# RELATING VEGETATION CONDITION TO GRAZING MANAGEMENT SYSTEMS IN THE CENTRAL KEISKAMMA CATCHMENT, EASTERN CAPE PROVINCE, SOUTH AFRICA

**By**

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**Submitted in fulfilment of the requirements for the degree of Masters of Science at the Nelson Mandela Metropolitan University**

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**DECLARATION**:

In accordance with Rule G4.6.3, I hereby declare that the above-mentioned treatise/dissertation/thesis is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

**SIGNATURE:** _____ **DATE:** _____

## DEDICATION

This study has been made possible through guidance and protection from Almighty God. Without Him I would have not reached this stage of my academia. May His name be praised and glorified at all times. I hereby dedicate this research and effort to Him.

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## ABSTRACT

Vegetation degradation in South Africa has been identified as a serious environmental problem, especially impacting communal areas. This study investigated the spatial distribution of vegetative condition, along with related changes, deterioration and trends, across the communal villages of the central Keiskamma catchment, Eastern Cape Province. The principal hypothesis of this study was that differences in grazing management strategies may explain the variations in vegetation condition within these communal areas. This investigation assessed the status and condition of vegetation in relation to local institutional grazing management systems, in association with factoring in relevant topographical and physical elements. Topographic homogeneity of the study area was tested by extracting topographic parameters from a DEM and performing a Chi squared test.

Remote sensing techniques were used to analyse the spatial and temporal variations in vegetation condition between the villages. Landsat TM images, from 1984 and 1999, in conjunction with SPOT imagery of 2011, were used to assess the spatial trends in vegetation. Land use and cover maps were generated, comprising five categories of land cover, viz. intact vegetation; transformed vegetation; degraded vegetation; bare surfaces; and water. The classification of the images was achieved using the supervised object-oriented classification techniques, which aggregates pixels of each class into homogeneous objects. Information regarding existence and functionality of local institutional structures was obtained through structured interview method. Vegetation condition was correlated to grazing management systems, with the logistic regression confirming a significant relationship between vegetation condition and grazing management systems.

Analysis of vegetation condition trends revealed a decline in pristine vegetation with an increase in degraded vegetation and exposed soil throughout the villages. However, it was observed that the decrease in pristine vegetation, with the associated increase in degraded vegetation and soil, do not occur evenly among the villages of the central Keiskamma catchment; the communal areas surrounding certain villages exhibited severe degradation of soil and vegetation, while other villages demonstrated less or minimal deterioration in their environs. The topographic homogeneity of the study locale lent credence to the theory that the uneven distribution of vegetation conditions between the villages is not controlled by topographic factors. Analysis of the data, collected through interviews, revealed differences in the functionality of institutional structures between villages. A statistically significant

correlation between the vegetative condition and implementation of grazing management systems, supports the postulated concept that the variances in vegetation condition of the central Keiskamma catchment reflect the efficacy or inefficiency of the settlements' grazing management systems. Through gathering, analysing and assessing all the data, a conclusion was drawn, which advances that the primary requirement for remedial action in reversing the current decline in vegetation condition is strengthening the local institutional management regimes throughout all villages under study.

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| | |
|---|---|
| **ASD** | Analytical Spectral Devise |
| **CBNRM** | Community-Based Natural Resource Management |
| **DEAT** | Department of Environmental Affairs and Tourism |
| **DEM** | Digital Elevation Model |
| **NDVI** | Normalized Difference Vegetation Index |
| **GCP** | Ground Control Points |
| **GIS** | Geographical Information Systems |
| **KIA** | Kappa Index of Agreement |
| **NIR** | Near-Infrared |
| **PVI** | Perpendicular Vegetation Index |
| **RMS** | Root Mean Square |
| **RVI** | Ratio Vegetation Index |
| **SANCO** | South African National Civic Organisation |
| **SAVI** | Soil-Adjusted Vegetation Index |
| **SANSA** | South African National Space Agency |
| **SPOT** | Système Pour l'Observation de la Terre |
| **TIFF** | Tagged Image File Format |
| **SAVI** | Transformed Soil-Adjusted Vegetation Index |
| **TSAVI** | Transformed Soil-Adjusted Vegetation Index |
| **USGS** | United State Geological Survey |
| **VI** | Vegetation Index |

# CHAPTER 1

# INTRODUCTION

## 1.1. Introduction

Vegetation type and its biomass are considered significant mechanisms, affecting interactions between the biosphere and atmosphere (Roy and Ravan, 1996). Assessment of the quality and condition of native vegetation remains an essential part of ecological studies and planning processes (Parkes *et al.,* 2003). Evaluating the condition of vegetation provides information about the extent to which management affects vegetation resources (Thackway *et al.* 2006). Vegetation is essential in the carbon cycle, together with maintaining a climate balance. Vegetation condition can change over time, following different land uses, management systems and soil erosion (Oztas *et al.* 2003). Vegetation condition transformation and deterioration are major problems experienced in many rangelands, across the globe (Nyoike, 2008). Globally, economic losses due to rangeland vegetation degradation are estimated to be approximately US $7 per hectare (Arntzen, 1998). These rangeland vegetation changes are predominantly attributed to livestock grazing (Branson, 1985); which causes deterioration and reduction in vegetation species composition. According to Czegledi and Radacsi (2005), 49.2% of all forms of degradation in Africa are attributable to livestock grazing, and its mismanagement. The issue of rangeland vegetation alteration and deterioration is complex, varying in accordance with chronological and spatial elements; thus an assessment is required from ecological and anthropogenic perspectives, on both area and temporal bases (Nyoike, 2008).

In South Africa, 91% of the land is prone to land degradation (Hoffman and Ashwell, 2001). The distribution of land degradation in South Africa is perceived to closely correspond with the distribution of communal rangelands (Hoffman and Ashwell, 2001). The Eastern Cape Province is among South Africa's Provinces with the highest index of land degradation (Palmer and Anslie, 2006). A large portion of the land in this Province is communally owned (Palmer *et al.* 1997). Approximately 2.6 million hectares of this Province are degraded (Palmer *et al.,* 1997), a large part of which is found in communal rangelands (Lesoli, 2008). This problem is extreme in communal

areas of the former Ciskei and Transkei homelands (Palmer and Anslie, 2006). Severe loss of vegetation in these communal areas is linked to overgrazing, due to poor land management systems (Hoffman and Ashwell, 2001). Cocks *et al.* (2001) noted that there are difficulties faced by local level institutional structures within these communal areas in the endeavour to implement Community-Based Natural Resource Management strategies (CBNRM). These challenges result from the lack of recognition of the impact of the past and political changes faced in the former homelands environments (Cocks *et al*. 2001).

The human population in communal areas comprises a significant element of the communal rangeland ecosystem, making it imperative to understand how their activities influence and affect ecosystem functioning. For rangeland resource management policies and practices to be efficacious and effective, knowledge and socio-cultural practices should be taken into consideration (Oba and Kaitira, 2006). This is because rangeland resource users are responsible for making decisions and taking actions on how to use rangeland resources, driven by their knowledge and socio-cultural practices. In order to clearly understand the impacts of grazing on vegetation condition in communal rangelands, it is important to investigate the manner in which grazing is managed in these areas. Grazing is regarded as the most economical way of utilising rangelands (Oztas *et al.* 2003). However, uncontrolled rangeland grazing leads to the undervaluation and degradation of rangelands. Thorne *et al.* (2007) state that, whereas vegetation communities are affected differently, the management of livestock can cause malicious damage to vegetation. Moyo *et al.* (2008) also observe that the grazing management strategies currently employed in communal areas are principally controlled and dictated by interactions between social, ecological and institutional factors. According to Mokhahlane (2009), around 51% of Eastern Cape Province comprises open areas that are treated as open access lands.

Vegetation condition, in terms of species composition, soil cover and standing biomass production, is the potential primary productivity and soil protection of rangelands (Oztas *et al.* 2003). When exposed to uncontrolled grazing, vegetation composition can be completely transformed and decimated. Large areas of semi-arid rangelands across the world have been altered through unsustainable, uncontrolled livestock production and grazing (Lechmere-Oertel *et al.*, 2005). The authors attribute

the degradation of succulent thicket areas of the Eastern Cape Province to unsustainable grazing pressure. Consequences of grazing mismanagement include, *inter alia*, vegetation and soil habitat loss, pollution of water bodies and hindrance to vegetation recovery. The consequent outcomes of these factors have usually been environmental degradation and the loss of biodiversity. However, grazing can be managed in order maintain ecosystem balance (Haigh, 2008). This would necessitate the involvement and cooperation of every stakeholder (Lesoli, 2008).

Vegetation monitoring is one of the most significant elements and forms of vegetation conservation (Mehrabian *et al.* 2008). Besides mapping the extent and composition of native vegetation, the need to assess its condition for correct management has also recently been expressed (Zerger *et al.* 2007). GIS and remote sensing techniques have become popular in studying and quantifying vegetation condition. They constitute a powerful information extraction and analysis tool for appraising vegetation quality and condition. Remote sensing, in particular, has become the most useful tool in analysing the biometrical properties of vegetation, utilising different wavelengths of electromagnetic spectrum (Jarocinska and Zagajewski, 2009) and gauging vegetation condition through the use of vegetation indices. Vegetation reflects a distinctive spectral signature, which may be analysed using various techniques, in order to derive different and distinctive indices regarding vegetative condition. These techniques have been successfully and reliably employed in several studies, in various areas of the world, to extract information about the quality and status of vegetation (Jarocinska and Zagajewski, 2009; Haindongo, 2009 and Mhangara, 2011).

A number of studies have demonstrated that vegetation degradation is a widespread environmental problem in the Eastern Cape Province, with a special focus on the issue of grazing management and its implications for vegetation degradation particularly in the communal areas (see Bennett and Barrett, 2007, Bennett *et al.* 2010, Birch, 2000, Lesoli, 2008 and Moyo *et al.* 2008). Whereas Moyo *et al.* (2008) assessed the perceptions of the livestock keepers within the communal areas, Lesoli (2008) evaluated the vegetation and soil status, and individual perceptions regarding the condition of the communal rangelands, Haindongo (2009) investigated factors influencing vegetation stress, Mokhahlane (2009) investigated institutional factors affecting the use of communal rangelands and Birch (2000) determined vegetation

potential of natural rangelands. However, there is clear lack of the study which would seek to establish the relationship between the condition of vegetation and grazing management systems in the Eastern Cape Province.

## 1.2. Problem statement

Whereas vegetation degradation in the Keiskamma catchment is a widespread environmental problem, Mhangara (2011) noted that vegetation conditions vary among the communal villages of the central part of the catchment. Vegetation in good condition was identified in some of the communal villages of the catchment, in sharp contrast with other villages where serious vegetation degradation is evident. It is envisaged that the variations in vegetation condition across these villages reflects differences in the functionality of local level institutional structures responsible for grazing management. It is therefore important to establish the relationship between vegetation condition and grazing management systems in these villages and make recommendations on how local institutional structures can be improved to reverse vegetation degradation.

## 1.3. Hypothesis of the study

The primary hypothesis of this study is that "the different grazing management strategies across the villages of the present study area explain the variations in vegetation condition among them".

## 1.4. Aim of the study

The main aim of this study is to investigate the extent to which grazing management systems may explain the variations in vegetation condition in the villages of the central Keiskamma Catchment, Eastern Cape Province, South Africa.

## 1.5. The objectives of the study

The objectives of this study are:

- To assess the trends in change of vegetation condition in the villages of the central Keiskamma catchment between 1984 and 2011.
- To test the spatial homogeneity of the topographical characteristics, i.e. elevation, slope and aspect, of the study area.
- To explore the existence and functionality of the local level structures and institutions, which regulate the use of grazing resources in the study area.
- To relate the variations in vegetation condition to the different aspects of grazing management systems within the communal areas of the central Keiskamma catchment.

## 1.6. Key research questions

- Do the topographic characteristics of the central Keiskamma catchment exhibit homogeneity?
- How effective are the local institutions and structures responsible for regulating grazing management in the communal areas of the central Keiskamma catchment?
- Are the spatial variations in vegetation condition in communal villages of the central Keiskamma catchment a reflection of the differences in grazing management systems?

## 1.7. Dissertation outline

### 1.7.1. Chapter 1: Introduction

In Chapter 1, a general overview of vegetation degradation in Africa, with a closer look at the communal areas of the Eastern Cape Province, is provided. The effects of livestock grazing practices are also explored in this chapter. The main research problem is stated, the aim and specific objectives are outlined and questions guiding the study are also raised. An outline of the dissertation chapters is also provided.

### 1.7.2. Chapter 2: The central Keiskamma catchment and its characteristics

This chapter provides a background to the geographical characteristics of the study area. Physical characteristics, viz. altitude, slope, aspect, geology and vegetation and climatic conditions also presented. An overview of the land use types and village organisational structures of the study area is also provided.

### 1.7.3. Chapter 3: Literature review

This chapter reviews the literature pertaining to vegetation degradation; local level institutional management regimes; and physical factors affecting the distribution of vegetation conditions. It also reviews the use of remote sensing in vegetation condition analyses and statistical techniques relevant in variable relationships.

### 1.7.4. Chapter 4: Research methods

This chapter describes the various methods and techniques employed to ensure that the aims and objectives of the study are achieved. The methods utilised include GIS and remote sensing, structured interviews to investigate the existence and functionality of local institutional structures and their efficacy within the study area.

### 1.7.5. Chapter 5: Results

In Chapter 5, the results obtained using the methods described in Chapter 4 are presented. An analysis of vegetation condition trends is presented in the form of maps and graphs. The homogeneity of topographic variables and relationships between vegetation condition and grazing management attributes were achieved by calculating Chi Squared and Linear regression analyses. Information collected from local level institutional structures, using an interview schedule is presented.

### 1.7.6. Chapter 6: Discussion and conclusion

This chapter provides a discussion of the findings obtained in chapter 5. Local level institutional management regimes and their implications for vegetation condition trends are discussed. Recommendations regarding the strengthening local institutional structures for better vegetation resource management in the Keiskamma catchment are made. Directions for future research are suggested and a final conclusion of this study is made.

The subsequent chapter (Chapter 2) describes the physical setting of the study area.

# CHAPTER 2

# THE CENTRAL KEISKAMMA CATCHMENT AND ITS CHARACTERISTICS

## 2.1. Background information and location

The Keiskamma is one of the largest catchments in the Eastern Cape Province, South Africa. It is a rural catchment located in the semi-arid region of the Province, south of the City of East London and north of Port Alfred, on the former Ciskei coast. It is occupied by Xhosa speaking people. The Keiskamma River, which is the primary river, is at an elevation of 1500m. It cuts through a wide thicket-clad valley, to the Indian Ocean, near the small town of Hamburg, located south-western side of the river mouth. Its main tributaries are Tyume, Chalumna and Gulu, with the Tyume tributary having its headwaters in the Hogsback area (Mlondolozi 2008). The catchment covers an area of over 2745 $km^2$ (Hill *et al.*, 1991).

The central Keiskamma catchment, which is the focus of this study, lies in the geographical position of 32º51´19.36´´S 26º53´38.14´´E and 32º58´03.11´´S 27º12´09.51´´E. The study area comprises 15 villages, namely, Koloni, Qibira, Mnqaba James, Zihlahleni, Tafeni, Debe Valley, James Mama, Pewuleni, Mxumbu, Gqadushe, Kudikidikana, Matsamraleni, Debemarela, Mbizana and Njwaxa. Figure 2.1 shows the location of the study area within the Keiskamma catchment. The catchment is divided into three topographic regions: the coastal (lower reaches); coastal plateau (drought corridor or middle reaches); and mountain / escarpment zone (upper reaches) (Mlondolozi, 2008).

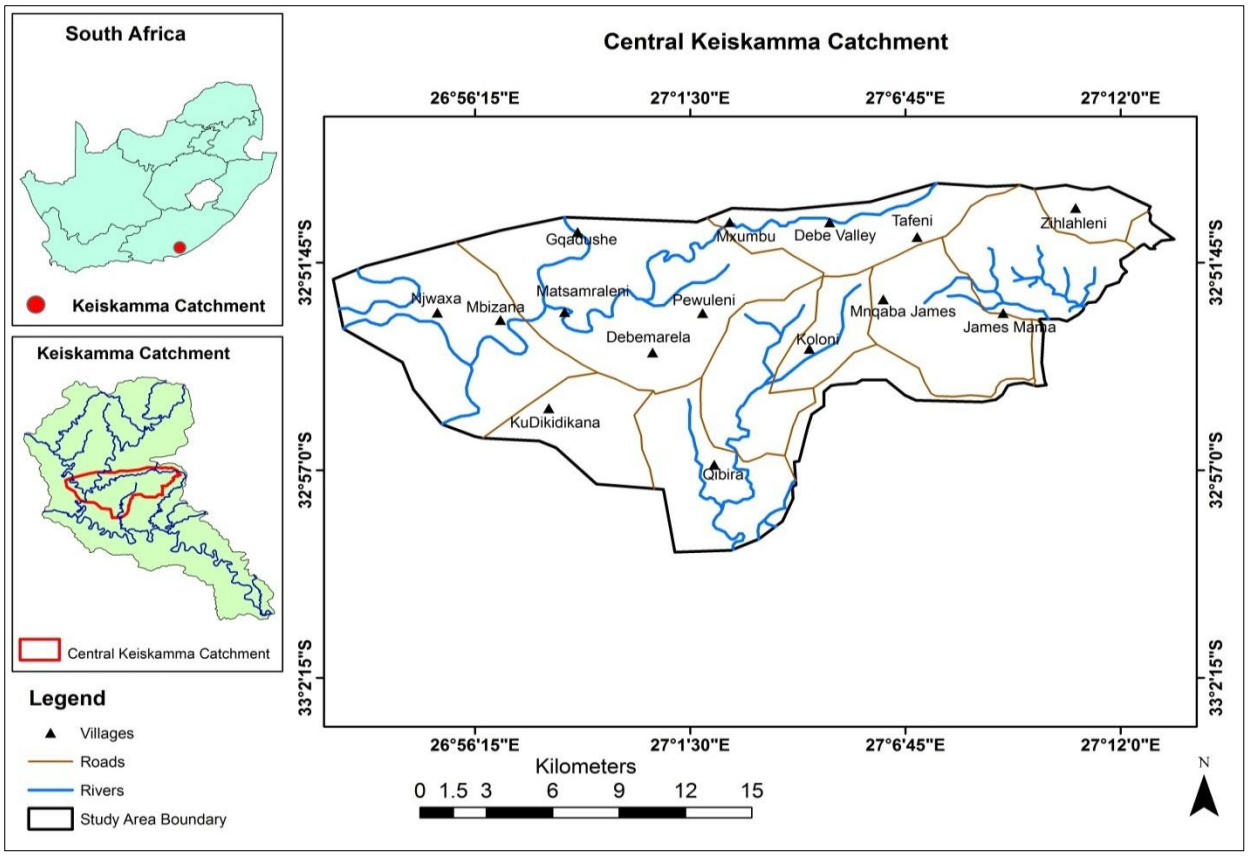


Figure 2.1: The study area

## 2.2. Topography

Most of the study area lies within the coastal plateau topographical zone. This topographical region is considered to be a drought corridor, which is semi-arid (Mlondolozi, 2008). It receives low precipitation, relative to the other topographical zones of the catchment. This region is predominantly characterised by relatively flat terrain, though there are a few portions of the region that have steep slopes. Figure 2.2 is a map of the topographical regions of the Keiskamma catchment.

