials in a rangeland constitutes serious degradation.

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6.3.2.5 Species Dominance at Sites

Table 6.11 shows the grass species identified at all the 21 study sites in Sterkspruit catchment, their ecological status with regard to response to grazing pressure, their grazing value, and the number of sites at which each species was identified and SPP average % presence on all sites. The grass species are assigned a forage factor or grazing value (on a scale of 0-10) based on how palatable they are to grazing animals. The seven most common grass species found at all the sites in terms of average abundance in transects are *Eragrostis chloromelas* (23.1%), *Aristida congesta* (12.57%), Karoo invasive grasses (9.95%), Forbs (9.71%), *Hyperrania hirta* (8.05%), *Cynodon dactylon* (4.9%), and *Eragrostis plana* (4.76%). These grasses are hardly of any grazing value, with forage factors ranging from 0 to 2, except for *Hyperrania hirta*, at a moderate score of 4. The only species of fairly high grazing value are *Andropogon appendiculatus* (7) and *Heteropogon contortus* (7) and these were found at two sites only, being sites 2 and 3. Apart from *Hyperrania hirta*, which was found at thirteen sites,

Table 6.11 Grass Species Dominance at Study Sites in Sterkspruit Catchment

Species ID	Ecological status	Grazing value (0-10)	Sites where species present	Species average % on all sites
Eragrostis capensis	Decreaser	4	14	4.52
Andropogon apendiculatus	Decreaser	7	3	0.43
Heteropogon contortus	Decreaser	7	5	1.33
Bracaria serrata	Decreaser	2	1	0.09
Helichrysum odoratissiumum	IncIa	0	7	1.57
Hyparrhenia hirta	IncIb	4	13	8.05
Sporobolus africanus	Inc IIa	2	5	1.05
Eragrostis chloromelas	Inc IIb	2	21	23.1
Eragrostis curvula	IncIIb	4	1	0.09
Merxmuellera disticha	IncIIb	2	7	2.43
Cynodon dactylon	IncII2c	2	13	4.9
Eragrostis superba	Variable	2	1	0.09
Eragrostis plana	Inc IIc	2	14	4.76
Eragrostis lehmanniana	Inc IIb/IIc	0	9	1.67
Aristida congesta	IncIIc	0	21	12.57
Tregus berteronianus	IncIIc		3	0.57
Microchloa caffra	IncIIc	0	9	1.09
Pennisetum clondestnum	Inc2c		7	2.8
Forb	IncIIc	0	21	9.71
Karoo	Invader	0	20	9.95
Paspalum dilatatum	Invader	4	3	1.05

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three species of moderate grazing value were identified: *Paspalum dilatatum* (4) at three sites, *Eragrostis curvula* (4) at one site, and *Eragrostis capensis* (4) at fourteen sites. The rest of the grass species are of little or no grazing value (2 to 0). This point can be illustrated by examining the species *Aristida congesta*. The grass hardly has a leaf area, its wiry stem lacks moisture, and it produces and propagates a lot of seeds.

This state of affairs shows that while these rangelands may appear to have considerable basal cover they are badly degraded in terms of supporting grazing animals.

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6.5.3 Woody species composition at study sites

Woody species were also assessed and Table 6.12 is a summary of the species identities and % coverage at the study sites. Only nine sites had any significant woody species cover. A number of the bushes such as *Acacia mearnsii, Glasocoma telifolis, Pasarona, Rhus longespina* and *Stoebe Stoebe vulgaris* were of invasive Karroid species. The presence of these bushes in grazing lands indicates a form of degradation of the rangelands as it represents invasion of grassland by woody species. It was observed that people in Magwiji make use of some of the woody species for building purposes and for wood fuel. Although *Acacia mearnsii* was the predominant species along the rivers upstream of the Holohlahatsi dam, villagers collecting firewood ignored it in preference for other species with qualities that make for more efficient combustion. The first five sites had been saved from serious exploitation for wood because of their

Table 6.12 Woody Species Identified at Study Sites in Magwiji and Hinana Villages

Site No.	% cover	Species ID	Ave Height (m)	% of total cover
1	60	*Opuntia oruculada*	2.5	5
		Acacia mearnsii	3.5	15
		Lucorcidia serialis	2.4	60
		Glasocoma telifolis	1	10
		Pasarona	1.2	5
		Rhus longespina		5
2	65	*Lucorcidia serialis*	2	60
		Pasarona	1	20
		Rhus longespina	1	5
		Rasmosas paredi	2.5	5
		Acacia mearnsii	0.6	6
		Diasparos lyciodis	2.5	4
3	40	*Lucorcidia serialis*	3	70
		Pasarona	1	10
		Diasparos lyciodis	3	2
		Ramosas paredi	2	5
4	40	*Lucorcidia serialis*	2	50
		Pasarona	1	20
		Diasparos lyciodis	3	5
		Ramosas paredi	2	5
		Rhus erosa	1.5	2
5	50	*Lucorcidia serialis*	2.5	60
		Pasarona	1	10
		Diasparos lyciodis	2.5	3
		Ramosas paredi	3	20
		Rhus erosa	1.2	1
6	0	none	n.a.	n.a.
7	25	*Chrysocoma telifolis*	0.6	80
		Diasparos lyciodis	0.5	3
		Rhus erosa	0.5	2
		Planted aloes (conservation)	1.6	15
8-15	0	none	n.a.	n.a.
16	25	*Stoebie vulgaris*	0.4	90
17	30	*Stoebie vulgaris* (green)	0.3	90
18	20	*Stoebie vulgaris*	0.3	90
19-21	0	none	n.a.	n.a.

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relative inaccessibility from the village; they are located upstream of the Holohlahatsi dam and getting to the sites involves travelling some seven kilometers on the precipitous slopes on either side of the dam, or climbing up and down the considerably high mountains. Site 7 comprised mostly short bushes of *Chrysocoma filifolis, Dysparos lycioides, Rhus erosa*, and some aloe species which had been planted by the villagers as part of a gully reclamation project. Sites 16, 17, and 18 had some *Stoebe vulgaris* bushes which had invaded the rangeland. Though the *Stoebe* species are supposed to be unpalatable to livestock, goats were observed browsing them, perhaps out of desperation, in the absence of more palatable species.

6.5.4 Rangeland condition

The ascribing of ecological status of grass species and forbs on the basis of their reaction to grazing has important implications for land degradation. Some grass species are palatable and are more preferable to grazing animals than the other species. Species of low grazing value "invade" some rangelands as part of the process of plant succession resulting from sustained grazing intensity – thereby acting as indicators of the degradation status of the rangelands. Using data from the vegetation condition assessment field procedures, grass species identified in the field were classified according to the relevant terminology into decreasers, increasers, and invaders; they were put into tables and/or graphs for analysis. The classification used in this study was taken from Trollope, *et al* (1990: 60). Forage factors were taken from Trollope (1986).