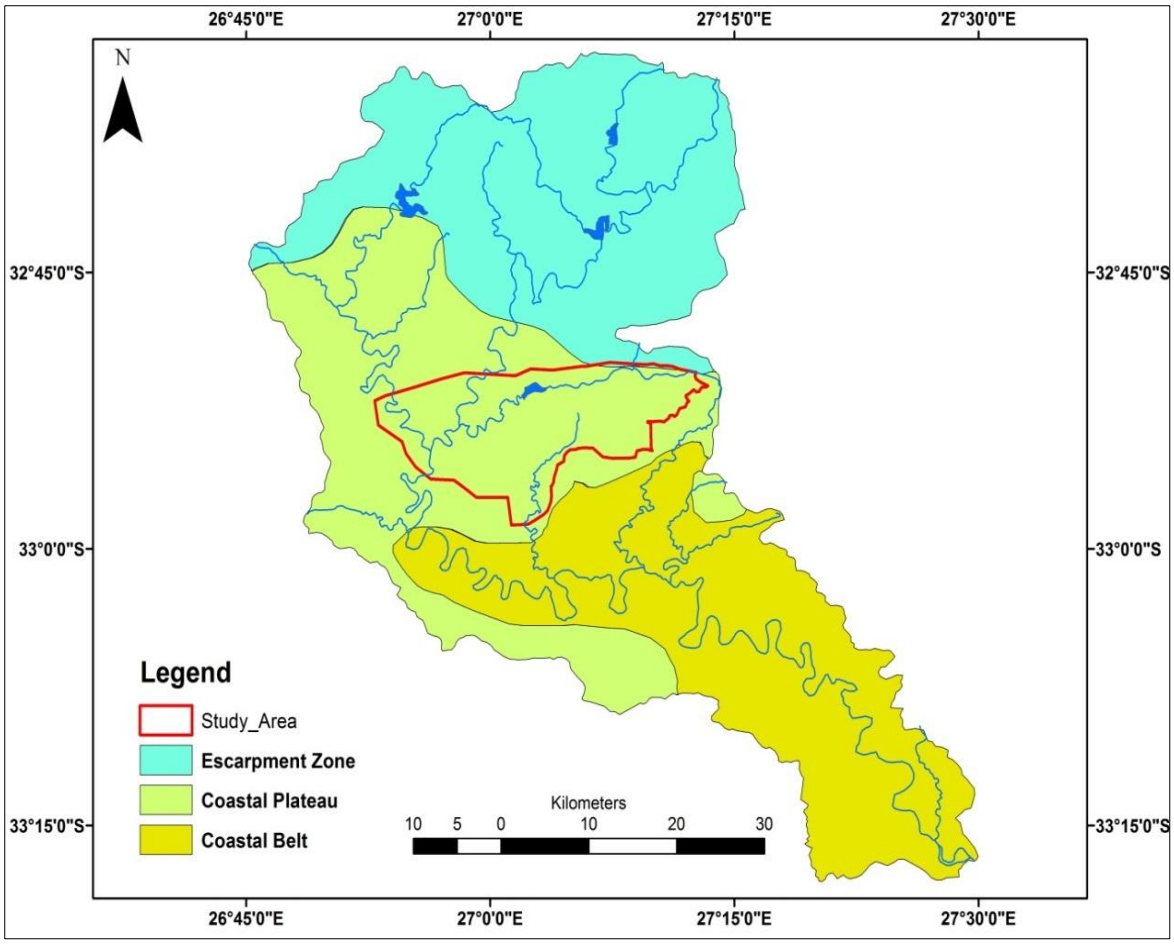


Figure 2.2: Topographic regions of the Keiskamma catchment

### 2.2.1. Elevation

The elevation surface of the study area was generated from an Aster DEM, and was found to range from 297 to 751 metres above sea level. Figure 2.3 and 2.4 illustrate the altitudinal characteristics of the study area.

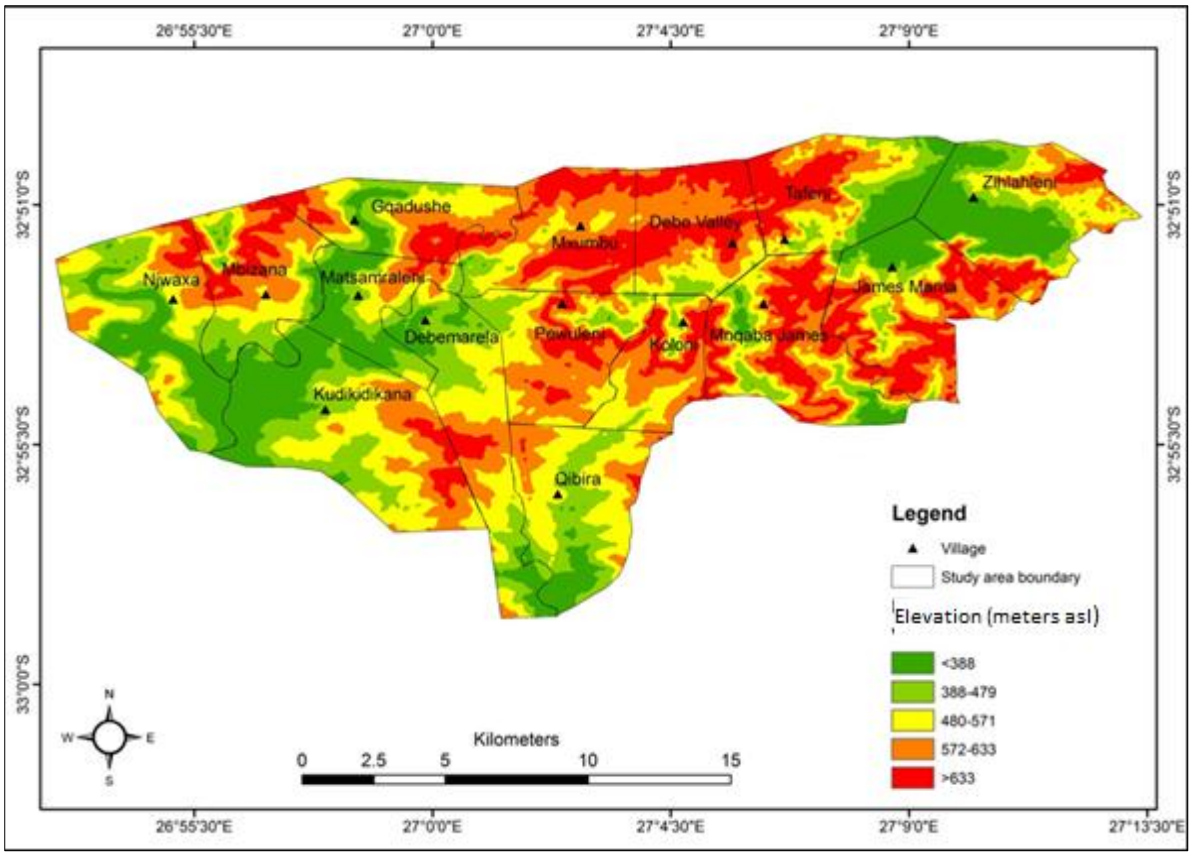


Figure 2.3: Variation in the elevation above sea level of the study area

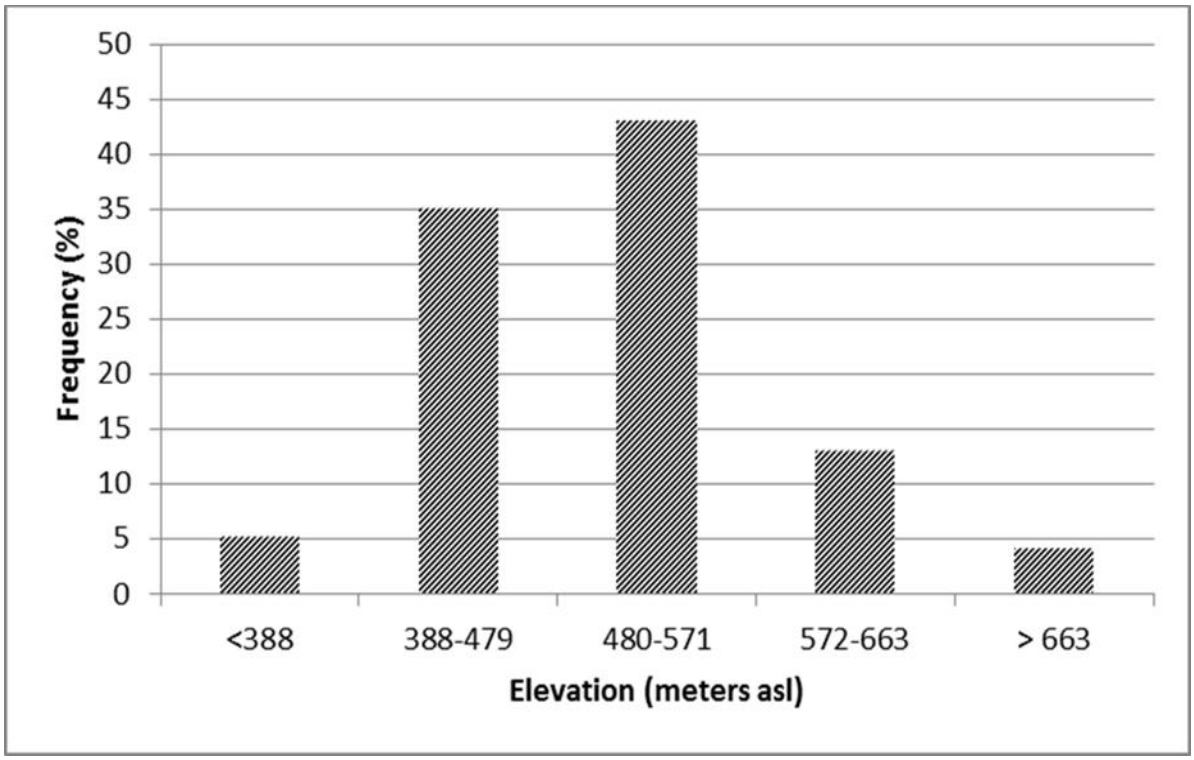


Figure 2.4: Elevation classes of the study area.

### 2.2.2. Slope

The slope surface of the study area was calculated from DEM, and was classified into four categories in ArcGIS. It was found that the slope surfaces range from $0^0$ (gentle slope) to $36^0$ (steep slope). However, large portions of the study area are dominated by gentle slope (see Figure 2.6). Figure 2.5 and 2.6 illustrate the slope characteristics of the central part of the Keiskamma catchment.

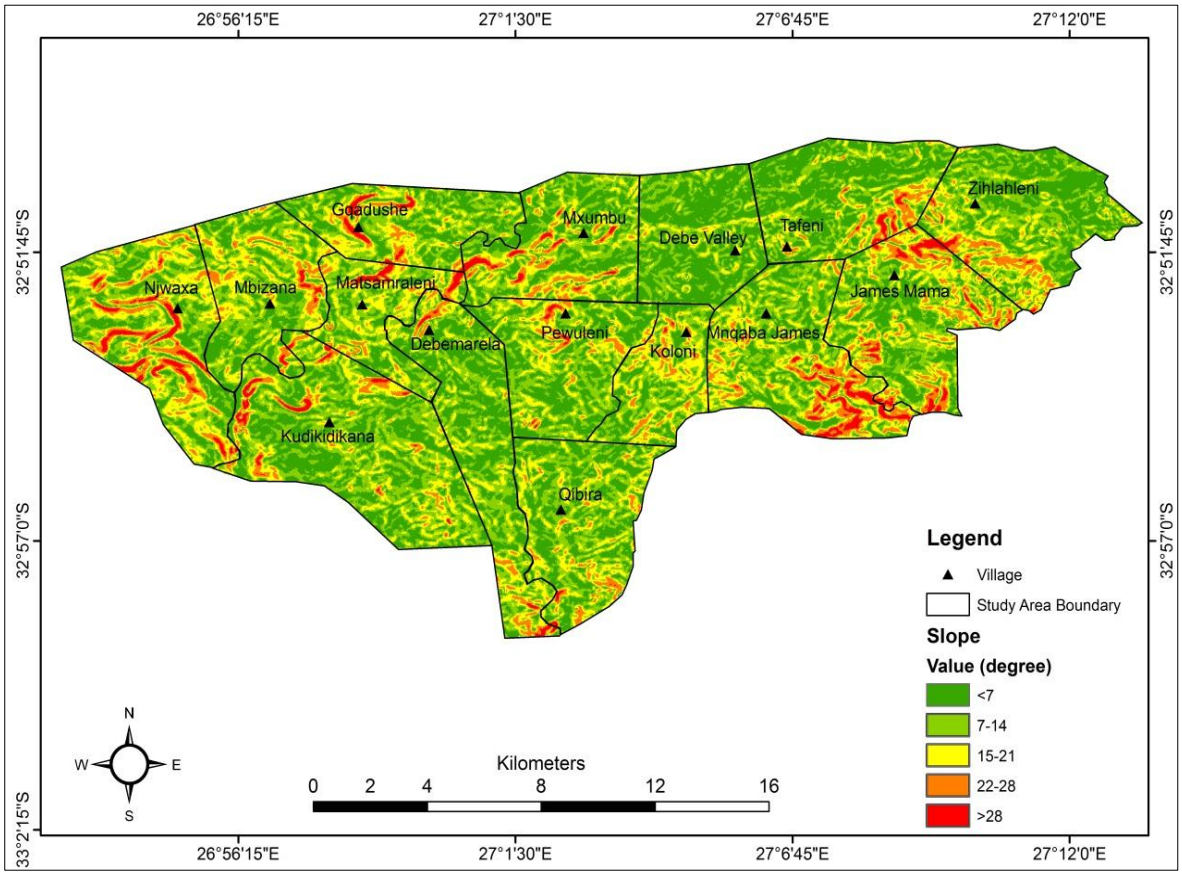


Figure 2.5: Slope map of the study area

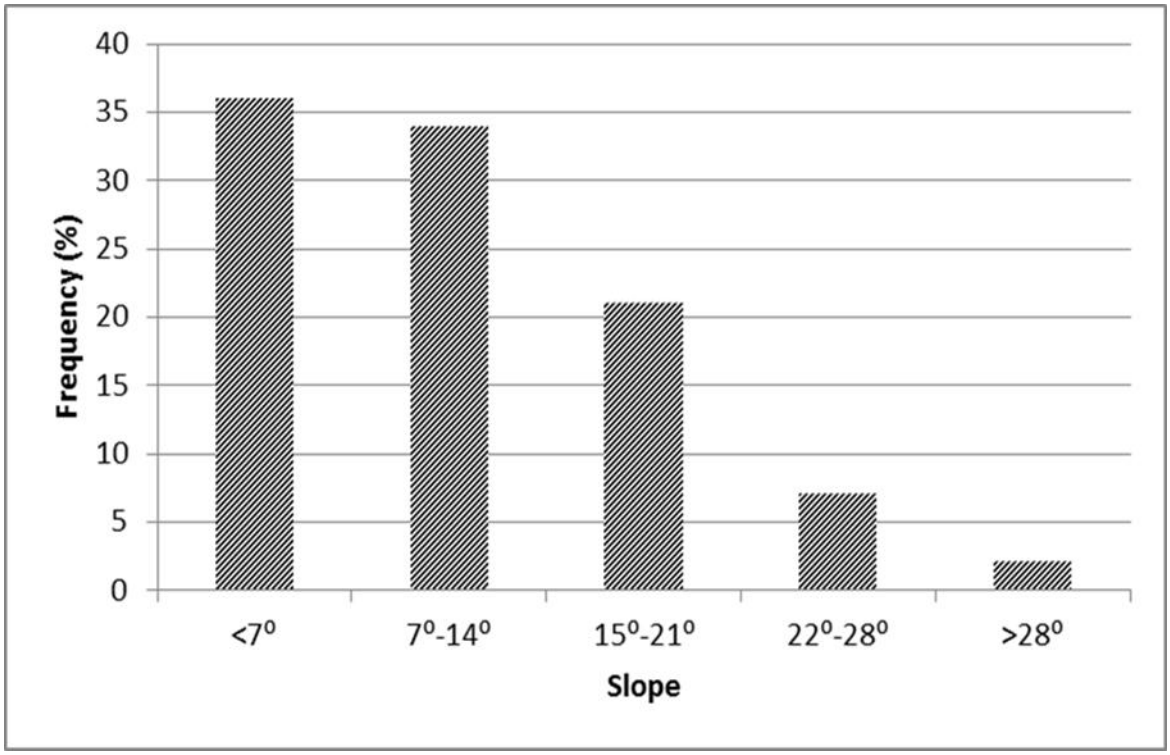


Figure 2.6: Slope classes of the study area

### 2.2.3. Aspect

The slope aspect of the study area was another topographic attribute of the study area calculated from DEM. It was found that the principal region of the study location is dominated by east and south facing slopes. Figures 2.7 and 2.8 are slope aspect characteristics of the study area.

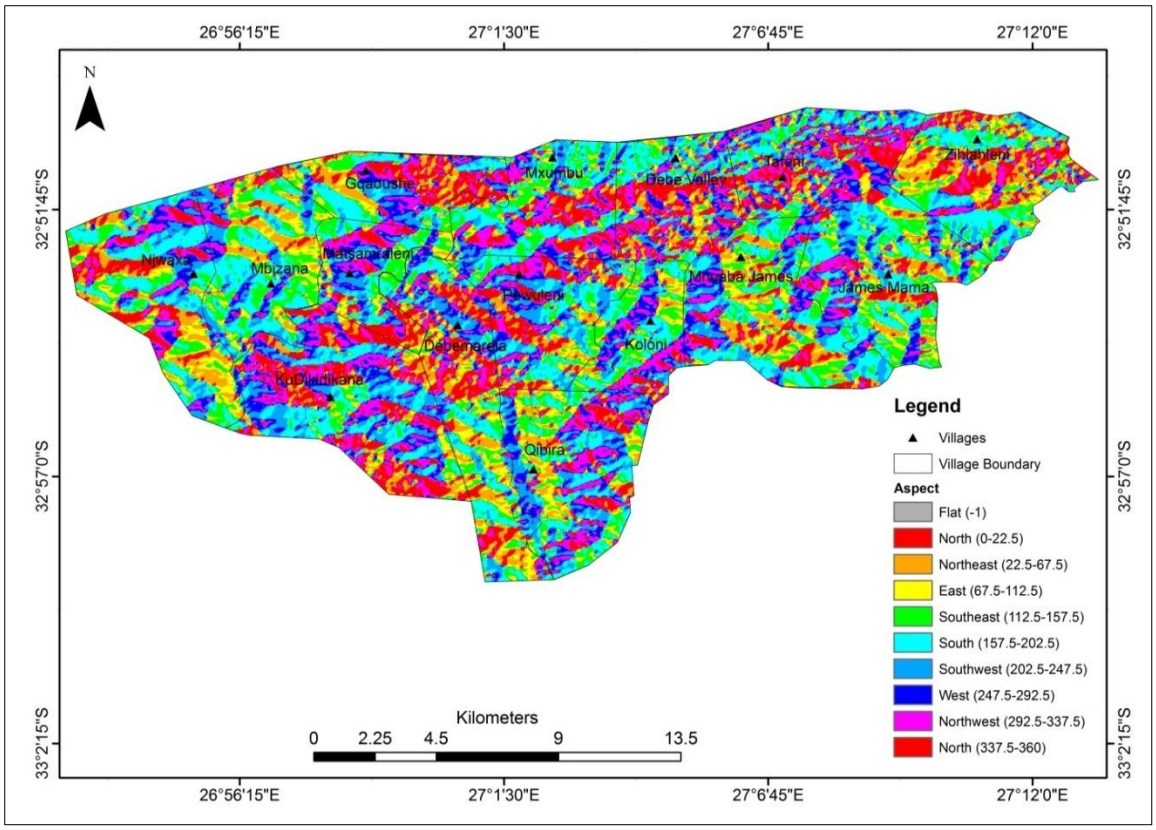


Figure 2.7: Aspect map of the study area

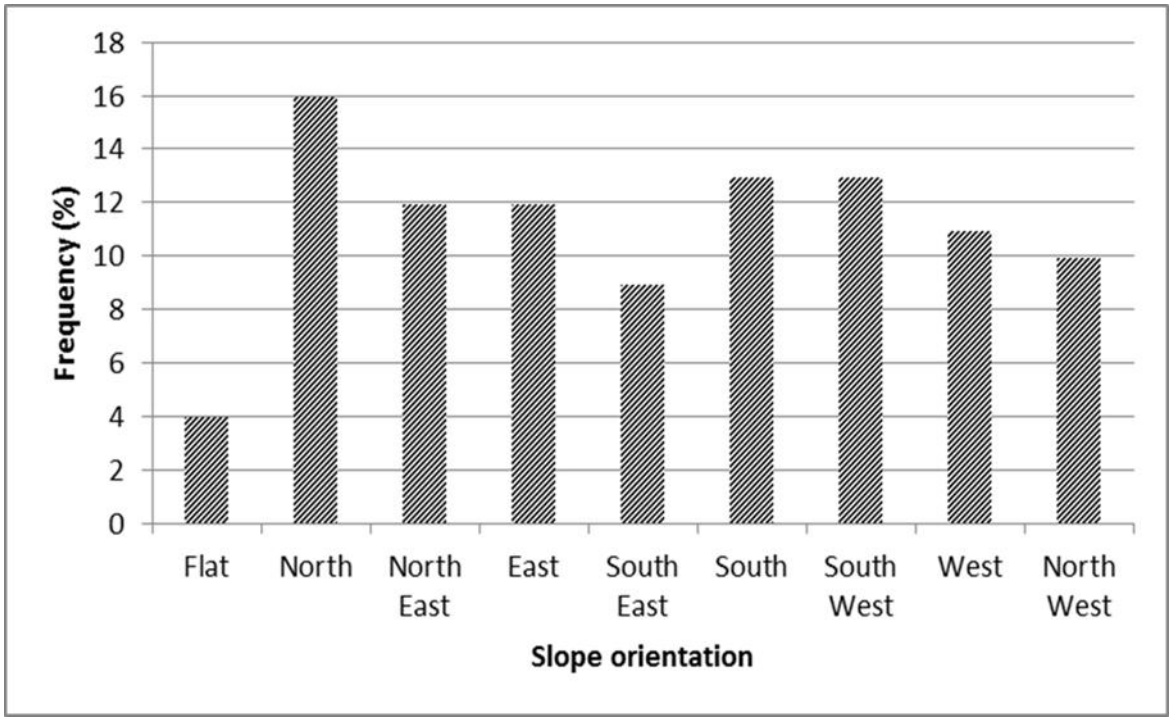


Figure 2.8: Slope orientation classes of the study area

## 2.3. Climate and rainfall

The Keiskamma catchment experiences climatic differences primarily associated with topography, particularly altitude and distance from the ocean (Mhangara, 2011). The study area is characterised by low humidity, an annual average temperature of 16 °C, annual minimum and maximum temperature of 7°C and 25°C respectively (South African Weather Service). The area receives an average annual rainfall of 600 mm (Mlondolozi, 2008). Rainfall principally occurs during the summer months, with the winter months constituting the driest period. Figure 2.9 shows the average monthly minimum and maximum temperature. Figure 2.10 depicts the average monthly precipitation.

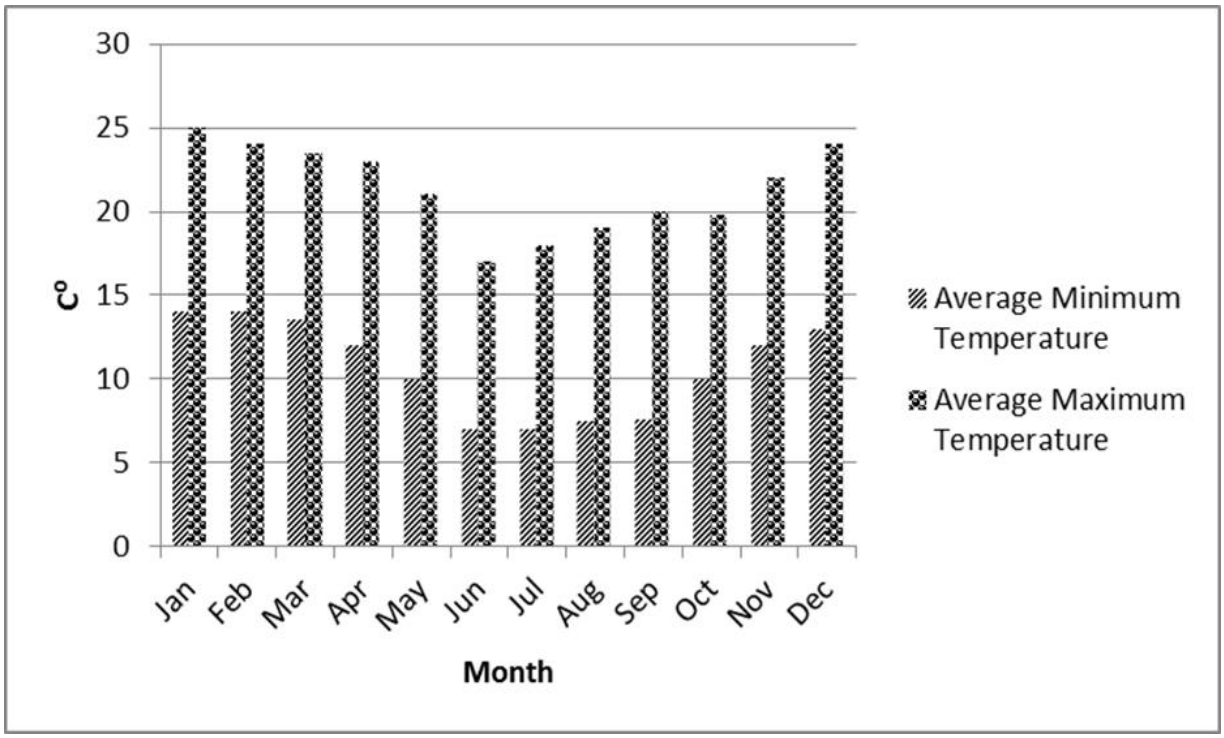


Figure 2.9: Average minimum and average maximum temperature (°C) of the study area (Source: South African Weather Services, 2012)

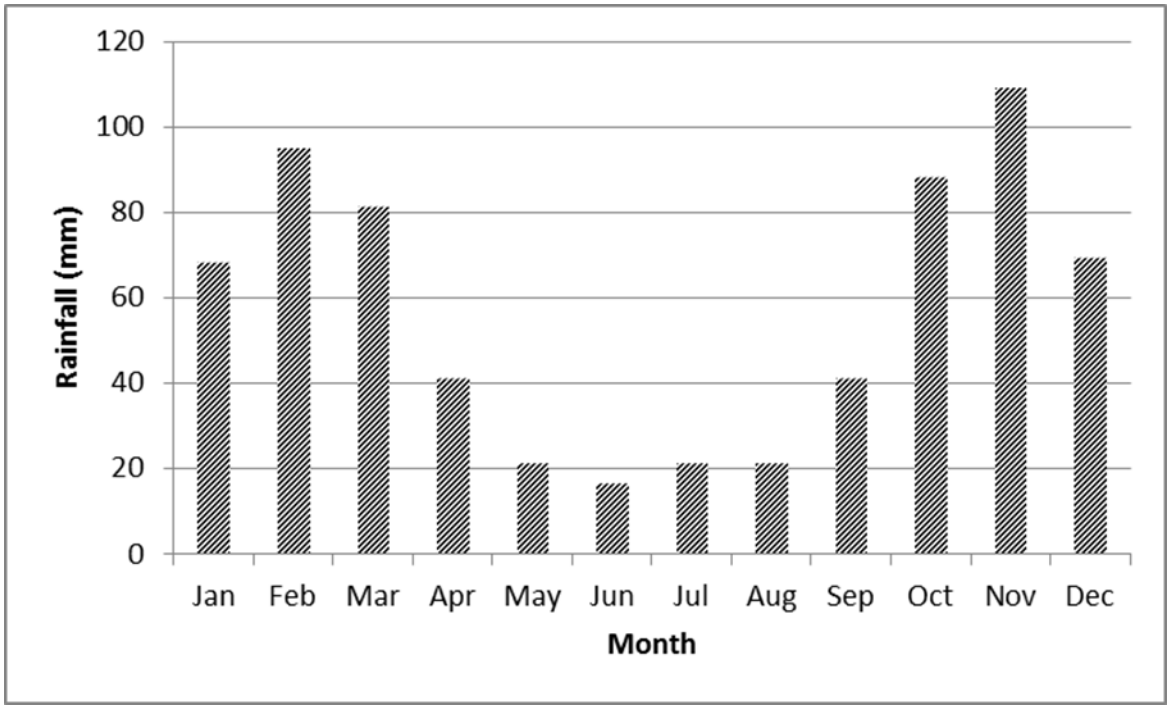


Figure 2.10: Monthly average rainfall (mm) in the study area (Source: SAWS, 2012)

## 2.4. Geology

Although rainfall is regarded as the primary common source of soil moisture for vegetation, there are some vegetation classes which depend fully on groundwater for growth and health (Eamus, 2009). The geology of the study area consists of erodible shale, mudstone and sandstone belonging to the Adelaide Subgroup, which forms part of Beaufort Group rocks of the Karoo Supergroup (Council of Geoscience, 2000). Figure 2.11 is a map showing the geology of the study area.

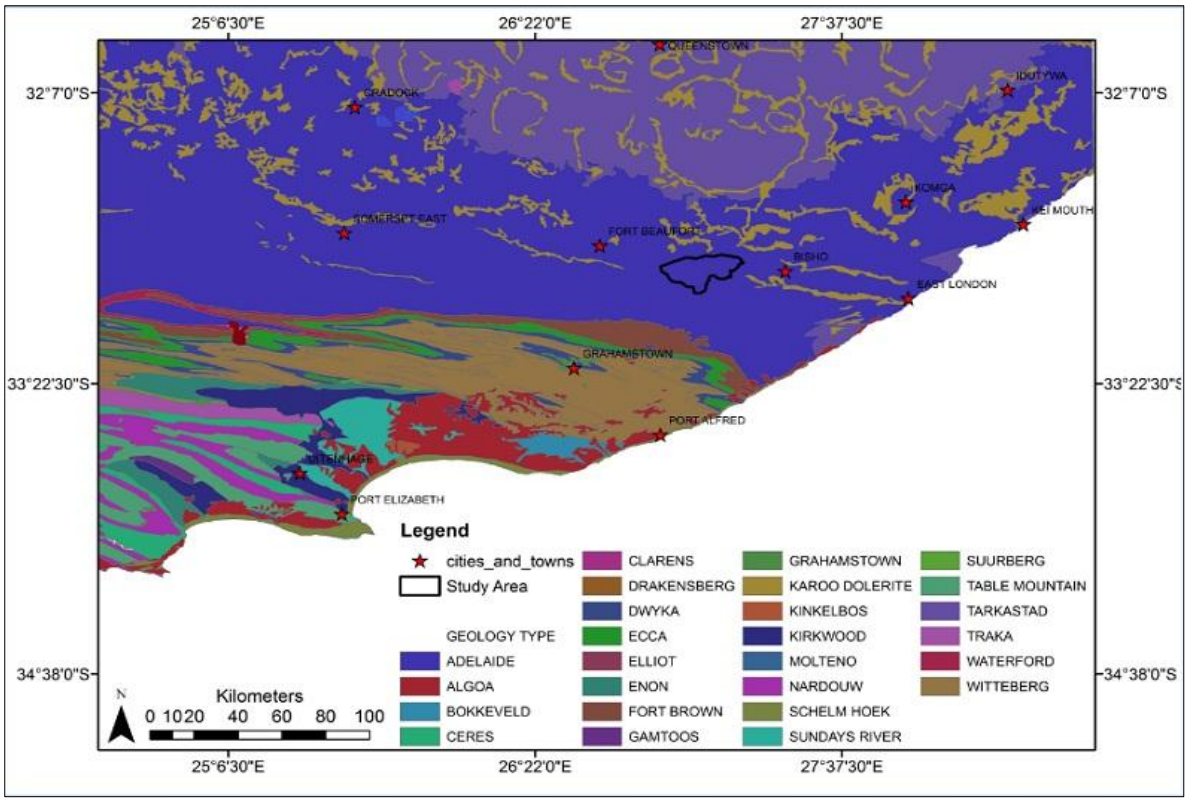


Figure 2.11: Geology map of the study area (Source: Council of Geoscience, 2000)

## 2.5. Soils

Soils in the study area are very heterogeneous, but are predominantly sedimentary (sand – and mudstones) with some distinction when intrusions of igneous rock (doleritic dykes and sheets) result in red soils occurring in some areas (de Bruyn, 1998). The study area is characterised by a dystrophic type of soil (DEAT, 2000), implying variations in the nutrient amounts available in the soils. Some soils have sufficient while others have minimal nutrients. According to DEAT (2000), soils of the study area are of a depth less than 450mm. They vary from a clay class in the top soil of less than 15%; deep solonetic soils, originating from the dolerites of the Beaufort Group, and deep loamy soils derived mudstone and sandstone of the Beaufort Group of the Karoo Sequence (Bredenkamp *et al*.1996). This clay class plays significant role in permeability; it affects the rate at which water moves from the top layer of soil to the lower one. On steeper slopes, these types of soil tend to be shallow, but may also be extraordinarily deep in valley regions (Bredenkamp *et al*. 1996).

## 2.6. Vegetation and biomes

Vegetation in the central Keiskamma catchment was classified on the basis of the Acocks (1988) veld types. The study area is characterised by three types of natural vegetation, namely, the valley thicket; Eastern Thornveld; and Highland Sourveld and Dohne Sourveld forest. Valley thicket comprises thickets of woody shrubs and trees, which exist in the river valleys of Eastern Cape Province. Naturally, this forest has a closed canopy of up to 6m in height of evergreen vegetation species (Bredenkamp *et al*., 1996). There are different kinds of species constituting the valley thicket, including, *Plumbago auriculata* and *Euphorbia triangularis* (Bredenkamp *et al.* 1996). Degradation of the valley thicket in the Eastern Cape Province has been attributed to the preference for grazing by goats (Bredenkamp *et al.* 1996). The high rate of overgrazing in the Province has resulted in the invasion the savannah and grassland into the previous thicket cover.

The Eastern Province Thornveld is defined by small, less than 3 m tall, Sweet Thorn Acacia Karoo trees and invasive thicket species (Bredenkamp *et al.* 1996). It is preferred for grazing by cattle, goats and sheep; however, overgrazing has led to the loss of grass species and an increase in woody plants. The Highland and Dohne Sourveld types are characterized by a dense grass cover occurring in rocky and leached soil, derived from sequence of sediment and dolerite (Bredenkamp *et al*., 1996). These types of veld are common in areas at altitudes of 600 to 1400 meters above sea level. They are mainly used for grazing, which has resulted in heavy overgrazing of these veld types in the regions of Eastern Cape and Kwazulu Natal Provinces (Hardy *et al.* 1999).

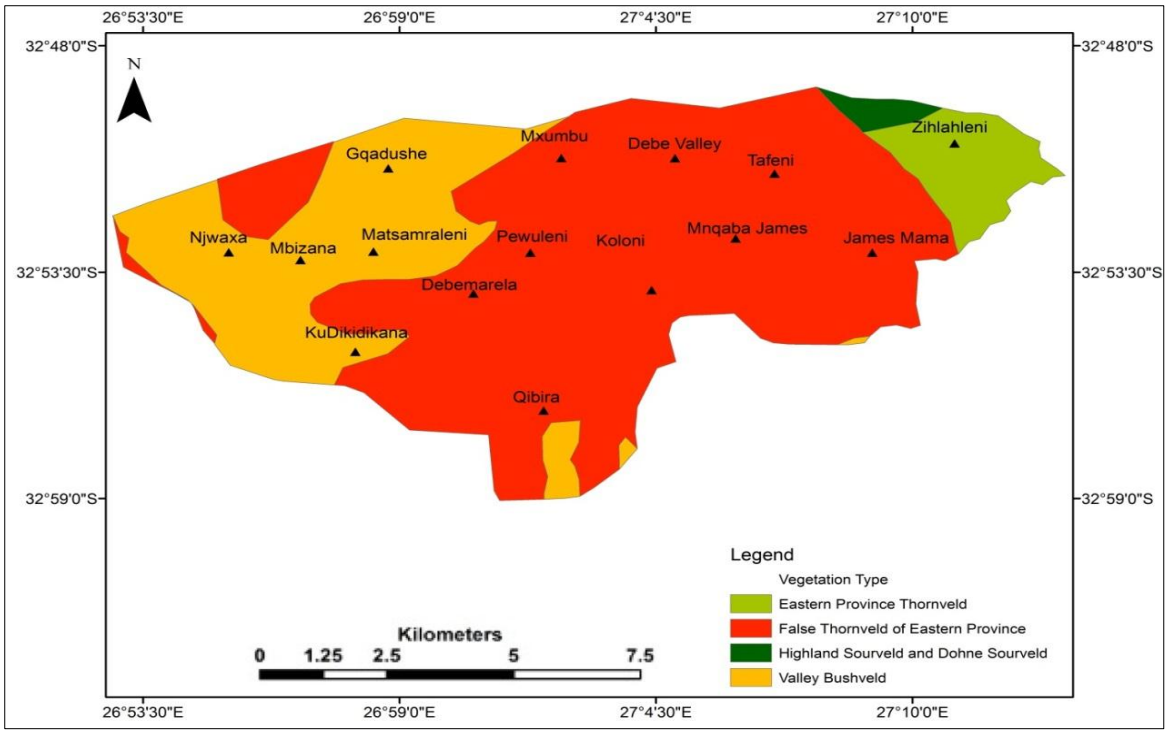


Figure 2.12: Vegetation types found in the study area (Source: Acocks, 1988)

## 2.7. Land use

The land in the central Keiskamma catchment is largely communal and is utilised for livestock grazing, with little arable land. Of the minimal arable land available, large portions are abandoned, with the fenced areas surviving as the only cultivated land. The abandoned arable lands have been converted to grazing land. However, uncontrolled grazing in large portions of the study villages has already caused land deterioration (Mhangara, 2011). Although there is electricity in all the villages under study, the villagers are still highly dependent on wood for fuel. This has promoted deforestation, which has in turn contributed significantly to the degradation of vegetation resources.

## 2.8. Local institutional structures

Each individual village of the central Keiskamma catchment has an institutional committee regulating their grazing management system; in addition to overseeing the grazing management practices in their respective villages. The institutional committees are selected by village members, and should comprise 16 members. Some

of the villages have fully-staffed committees, while others have fewer than 16 members. The committees function under a lady Chief, who is the ultimate authority, having final decision and control as to how the land should be utilised and managed. Working side by side with village authorities are also municipal councillors, elected by local government. Details of the co-existence of these two structures are provided in the relevant section of the results chapter.

A literature review regarding grazing management issues and approaches to analysing vegetation condition are provided in the subsequent chapter.

# CHAPTER 3

# LITERATURE REVIEW

## 3.1. Introduction

This chapter reviews the available literature pertaining to the assessment of vegetation condition, along with discussing the remote sensing and GIS techniques used to assess vegetation condition. Furthermore, this section evaluates and addresses issues related to community-based natural resource management, together with an appraisal of the functionality of the institutions responsible for grazing management systems. A review of the challenges faced by these institutions, within the South African context is provided. The influence of topographic variations on vegetation and statistical techniques relevant to analysing vegetation condition are also reviewed in this chapter.

## 3.2. Vegetation dynamics

Vegetation dynamics occur over a wide range of spatial and temporal scales (Heil *et al*. 1996). Vegetation change tends to have a negative impact on biodiversity, conservation status and productivity of rangelands (Macharia and Ekaya, 2005). Vegetation condition may be analysed from various perspectives, which encompass the productive capacity for economic goods; ecological productivity; ability of the land to regenerate its vegetative capacity, and the extent and type of past vegetation disturbances (Thackway *et al.* 2006). Levin (1992) indicates that the spatially localised, essentially random disturbances in vegetation interrupt the orderly processes that would otherwise drive the vegetation uniformly towards a relatively monotonous end-state.

Rangelands are regarded as vegetation resources required for livestock grazing, constituting up to 50% of the terrestrial global landscape (Wilcox and Thurow, 2006), but estimates of this proportion vary in accordance with the way they are defined (Friedel *et al.* 2000). However, the capacity of the rangelands to fulfil the requirements of supporting or garnering livelihoods is placed on the integrity of soils

and ecological conditions (Birch, 2000). Rangeland conditions may vary, in relation to the climatic and geologic conditions of different areas (Williams and Kepner, 2002). These conditions can be better understood if records about the previous and current state of the land are kept, documenting the influences that cause alterations in the state of rangeland and the direction of these transformations (Friedel *et al*., 2000).

While it is difficult to fit rangelands into categories based on ecological criteria (Mokhahlane, 2009), rangelands may also be categorised based on the rights of access to their resources. Rangelands may be regarded as private property, where an individual possesses the sole rights of control or may be used as common-property, where the degree of control is distributed among a group of people (Bennett and Barrett, 2007). Communal rangelands are mostly utilised for specific reasons, including the collection of fuel wood, livestock grazing and medicinal plants (Mokhahlane, 2009). One of the characteristics of communal rangeland users is that they are more interested in livestock production than managing the land, making vegetation resource degradation common in these shared locations.

### 3.3. Rangeland functionality

Initiating a subjective and user-defined classification of organisms has been a useful approach for determining the response of ecosystems to changes in the environment (Epstein *et al.* 2001). Rangelands are regarded as poor in resources, underscoring the significance of assessing and establishing the efficient use of these scarce resources at a scale incorporating the overall terrain (Tongway and Hindley, 2004). An understanding of how rangelands function is important; these are controlled by the way in which the community utilises it and acts to conserve and make use of its resources (Tongway, 1993). The landscape function analysis aims at explaining changes in rangeland resources (e.g. vegetation species composition), in the context of ecosystem processes and the quality of soil-related habitat (Tongway and Hindley, 2004). A rangeland may be functional when it is rich in resources and becomes dysfunctional when it has a shortage of natural resources.

The main component of analysing land functionality is the strategy used to determine how the ecosystem responds to environmental changes. The landscape functional

analysis approach is used to determine if the association between the vegetation and environment is balanced (Epstein *et al.*, 2001). Rangelands can be classified on the basis of the ability of the landscape to sustain the current ecosystem and manage the processes occurring within it. Tongway and Ludwig (2002) analysed the concept of landscape function within the rangeland paradigm. The rangeland continuum occurs between the highest and the lowest degrees of function (i.e. optimal and worse) (Tongway and Hindley, 2004). Though a rangeland has its own continuum (i.e. from excellent to poor, or from best to worst), the position of a given landscape along this continuum relies on the judgment of the value of landscape (Tongway and Ludwig, 2002). Changes in vegetation species composition may come about through continual, unrotated grazing of livestock in an area. As a result, changes in production and biodiversity are determined by the direction taken by the landscape function.

Palmer *et al.* (2001) compared functionality of commercially and communally managed rangelands in Peddie district. Their study found that communal rangeland had low vegetation cover, in sharp contrast to the commercial rangeland where high vegetation cover aided in controlling water and nutrient flow. On this basis, functionality of communal rangeland ecosystem can be linked to management systems.

### 3.4. Livestock grazing

Livestock grazing is the dominant land use type, compared to cultivation in the communal rangelands. It provides a livelihood and subsistence to a large number of people across the world (Quaas and Baumgartner, 2011). It is considered to be elemental for the vegetation growth, as it allows vegetation to establish new leaves. However, it also represents a major human alteration of the naturally occurring vegetation in rangelands throughout the world (Hayes and Holl, 2003). Livestock grazing may cause soil and vegetation degradation (Warren *et al*. 2001) and is considered an ecological disturbance affecting the vegetation community (Huntly, 1991). Marty (2005) points out that livestock grazing is usually perceived as a threat to biodiversity. Overgrazing can cause losses in vegetation composition. It hinders the vegetation recovery process and creates patchy vegetation, interspersed with bare surfaces. This may have a direct impact on soil moisture, through an increase in

runoff and reduced infiltration (Rietkerk *et al.* 2000). Haigh (2008) attributed natural vegetation clearing in Australia to livestock grazing.