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Rangeland condition in Magwiji and Hinana grazing lands was characterized according to grass species response to grazing (figure 6.13). For ease of analysis, the species descriptors can be characterized in terms of grazing quality indicator codes as follows: Increaser IIc (very excessively overgrazed), Increaser II2b (excessively overgrazed), Increaser IIa (moderately overgrazed), Increaser Ia and Decreasers (selective grazing), and Invasives (unpalatable). In the context of this terminology all sites were found to be excessively-to-very excessively overgrazed to some extent, with the percentage of Increaser IIc and IIb species ranging from 32% (site 17) to 94% (site 1). Very excessively overgrazed sites include site 12 at 94%, site 15 at 70%, and sites 11, 13, 19, 20, and 21 at between 50% and 70%; the rest of the sites have Increaser IIc species percentages of below 50% (22-48%). When Increaser IIc and Increaser IIb species

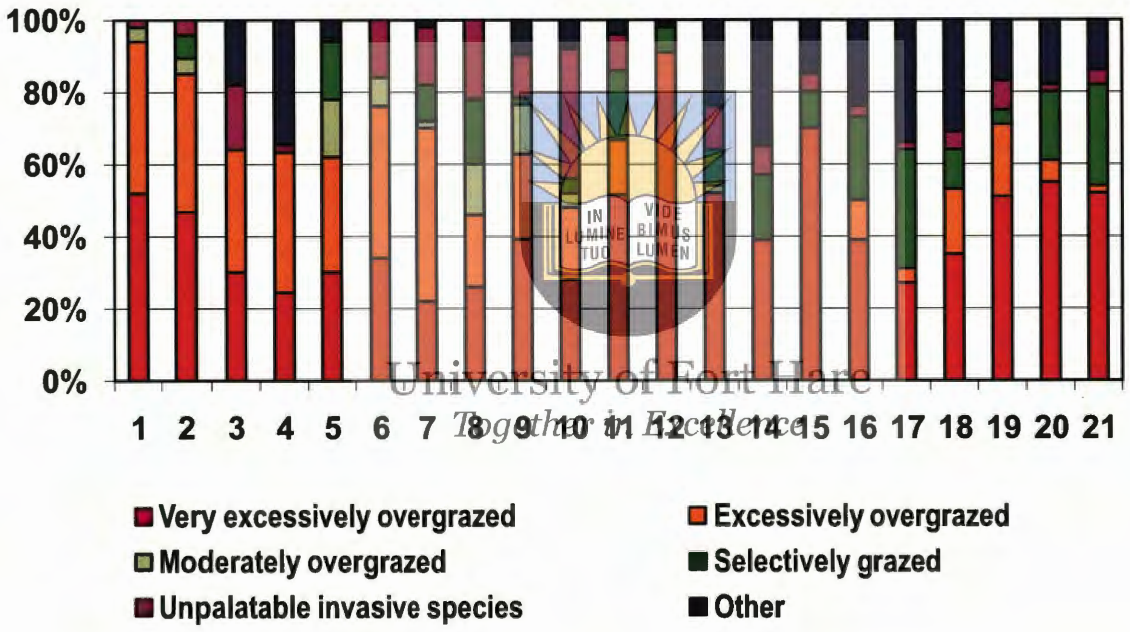

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Figure 6.13 Rangeland condition in Magwiji and Hinana villages based on grass species response to grazing

scores for each site are combined a total of 17 sites fell into the category excessively overgrazed-to-very excessively overgrazed (combined score of over 50%). Species indicating some undergrazing /selective grazing were quite substantial at site 17 (33%), site 21 (28%), site 20 (25%), sites 11 and 16 (20%), sites 14 and 8 (18%), site 5 (16%), sites 15 and 18 (15%), and sites 7 and 13 (10%). The graph in Figure 6.12 depicts the rangeland condition (in terms of responses to grazing) at the various study sites.

Unpalatable invader grass species had colonized a number of sites. In particular, sites 3 (18%), 6 (16%), 8 (22%), 10 (36%), 17 (24%), 18 (15%) and 19 (13%) have substantial amounts of invasive grass species. Such high percentages of invasives are a manifestation of degradation of the rangelands as these grasses are hardly of any grazing value.

6.6 Synthesis of site-specific findings

According to the evidence of the LDI, only three sites were not badly degraded; the rest were at various stages of degradation, with erosion severity and presence of gully as the main contributors to the land degradation index. Physical soil degradation was indicated by soil strength as shown by relatively high penetration resistance readings. Soil bulk density measurements at sites 3, 7, 8, and 9 showed signs of compaction to the extent of interfering with root growth. The rest of the sites did not have high values as one would expect from a heavily trampled landscape. The generally low organic content of the soils was consistent with high SBD. Hydraulic gradient between upper slopes at the base of the mountains and ravine/valley bottoms set the stage for powerful overland flow; concentrated flow from inter-spur slopes resulted in sheet and gully erosion in certain localities.

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Chemical soil degradation was investigated. Soil chemical indicators revealed high exchangeable calcium and sodium percentages in the soil. This explained the soils' predisposition to gully erosion. Soils were highly acidic as indicated by pH levels; soils were highly saline as indicated by EC tests. Phosphorus deficiency and generally low levels of organic C were some of the indicators of the poor condition of the soil.

Grass species composition changes had occurred in response to sustained grazing pressure (and frequent droughts); this was shown by the predominance of increaser II species and perennials at the expense of other species at most of the sites.

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CHAPTER SEVEN

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7 THE NEXUS OF LANDSCAPE SENSITIVITY, LAND USE DYNAMICS, AND LANDSCAPE RESILIENCE IN LAND DEGRADATION IN STERKSPRUIT CATCHMENT: A SYNTHESIS

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One intriguing question is why an environmental apocalypse has not occurred in Sterkspruit as a result of its long history of land degradation and despite its dire circumstances, as portrayed in previous studies (Beinart, 2003; Bundy, 1979; MacMillan, 1930). It is suggested that a degree of equilibrium has been reached between the landscape's propensity for environmental degradation (sensitivity), land use changes over the years (dynamics), and the landscape's ability to adjust to degradation and, to some extent, to recover from it (resilience). The effects of frequent droughts in the area, which include the appearance of bare patches denuded of vegetation, often create the impression of widespread degradation. However, following the return of the rains the hitherto preserved grass seeds germinate in the loose soil of the trampled rangelands; the bare patches recover and become green with vegetation. This is borne out by the analysis of the land cover change maps which is provided in Chapter 5 (Figures 5.1 and 5.2).

7.1 Landscape Sensitivity

Landscape sensitivity is the capacity of the landscape to respond to environmental perturbations. It refers to the response of landscape systems to disturbance or damage on different temporal and spatial scales (Thomas, 2001). Sensitivity has to do with instability versus stability of a landscape (Miles, *et al*, 2001). Stable systems are those that absorb progressive change over time and only become unstable when threshold values of system parameters are exceeded (Thomas, 2001). Unstable or 'fragile' systems are those that are sensitive to small perturbations. It is suggested that Sterkspruit catchment is environmentally sensitive landscape in terms of its climate, the quality of its soils, and its land use history.

7.1.1 Climatic variability

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In terms of rainfall amounts the area experiences frequent droughts. If drought is defined as rainfall below average Sterkspruit TNK station recorded 31 years of below average rainfall in the period 1940-1998, Bensonvale, 29 years between 1940 and 1992. This translates to 52.5% of the years of record for Sterkspruit TNK and 54.7% for the years of record for Bensonvale. Some of the droughts lasted for several years at a time; for example, at Sterkspruit TNK, from 1992 to 1997, and at Bensonvale from 1980 to 1985. In addition to the inter-annual and intra-annual rainfall fluctuations linear trend lines on rainfall graphs for stations in the area indicate an overall continuous decline in rainfall amounts over the years (Figures 5.10-5.15).

The droughts have devastating effects on the vegetation and livestock of the area. Their effects are exacerbated by the high temperatures which are sometimes experienced in the area, as evidenced by figures of up to 36.7^{0}C for January and up to 23.5^{0}C for July (Els, 1971). With a mean annual evaporation rate of 1500-1600 mm for the area (Midgley, *et al*, 1990) the high temperatures result in moisture stress for crops or crop failure. In the rangelands annual plants die off during the droughts, resulting in bare ground; perennial plants may survive but will be under intense grazing pressure. When the rains return in the form of the intense thunderstorms characteristic of the area the previously parched landscape is exposed to erosion by the resulting large amounts of run-off. Several of the stock dams built during betterment implementation – have been silted up or have had their walls breached by massive volumes of overland flow.

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7.1.2 Landscape geometry

In the highland areas the landscape is configured in such a way as to create barriers to the free movement of livestock between different parts of the rangelands.

7.1.2.1 Environmental barriers to free movement across the landscape

The orientation of the mountain ranges and the sharp rise from the valleys to the mountain tops sets the scene for grazing patterns in the area. “Environmental barriers can limit the frequency of movement of individuals; they also modify the way of space utilization by influencing the shape and size of the home ranges or territories of individuals” (Dobrowolski, *et al*, 1993).

In Magwiji the main grazing camps are in the valleys and on the mountains south and east of the Holohlahatsi dam. Livestock use the valleys more frequently for grazing and for movement to the different parts of the rangelands. The mountain pastures are not easily accessible and are not used by livestock as much as are the valleys. Consequently, the valleys show more evidence of degradation in the form of livestock tracks and overgrazed patches. The rangelands near the homesteads are naturally confined by the mountains to the south and east of the villages and the restriction of movement of small livestock, bulls and horses to this area has resulted in considerable land degradation.

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In Hinana village the rangelands near the homesteads are set up on a plateau around the mountains. Movement to other rangelands involves negotiating a sharp descent through a restricted number of exits to the river below and onto the mountains across the river. This means that livestock are frequently confined to the home rangelands and are moved from and onto the plateau through a restricted and predetermined number of routes. The effect of all this is to predetermine the pattern of livestock pressure on the land and, ultimately, the resulting land degradation patterns. In this sense landscape processes “...be they of physical, ecological, psychological, or technical kind, are controlled by the spatial organization of their environmental setting" (Gullinck, *et al*, 1993).

These patterns of livestock movement and confinement are replicated in other villages near the mountains, such as Jozana's Nek, Voyizane, Mangweni, and Bhongolethu. In other villages in the lower areas of the catchment such as Bensonvale, Tapoleng and Magadla, livestock movement is not as confined by physical barriers since grazing areas are open to more intense pressure. Here there tends to be more bare ground in the dry season and in drought years than in the higher areas. However, when the rains return the bare patches are once again reduced in size as the grass comes to life.

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7.1.2.2 Active terrestrial planation cycle

In terms of WM Davis' model based on terrestrial planation theory of a normal landform development cycle where fluvial erosion plays the main role (Wardenga, 2004) the highland areas of the catchment are in the 'juvenile stage', with narrow valleys; the lowland areas are in the 'mature stage' with wider valleys and inter-valley ridges. The Witteberge mountains were formed by the headward erosion of rivers into the almost horizontal beds of the Beaufort series and the degradation process is still active; "... vertical gully or donga-erosion is the immediate result of the slightest disturbance of any of the components in the delicate natural balance between soil types, slope, vegetation, intensity of precipitation and rainfall-run-off relationship" (Els, 1971: 12). This makes the area highly susceptible to erosion. The concentrated flow of run-off in the steep inter-spur valleys accounts for some of the most dramatic manifestations of degradation in the form of piping erosion and gullies. Related to this erosion is the generation of sediments which pose a serious threat to dam capacities through sedimentation.

7.1.3 The contribution of soil quality to landscape sensitivity

As described in chapter 2 the soils of the slopes of the high ridges are generally thin with a crumbly structure derived from basaltic lava overlain by a layer of cave sandstone. This makes the soil susceptible to erosion by the massive amounts of overland flow running down the steep slopes, especially where basal cover is relatively low. In the valleys of the highland areas and in the lowland areas the light grey loam soils rest on a yellow sticky clay (duplex soils) and limestone subsoil. Sub-surface flow of run-off builds up in this situation, where permeable soil overlies less permeable substrate. The calcareous subsoil and the relatively high levels of Na detected in the soils at all the sampled sites make the soils highly dispersive and subject to gully erosion.

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7.1.3.1 Soil attributes and soil physical degradation

Soil penetrometer resistance was quite high on a number of sites such as 1, 2, 6, 9, 11, and 14. Penetrometer resistance was an indication of the degree of hardness of the soil. This soil strength was due to a number of factors, among which livestock trampling played a major role. The soil condition interferes with plant root growth and earthworm activity, making it difficult for plants to establish themselves on bare patches and for the soil to acquire adequate moisture from rainfall run-off. The hardness of the soil tended to interfere with the infiltration capacity as this was found to be quite low at sites such as 2, 4, 7, 11, 12, and 18.

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Soil infiltration capacity is related to penetration resistance in that soil hardness makes it difficult for the run-off water to penetrate the soil. Soil losses through erosion were, among other things, related to infiltration capacity and penetration resistance. Increased soil penetration resistance contributes to large amounts of runoff on steep slopes. In turn, concentrated flow of runoff in certain localities results in soil detachment and its transport to other areas of the landscape. It can be stated, therefore, that a soil with a high penetration resistance and a low infiltration capacity is predisposed to erosion and contributes to general land degradation.

7.1.3.2 Soil chemical degradation

The soils at all the 21 sites had low pH values, in particular, sites 10-13 and 19-21; this indicated that the soils ranged from moderately acidic to strongly acidic. Such acidity is indicative of nutrient deficiencies in Ca, Mg, and K, and deficiencies in micronutrients such as Fe, Cu, Zn, and Mn. The EC tests showed that soils at all the sites were strongly saline. The Na levels measured in all samples showed high amounts of sodium, confirming that all soils were strongly saline. Only salt-tolerant plants do well in such an environment.

Tests for Ca showed that all sites had excessive amounts of Ca. The resulting dispersive characteristic of the soils makes them prone to erosion. When combined with excessive sodium amounts this accounts for some of the dramatic gully erosion seen at sites such as 7 and 8. While there were adequate levels of Mg for plant nutrition at all sites, uptake of the nutrient by plants decreases with decreasing temperature and there is generally low uptake by grasses. P levels were recorded in the range 1.77-4.79 mg/kg. These levels are inadequate on the whole as 3-6.5 mg/kg is regarded as deficient for grass and cereals. Most of the sites showed phosphorus deficiency; this is serious degradation as phosphorus is essential for such physiographic functions in plants as rooting, shooting, flowering and fruiting. The generally low levels of organic C recorded at all sites (0.42-1.98%) meant that there were low levels of the essential plant nutrient elements N, P and boron (B). This clearly restricted plant growth. All in all, the combination of compacted soils generating high volumes of run-off, highly dispersive soils, and inadequate basal cover engendered by frequent droughts and plant nutrient deficiencies predisposes the soil to erosion.