The impact of grazing on vegetation has received much attention in the recent years (Cingolani *et al.* 2005). Grazing pressure is the term used when livestock grazing of the land does not correspond to carrying capacity of the related rangeland (Williams and Kepner, 2002). The pressure exerted by grazing animals also determines the condition of grazing land. Overgrazing is not determined by livestock numbers grazing in one area, but by the time taken grazing the same area (Czeglédi and Radácsi, 2005). The way in which vegetation responds to grazing is dependent on the season and period of grazing. The most effective way of implementing sustainable grazing land management in communal areas is to practice collective action for natural resource management (Benin and Pender, 2002). However, grazing management decisions are facilitated by land owners' perceptions regarding social responsibility and property rights (Kreuter *et al.*, 2006). The adoption of sustainable grazing management systems can be explained by property rights associated with grazing resources, within the cultural, ecological and social setting (Benin and Pender, 2002).

### 3.5. Property rights

Livestock grazing in many rangelands is subject to the rights of access to grazing resources (Swallow and McCarthy, 2000). Rights of accessing grazing resources are driven by the degree of belonging (Ostrom, 1990). The degree of belonging is something which plays a significant role in the access to and exclusion from property (Kreuter *et al.* 2006). Ostrom (1990) defines property rights as enforceable authority to undertake particular actions in certain domains. Property rights administer who can do what with resources (Meinzen-Dick and Di Gregorio, 2004). Perceptions related to natural resource exploitation issues and the recommendations to address such issues require the recognition of property rights and rules implemented to administer them (Schlager and Ostrom, 1992). Property rights may be granted to an individual who takes full charge of the property, or may be assigned to a group of people, where the ownership is shared among individuals within that group. The individuals or groups of people possessing the rights of ownership and use of the property are the ones who

decide on how the property should be utilised and managed (Ngaido and Kirk, 2000). When property rights are not enforced, there is open access because there is no individual responsible for grazing resource management (Adhikari, 2001).

### 3.5.1. Property rights under commonage systems

Common property is not everyone's property but property owned by a group of individuals. Common property resources are considered a significant feature of social and institutional activities designed to satisfy daily needs of village groups (Ramanathan, 2002). Rangelands have been subject to a wide range of ownership arrangements, guided by different organisations which regulate access of use (Ngaido and McCarthy, 2004). In common property, resource users have equal access to available resources (Swallow and McCarthy, 2000); that is why it is often difficult to divide common-pool resources among stakeholders. Common property rights are common in communal rangelands (Ramanathan, 2002). Common property rights are social conventions that reflect agreements among persons about how the assets are held or used (Ngaido and McCarthy, 2004).

Giving the rights to property, or at least long-term rights to grazing, to the local communities is the most significant tool for sustainable management (Telahigue and Abdouli, 2001). Evidence from communal property regimes, in relation to natural resource system, has discovered a wide range of property regimes extensively used in modern society (Ostrom, 1990). Sustainable resource management does not depend on individual institution of a property rights regime but also on a well-specified property rights system and a similarity of that system with its conservational and social context (Hanna and Munasinghe, 1995).

### 3.5.2. Common-property resources management

Managing community-based natural resources is primarily done to promote human well-being and to share authority for ecosystem management at a local level (Fabricius *et al.* 2007). Southern African communal lands are responsible for supporting a large number of rural communities, many of which live in destitution (Shackleton *et al*. 2002). Several researchers have emphasised the importance of natural resources, within communal areas, for livelihoods, subsistence and household

economies (Cousins, 1999; Shackleton *et al.* 2001; Ngaido and McCarthy, 2004). People in communal villages rely on local common-pool resources for a livelihood.

These resources may be owned by national, regional or local government, and can be used as common access resources (Ostrom, 1990). Natural resources in communal areas appear to be principally utilised for livestock grazing and firewood. More importantly, livestock farming in communal areas constitutes a significant percentage of the rural economy (Benin and Pender, 2002). Due to the economic value of livestock in communal villages, livestock owners become more interested in multiplying the number of their livestock (Neely and Butterfield, 2004).

Communities that rely on common property resources usually integrate community-based resource management, which differs in the levels of success in achieving sustainable use (Berkes, *et al.,* 1989). Berkes *et al.* (1989) indicate that common property resources share two characteristics: firstly, the control of access to the potential users is problematic, where the physical nature of resources is such that controlling access of the potential users is costly and sometimes impossible. Secondly, the element of the right to exclude others from accessing the resources and to regulate its use is always the case. Evidence about exclusion is observable in situations where natural resources are held as open-access. Data obtained regarding communal property suggests that access prohibition or denial of use under communal properties is not treated as exclusion but as a rule (Berkes *et al.,* 1989). Community-based resource management only allows the members of the community to share the value of the natural resources within their area, excluding those who are not considered stakeholders.

### 3.5.3. Challenges faced in common resource management

Like any other management strategy, common resource management faces various challenges, some of which are generated internally (within the stakeholders), while others are external (by those who are not beneficiaries but interested in resources) (Fabricius *et al*. 2007). Internally generated challenges include the unwillingness of beneficiaries to take part in resource management, disagreement regarding rules and policies governing natural resource management, difference in the resource interest, and a lack of awareness of the rules and policies governing resource management among the beneficiaries (Fabricius *et al*. 2007). Externally generated challenges

include the lack of financial support from both local and national government; lack of cooperation by the neighbouring communities and climate vulnerability. The most documented consequence of communal rights is that they lead to high transaction and enforcement costs, if the communal owners attempt to change the rules to reduce the externalities of their mutual overuse (Ostrom, 1990). Another challenging issue cited by Cocks (2010) in the former Ciskei homeland is to do with the local municipal government and community structures, which are not taking enough responsibility to manage communal resources. Successful common resource management systems are subject to institutions through which access is attained (Agrawal, 2011).

### 3.5.4. Institutional role in common resource management

The role of institutions in common-property resource management has received serious attention in the studies of natural common resource management (Ngaido and Kirk, 2000; Bruce, 1986; Lawry, 1990; McCarthy *et al.*, 2004). Most communal areas manage their common-property resources under the leadership of local level institutions. These structures remain the ones responsible for implementing resource management strategies. Their resource management systems may vary from village to village, depending on community objectives regarding resource use. These institutions are made up of both formal and informal rules, guiding peoples' behaviour (Mokhahlane, 2009). Local level institutions are of significance in communal rangeland management, where local level livelihoods rely on rangeland resources (Dong *et al.* 2009). These institutions may, consequently, improve the management of natural vegetation resources because they gain their social importance by constraining social actions (Poteete and Welch, 2004). They are responsible for setting the rules by which the community should operate (Mokhahlane, 2009).

Ngaido and Kirk (2000) suggest two assumptions that may guide approaches to local level structures in resource management. The first assumption is that traditional local level entities, with their rules and regulations, may take over the role of the state, in managing common resources at a local scale. Secondly, local communities are the primary beneficiaries of communal rangeland resources and they should be responsible for managing them (Bruce, 1986; Lawry, 1990). However, the remaining question is whether these local level structures are existent and effective enough to be

responsible for communal rangeland resource management. These institutions range from traditionally to democratically elected institutions.

#### *3.5.4.1. Traditional leadership institution*

Traditional leadership institutions are valued for their role in natural resource management with different levels of legality and control in almost all African Countries (Shackleton *et al.* 2002). In fact, preceding the colonisation and democratisation of African countries, African people had no other system of governance except traditional institutions (Meer and Campbell, 2007). These institutions were regarded as a potential resource of great value because of their assistance in maintaining civic morale and social order in difficult situations (Sklar, 1994). However, the functioning of these institutions has been severely affected by the emergence of imperialism and colonisation in most African countries (Maphosa, 2010). Some became completely extinct, while others had their authority and existence undermined (Sklar, 1994).

Nthai (2005) states that several laws were brought into being to control traditional leadership in South Africa. These laws allowed traditional leadership institutions during the apartheid era to operate with little or no interference by the central government (Khan and Lootvoet, 2001). However, the change from apartheid to the democratic dispensation resulted in further law reform in natural resource management (Tewari, 2001). This transition has signalled the inception of a new economic, social and political rationality, allowing the new Government to invest in a range of reforms, in relation to a new democratic arrangement (du Plessis and Scheepers, 2000). This brought serious challenges to the existence and operation of traditional leaders. The position of traditional leadership institutions had to be reassessed within democratic setting (du Plessis and Scheepers, 2000).

#### *3.5.4.2. Integrating traditional leadership into democratic government:*

#### *The concept of mixed government*

Many former African colonies are known to be practicing mixed government (integration of traditional leaderships into democratic system of governance). Mixed government is a concept borrowed from history, from a political thought by Sklar

(1994). This concept, according to Bank *et al.* (1996), implies cooperative interaction among distinct and independent governmental institutions. Although the concept of mixed government requires cooperation among independent governmental institutions, this is not always the case in South Africa. Traditional leaderships are not appropriately represented by the existing democratic system (Cele, 2011).

Bank *et al.*, (1996) state that traditional leadership is integrated into democratic governance to serve as a form of rule which *"conserves traditional authorities as a source of politics without reducing the authority of the sovereign state"*. However, the introduction of SANCO system (South African National Civic Organisation) has undermined the presence and authority of traditional leadership (Bank *et al*., 1996). The youth in particular claims that it does not see the relevance traditional institutions in the future local government. The SANCO system has influenced the local communities in believing that traditional leadership has authority because they are not elected by the people (Bank *et al*. 1996).

In the Eastern Cape Province, the contemporary Minister of Housing and Local Government, in 1995, stated: "*There will be no headmen in this province anymore. We want people who are democratically elected*" (Bank *et al*., 1996). This has led to traditional leadership institutions ceasing to participate in local government meetings and functions, and their reluctance to share power with democratically elected resident associations (Bank *et al.* 1996). Traditional leaders insist that they will not be pushed away by SANCO, because they believe they have a significant role to play in the future of their communities (Bank *et al.* 1996).

The idea of mixed government remains an issue of concern in South Africa. The White Paper (2003:15) suggested that South Africa is facing a serious problem with regard to the integration of traditional leadership institutions within the democratic system of governance. Although the importance of traditional leadership institutions in the democratic South Africa is recognised, their exact roles and functions at community level are not clearly outlined (Khan and Lootvoet, 2001). According to Section 5 of the Traditional Leadership and Governance Framework Act of 2004, traditional leaders are entitled to partner with their respective local municipalities on development and service delivery issues (Khan and Lootvoet, 2001). This should be

based on the principles of mutual respect and acknowledgement of the respective roles (Bank *et al*. 1996).

In his study undertaken to determine success or failure in integrating traditional leadership institutions into the democratic system of governance, Maphosa (2010) stated that it is not easy to tell whether the integration was a success or not, based on number of suppositions:

(a) There are several challenges existing, related to traditional authority practices in matters regarding development and service delivery at the community level.
(b) There is inconsistency within these institutions, regarding democratic principles of governance, in spite of their long period of existence (Ismail *et al.* 1997).

In their investigation of the challenges to the implementation of Community-Based Resource Management (CBRM) in the Eastern Cape Province, Cocks *et al.* (2001) found that the South African Government does not want to grant legal land ownership status to local community. This makes it difficult for the community to implement effective CBRM. Based on the issues discussed in this section, it may be concluded that the integration of traditional leaderships into the democratic system of governance at a local level in South Africa has so far not succeeded. The failure of this system is attributed to lack of a clear definition of the roles that traditional leadership institutions and democratic councils should play (Maphosa, 2010).

### 3.5.5. Community role in managing common-property resources

A successful common resource management strategy seeks to involve community members in taking steps towards resource management. Riginos and Herrick (2010) indicate that communal rangeland monitoring should not just consult community members during the design of the rangeland monitoring programme, but should make community members its centre. The foundation and establishment of monitoring should be based upon the knowledge and experience of the households responsible for using communal rangeland resources (McCarthy *et al.* 2004). Without their engagement, the sustainability of the communal rangeland resource management will be at high risk, as these groups are the primary consumers of rangeland resources (Riginos and Herrick, 2010). Their dedication and support are fully required to responsibly monitor the rangeland resources. The capacity of the community to

operate or engage themselves in common resource management stems from its ability to create formal and informal frameworks to achieve goals of collective action (McCarthy *et al.* 2004). When every stakeholder pledges to adhere to governing policies and rules, resource management becomes much easier.

### 3.5.6. Grazing management

It is well-known that overgrazing has serious consequences, damaging the nutritional component of vegetation which negatively impacts its regeneration (Gay *et al*. 2009). The only way to prevent this damage is to remove livestock from vulnerable grazing areas to alternate areas with sufficient forage - a rotational grazing practice. Rotational grazing can act as an economic way of providing forage to livestock. Gay *et al.* (2009) state that the timing of livestock rotation should be guided by vegetation regrowth rate rather than a fixed time schedule. The successful implementation of the rotational grazing system should be accompanied by an efficient fencing system, providing effective control of livestock grazing (Undersander *et al.,* 2002). However, the existence of a fence should not limit where the rotational grazing takes place. Instead, the best utilisation of vegetation resources should drive the rotation (Gay *et al.* 2009).

#### *3.5.6.1. Fencing as a way of managing livestock grazing*

One of the important issues regarding vegetation resource protection is fencing; livestock browsing without control is often detrimental to vegetation resources. Fencing is the most effective method to restrict and exclude unauthorised access to vegetation resources. Unrestricted livestock access increases vegetation resource degradation through livestock browsing and vegetation trampling (Turner, 1989). Controlled grazing systems can be optimised by planning and yearly management of fencing systems (Gay *et al.,* 2009). Fencing systems allow livestock to browse a portion of rangeland, preserving other portions. It ensures the successful implementation of rotational grazing. Fencing also allows the regrowth of vegetation on previously grazed pasture.

#### *3.5.6.2. Herding and kraaling*

Livestock herding and kraaling may be considered a way of practicing a sustainable communal grazing management system, in cases where rotational grazing is not applicable at all, or due to lack of fencing. Moyo *et al.* (2012) recommend that, in a case where kraaling and herding of livestock are practiced, there is no need for rotational grazing camps. The time spent by grazing animals may easily be restricted by herding and kraaling; herded and kraaled livestock spend less time in grazing land than livestock that free-range (Bayer, 2011). The absence of livestock kraaling allows livestock to graze continually, even during the night. Several studies which have monitored grazing patterns in communal rangeland have focussed on livestock kraaling and herding (see Bayer, 2011; Baars and Ottens, 2000; Moyo *et al*. 2012). However, a decrease in vegetation resource quantity and quality in some communal grazing lands has been attributed to kraaling (Kristensen *et al.* 2007).

Differences in grazing management systems can lead to variations in vegetation condition (Klinka *et al.*, 1985), resulting in diverse impacts on vegetation condition.

### 3.5.7. Conflicts in resource utilization and management

The competition for natural resources access and utilisation always creates management conflicts (McCarthy *et al.* 2004). These conflicts may be caused by divergence in cultural values and social norms (Uprety, 2008). Most of the resource management conflicts occurring in communal areas are centred at institutional rather than household levels. Joshi *et al.* (2006) point out that local institutions are the major target of different political and social conflicts. These may include structural inequalities attributed to legal definitions of ownership and resource use (Warner and Jones, 1998).

Conflicts between village groups may also exist, and are caused by the unwillingness by one village group to respect resources of another village group (Warner and Jones, 1998). According to Cocks *et al.* (2001), the lack of statutory power limits the ability of the community and their local institutions to enforce decisions regarding resource management. Sustainable grazing management will ultimately be hampered by these conflicts.

### 3.6. Obtaining information regarding natural resource management

Natural resource-based studies that seek to identify the causes of natural resource depletion have also sought to obtain knowledge regarding natural resource management (Zammit and Cockfield, 2000; Shackleton *et al.* 2002; Fabricius *et al.* 2007). This is because sustainability of natural resources is highly controlled by the cooperation among stakeholders in order to effectively manage natural resources (Reed *et al.* 2009). Shepherd (2004) observed that ecosystem well-being cannot be analysed without analysing human impacts thereof; humans are the most significant component of the ecosystem that provides mechanisms for managing it. The most reliable way to determine natural resource management strategies is to conduct interviews (Kvale and Brinkmann, 2008).

Studies that sought to obtain information regarding natural resource management have employed the interview method of data collection (Heltberg, 2001; Mendham *et al.* 2012; Alkan *et al.* 2010). Harrell and Bradley (2009) defined the interview method of data collection as a discussion between an interviewer and individual, meant to gather information on a specific set of topics. Woods (2011) indicates that interviews are extensively used to enhance and extend our knowledge regarding individual thoughts, feelings and attitudes and interpretations. Phellas *et al.* (2011) note that an interview is a more flexible qualitative data collection method than the questionnaire and, if appropriately employed, can normally collect information of greater depth and can be more sensitive to contextual variations in meaning.

Various types of interview techniques that are widely used in data collection include structured or standardized, semi-structured and unstructured or in-depth interviews as well as focus group discussions. These methods are all useful, depending on the area they are applied in (Mathers *et al.* 2002). In structured interviews, all the participants are presented with the same questions that should be answered in the same way (Mathers *et al.* 2002). The questions herein may be expressed in a manner that limits interviewee to a certain extent (Woods, 2011). This restricts respondents to express their feelings regarding the aspect investigated (Mathers *et al*. 2002).

In unstructured or in-depth interviews, the interviewer approaches the interview in the form of having a discussion with respondent regarding a certain topic under investigation (Mathers *et al.* 2002). These are shared experiences in which the interviewer and interviewee come together to form a context of conversational confidence in which participants feel comfortable giving their story (Ramos, 1989). However, because each interviewee is asked a different series of questions, this style lacks the reliability and precision of a structured interview (Morse and Corbin, 2003). Its nature makes it deviate from the ideals of quantitative research; a process in which distance and control are highly valued (Morse and Corbin, 2003). When the unstructured interview session begins, participants are often unaware of the path that an interview might take or what secrets they might reveal (Morse and Corbin, 2003). Morse and Corbin (2003) noted that when there is a comfortable atmosphere of the home and when there is trust, interviewees may end up revealing information, which they would not reveal under normal circumstances.

Looking at in-depth interviews, distinct interviews with a small number of respondents to explore their opinion on a specific idea or situation are involved (Boyce and Neale, 2006). This type of interviews is useful when you want detailed information about a person's thoughts and behaviours or want to explore new issues (Guion *et al.* 2011). The advantage of using this type of interview is that it gives more detailed information than that which can be acquired using other data collection methods; it provides a more relaxed environment for data collection because interviewees may feel more comfortable having a conversation with you as opposed to filling out a survey (Boyce and Neale, 2006).

Semi-structured interviews give the interviewer more freedom to explore issues as a matter of course rather than pre-empting issues (Pathak and Intratat 2012). A semi-structured interview begins with wide-ranging and more general questions or topics (Arksey and Knight, 1999). Although it is of significance to pre-plan the key questions, a semi-structured interview is conversational, with questions flowing from previous responses when possible (Guion *et al.* 2011). Its advantage is that it provides room for conversation without deviating from the topic (Boyce and Neale, 2006). Several studies have employed the semi-structured interview technique to obtain information regarding natural resource management (Hazell *et al.* 2001; MacDonald

*et al.* 2013; Birnbaum, 2007). It was on this basis that the current study employed this approach to determine local-level institutional management functionality in the central Keiskamma catchment.

## 3.7. Influence of physical terrain on vegetation condition

It is important to understand the influence of the physical terrain before attempting to analyse variations in vegetation condition. According to Dorner *et al.* (2002), vegetation studies that disregard the influence of topography place themselves in the danger of misinterpreting results and making incorrect recommendations to the management fraternity. Vegetation condition can vary with variations in topographic pattern (Coban *et al.* 2010), as it creates permanent natural breaks in vegetation patterns (Turner 1989; Swanson *et al.* 1998). Coban *et al.* (2010) identify detailed changes that occur in forested areas having a complex vegetation structure, located on steep slopes with varying topographic characteristics.

### 3.7.1. Elevation

Elevation is responsible for the altitudinal 'zonality' of soil and vegetation (Florinsky and Kuryakova, 1996). This elevation-vegetation correlation was investigated by Munger (2007); who established that areas with the highest elevation (altitudes between 550 m and 660 m) were found to have relatively low NDVI values, likely due to water cover, steep slopes and exposed areas, while areas with low elevations were ascertained to have high mean NDVI values and the greenest vegetation. Jin *et al.* (2008) conclude that elevation is unambiguously proven to be one of the major factors controlling vegetation growth in the Qilian mountain areas; NDVI values increase with an ascent in elevation, reaching a peak value at around 3400 m, subsequently progressively declining as the elevation exceeds this point.

### 3.7.2. Slope angle

Slope angle is one of the focal topographic variables determining the state and quality of vegetation. Slope gradient also determines the drainage amount, erosion and runoff occurring on the land (Poole *et al.* 2001). Munger (2007) noted that flat and gentle slopes are predominantly vegetated, while steep slopes have a characteristic vegetation zonation. In his study, areas with gentle slopes (slope angles between 2°

and 10°) had the highest greenness NDVI values (0.513) of vegetation, followed by moderate slopes (10° to 20°) with a mean NDVI value of 0.495.