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Substantial amounts of P and N are removed from the landscape along with sediments when top soil is removed by running water during the erosion process. These two nutrients are the main constituents in livestock manure; since most of the arable lands in Sterkspruit catchment have been abandoned they have not been manured for crop production. Soil tests on samples from Hinana and Magwiji villages showed low levels of organic C (source of N) and P.

7.1.4 Vegetation species composition changes in response to grazing pressure

One response by the landscape to intense grazing pressure has been the increase decreaser II species in the rangelands at the expense of other species. The graph in figure 6.13 shows levels of grazing pressure; sixteen of the study sites fell into the category of the excessively grazed to very excessively overgrazed (i.e 50+%), with the percentage of Increaser IIc and IIb species ranging from 32% (site 17) to 94% (site 1). While these species may be resilient in the face of heavy grazing, they do not offer adequate protection to the soil in terms of basal cover. By and large, they tend to have long narrow leaves. The inadequately protected soil is left exposed to erosion by running water.

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7.2 Land Use Dynamics

The history of land use changes in the catchment has some bearing on the landscape's sensitivity to environmental perturbations.

7.2.1 Land use/land cover changes (conversion of old fields to grazing land)

With a few exceptions scattered over the landscape, virtually all the old arable fields around Magwiji and Hinana villages have been turned into grazing lands. This includes all the rangelands not located in the mountains. Various reasons given for the abandonment include crop destruction by livestock no longer confined in fenced grazing camps. The fences installed during the days of the betterment programme had long been removed or vandalized to such an extent they could no longer hold back any livestock. Soil chemical tests showed that these lands had very low levels of plant nutrients such as organic C (and therefore of N), P and Mg. The state of abandonment exposes the lands to soil erosion. Previous studies have shown that abandoned arable lands were predisposed to soil erosion (Rowntree, 2003; Sonneveld, *et al*, 2005).

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Magwiji village was relocated to its present site from a site some 6-8 kilometers away, located south and southeast of the Holohlahatse dam. Study sites 1-6 in the rangelands were actually located on what used to be the sites of Magwiji homesteads and fields. The vegetation on these sites only established itself after the migration of the village and is therefore of secondary succession. Like the abandoned arable lands near the villages these rangelands are prone to soil erosion. Chemical tests on soil samples from these rangelands also showed low levels of plant nutrients such as organic C, P and Mg.

7.2.2 Socio-economic factors

An analysis of the patterns of livestock ownership and rangeland use practices in the catchment is useful in indicating their potential contribution to land degradation. They can also indicate the impacts of land degradation on the biophysical environment in the catchment.

7.2.2.1 Livestock ownership patterns

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Analysis of the livestock questionnaire survey data for Magwiji village revealed that 26.09 % of households owned 65.91% of cattle, 32.6% of households owned only 10.43% of the cattle , and 28.3% of households owned no cattle at all (table 5.3). In Hinana village a single household owned 22.5% of cattle in the sample (n=48), 39.9% of households owned 34.5% of cattle, and 52.2% of households owned no cattle at all. Small livestock ownership showed similarly large disparities in both villages, with Hinana showing greater differences between the various categories of households (Figures 5.24 and 5.25). In both these villages livestock ownership is concentrated in very few households and thus raising questions on the notion of communal rangeland resources.

Such disparities in livestock ownership between households may be a source of disagreements over how to manage the communal rangelands. The few households who can afford large numbers of livestock may continually increase their livestock numbers at the expense of the poorer households – a tragedy of the commons situation. Decisions on how best to manage the communal rangelands may not meet the needs of those who own very few animals or none at all. That may jeopardize the long-term prospects of these rangelands. The patterns of livestock ownership also raise questions as to whether the size of the human population in a given area unit by itself is an appropriate indication of population pressure. Another question is whether the wealthier livestock owner should continue to operate in a communal setting or whether he/she should move to the commercial sector.

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7.2.2.2 Droughts and changes to livestock numbers

The Sterkspruit area experienced a prolonged drought in the period 1992-1997; this was followed by droughts in 2002 and 2007. Livestock figures for the ten-year period from 1998 to 2007 showed significant differences in changes to livestock numbers in response to these droughts. Table 5.1 shows that Hinana cattle varied by a CV of 9.6% compared to Magwiji cattle at a CV of 10.7%. This culminated in a net loss for Hinana and a net gain for Magwiji (figure 5.23). Figures for goats were 38.3% for Hinana and 30.3% for Magwiji goats, representing a net gain for Hinana and a net gain for Magwiji. The sheep figures were 47.6% for Hinana sheep and 24.4% for Magwiji sheep, translating to a net loss for Hinana and a net gain for Magwiji. Short-term changes due to drought or disease outbreaks can be quite devastating to the farmer. For Magwiji the longer-term overall numbers leveled off positively; for Hinana there were net losses, except for goats. Some farmers provided supplementary feeds for their animals while the poorer ones suffered losses. Drought predisposes rangelands to degradation in terms of the quality of grazing and browsing resources; livestock numbers decline or rise in tandem with changes in the quality of the rangelands.

7.2.2.3 Rangeland use patterns and their impacts

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The rangelands are used for communal livestock grazing. Magwiji village has 8 grazing camps situated in the valleys and mountains south and east of the Holohlahatsi dam. The grazing camps at Magwiji are separated from the surrounding countryside by the rugged and steep terrain of the mountains surrounding them. They are used virtually exclusively by the livestock owners of Magwiji. Cattle are not regularly kraaled but are kept in the camps continuously and they are only brought to the villages once every week for inspection as well as for dipping. The rangelands next to the homesteads are used for grazing by livestock such as goats, sheep, and horses. A fenced area, which belonged to one household is used for grazing by bulls and horses; other householders could apparently bring their bulls and horses to graze by arrangement.

The camps in Hinana are in the mountains to the southwest, south and east of the village. Unlike the case of Magwiji, the Hinana camps are not exclusively controlled by the people of Hinana. Since the removal of the betterment fences the camps are more accessible and subject to use by people from other villages. The rangelands near the homesteads are used for goats, sheep, and horses. The practice of not kraaling (free ranging) cattle means that there is no accumulation of manure in the kraals and, ultimately, no manure application in the fields. While P attached to soil particles is washed away in overland flow, replacement of P through manuring of the abandoned arable lands was hampered by the non-kraaling practice of the cattle raisers. Even where goat and sheep manure was available it was hardly applied since most of the fields were no longer being cultivated. The low levels of soil organic C in the soils is also related to the fact that due to grazing pressure hardly any organic matter in the form of dead grass or leaves accumulates on the ground.

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Non-livestock uses of rangelands include as sources of firewood, thatch grass, soil and water used for brick moulding. Areas immediately next to homesteads were used as home gardens, nutrition gardens near the river in Magwiji and several other places. This contributes to the agro-biodiversity (biodiversity) of the rangelands. Each village had a designated sheep shearing shed where, once a year, sheep were sheared and the wool sent to the market. Mixed use of rangelands for cattle, goats, and sheep is considered healthy for the sustainability of the rangelands.

The lands next to the homesteads are used as home gardens or as orchards with mostly peach trees. This pattern is repeated at other locations in the catchment. In Magwiji some nutrition gardens are found next to the Sterkspruit River, which is the source of the irrigation water used in these gardens. Further down the river there are other gardens belonging to different villages. Also in Magwiji, across the river and to the east of the village, a fairly large area has been fenced off from the rest of the rangelands, and is used for grazing bulls and horses. The grass cover is quite good and consists of *Hyperrania hirta*, *Themeda triandra*, and other species. Brick moulding activity was carried out next to rivers at several locations in the catchment. A tourism project was being developed around the dam; it consisted of chalets for accommodating tourists and planned activities included fishing, hiking and mountain climbing. While these activities helped to diversify the livelihoods of the catchment area the wastes from brick moulding activity tended to contribute to the sedimentation of the surface water sources.

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7.3 Landscape Resilience

A landscape's ability to recover from or to adjust fairly easily to environmental perturbations is referred to as its resilience. Ecological resilience refers to (i) the capacity to absorb or to repair ecosystem functions in the wake of a shock or damaging activity, and (ii) the degree of disturbance that can be absorbed before an unpredictable and convulsive change in system function occurs (Holling, *et al*, 1998).

7.3.1 Gully stabilization and sediment entrapment

Gullies that have reached the bedrock, or have accumulated sediment at their bases, or have stopped cutting back, stabilize. Vegetation grows at their bases and on the sides.

While a gully will not fill up on its own it may undergo some partial recovery (see Appendices H and I). Gullies at sites 1, 2, 3, 8, 9, 10, 11, 15, 17, 18 and 20 showed signs of stabilization. One result of erosion is the sedimentation of reservoirs and rivers. However, not all sediment that is carried down the slope ends up in the rivers and dams. Some of it is spread on the landscape and this was quite evident at two sites (sites 10 and 12). As indicated, the penetrometer resistance and infiltration capacities of these sites are noticeably different from the rest. Gully stabilization and sediment entrapment on land are aspects of resilience as they illustrate the landscape's adjustment to degradation. Such sites have the potential to be fully rehabilitated through human efforts.

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7.3.2 Drought-resistant and perennial grasses

Measurements for K showed that all the sites had adequate amounts. K enables plants to develop drought tolerance attributes. This is a useful survival strategy in this drought-prone area. On all the 21 study sites the majority of the grass species were perennials (table 6.6). These grasses are more resilient than annual grasses and many of them can survive droughts and provide the soil with some kind of protection against erosion.

7.3.3 Drought cycles and post-drought recovery

Available records show that the Sterkspruit area has had a long history of droughts – in the sense of below average rainfall. Sterkspruit TNK recorded 31 years of drought in a 59-year period, while Bensonvale recorded 29 years of drought over a 53-year period. Some of the droughts lasted for several years at a time and were often accompanied by crop failure and livestock losses. What is remarkable is that when the droughts ended and the rains returned the bare patches recovered and became green once again. Livestock numbers recovery, either through calving or through replacement purchases, took longer to recover, as there usually is a time lag between the end of the drought and full recovery. An analysis of changes in livestock numbers for Magwiji and Hinana villages over the ten-year period 1998-2007 showed net gains in cattle, goats and sheep for Magwiji. For Hinana village, net gains were only in goat numbers. It is relevant to note that serious droughts had occurred in 1992-1997, 2002 and 2007. Once again Magwiji had recovered whilst Hinana village was taking longer to recover. Those farmers who had been able to do so had resorted to providing supplementary feeds for their livestock. A previous study found that despite drought-induced fluctuations livestock numbers for the area had remained at more or less the same level for almost 100 years (Vetter, 2003).

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7.3.4 Mixed rangeland use

The practice of common use of rangelands by mixing cattle, goats and sheep is seen as a more efficient use of rangeland resources. Grass, forbs, and browse are utilized much more uniformly than would be the case with one species of animal. While cattle grazing leaves the grasses shorter and less coarse, thus making them more palatable to goats and sheep, the goat's use of browse plays the role of biological brush control. The common use practice contributes to landscape resilience as it has the effect of balancing the overgrazing tendency of any one group of animals.

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7.3.5 Ground water and surface water availability (springs, rivers, dams)

The Sterkspruit catchment is well endowed with natural springs many of which are quite prolific. They provide water to livestock during the dry season and during the many droughts that occur in this area. The Sterkspruit Rver is perennial in nature both above the dam and below the dam wall. The Holohlahatsi dam just to the southeast of Magwiji village has a large capacity and provides many of the communities in the catchment and their livestock with water. The Kromspruit River also provides much needed water but when a drought lasts for two or more seasons many sections of the river dry up. These sources of water help to sustain life and to enable the people and their livestock to go through drought periods and to bounce back when the rains return. They add to the resilience of the landscape.

CHAPTER EIGHT

8 CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the key findings as well as the conclusions and recommendations of the study. It does so in terms of the nexus between landscape sensitivity to environmental perturbations, land use history, and landscape resilience. It suggests the way forward for solutions to some of the observed problems and possible further research.

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8.1 Conclusions

The study confirmed that land degradation had occurred in Sterkspruit catchment over the years. The most visible manifestation of degradation was soil erosion, with gullies, rills, and sediment deposits. Gullies are evident in several parts of the catchment such as around the villages of Magwiji, Sunduza, Hinana, Mlamli, and Voyizane. Sediment deposits are evident along the sides of the untarred roads and in the many stock dams that have been silted up. Rill erosion is evident in the numerous sites of the sediment deposits. The variable climatic conditions and land use changes had predisposed the land to degradation and livestock grazing pressure had precipitated the land degradation. Soil erosion was due to a combination of very erodible soils and highly erosive intense rainfall. The soils were generally sodic in nature with limestone-rich sub-soils, making the soils highly dispersive.

The vegetation of the area has been transformed from mountain grassland of medium height to a secondary form of short grassland. Hard plough pan areas with very little vegetation on them are observable on north facing steep slopes in abandoned arable lands. During the dry season, and in drought years, areas of bare ground become apparent in several parts of the catchment. However, with the return of the rains most of these areas experience either partial or full recovery as the bare areas are covered with vegetation. Very few trees are visible in the lowland areas, and these are mostly in the river valleys and around the villages. The mountain areas have trees in the valleys, mountain tops, and mostly on south facing slopes. A more insidious form of land degradation involved changes to grass species composition and, in the mountain areas, bush encroachment on grassland in response to sustained grazing pressure.

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Land degradation has had a number of effects on the biophysical environment of the area. In the rangelands, degradation manifested itself through reduced grass basal cover, low biomass productivity (especially in the dry season), changes to grass species composition, and bush encroachment on grassland. Palatable annual grass species had been replaced by less palatable perennial grasses in response to sustained grazing pressure and the frequent droughts common to the area.

The physical and chemical condition of the soil was also impacted by land degradation in several ways. As indicated by soil penetration resistance and infiltration capacity tests soils at many of the sites were hard and on the whole, the infiltration capacities of the soils were generally low. This created ideal conditions for the fast build-up of overland flow once the crevices have been filled up. The reasons for this are that the soils were once ploughed, left to lie fallow while being grazed and over the years were heavily trampled. Soil chemical tests indicated high levels of soil salinity and acidity; there were deficiencies in nutrients such as organic C, P and Mg.

The landscape had over the years adapted to the degradation, and in some ways had recovered from it. Soils in the sampled sites had adequate quantities of K, enabling them to withstand the drought conditions frequent to the area. Generally, more resilient grass species had replaced the less grazing-tolerant species. In several locations gullies had stabilized and several had stopped any further erosion. Some of the degradation was more apparent than real. This was especially so with respect to bare ground. Much of it was bare in the dry season or in drought years; with the return of the rains the bare patches were gradually covered by vegetation.