### 3.7.3. Aspect

The concept of site exposure or its counterpart, shelter, is widely understood to have a prominent influence on vegetation micro-habitats (Wilkinson and Humphreys, 2006). This concept is contingent upon the latitudinal and longitudinal characteristics of the area under study. It is believed that in the northern hemisphere, south-facing slopes get more solar energy than north-facing slopes and are consequently defined by lower water availability (Holland and Steyn, 1975); that is why south-facing slopes in the northern hemisphere have the highest proportion vegetation than north-facing slopes in the same hemisphere. The reverse is true for the southern hemisphere.

The influence of site exposure on vegetation condition was further investigated by Munger (2007), who discovered that slopes facing east and west had the greenest surfaces, with mean NDVI values of 0.504 and 0.502, respectively, while north-facing slopes and south-facing slopes had the lowest mean NDVI values, 0.490 and 0.488, respectively. Jin *et al.* (2008) ascertained that vegetation growth in the Qilian mountain areas is principally affected by aspect. The impact of aspect on vegetation growth was found to be significant in the altitudinal zone of 3200 m and 3600 m.

Many geographic areas have digital datasets which describe topography at various scales (Pike, 2000). Computer programs facilitating the manipulation of topographic information are widely available; as either ‘stand-alone’ software or forming a fundamental component of several GIS packages (Pike 2000).

## 3.8. The role of remote sensing in monitoring vegetation condition

According to Elzinga *et al.* (1998), the purpose of monitoring is to provide an early warning system regarding the current sequence of actions in terms of their sustainability or otherwise. Monitoring aids in identifying problems brought about by current processes, before they get entrenched. Monitoring vegetation pattern and composition in the contextual setting of space and time has limitations, if conducted using conventional only methods (Roy and Ravan, 1996). Remote sensing techniques

have evolved into a significant and reliable tool for monitoring and analysing vegetative condition. According to Adam *et al*. (2009), remote sensing techniques provide timely, up-to-date and accurate data, permitting sustainable and effective vegetation management. The application of remote sensing in rangelands provides effective routes for collecting details about vegetation condition (Amiri and Tabatabaie, 2009). Several studies have successfully used remote sensing technology to map and assess vegetation condition (Beck *et al.* 2006; Hunt *et al.* 2003).

### 3.8.1. Remotely-sensed data for vegetation condition analysis

Satellite imagery, particularly Landsat, has been widely used for assessing vegetation condition (Hunt *et al.* 2003). Landsat imagery is an invaluable asset in land use/cover change detection studies because of its huge archive of data which dates back to 1972 (Mhangara, 2011). Landsat-5 TM, launched on the 1$^{st}$ of March 1984, is the fifth generation of the Landsat programme, which provides a global archive of imagery. The Systeme Pour I'Observation de la Terre (SPOT) sensor, launched in 1978 by the French Space Agency, Centre National d'Etudes Spatiales (CNES) (Lillesand *et al.* 2008), constitutes an exceptional source of information for assessing, monitoring, predicting and managing land cover conditions (Levin, 1999). SPOT provides a high spatial resolution, making it ideal for small scale land use or land cover assessment (Levin, 1999). It supplies accurate information about the earth, covering a surface area of approximately 3,600km$^2$ per scene. This system provides a perpetual collection of data, given the improved technical ability and performance of its sensors (Lillesand *et al.* 2008). The SPOT-5 VGT sensor, launched in 2002, is designed to assess and monitor vegetation cover and other land surfaces (Xu *et al.* 2004). Several studies have used these satellite images for mapping surface vegetation condition (Zerger *et al.* 2007; Mroz and Bialous, 2004).

### 3.8.2. Vegetation spectral properties

From a remote sensing perspective, vegetation condition is assessed and monitored in terms of spectral reflectance. The data collected by remote sensors represent the spectral reflectance and emittance characteristics of vegetation (Hoffer, 1986). Spectral reflectance and chlorophyll fluorescence are the most useful, non-invasive methods that can be utilised to measure the degree and extent of vegetation stress (Richardson and Berlyn, 2002). Vegetation has a spectral signature, caused by

chlorophyll absorptions of a portion of the electromagnetic spectrum, called photosynthetic active radiation. Schanda (1986) distinguishes two types of chlorophyll, type *a* and type *b*, which absorbs light energy at 0.43 to 0.66 µm and 0.45 to 0.64 µm, respectively. Adam *et al.* (2009) state that the successful assessment and monitoring of vegetation condition using remote sensing requires information about vegetation spectral properties, variations in vegetation condition, and broad- and narrow-bands. It also requires a deeper understanding of electromagnetic radiation principles, information at appropriate spatial and spectral resolution, and reliable methods for extracting information about vegetation.

Spectral characteristics of vegetation change from one season to another. van Til *et al.* (2004) observed that the spectral properties of vegetation transform during the growing season. Remote sensing assesses vegetation condition on the basis of spectral characteristics of plant leaves. For a reliable assessment, remote sensing data should provide suitable spectral, spatial and temporal resolutions (Lee *et al.*, 2007). Spectral characteristics of vegetation are controlled by various factors, which include absorption, transmission and reflection of incoming solar radiation (van Til *et al.* 2004).

Several studies have indicated that different vegetation types and conditions reflect and emit various amounts of energy in a single spectral band (Levin, 1999, Richards and Jia, 2006, Campbell, 1996). For green vegetation, most of the energy in the visible wavelengths (below about 0.72 µm) is absorbed by chlorophyll, with less absorption and higher reflectance in the green wavelengths (about 0.55 µm) between the two chlorophyll absorption bands (Hoffer, 1986). This is because chlorophyll has absorption bands in the blue and red regions of the visible spectrum, with a peak in the green band; this is why chlorophyll pigmented plants are seen as green (Richards and Jia, 2006). Figure 3.2 shows the spectral characteristics of vegetation; the peak reflectance of green vegetation is obtained in the green wavelength of visible spectrum. The reflectance increases dramatically in the near-infrared portion of electromagnetic spectrum where spectral profiles of vegetation clearly show, due to the presence of chlorophyll (Trodd, 2009). Healthy green vegetation has a distinctive interaction with energy in the visible and near-infrared portions of electromagnetic spectrum (Idrisi Taiga manual, 2009).

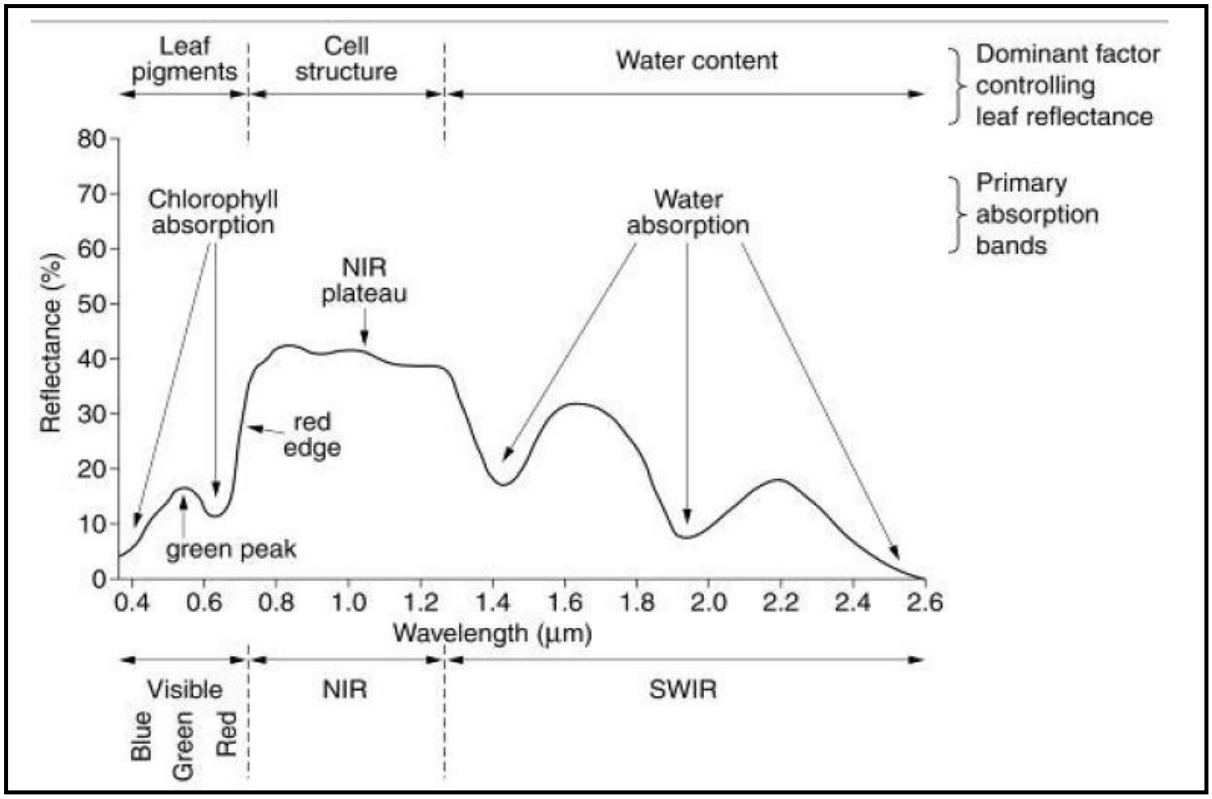


Figure 3.2: Green vegetation reflectance across various portions of the electromagnetic spectrum (Source: Bogonko, 2005)

### 3.8.3. Vegetation indices

The assessment and monitoring of vegetation condition using remote sensing techniques have required the use of vegetation indices (VIs) (Amiri and Tabatabaie, 2009) as a precise radiometric measure of the spatial and temporal change in photosynthetic activity (Huete *et al.* 1997). These are feature extraction operations intended to yield estimates of vegetation cover from imagery (Philpot, 2011). Vegetation indices provide an efficient and reliable way of monitoring and mapping vegetation condition. They have proven to be sensitive indicators of the presence and state of vegetation (Levin, 1999). They provide information about vegetation cover on the ground, using a combination of reflectance measurements from different portions of the electromagnetic spectrum (Campbell, 1996).

Several indices for assessing vegetation health and density are dependent upon the contrast between the red and near-infrared reflectance (Amiri and Tabatabaie, 2009). This contrast has been widely used to generate several vegetation indices, which include the Simple Vegetation Index (SVI) (Pearson and Miller 1972), Normalised

Difference Vegetation Index (NDVI) (Rouse *et al.* 1974) and Soil-Adjusted Vegetation Index (SAVI1,3,4) (Pearson and Miller, 1972). Vegetation indices obtain information about surface characteristics from multi-spectral measurements, taking advantage of the differences in the reflectance patterns between green vegetation and other surfaces (Payero *et al.* 2004).

Several studies have indicated that integrated vegetation indices can be directly related to vegetation extent and primary productivity (Tucker *et al.* 1983; Silleos *et al.* 2006; Payero *et al.* 2004; Huete *et al.* 1997). In all vegetation indices, two basic assumptions are made: firstly, algebraic combinations of remotely sensed spectral bands can provide useful information about vegetation. Secondly, all bare soils in an image form a line within spectral space (the soil brightness line), as the line of no vegetation (Tucker *et al.* 1983). Spectral vegetation indices have been employed to predict ecological variables (Lawrence and Ripple, 1998). Though several vegetation indices are available, their effectiveness and efficiency in characterising vegetation condition can only be realised if the appropriate index is selected (Payero *et al.* 2004).

Vegetation indices are usually related to the environmental conditions of a place at the local scale, whereas at a regional scale, they more often pertain to broad land cover types (Curran *et al*. 2000). Their derivation may be influenced by various factors, depending on the environment of the area under study. Soils will always have an influence on vegetation indices, unless vegetation completely covers the area under study (Russell, 2004). They are mostly commonly derived from low spatial resolution or high temporal resolution satellite imagery (Thomson and Conner, 2000). Vegetation indices may be classified into two groups, namely, slope-based and distance-based vegetation indices (Jackson and Huete, 1991). These vegetation indices differ on the basis of the orientation of a line of equal vegetation intensity, regardless of moisture conditions (Mróz and Bialous, 2004). Both the distance- and slope-based vegetation indices are capable of analysing land cover, depending on the extent of the vegetation cover and soil conditions in a given environment.

#### *3.8.3.1. Distance-based vegetation indices*

Distance-based vegetation indices are based on the soil-line concept. The pixels located near soil line are assumed to be soil, whereas those located further from the soil line are assumed to represent vegetation (Mróz and Bialous, 2004). They measure the degree of vegetation present by gauging the differences between any pixel's reflectance to that of the bare soil (Chang *et al.* 2005). They are most useful in arid and semi-arid regions, where surfaces are dominated by mixtures of vegetation and soil. Their primary goal is to minimise the effect of soil brightness, in instances where pixels contain a mixture of green vegetation and soil background (Ramachandra, 2007).

The most commonly used distance-based vegetation indices include the Perpendicular Vegetation Index (PVI), which was propounded by Wiegand *et al.* (1977). Sensitive to atmospheric variation, the PVI defines for each pixel in a given dataset, the distance that the vegetation radiance is located from the plain of soil reflectance (Zerger *et al.* 2007). It monitors variations in bare soil reflectance imposed by vegetation; thereby vegetation cover is expressed independent of soil. It relies on the assumption that the perpendicular distance of the pixel from the soil line is closely related to vegetation cover (Idrisi Taiga Manual, 2009). The disadvantage of the PVI is that it has a poor dynamic range, although it is sometimes better at perceiving differences in vegetation in scenarios of low vegetation coverage, as compared to the NDVI (Zerger *et al*. 2007).

Proposed by Huete (1988), the Soil-Adjusted Vegetation Index (SAVI) is another more frequently employed vegetation index, applicable where there is low vegetation cover and exposed soil surfaces. It was developed to overcome the weakness of the NDVI in discriminating vegetation signals where soil brightness is very high (Mróz and Bialous, 2004). It is more applicable in arid and semi-arid regions, due to its ability to minimise the effects of the soil background noise on vegetation signals and attempts to supply equal vegetation index results for both dark and light soils. This requires specifying the soil brightness correction factor (L) through trial-and-error, depending on the amount of vegetation to be analysed (Idrisi Taiga Manual, 2009). Other SAVI versions include the Modified Soil-Adjusted Vegetation Index (MSAVI 1 and MSAVI 2) and the Transformed Soil-Adjusted Vegetation Index (TSAVI). These

vegetation indices were developed to overcome the sensitivity of SAVI and add to its ability in distinguishing and discriminating bare surfaces (Qi *et al.* 1996. Their primary disadvantage is that they tend to sacrifice a quantity of overall sensitivity to vegetation changes (amount or cover) in correcting soil brightness (Hancock, 2006). TSAVI was developed to compensate for soil variability, due to changes in solar elevation and canopy structure (Gong *et al*. 2003), assuming that for bare surfaces, the index value is equal to zero and to 0.7 for every densely vegetated surface.

#### *3.8.3.2. Slope-based vegetation indices*

Slope-based vegetation indices are arithmetic permutations that focus on the contrast between the spectral response patterns of vegetation, in the red and near-infrared portions of the electromagnetic spectrum (Idrisi Taiga Manual, 2009). In slope-based vegetation indices, the position of each point, in 2-dimensional NIR-Red space, is geometrically equivalent to the slope (tangent) of the line connecting the origin of reference and the particular point on the scattergram (Mróz and Bialous, 2004). Their values represent both the state and abundance of green vegetation biomass and cover (Idrisi Taiga Manual, 2009).

The most commonly used slope-based vegetation indices include the Ratio Vegetation Index (RVI) and Normalised Difference Vegetation Index (NDVI). RVI is the most straightforward vegetation index (Russell, 2004), which records the difference between the red and near-infrared bands for vegetation pixels, with high index values produced by combinations of low red (because of absorption by chlorophyll) and high infrared (as a result of leaf structure) reflectance (Idrisi Taiga manual, 2009). While it can be sensitive to changes in vegetation during peak growth, it cannot easily sense differences when vegetation is sparsely distributed (Jackson and Huete, 1991). The problem with the RVI is that it fails to sense vegetation presence only, due to topographic effects and variations in the sun's illumination angle (Mróz and Bialous, 2004).

The Normalized Difference Vegetation Index is the most widely used, satellite-derived vegetation index for assessing vegetation health and density (Bellone *et al.* 2009). NDVI application has received much attention in forest monitoring, crop yields and rangeland carrying capacity (Bellone *et al.* 2009). Information from the red

(high absorption) and near-infrared wavelengths (high reflectance) combined into the Normalised Difference Vegetation Index (NDVI) is used as traditional technique for assessing and monitoring vegetation (Tucker *et al.* 1983). The NDVI value is calculated as follows:

NDVI= [NIR-RED] ÷ [NIR+RED]

The NDVI is useful in arid and semi-arid environments due to its ability to discriminate between vegetation and soil in cases where there is sparse vegetation cover. It was on this basis NDVI was preferred for use in this study.

### 3.8.4. Remote sensing image classification

The classification of vegetation is a fundamental tool for obtaining knowledge about the vegetation cover and its relationship with the earth's environment (Mueller-Dombois, 1984). Monitoring vegetation condition is accompanied by the classification of remote sensing images (van Til *et al*. 2004). The main purpose of image classification is to analyse the distribution of vegetation types and determine their ecological relationships. For the purpose of classification and mapping of vegetation over a large scale, remotely-sensed data are used (Perumal and Bhaskaran, 2010). Yongxue *et al.* (2006) defined remote sensing image classification as land use/cover class extraction from satellite imagery. It involves aggregating the pixels of an image to a set of classes, such that pixels in the same class are of similar spectral properties (Hasmadi *et al.,* 2009). The unsupervised and supervised classification approaches can be used. The unsupervised classification involves the examination of unknown pixels in an image and combining them into a number of classes on the basis of the natural groupings or clusters present in an image (Babykalpana and ThanushKodi, 2010). This method is designed to automatically group the pixels without prior knowledge of the features represented by each pixel (Babykalpana and ThanushKodi, 2010). On the other hand, the supervised classification involves the need for prior knowledge of the ground cover of the study site (Hasmadi *et al.,* 2009). The user decides the number and types of classes to be extracted. It requires training data to generate classes defined by user. The same generated training data are used to train a classification algorithm (Kamaruzaman *et al.,* 2009). It is on this basis that the supervised classification was preferred ahead of unsupervised approach in the current study.

In the supervised classification method, there are two approaches for image classification; pixel-based and object-oriented supervised classification methods. The pixel-based supervised classification approach is the most popular supervised classification method. However, this method has been criticised lately due to its ambiguous statistical definition of land cover classes (Barrile and Bilotta, 2008). These limitations include pixel mis-classification and unclassified pixels (Fu *et al.*, 2012). The supervised object-oriented classification method was developed to overcome these limitations. This method, which groups adjacent pixels into image segments according to their spectral similarities (Idrisi Taiga manual, 2009), is a reliable classification algorithm for image classification. It aggregates image pixels that share similar attributes such as the Digital Number (DN) value and spectral characteristics (Yongxue *et al.*, 2006). The image objects are created through the image segmentation technique. Babykalpana and ThanushKodi (2010) defined image segmentation as partition and pick-up of homogeneous regions of an image. Object-oriented classification has recently gained popularity due to its ability to overcome traditional per-pixel classification limitations by providing accurate classification (Corcoran and Winstanely, 2007). Several studies that have attempted to perform remote sensing image classification in recent years have employed this classification technique (Li *et al.*, 2010; Benz *et al.*, 2004; Aplin and Smith, 2008). It is on this basis that the current study chose the supervised object-oriented classification ahead of its pixel-based counterpart.

### 3.8.5. Validating remotely-sensed data by ground truth data

Remotely-sensed data necessitates ground based validation. Data received from the remote sensors are generally not perfectly correlated with the actual condition of the earth's surface (Park, 1984). There is no map which provides completely accurate information; mapping and interpretation of vegetation conditions is limited to certain adjacent scales of observation. Arieira *et al*. (2011) recommend integrating remotely-sensed data and ground observations, to reduce uncertainties and increase the reliability of the results. Their study revealed that an improvement of vegetation mapping could be achieved by increasing the number of field observations. Fuller *et al.* (1998) integrated field surveys and remote sensing data for a biodiversity assessment in the tropical forests and wetlands of Sango Bay, Uganda. They observed

that an integration of field observation and remote sensing assists in the generation of biodiversity maps useful for conservation planning.

Traditionally, a correction of digital data was done using photo-interpretation (Congalton, 1991). This was because photo-interpretation was accepted as accurate without confirmation, based on the assumption that it is 100% correct (Congalton, 1991). Zavoianu *et al.*, (*2001*) define accuracy assessment as the degree of closeness of results to the value accepted as true or correct. The main objective of performing accuracy assessment is to provide an index of the degree of correctness of a map or classification (Foody, 2002). In remote sensing, this is achieved by overlaying a reference image and simulated image (Geri *et al.*, 2011). Accuracy assessment in remote sensing is achieved by using the error matrix (ERRMAT) method and the Kappa Index of Agreement (KIA).