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The deterioration in the quality of the land had led to the abandonment of most of the arable land in the catchment area. With the exception of a few relatively small areas of cultivation along sections of the Sterkspruit river and on home gardens in the villages most of the arable lands were either permanently uncultivated or intermittently cultivated. Though farmers indicated several reasons for this such as frequent droughts and crop damage from livestock, declining returns from soils depleted of nutrients was a major consideration. Most of the former arable lands had been turned into grazing lands. Efforts to rehabilitate the degraded land included stone packing of gullies, fallowing, and planting grass over filled up gullies.

Several families were dependent almost entirely on government grants for their livelihood; with no arable farming, some people just use the villages for residential purposes. Those who were capable of doing so tried to earn a living through non-agricultural means and off-farm activities such as running spaza shops, piece work on projects such as brick making, construction, and road maintenance.

8.2 Contribution to new knowledge

The study's contribution to new knowledge includes the suggested more simplified, visually-based Veld Degradation Index (VDIV) for assessment of rangeland degradation. This method requires less equipment and [illegible] personnel than the step-point and disc pasture meter methods; it could be carried out by one person but intimate knowledge of grass species would still be indispensable. The quantification of grazing land lost to gully erosion is a novel idea; most studies on land degradation concern themselves with quantification of soil losses and reduction in vegetation cover. The study also proposes a catchment-wide soil loss estimation on the basis of measurements at sample sites (from a known date) – as an alternative method to the more established methods such as RUSLE and SLEMSA. In addition, the study established the fact that far from being a progressive denudation of the landscape, reduction of grass basal cover in Sterkspruit catchment was rainfall dependent. It declined with continued grazing pressure in the dry season and in drought years; it increased with the return of the rains and the recovery of the grass.

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8.3 Recommendations regarding responses to land degradation

The communal farmers' responses appear to have been to abandon arable agriculture (except for the home gardens) and turn the fields into grazing lands, to rely on non-agricultural sources of income, to provide supplementary feeds to livestock, and to purchase replacement stock after each drought. It is suggested that in addition to these measures they can embark on rehabilitation of degraded land through the following activities:

- Sediment entrapment as part of rehabilitation of slopes where erosion is still active
- Planting of leguminous trees in natural pastures to help build up of phosphorus; fencing of trees until they cannot be browsed to death
- Engaging in agroforestry activities combining livestock and trees/crops
- Kraaling of animals for accumulation of manure and spreading of manure in arable fields (to replenish P and N)
- Some controlled burning to discourage bush encroachment.
- Rehabilitation measures should avoid lengthy exclusion periods as this may lead to the death and decomposition of grass from lack of grazing.

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8.4 Recommendations regarding further research

This section looks at recommendations focusing on recovery and rehabilitation of the degraded land. The suggestions made here are in the context of sustainable rural livelihoods – integrating soil and water conservation with food security issues.

- Investigate the potential of setting up marketing infrastructure for livestock sales to encourage a culture of selling livestock when they are ready for the market
- Investigate the impediments to reviving irrigation-based agriculture in the area – to improve food security and increase the resilience of the landscape in the face of persistent droughts
- Investigate possibilities of increasing non-farm sources of livelihood for the area (apart from brick-making, spazas, tourism project around Holohlahatse dam) – to alleviate pressure on land-based livelihoods
- Investigate the feasibility of multi-faceted projects encompassing land rehabilitation, conservation and food security aspects

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APPENDIX A

Location of study sites (central position of site) for vegetation condition assessment transects

Magwiji sites	Latitude and longitude	Altitude
1	-30 39’ 4.3” x 27 23’ 0.15”	1605m
2	-30 39’ 35” x 27 22’ 43”	1605m
3	-30 39’ 1.6” x 27 22’ 6.7”	1576m
4	-30 39’ 1.2” x 27 21’30.8”	1587m
5	-30 39’ 10” x 27 21’ 35.8”	1575m
6	-30 38’ 44.5” x 27 21’ 24.8”	1576m
7	-30 37’ 59.5” x 27 21’ 30.1”	1536m
8	-30 38’ 01.6” x 27 22’ 34”	1537m
9	-30 37’ 41.8” x 27 22’ 12.06”	1524m
10	-30 37’ 50.9” x 27 22’ 11.1”	1535M
Hinana sites		
11	-30 34’ 55.3” x 27 26’ 36.5”	1661m
12	-30 35’ 00” x 27 26’ 31.8”	1665m
13	-30 35’ 2.7” x 27 26’ 27.4”	1666m
14	-30 35’ 8.9” x 27 26’ 32.8”	1678m
15	-30 35’ 10.8” x 27 26’ 19.3”	1651m
16	-30 34’ 19.6” x 27 26’ 52.7”	1642m
17	-30 34’ 19” x 27 26’ 53.2’	1670m
18	-30 34’ 11.2” x 27 26’ 51.1”	1627m
19	-30 34’ 05” x 27 26’ 51.7”	1615m
20	-30 34’ 26.5” x 27 27’ 21.4”	1600m
21	-30 34’ 33.6” x 27 27’ 39.7”	1549m

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APPENDIX B.1

Example of soil loss calculation from gully erosion (site 2)

Measurement Number	Width at lip (W_1): m	Width at base (W_2): m	Depth: m
1	17.5	5.5	1.8
2	7.1	4.3	2.0
3	9.0	7.0	1.94
4	1.4	0.5	0.96
5	18.7	0.5	1.7
6	16.0	6.0	2.5
7	10.9	4.6	2.9
8	8.3	3.4	3.5
9	2.0	2.0	2.4
10	17.4	8.7	1.9
11	17.37	8.8	3.80
12	15.4	5.6	4.4
13	13.16	2.45	5.8
14	39.0	30.0	2.8
15	24.3	18.15	3.5
16	20.0	16.2	3.13
17	14.5	10.0	2.4
18	10.2	7.4	1.4
19	9.17	6.5	1.6
20	7.1	6.1	0.6
Sum of all measurements	279.5	276.65	50.43
Average (m)	W_1 = 13.9m	W_2 = 7.7m	Depth (d) = 2.5m

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NB: To get the average, divide the sum of all the measurements by the number of measurements taken.

Procedure:

1 Calculate the average cross-sectional area of the gully, using the formula ½ **(W_1+W_2) x d**: ½(13.9+7.7) x 2.5 = **27m^{-2}**

2 Calculate the volume of soil lost from the gully whose length was measured at 530.2m. Cross-sectional area x length: 27 x 530.2 = **14315.4m^{-3}**

3 Convert the volume lost to a per meter equivalent, assuming a catchment area of 1km^2 or 1 000 000 m^2. Volume lost/catchment area: 14315.4/1 000 000 = **0.0143154 m^{-3}/m^{-2}**

4 Convert the volume lost to tons per hectare over the whole catchment area.

Soil loss x Bulk density (tm^{-3}) x 10 000: 0.01431x1.39 x10000 = **198.98 t.ha^{-1}**

APPENDIX B.2

Example of soil loss calculation from sheet erosion (site 11)

Measurement Number	Maximum height of pedestal in locality (mm)
1	140
2	180
3	100
4	130
5	200
6	70
7	130
8	160
9	200
10	270
11	200
12	140
13	300
14	120
15	180
16	130
17	290
18	130
19	80
20	300
Sum of all	3500
Ave. pedestal height	175

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Procedure: To calculate average, divide the sum of all the measurements by the number of measurements taken.

Using data from site calculate the t/ha equivalent of the net soil loss (represented by the average pedestal height). Using a bulk density of 1.55g/cm3, a 1mm loss of soil is equivalent to 15.5 t/ha.

Average Pedestal Height (mm) x Bulk Density: **175X15.5 = 2712.5 t/ha**

APPENDIX B.3

Example of soil loss calculation from rill erosion (site 10)

Measurement	Width cm	Depth cm
1	9	15
2	50	10
3	40	15
4	60	10
5	40	5
6	30	5
7	30	12
8	25	10
9	30	12
10	23	5
11	15	5
12	90	5
13	50	5
14	30	5
15	20	5
16	20	15
17	20	15
18	30	5
19	35	5
20	29	5
Sum of all measurements	682	Depth =163
Average	Width =34.1	Depth = 8.15
Length of rill = 64.6m		
Contributing catchment area to rill:54.5m²		

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NB: To get average, divide the sum of all the measurements by the number of measurements made.

Procedure:

1. Convert the average width and depth of the rill to metres (by multiplying by 0.01). In this example: (34.1)x0.01 = **0.341m**; (8.15)x0.01 = **0.0815m**
2. Calculate the average cross-sectional area of the rill using the formula for the area of an 'inverted' triangle (the shape of a rill): ½ horizontal width x depth. ½(0.341) x 0.0815 =**0.01389m^2**
3. Calculate the volume of soil lost from the rill: cross-sectional area x length: 0.01389 x64.6 = **0.89729m^3**
4. Convert the total volume lost to a volume per square metre of catchment: volume lost / catchment area = soil loss: 0.89729 / 54.5 = **0.016464m^3/m^2**
5. Convert volume per square metre to tonnes per hectare: volume m2 x bulk density x 10 000: 0.016464 x 1.56 x 10 000 =**256.84t/ha**

APPENDIX C

Soil loss at Magwiji and Hinana villages (tons.ha^{-1})

(a)

Site	Gully	Sheet	Rills
		Magwiji Village	
1	150.006	171.4236	171.4236
2	198.98	1327.45	
3	14.946	1593.3	1109.388
4		2324	
5	26.4234	2679	8.3754
6	66.6468	1530	
7	625.022	2100.25	165.788
8	668.7846	2259.9	532.008
9	54.5392	3195.1	
10	4.2432	2574	256.8384
		Hinana Village	
11	81.71445	2712.25	
12		1638	411.84
13	48.49803		
14	1435.5		
15	19.5381	1132.2	229.1481
16		1523.8	
17	31.29928	1487.35	612.0423
18	34.90536	15.9422	
19		8.4475	112.1363
20	10.9709	1577.125	
21	19.18448	599.95	

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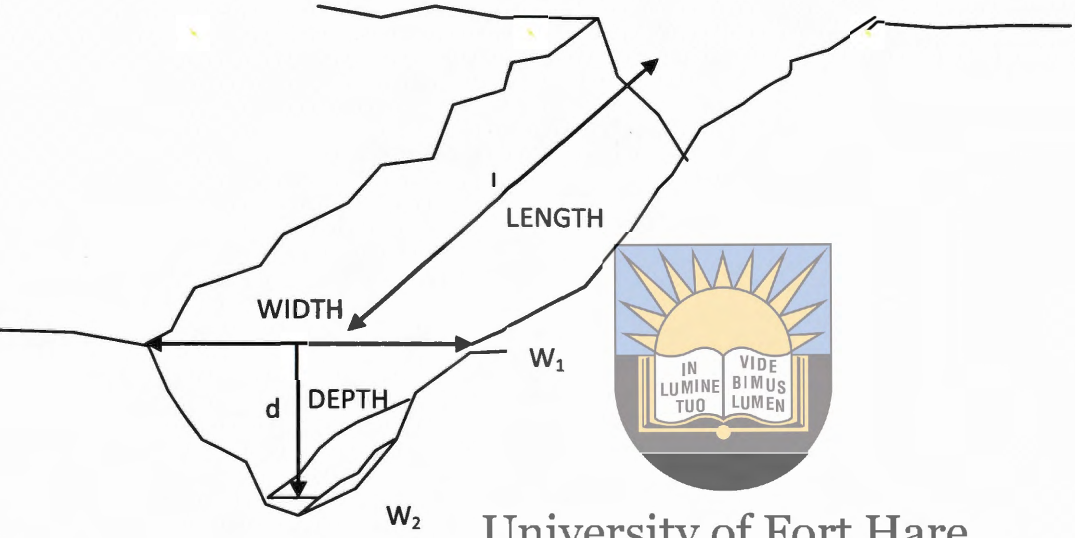
(b)

	Gully		Sheet		Rills	
	M	H	M	H	M	H
	150.006	81.71445	171.4236	271.25	171.4236	411.84
	198.98	48.49803	1327.45	1638	1109.388	229.1481
	14.946	1435.5	1593.3	1132.2	8.3754	612.0423
	26.4234	19.5381	2324	1523.8	165.788	112.1363
	66.6468	31.29928	2679	1487.35	532.008	
	625.022	34.90536	1530	15.9422	256.8384	
	668.7846	10.9709	2100.25	8.4475		
	54.5392	19.18448	2259.9	1577.125		
	4.2432		3195.1	599.95		
			2574			
Tot	1809.591	1681.611	19754.42	8254.065	2243.821	1365.167
Mean	201.0657	210.2013	1975.442	917.1183	373.9702	341.2917
STD	260.8949	495.5921	854.8973	693.7497	399.3894	218.6102

APPENDIX D

Dimensions measured in estimation of soil loss from gully erosion.



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APPENDIX E

Grass biomass productivity at Magwiji and Hinana villages

	Magwiji		**Hinana**
sites	kg.ha^{-1}	sites	kg.ha^{-1}
1	1106	11	922
2	1125	12	1137.4
3	1034	13	1156
4	936.5	14	1548.37
5	989	15	1161.4
6	963	16	832
7	865	17	760.5
8	1008	18	728
9	1034	19	676
10	988	20	1265.16
		21	902.94
Total	10048.5		11089.77
Mean	1004.85		1008.161
Standard Deviation	76.66161		268.2537

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APPENDIX F

Questionnaire Survey On Land Degradation In Magwiji & Hinana Vilages Sterkspruit

Section A: Household Demographic Profile

1. Gender Of Head Of Household

M		F	

2. Age ____

3. How many people make up your household?

Adults		Under 13s		Total
M	F	M	F	(M,F)

4. How long have you lived in Magwiji village?

	Years

5. Household income (R per month/year)

Livestock	Crops	Meat	Wool/mo hair	Eggs	Milk		Off-farm work	Other, specify

6. Household expenses

Item	Amount (R)	weekly	monthly	annually
a. Groceries				
b. fuel, transport, telephone				
c. clothing & furniture				
d. medical				
e. educational				
Total				

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7. Do you save any money in any of the following?

Institution	Amount/month (R)	Amount/year (R)
Bank		
Burial club		
Mgalelo		
Other		
Total		

8. Source of energy (heating, lighting, cooking)

Electricity	Fuelwood	Dung	Paraffin	Gas	Other, specify

9. Source of water for household use

Com'nal well	Own well	Com'nal tap	Own tap	Borehole		Other, specify
				Com'nal	Own	

10. 1 Are you a member of any farmers' organization or community organization?