The error matrix measures the relationship between image classification results and measured ground conditions (Collingwood *et al.*, 2009). It is regarded as standard procedure for accuracy assessment (Foody, 2002). On the other hand, the KIA is a discrete multivariate technique which is used to statistically evaluate the accuracy of classified data (Collingwood *et al.*, 2009). It is commonly used to quantify the agreement between two images on a categorical basis. For this agreement to be obtained, two images must be categorized into equal groups (Schouten, 1982). It considers the effect of chance agreement in the error matrix (Collingwood *et al.*, 2009). The advantage of the KIA over the standard error matrix is that it measures both overall and individual class accuracy (Collingwood *et al.*, 2009). Several studies that evaluated the efficiency and effectiveness of both the error matrix and KIA for accuracy assessment have recommended the KIA for accuracy assessment (Rossiter, 2004; Pontius, 2000; Geri *et al.*, 2011). Against this background, the present study also uses KIA for accuracy assessment.

According to Amiri and Tabatabaie (2009), in order to determine the suitable indices for vegetation cover and production assessment, a contemporaneous analysis of remotely-sensed and field data should be undertaken. True, actual ground measurements are required for several steps in the image processing procedure (Clark *et al*. 1999). Field based measurements are important for the establishment of a gradient of conditions, to test ecological indicators and the sensitivity of remote

sensors. Studies focused on biomass estimation, using remote sensing have attempted to couple ground-based vegetation quantification to satellite remote sensing (Roy and Ravan, 1996). Williams and Kepner (2002) employed remotely sensed measurements and compared them with field samples to determine rangeland stress patterns.

### 3.9. Statistical applications in vegetation management

Several studies have been conducted to determine factors influencing vegetation condition distribution at both small and large scales (Nakagoshi and Ohta, 1992; Nyoike, 2008; Zhu *et al*., 2011). However, determining whether indeed identified factors are the ones responsible for vegetation condition distribution requires the quantification of the relationships between the spatial vegetation condition trends and identified factors. Quantifying human-induced factors influencing vegetation condition trends requires testing homogeneity of physical variables of the region under study (Lezama *et al.* 2013; Runkle and Whitney, 1987; Oldeman, 1988).

#### 3.9.1. Testing homogeneity

Testing for homogeneity is essential for purposes of comparing variances between two or more populations (Schaalje and Despain, 1996). Mattiuzzi and Markowicz (2000) defined homogeneity as the state of being of uniform structure or composition with respect to one or more specified properties. For homogeneity assessment, statistical tests are conducted on the results acquired from different parts of materials in order to confirm whether the same properties have been witnessed (Mattiuzzi and Markowicz 2000). A well-known statistical test for homogeneity is based on the Chi-square statistical test. Chi-squared test is expressed as:

$$X^2_0=\sum (O_i-E_i)^2/E_i$$

Where $O_i$ is the observed frequency and $E_i$ is expected frequency in the $i^{th}$ value.

However, homogeneity assessment needs to be accompanied by hypothesis testing. Hypothesis testing is the scientific procedure to determine if a hypothesis is acceptable or not (Kharin, 2008). The hypothesis provides a direction to the collection and analysis of data. A null hypothesis ($H_0$) is a claim that there is no significant difference in the distribution of variables observed (LeMire, 2010).

Hypothesis testing is accompanied by defining the confidence interval/significance level, which provides the quality level of the hypothesis testing procedure (Wood, 2012). The current study tested the homogeneity of topographic variables across the study villages, by comparing the chi-squared and critical values to make decisions about the topographic homogeneity of the study area. It also used the logistic regression (described in section 3.9.2) to determine the relationship between grazing management practices and vegetation condition.

### 3.9.2. Determining the degree of relationship among variables

Statistical methods are very useful in determining the relationship among variables. They define the degree of relationship among variables, significance of group differences, prediction of group membership, structure, and questions that focus on the time course of events (O'Neil, 2009).

In instances where a relationship is to be determined between categorical and predictor variables, the logistic regression is well suited (Peng and So, 2002). According to Tranmer and Elliot (2008), the logistic regression considers the fact that the dependent variable is categorical and variables are dichotomous (presence/absence). It works on the basis of the logit transformation of the dependent variables. The transformation generates a continuous logarithmic curve from non-continuous data so that a regression model can be developed (Healy, 2006). The logistic regression equation is expressed as:

$$\Theta = [e^{(\alpha+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_i x_i)}]/[1+e^{(\alpha+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_i x_i)}]$$

Where α is the constant of the equation and β is the coefficient of the predictor variables.

The relationship between variables is determined by comparing the Chi-square and critical values at a certain significance level (Kostalova, 2010). In the present study, the logistic regression was used to determine the relationship between vegetation condition and the presence or absence of certain grazing management attributes in the villages of the study area.

The subsequent chapter presents the methods used to achieve the objectives of the study.

# CHAPTER 4

# RESEARCH METHODS

## 4.1. Introduction

This chapter outlines the methods and techniques employed to ensure the achievement of the objectives of this research study; which were accomplished by applying GIS and remote sensing methods; on-site field measurements and observation; and interviews. Aster DEM was used to determine topographic homogeneity across villages. Satellite images, taken in 1984, 1999 and 2011 were utilised to analyse vegetation condition trends. The selection of the satellite imagery was influenced by their availability and quality. Field surveying, through observation and measurements of the location under study was conducted to evaluate the regions identified from 2011 NDVI imagery through density measurements. Structured interviews were conducted to determine the existence and efficacy of local level structures responsible for implementing grazing management strategies within fifteen selected villages. Vegetation condition was then related to grazing management systems using the logistic regression.

## 4.2. GIS and remote sensing methods

The analysis of trends in vegetation condition required the application of GIS and remote sensing to the above mentioned temporal imagery. The image acquisition and processing procedures, as well as testing for homogeneity are described in the subsequent sub-sections.

### 4.2.1. Data acquisition

The current study employed Landsat-5 TM and SPOT-5 satellite images for vegetation condition analysis. Landsat-5 TM image scenes captured in 1984 and 1999 were downloaded from the USGS website, while SPOT-5 imagery was acquired from the South African National Space Agency (SANSA). Their selection was based on their medium spatial resolution - 30mx30m and 20mx20m, respectively; their ability to spectrally distinguish vegetation from soil; and their cost-free availability. The

local growing season is usually important for assessing vegetation condition (Kakembo, 2003); therefore, the sets of images acquired were captured in April, as this is when foliage is in its growing stage. According to the information obtained from the South African Weather Service, the rainfall preceding the capture of these imagery sets was normal; hence they are comparable in terms of vegetation condition. Landsat-5 TM images were received in Universal Transverse Mercator (UTM) World Geodetic System 1984 ellipsoid and SPOT-5 image set was received in UTM coordinate system. Both Landsat-5 TM and SPOT-5 were received in Tagged Image File Format (TIFF), and subsequently exported to the Idrisi GIS programme, where they were prepared for processing.

Shapefiles of the study area were created by digitising. Two point shapefiles were established to represent villages and sample points within the study area, along with two line shapefiles representing roads and rivers and polygon shapefiles representing the boundaries of each village in the study area. The village boundary shapefiles represented villages and their respective grazing camps. Village boundaries were determined by way of consultations with the local village councils. These shapefiles were projected into UTM, for easy use with satellite images. The shapefiles, excluding roads, were overlaid on the satellite images. Polygon shapefiles of a vegetation map of South Africa were acquired from SANBI, in conjunction with shapefiles obtained from the Council for Geoscience, extracted from the geology map of South Africa. The shapefiles for the study area, from the South African vegetation and geology map shapefiles were extracted using the clip tool in ArcGIS.

A Digital Elevation Model (DEM) with a spatial resolution of 30mx30m, in TIFF format, with the UTM coordinate system, in World Geodetic System 1984 Datum was acquired from SANSA. The DEM was exported to Idrisi Taiga software for generating and analysing the topographic characteristics of the study area. Ground Control Points (GCPs) were collected to serve as reference points for the geometric correction of image scenes. Road intersections and stream junctions served as the main reference points.

### 4.2.2. Image pre-processing

The process of geometric correction was achieved using the image resample module in Idrisi Taiga remote sensing software. This technique is the most preferred if the images are to undergo classification (Richards and Jia, 2006). SPOT-5 image scenes were projected to the UTM coordinate system using the World Geodetic System 1984 ellipsoid to fit the spatial parameters of Landsat-5 TM image sets. Resampling of image bands was achieved by using the Nearest Neighbour resampling algorithm, based on eleven control points, common to all images. The Root Mean Square (RMS) errors was calculated and found to be 0.000650.

The area in which the study is undertaken could not completely appear in a single acquired DEM set; it is shared between two DEM scenes. Two DEMs based on different Aster imagery sets were 'concatenated' in IDRISI Taiga GIS where they were spatially combined to produce a single image. The two images were joined utilising the Automatic Placement Using Reference Coordinates algorithm. This algorithm is an image mosaicking algorithm which allows the images to be combined automatically by selecting a common row or column in all images to be concatenated (Idrisi Taiga Help Systems, 2009).

### 4.2.3. Testing homogeneity of topographic characteristics

Topographic characteristics, viz. elevation, slope and aspect, were calculated from the DEM. The class frequency for each of the topographic variables was calculated in the Idrisi Taiga database. A null hypothesis that there is no significant difference among the class frequencies of each of the respective topographic variables was tested. A Chi-Squared test was performed to determine whether there was homogeneity in the spatial distribution of each topographic characteristic among villages. The critical value used was 3.84 at 95% probability level. The Chi-squared value was then compared with the critical value to determine whether there was topographic homogeneity among villages.

### 4.2.4. Assessing vegetation condition trends

Normalised Difference Vegetation Index (NDVI) images for the specified years were created using the formula:

The NDVI is the most versatile valuable and useful Vegetation Index (Bellone *et al.* 2009), with values ranging between -1 and +1, where the -1 value indicates a surface with no vegetation and +1 indicates green healthy vegetation. The selection of NDVI ahead of other vegetation indices in this study is justified by its capability to clearly show the condition of vegetation that prevails in the study area, comprising intact, transformed and degraded thicket, grassland and distinct bare areas. NDVI has been recommended for vegetation condition mapping due to its ability to minimize topographic effects (Ramachandra, 2007). The ability of the NDVI to minimise soil background noise in semi-arid environments, where intershrub-bare surface mosaics exist has been highlighted by some studies (Phillips *et al.* 2008; Ramachandra, 2007). The relationship between vegetation condition and local grazing management systems is examined later in section 4.5 of this chapter.

#### *4.2.4.1. Image classification method*

Vegetation condition categories were classified on the basis of the NDVI analyses. Three vegetation condition classes, namely intact vegetation, transformed vegetation and degraded vegetation were extracted from the multi-temporal NDVI images. Additional categories also extracted from multi-temporal NDVI images are bare surface and water. The classification of these multi-temporal images was achieved by employing the supervised object-oriented classification/image segmentation algorithm built in the Idrisi Taiga GIS software. This supervised classification method simply groups pixels according to their homogeneous spectral properties. Satellite images for the respective years were classified independently.

The use of the object-oriented classification method in the current study overcomes the disadvantages of the traditional ‘per-pixel’ classification methods. By grouping pixels of the same spectral properties into homogeneous objects; objects are identified in terms of spatial patterns of similarity and spectral properties of the pixels, a process known as segmentation (Aplin and Smith, 2008). This ensures that landscape patterns

are presented in a meaningful way, on the basis of the segments. The object-oriented classification approach also eliminates the mixed-pixels problem (Mhangara, 2011).

#### *4.2.4.2. Classification accuracy assessment*

An accuracy assessment process was undertaken, to validate the vegetation classes. Twenty sample points were verified in the field, per class using the stratified (purposeful) random sampling method. Their GPS readings were taken using the centimetre level precision Ashtech®ProMark2™ Global Positioning System (GPS) receiver. The sample points constituted features (particularly vegetated surfaces) common to the respective imagery sets. The collected field verification points were overlaid on the NDVI images for each year and vector layers were digitised around these points, to create a training file. Two images classified and based on ground truth data were then compared for all years, utilising the error matrix analysis algorithm, built into the Idrisi Taiga software. Estimates of error were provided by module results, i.e.:

- Error of Omission - occurs when pixels of class 1 were wrongly assigned to class 2, and from class 1 perspective, these pixels should have been assigned to class 1 but were omitted.
- Error of Commission - occurs when pixels of class 2 were wrongly assigned to class 1, and from class 1 perspective, these pixels shouldn't have been assigned to class 1 but were included.

The Kappa Index of Agreement (KIA) value for each image was calculated and is provided in Table 4.1.

Table 4.1: Accuracy assessment results

| YEAR | OVERALL ACCURACY | KIA |
|---|---|---|
| 1984 | 0.7897 | 0.8054 |
| 1999 | 0.8454 | 0.7797 |
| 2011 | 0.8302 | 0.7670 |

## 4.3. Field observations

Adams and Gillespie (2006) observed that remotely sensed spectral images are a proxy for being in the field. However, since remotely-sensed data are subject to error, field observations are required to validate imagery details. As pointed out above, 20 sample points per vegetation class were verified for purposes of accuracy assessment. General variations in vegetation condition across the study area were noted. Sites representing three classes of vegetation, viz. pristine (mainly thicket and grass) vegetation; transformed and degraded vegetation were visited for ground verification.

## 4.4. Semi-structured interviews

A semi-structured interview schedule (Appendix B) was prepared and presented to the local level institutional committee members responsible for regulating grazing management systems within the study areas. The existence and effectiveness of local level institutions responsible for regulating grazing management systems within the central Keiskamma catchment were explored. Information pertaining to knowledge of management and past management regimes was obtained through this method. In this regard, information about the absence or existence of gazing management systems was obtained from local level institutional committees during meetings held in their respective community halls.

## 4.5. Relating vegetation condition to grazing management systems

During the interviews, cognisance was taken of the presence or absence of certain grazing management practiced within individual villages. Vegetation conditions were then related to these attributes by digitising points on NDVI images representing villages with such dichotomous conditions (presence/absence). A total of 300 points were randomly digitised, with at least twenty points digitised within the vicinity of each village. The digitised vector point files were rasterized, using the 'RASTERVECTOR' module in IDRISI Taiga version. The 'EXTRACT' module in Idrisi was used to extract attribute value files from the 2011 NDVI image. The attribute value files were used as a surrogate for vegetation condition. The absence (0) or presence (1) of certain grazing management systems within specific villages was

related to vegetation condition (NDVI extracted values); using the Logistic Regression facility built into the IDRISI Taiga GIS. The Chi Squared test value for the relationship between the dichotomous scenario and vegetation condition was provided in Logistic Regression analysis module results. The appropriateness of the Logistic Regression for this purpose was appraised in Chapter 3, section 3.9.2.

The results obtained using the methods explained above are presented in the subsequent chapter.

# CHAPTER 5

# RESULTS

## 5.1. Introduction

This chapter provides the results obtained using different methods and techniques outlined in Chapter 3. The spatial homogeneity of the physical variables was tested. These variables are used as a control to test whether the villages occur within a supposedly homogenous topographic and altitudinal setting. NDVI values for different years were used to depict variations in the vegetation condition across the villages, as a basis for determining and comparing vegetation condition among the villages, in relation to the functionality of local institutions. The NDVI images also served as base images from which different vegetation classes were extracted. Supervised object-oriented classification was used to extract vegetation condition categories from NDVI images. The existence and effectiveness of local institutional land management systems are explored in this chapter. The efficacy of the local institutions was assessed in the light of vegetation condition.

## 5.2. Testing the topographic homogeneity between villages

The spatial distribution of topographic variables was explored in order to establish whether the differences in vegetation condition are driven by the inconsistency in the distribution of these variables. Chi-Squared tests were performed for each topographic variable in order to test their homogeneity across the study area. Establishing homogeneity would serve to ascertain that the differences in vegetation condition among the villages are not a product of significant variations in the topographic variables. The topographic variables explored are elevation, slope and aspect. A 20m DEM was used to extract topographic variables and their homogeneity or otherwise was tested as described in the sub-sections that follow.

### 5.2.1. Elevation

The spatial distribution of elevation categories among the villages was explored and compared. The elevation map was provided in Section 2.2.1 of Chapter 2. The elevation value ranges from 297 m to 751 m asl. Figure 5.1 provides information of elevation distribution across villages.

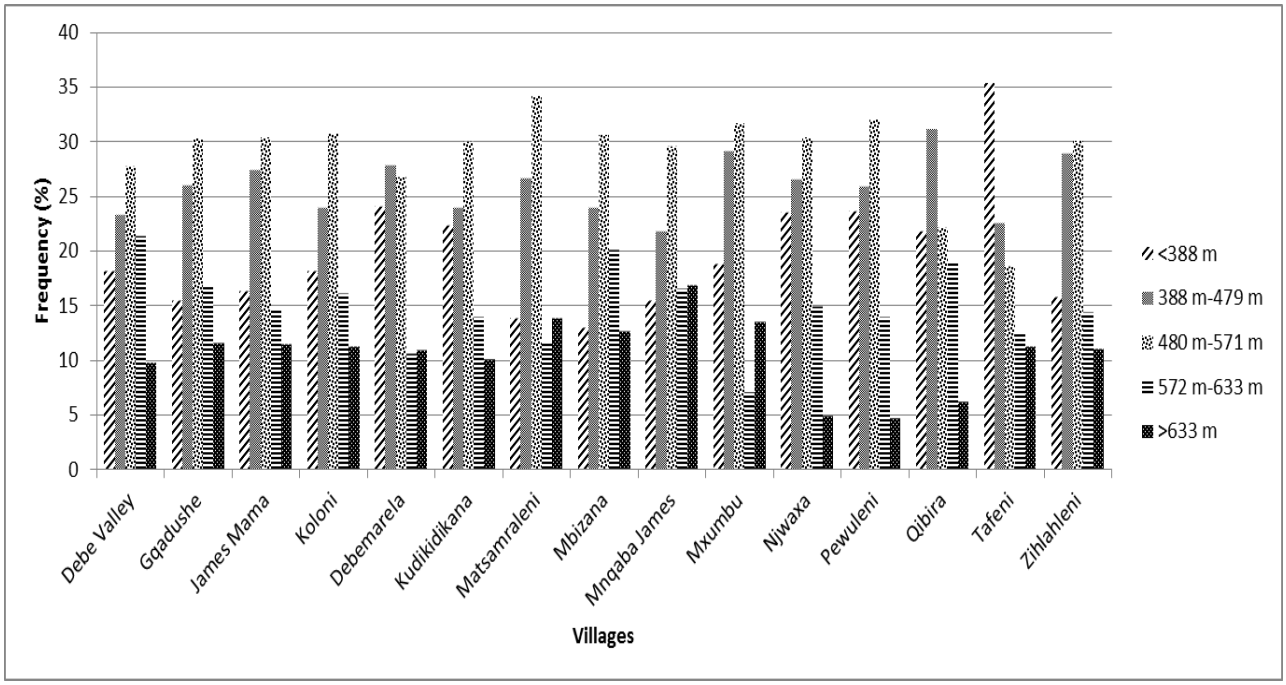


Figure 5.1: Frequency of elevation across the villages of the study area

A chi-squared ($X^2$) test was performed in order to establish whether there is a significant difference in altitude across the villages under study. The $X^2$ was calculated in Microsoft Excel and found to be 0.994, which is less than the critical value of 3.84 at a 5% significance level. The null hypothesis is therefore accepted; there is no significant difference in altitude among the villages of the study area. By implication there is homogeneity in altitudinal characteristics across the villages under study.

### 5.2.2. Slope angle

Slope angle, as an important control on vegetation distribution, is a topographic attribute whose variation among the villages had to be tested. The slope map is provided in Chapter 2 Section 2.2.2. The slope angle values of the study region range from $0^0$ to $36^0$. The frequency distribution of slope angles among the villages of the location under study is depicted in Figure 5.2.

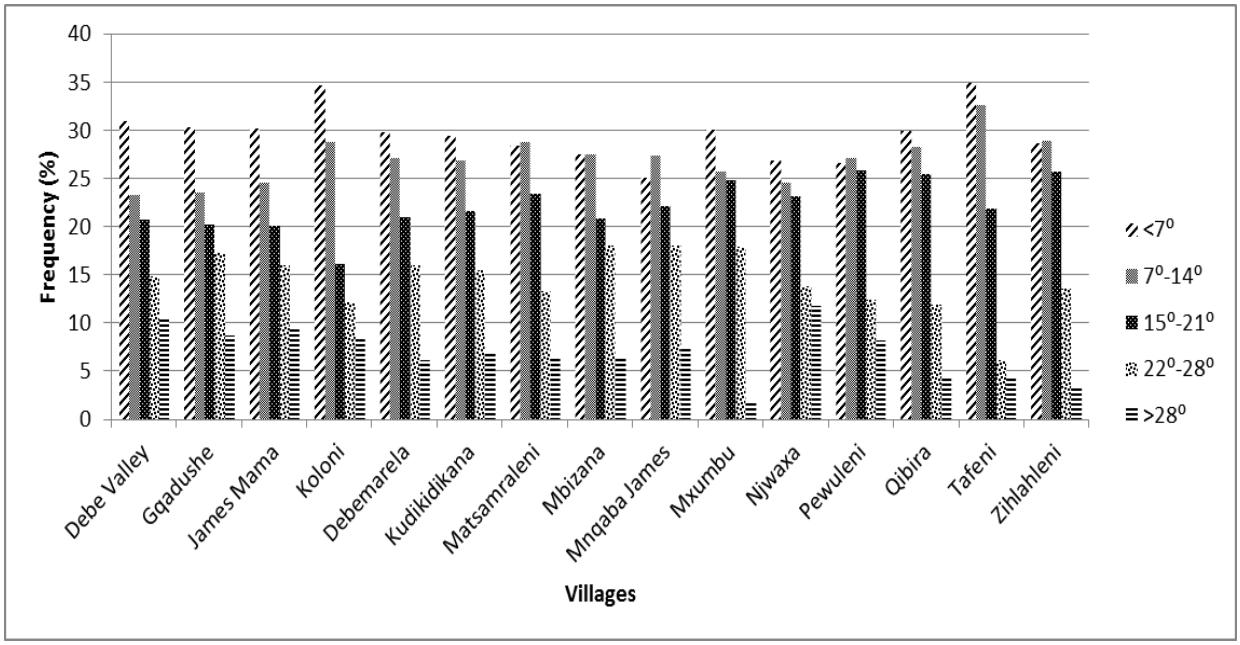


Figure 5.2: Frequency of slope angle class across the villages

From Figure 5.2, it was found that the slope angle class less than 7⁰ is dominant across the villages, occupying 29.5% of the entire area. In order to test whether slopes did not vary significantly across the study villages, a chi-squared ($X^2$) test was also performed. The null hypothesis in this case was that slope angle does not vary significantly across the villages of the study area. The ($X^2$) value was found to be 0.999, which is less than the critical value of 3.84 at the 0.05 probability level. The null hypothesis is therefore accepted; there is no significant variation in slope among the villages of the study area. By implication there is homogeneity in slope characteristics across the villages under study.

### 5.2.3. Aspect

Spatial distribution of slope orientation across the study area villages was examined, by determining the frequency of each slope orientation class in the respective villages. An aspect map of the study area was presented in Chapter 2 Section 2.2.3. Figure 5.3 depicts the spatial variations in slope aspects across villages.

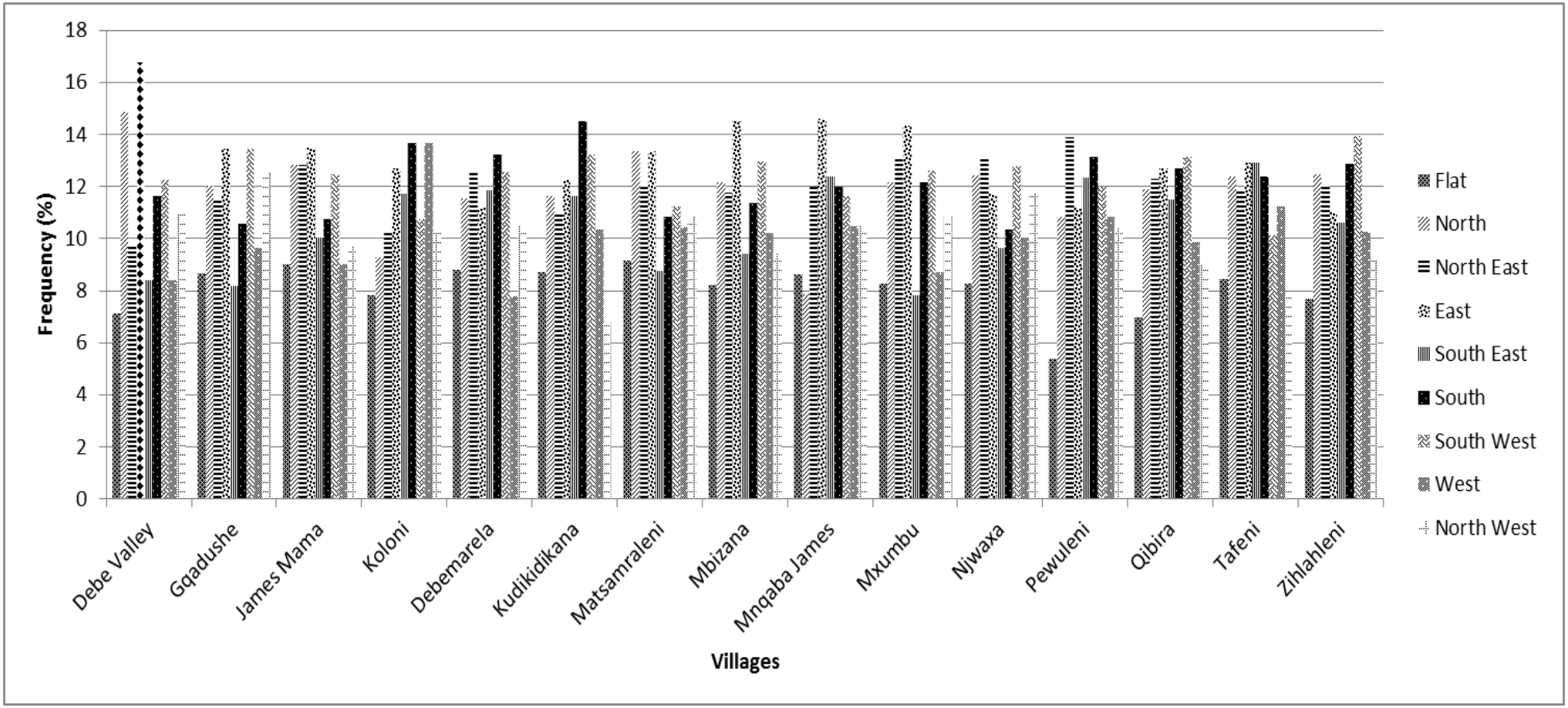


Figure 5.3: Frequency (%) of each slope aspect class in each village

A Chi Squared test was performed in order to determine whether slope orientation did not vary significantly across the villages of the study area. The $X^2$ value was calculated and found to be 0.999, which is less than the critical value of 3.84 at the 0.05 probability level. The null hypothesis is therefore accepted; there is no significant variation in slope among the villages of the study area. By implication there is homogeneity in the distribution of slope orientation across the villages in the study area.

The results obtained from homogeneity tests of topographic variables across villages revealed that there no significant variation in the distribution of elevation, slope and aspect across the villages. On the basis of this, the study area could be considered homogenous in terms of slope and aspect and elevation. Vegetation condition across the villages is therefore assessed on this understanding. The forthcoming section compares vegetation condition among the villages.

## 5.3. Assessment of vegetation condition

An assessment of variations in vegetation condition for the period of 1984 to 2011 was done. Information collected through structured interviews indicated that local level institutional structures responsible for grazing management were functional in the pre-1994 period, during the apartheid dispensation. However, they started deteriorating at the inception of the democratic system of governance. The gradual deterioration of these structures has resulted in some of them becoming completely dysfunctional, with those still functioning experiencing gradual deterioration. Therefore, an analysis of temporal imagery between 1984 and 2011 could provide an understanding of the gradual changes in vegetation during the pre- and post-1984 dispensation periods. NDVI images were used to assess vegetation conditions in this study (see Figures 5.4 to 5.10). Figures 5.4 to Figure 5.9 show the spatial trends in vegetation condition, throughout the period between 1984 and 2011, within the study area.

Figure 5.4 to Figure 5.9 show the spatial trends in different vegetation condition, throughout the period between 1984 and 2011, within the study area.