Yes	☐	No	☐

10.2 If yes, which one? ____

10.3 State two advantages of belonging to this organization:

a)____

b)____

SECTION B: LIVESTOCK PRODUCTION AND RANGELAND CONDITION

11. Changes in household livestock numbers

Livestock	2002	2007	Reasons for gains/losses in livestock numbers			
			Loss due to death	Sold/slaughtered	Purchased	Natural increase (calving)
cattle			_	_	+	+
sheep			_	_	+	+
goats			_	_	+	+
pigs			_	_	+	+
donkeys			_	_	+	+
horses			_	_	+	+

12. Indicate the usefulness of each animal to you on a scale of 1-4 using the listed criteria

	meat	milk	Manure	hides	Wool/mohair	sales	Draught power	ceremonies
cattle								
Sheep								
Goats								
Pigs								
Donkeys								
Horses								

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13. What is your assessment of the condition of the rangelands?

	Mountain pastures	Lowland pastures
a. Very good condition; improving		
b. Good; plenty grass		
c. Fair; fair amount of grass		
d. Poor; some grass; bush encroachment		
e. Very poor; little grass		
f. I cannot say; do not know		

14. Seasonal patterns of grazing (0: Never; 1: Dry season; 2: Rainy season; 3: Part Rainy season/part dry season; 4: All year)

	Feeding stalls	Home gardens	Rangelands near homesteads	Harvested fields	Distant rangelands (2km+)
Cattle					
Sheep					
Goats					
Pigs					
Donkeys					
Horses					

15. Do you give supplementary feeds to any of the following? Give details.

	Type of feed	Cost/year (R)	Time of year given/season
Cattle			
Sheep			
Goats			
Pigs			
Donkeys			
Horses			

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16a. What are the sources of drinking water for your livestock?

	River	Dam	Borehole	Well	Spring	Other/specify
Cattle						
Sheep						
Goats						
Pigs						
Donkeys						
Horses						

16b. Are the water sources adequate? ______________________________

17a. List six (6) forms of wildlife members of your household have reported sighting in the rangelands (in recent times).

17b. List six products members of your household obtain from the rangelands (including from rivers and dam)

C. CROP PRODUCTION AND LAND MANAGEMENT

18. What is the size of your household's landholding in hectares: (home garden and field)

Home gardens		Field	
None		None	
0-0.40 ha		0-0.50 ha	
0.4-0.6 ha		0.5-3 ha	
0.6-1 ha		3-7 ha	
Over 1 ha		Over 7 ha	

19. State the number of trees reserved by your household as follows:

	Home garden/homestead	Field
Exotic trees		
Fruit trees		
Non-fruit trees		

Indigenous trees		
Fruit trees		
Non-fruit trees		

20. List the crops you grow on your farmland

Home garden				
Field				

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21. Describe the fertility level of your farmland and give a reason for your description.

Farmland soil fertility level		Reason (indicator)
High fertility		
Moderate fertility		
Low fertility		
Very low fertility		

22. What do you use for improving the fertility of your farmland soils?

	Home garden	Field
Cattle manure		
Sheep/goat manure		
Chicken manure		
Compost		
Inorganic fertilizers		
Other, specify		

23. List soil erosion indicators on your farmland (and in the rangelands) and their causes.

Erosion indicators	Causes
Gullies	
Stoniness	
Sedimentation	
Loose soil	
Other, specify	
Other, specify	
Other, specify	

24a. Have you ever been involved in (or would you consider joining) any community-based SWC conservation project?

	Been involved	Never involved	Would join	Would not join
Gully reclamation				
Construction/repair of contour ridges				
Other, specify				
Other, specify				

24b. If not interested in communal project, give reason

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APPENDIX G

Method for carrying out t test for two sample means

1. Hypothesis

$H_0 : \mu_1 = \mu_2$

$H_1 : \mu_1 < \mu_2$ (One tailed: Magwiji is hypothesized to be lower)

2. Formula

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma\bar{X}_1 - \bar{X}_2}$$

Where $\sigma\bar{X} - \bar{X}2$, the standard error of the difference between the means, is calculated as follows:

$$\sigma\bar{x}_1 - \bar{x}_2 = \sqrt{\frac{N_1S_1^2 + N_2S_2^2}{N_1 + N_2 - 2}} . \sqrt{\frac{N_1 + N_2}{N_1N_2}}$$

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NB: degrees of freedom = $N_1+N_2 - 2$, and the critical value at $\alpha=.05$, d.f. (10+11-2) = 19, is -1.729 (Grimm & Wozniak: 467)

3. Calculation

$$t = \frac{10048.5 - 1008.16}{\sqrt{\frac{10(76.67)^2 + 11(268.25)^2}{21-2}}\sqrt{\frac{10+11}{10(11)}}}$$

4. Decision: If obtained t is greater than critical t, reject H_0 ; if it is smaller accept H_0.

5. Discussion: State whether the two means are significantly different, depending on decision in 4.

APPENDIX H

Gully erosion and gully stabilization at sites in Magwiji and Hinana

Site	W1 (m)	W2 (m)	W1-W2 (m)	Depth (m)	Slope %	Gully status
1	10.2	3.89	6.31	2.37	58	Stable*
2	13.9	7.7	6.2	2.5	56	Stable*
3	8.746	4.747	3.999	1.438	58	Stable*
4	No gully					
5	8.24	2.52	5.72	1.94	60	active
6	6.34	2.63	3.71	1.55	53	slightly active
7	17.36	13.43	3.93	2.39	50	slightly active
8	15.33	6.4	8.93	3.62	35	stable
9	9.93	7.35	2.58	1.92	48	stable
10	3.96	1.3	2.66	1.15	39	stable
11	12.8	10.45	2.35	2.5	45	stable
12	No gully					
13	10.76	6.01	4.75	2.24	54	Slightly active
14	No gully					
15	8.15	1.99	6.16	2.23	58	Stable*
16	No gully					
17	10.78	6.21	4.57	1.22	47	stable
18	8.86	5.68	3.18	2.14	48	stable
19	No gully					
20	7.13	6.09	1.04	0.81	47	stable
21	9.07	5.176	3.894	1.65	55	active

W1: Average width of gully mouth; W2: average width of gully bottom; *stable with rocks at base of gully

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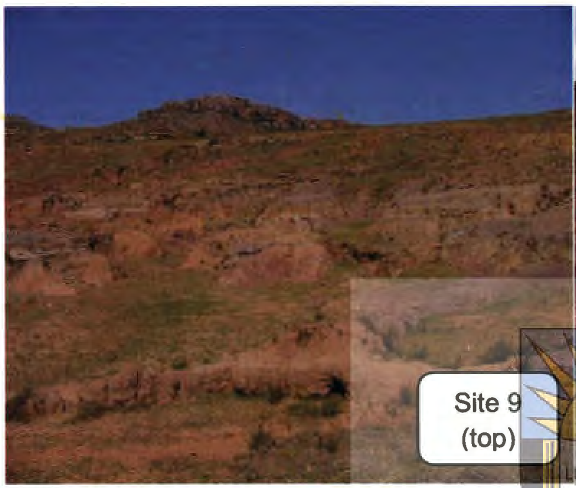
APPENDIX I

Gully stabilization at sites in Magwiji



Site 9 (top)

Site 10 (top)

Site 10 (bottom)

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