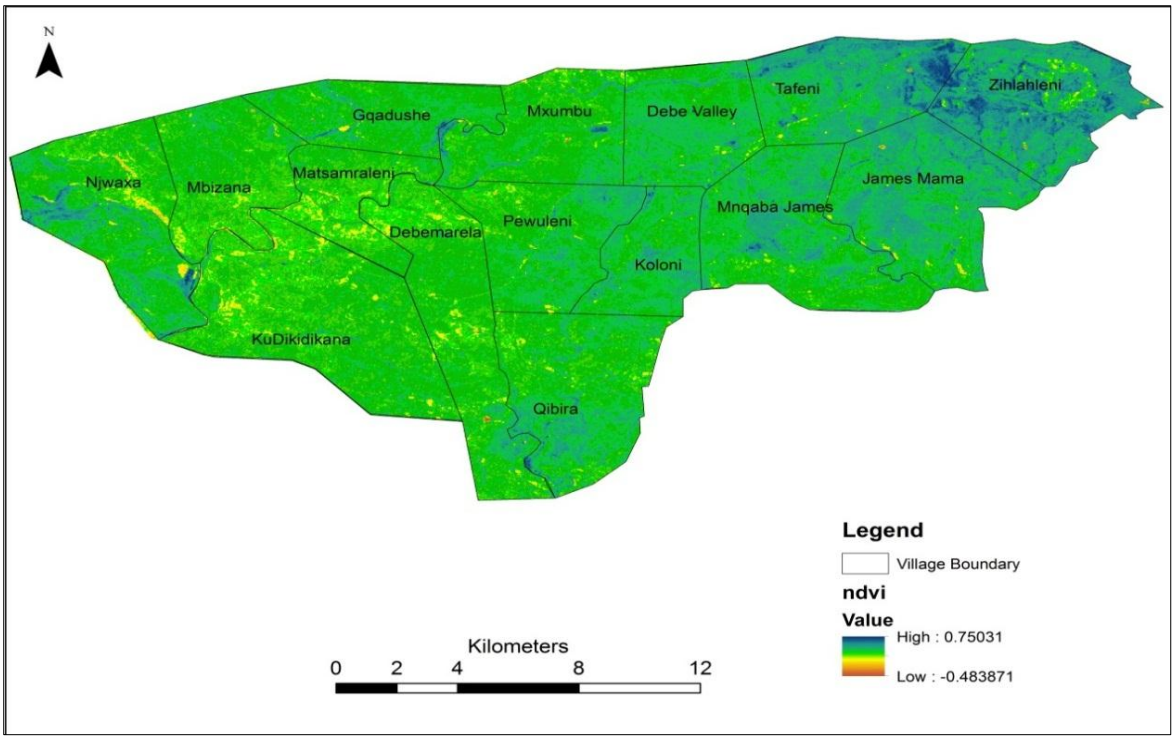


Figure 5.4: 1984 NDVI map of the study area

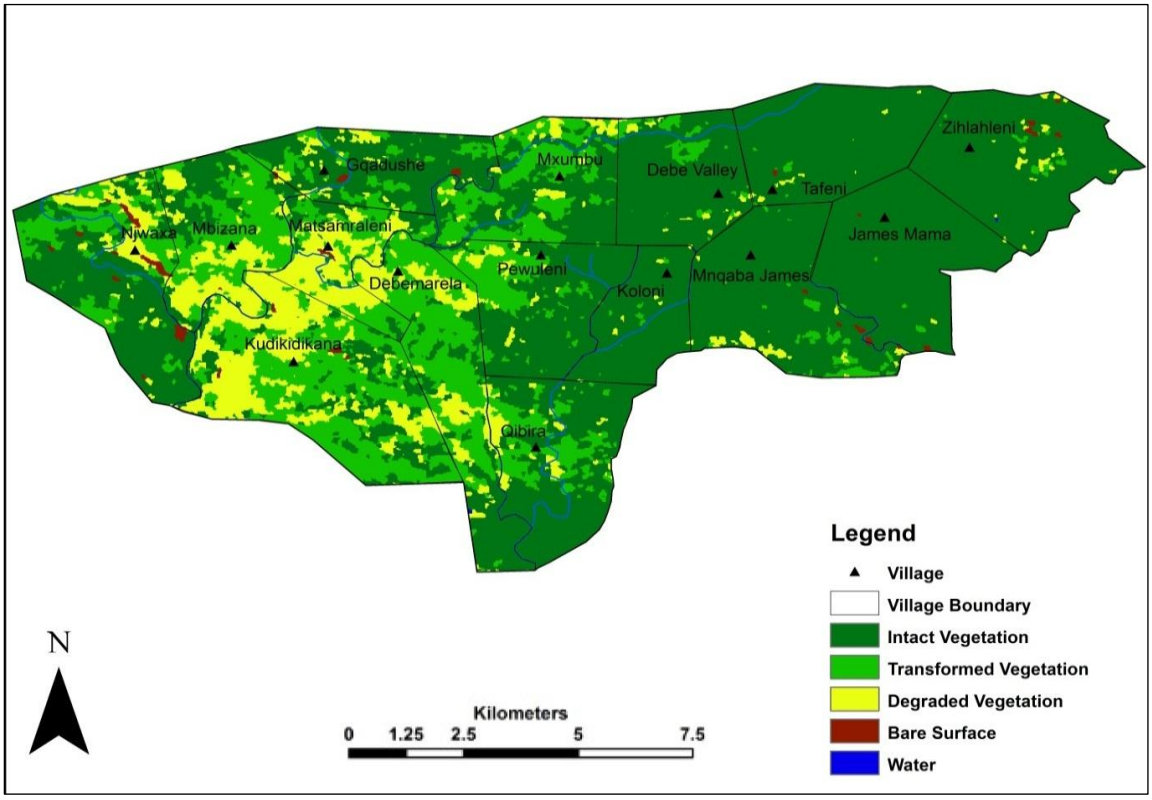


Figure 5.5: 1984 vegetation classification of the study area

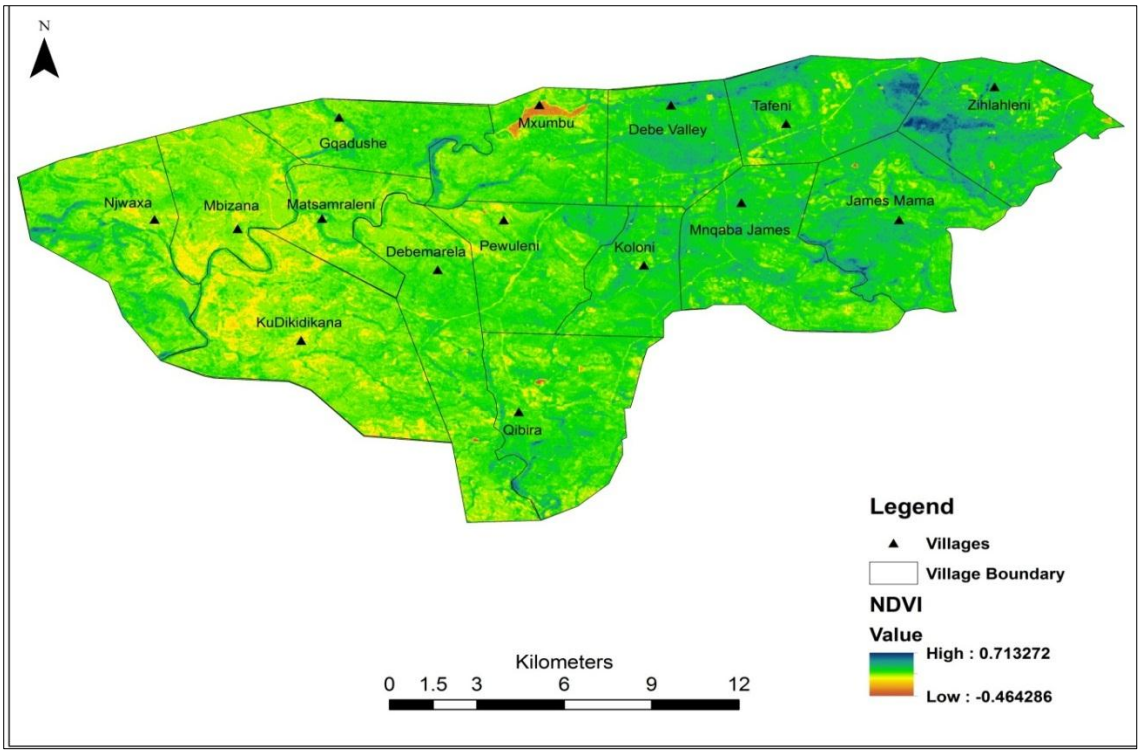


Figure 5.6: 1999 NDVI map of the study area

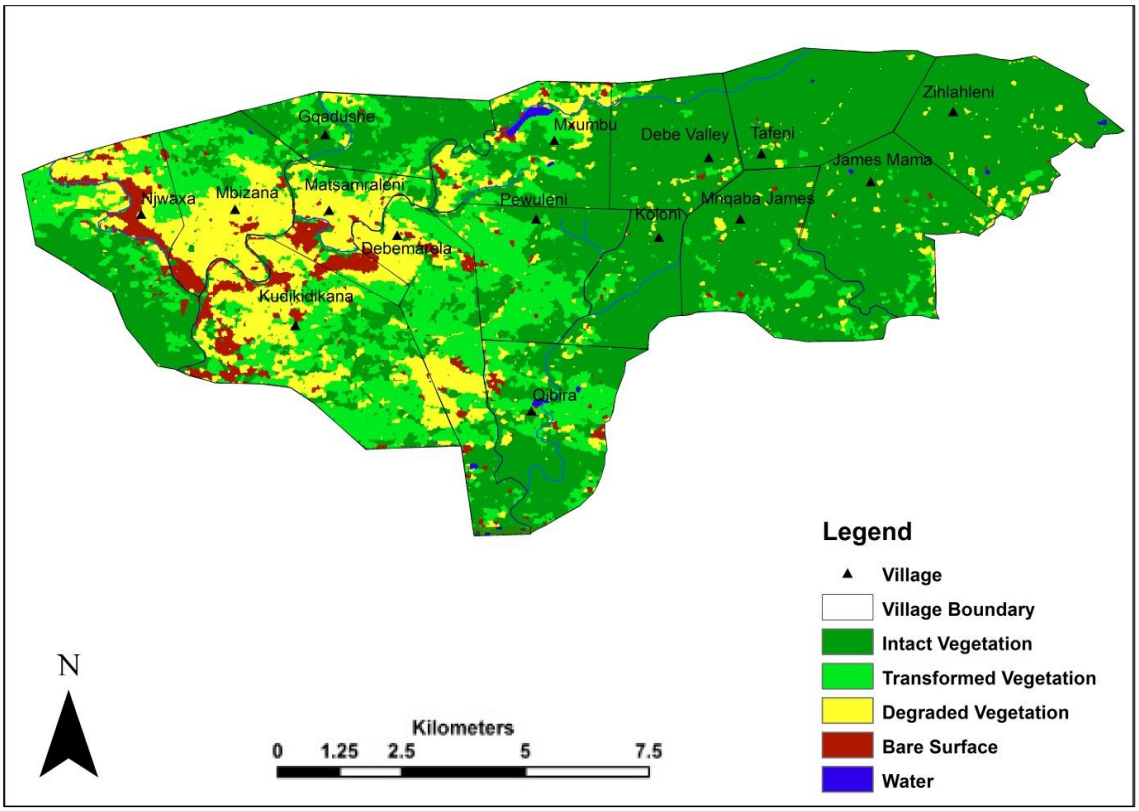


Figure 5.7: 1999 vegetation classification map of the study area

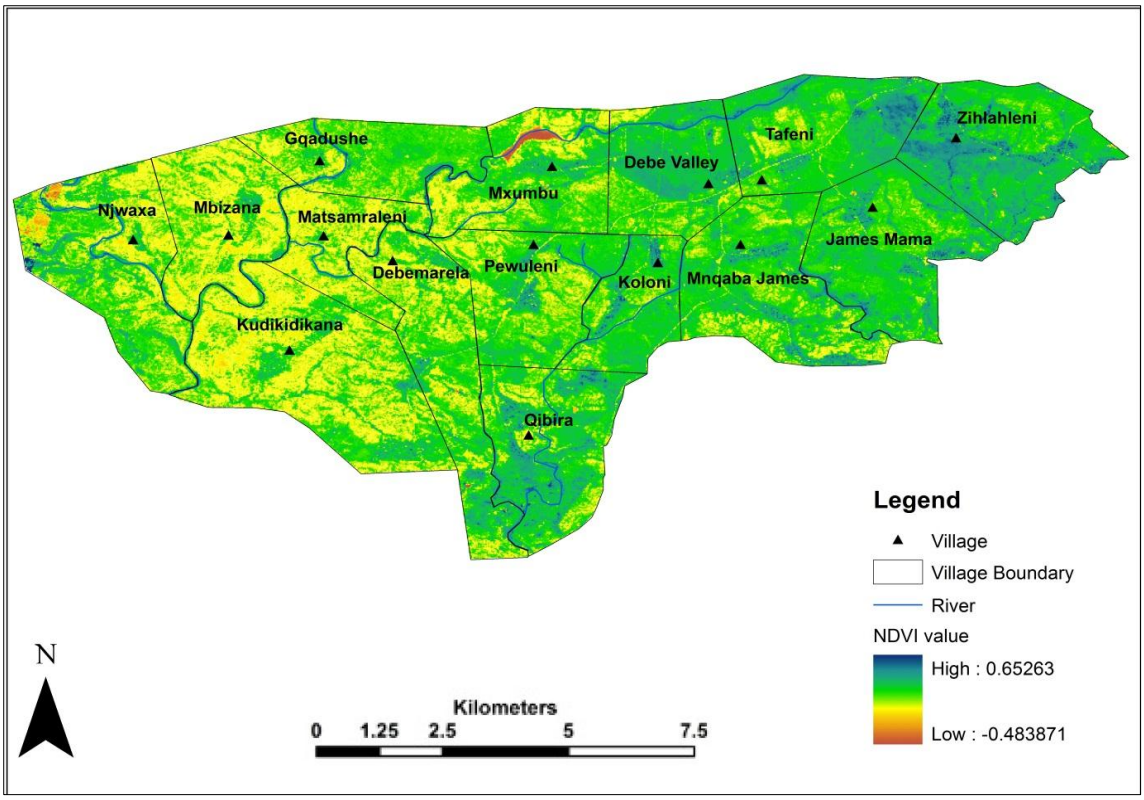


Figure 5.8: 2011 NDVI map of the study area

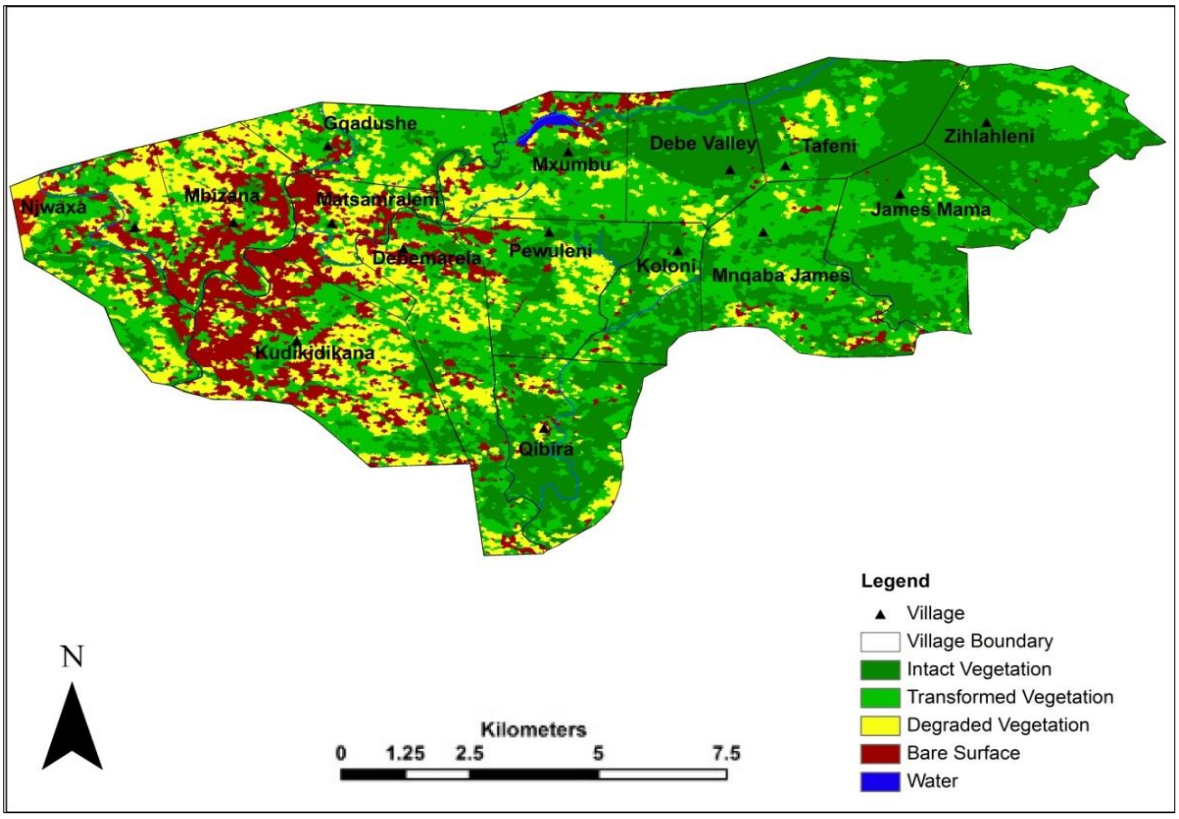


Figure 5.9: 2011 Vegetation classification map of the study area

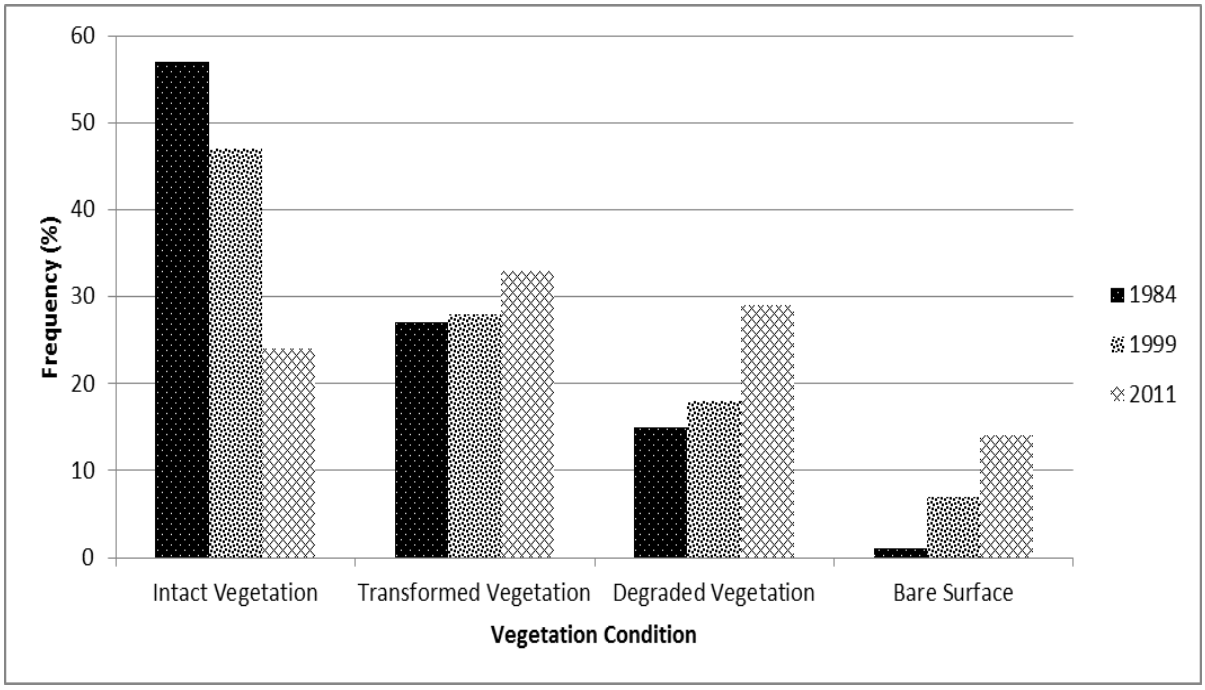


Figure 5.10: Area covered by each land cover class

The trends display an increase in degraded vegetation and bare surfaces, and a decrease in intact vegetation. Whereas the vegetation condition across all the villages was in a reasonably good condition in 1984, (see Figures 5.4 and 5.5) a gradual and consistent deterioration is noticeable, particularly in the villages to the west of the study area (see Figures 5.6 to 5.9). The villages of Mbizana, Kudikidikana, Matsamraleni, Debemarela, Njwaxa, Gqadushe and Mxumbu are particularly affected. An understanding of this pattern of vegetation deterioration was sought through conducting structured interviews in the local communities.

Plate 5.1: Intact and degraded vegetation

On the basis of the fact that there was a drastic change in vegetation condition over the period between 1984 and 2011, vegetation condition was then related to presence or absence of the investigated grazing management properties among the villages in the study area. This was done to gain some insight as to whether vegetation condition reflects the efficacy of the local level institutional structures responsible for grazing management systems. Management attributes explored as related to vegetation condition in Section 5.4, are provided in detail in Section 5.5.

## 5.4. Relating vegetation condition to grazing management systems

In this section, an attempt is made to relate vegetation condition in the villages of the study area to the grazing management systems. The presence or absence of management attributes was determined for each village. The logistic regression was performed to determine the relationship between vegetation condition and the presence or absence of certain management attributes. The null hypothesis formulated in each case was that 'there is no significant relationship between vegetation condition and specific grazing management practices'. Chi Squared values and degrees of freedom were calculated using the logistic regression analysis tools in Idrisi Taiga GIS environment. The Chi Squared value was then compared with critical value of 3.84, at the significance level of 0.05, with degrees of freedom as 298 to determine the significance of relationship. Table 5.1 provides the Chi Squared value for the

relationship between the respective grazing management attributes and the NDVI value, as a surrogate for vegetation condition.

Table 5.1: Table of NDVI-management attribute relationship

| MANAGEMENT ATTRIBUTE | CHI-SQUARED VALUE |
|---|---|
| Fencing | 183.71 |
| Herding | 49.7 |
| Kraaling | 96.78 |
| Rotational grazing | 183.71 |
| Conflict | 116.87 |
| Training | 49.4 |

Further details on logistic regression results are provided in Appendix D.

As can be noted in Table 5.1, the Chi-Squared values for all the management attributes exceed the critical value (3.84). By implication, the null hypotheses in regard to the respective management attributes viz;

- There is no significant relationship between vegetation condition and the presence/absence of fencing,
- There is no significant relationship between vegetation condition and livestock herding,
- There is no significant relationship between vegetation condition and livestock kraaling,
- There is no significant relationship between vegetation condition and rotational grazing,
- There is no significant relationship between vegetation condition and conflicts over grazing camps,
- There is no significant relationship between vegetation condition and training regarding grazing management systems,

are rejected; there is a clear relationship between the respective variables and vegetation condition.

It may therefore be concluded that the presence/absence of fences in the villages under study plays an important role in the condition of vegetation. Plate 5.2 shows intact vegetation in a completely fenced grazing camp (Qibira village) and degraded vegetation in a grazing camp with ineffective fencing (Debemarela village).

Plate 5.2: Fenced grazing land (a) and grazing land with old fence (b)

It can also be concluded that vegetation condition is related to the livestock herding practice.

Livestock kraaling is an important part of grazing management because it controls grazing at any time, restricting it especially at night. The rejection of the null hypothesis signifies the relationship between vegetation condition and the presence/ absence of the kraaling practice in the study area. Plate 5.3 shows livestock kraal in Koloni, one of the villages with effective grazing management systems.

Plate 5.3: Cattle kraal in a Koloni household

Rotational grazing is widely known as an effective and sustainable grazing management system; alternating animals' pastureland gives rangeland vegetation time to recover and regrow. However, an effective rotational grazing system is highly dependent on the effectiveness of fencing (Undersander *et al.,* 2002). Fences provide proximity to grazing camps, which enables livestock to be restricted to certain boundaries. It was found that rotational grazing is only practiced in those villages that have fencing around their grazing camps. Since the null hypothesis regarding rotational grazing was rejected, it can be said that the rotational grazing practice has a significant relationship with vegetation condition.

Conflicts over grazing camps between village groups were reported in some villages in the study area. Village groups had conflicts over the ownership of grazing camps and as to who should have access to the resources within. The rejection of the null hypothesis implies that conflicts over grazing land have a bearing on vegetation condition.

A comparison of villages that did or didn't receive grazing management training was made, and the responses obtained were related to vegetation condition. The rejection of the null hypothesis indicates that the relationship between grazing management training and vegetation condition is significant.

Management attributes related to vegetation condition in this section are discussed in section 5.5, in in the light of the responses obtained by means of the interview schedule. Figure 5.11, which is a 2011 image depicting NDVI values for these villages serves as a reference point against which the different management attributes are juxtaposed.

## 5.5. Functionality of local institutions

This section provides detailed information regarding the existence of local level institutions and effectiveness of their grazing management systems. The information was obtained using interview surveys. Semi-structured interview surveys were conducted with each traditional committee responsible for grazing management in all 15 villages of the study area. It was found that local institutional committees exist in each village; however, not all these structures are functional. They operate under the guidance of headmen, who are under governance of the female chief that oversees all 15 villages under discussion. Table 5.5 show village groups in terms of the functionality/dysfunctionality of the local institutions. The NDVI image, Figure 5.11 is a clear reflection of the vegetation condition related to this dichotomy.

Table 5.2: Villages with and without functional local institutions

| VILLAGES WITH FUNCTIONAL INSTITUTIONS | VILLAGES WITHOUT FUNCTIONAL INSTITUTIONS |
|---|---|
| James Mama | Njwaxa |
| Koloni | Mxumbu |
| Tafeni | Mbizana |
| Qibira | Kudikidikana |
| Debe Valley | Matsamraleni |
| Zihlahleni | Gqadushe |
| Mnqaba James | Pewuleni |
| | Debemarela |

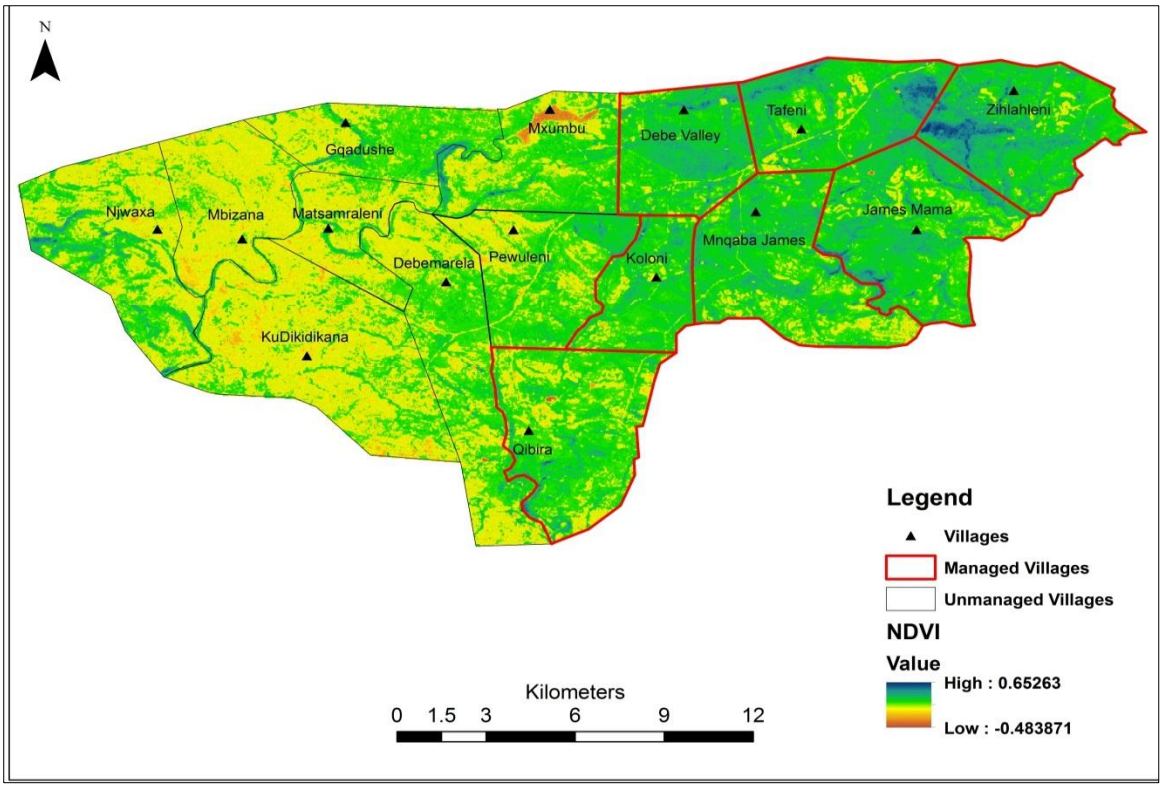


Figure 5.11: 2011 NDVI map showing villages with and without management functional institutions: The legend shows High and Low NDVI value.

### 5.5.1. Municipal council

Participants were asked if local level traditional leadership institutions are the only structures existing in the villages. All respondents reported that there are also other local level structures, in the form of municipal councils. It was reported that these municipal structures are supposed to act as a mediator between the municipality and local traditional leadership for service delivery, such as the provision of fences and appointment of rangers to oversee management systems. However, it was reported that these structures run parallel to local traditional councils. Participants also reported that the municipal structures are known and recognised by the community; however, the headman supposedly has more power than the ward councillor. This parallel scenario has negatively impacted on vegetation condition. Municipal councils believe they have more power, since they were democratically elected. They consider themselves as the link between the local municipality and village headmen for the purposes of natural resource management and service delivery. All villages in the study area are experiencing conflicts between these institutions. Despite the reasonably good vegetation condition in some villages, residents feel that it is deteriorating gradually and is a

lot worse than in the recent past. This can in part be explained by the superimposition of central government management structures over the pre-existing traditional systems.

### 5.5.2. Traditional leadership institutions

Under the authority of the headman, there is a local level institutional leadership committee, also democratically elected by the community members. The committee is made up of both males and females, and its tenure ends when community is no longer satisfied with its services. The committee does not get paid by either the community or government. Although the committees are designed to have 16 members, some villages have very few, while others have a full complement committee members. The introduction of the municipal council was cited by respondents as the reason for the reduction in the number of committee members in some villages.

Some traditional committee members felt that their authority was undermined and decided to resign. Others died, but it is not easy to replace them, because the younger generation does not value traditional leadership. Table 5.3 provides information regarding villages and their respective number of traditional committee members. It was evident as noted from field observations and 2011 NDVI image that the villages with a full complement of committee members had good vegetation condition, in contrast to the ones with few members where vegetation degradation was evident (see Figure 5.11). It could therefore be inferred that villages with a full complement or reasonable number of committee members do have functional institutions, as opposed to those with fewer committee members, which have dysfunctional institutions.

Table 5.3: Number of committee members per village

| VILLAGE | NUMBER OF COMMITTEE MEMBERS |
|---|---|
| Debe Valley | 15 |
| Gqadushe | 7 |
| James Mama | 13 |
| Koloni | 15 |
| Debemarela | 5 |
| Kudikidikana | 6 |
| Matsamraleni | 6 |
| Mbizana | 4 |
| Mnqaba James | 12 |
| Mxumbu | 7 |
| Njwaxa | 5 |
| Pewuleni | 8 |
| Qibira | 15 |
| Tafeni | 15 |
| Zihlahleni | 15 |

### 5.5.3. Management training

Participants were asked whether they received training about grazing resource management. It was found that resource management skills within the villages under study are largely generated among the communities. However, it was found that some villages' members have attended training workshops, where they were taught how to manage grazing resources. Villages were therefore grouped according to the attendance or non-attendance of grazing management training workshops (see Table 5.4). A comparison with vegetation condition (Figure 5.11) indicates that the villages where members attended grazing management training workshops have good vegetation condition. It is the same villages that also have functional local institutions.

Table 5.4: Attendance to resource management training per villages

| ATTENDED MANAGEMENT TRAINING | DID NOT ATTEND MANAGEMENT TRAINING |
|---|---|
| James Mama | Njwaxa |
| Koloni | Mxumbu |
| Tafeni | Mbizana |
| Qibira | Kudikidikana |
| Debe Valley | Matsamraleni |
| Zihlahleni | Gqadushe |
| Mnqaba James | Pewuleni |
| | Debemarela |

### 5.5.4. Views on vegetation condition

Interviews were conducted with institutional committees of each village to determine their views on the current condition of vegetation, as compared to the pre-1994 condition. The respondents from all villages acknowledged that there is deterioration in the condition of vegetation. It was also revealed that condition of vegetation was better before 1994, in contrast to the current status. The respondents had different thoughts with regard to the cause of vegetation stress. Respondents from Njwaxa, Mbizana, Kudikidikana, and Debemarela, which are the villages with dysfunctional institutions, stated that vegetation stress was caused by the cutting down of fences in grazing camps. Some respondents from Matsamraleni, Mxumbu and Gqadushe, which are also villages without functional institutions, indicated during interview sessions that the degradation of vegetation in the vicinity of villages is caused by livestock owners who are too lazy to take their livestock to far away grazing land. However, others felt that keeping livestock near the villages helps prevent theft of livestock, since there are no more fences or rangers to take care of cattle in many of the grazing camps.

### 5.5.5. Fencing of grazing lands

The relationship between the presence/absence of fencing was established earlier by means of the Chi-squared test. Fencing is an important grazing management practice that ensures the success of rotational grazing and trespass restriction. A survey was conducted to determine the state and effectiveness of fences in grazing and arable lands of the study area. It was reported that some villages still have effective fencing while others lack any. Observations made during field survey also confirmed this. However, it was also observed that there is

some deterioration of fencing in the villages that still have functional local institutions. Since 1994 (introduction of democratic dispensation), there has been a redistribution of grazing camps, which gave rise to conflicts over grazing camp ownership. This resulted in the cutting of fences by those who disputed grazing camps. Although there was cutting of fences, it was also reported that barriers in other parts of villages just deteriorated, due to age, coupled with the lack of reinforcement of fencing around these villages. Table 5.5 shows the responses from the villages regarding the state of fencing. As reflected by the 2011 NDVI image (Figure 5.11), villages that have effective fencing have good vegetation condition as opposed to those without.

Table 5.5: Villages in relation to state of grazing land fence

| **CONDITION OF FENCE** | |
|---|---|
| **EFFECTIVE** | **INEFFECTIVE** |
| Koloni | Kudikidikana |
| Debe Valley | Matsamraleni |
| Qibira | Njwaxa |
| Zihlahleni | Mxumbu |
| Tafeni | Mbizana |
| James Mama | Debemarela |
| Mnqaba James | Pewuleni |
| | Gqadushe |

### 5.5.6. Fencing of arable land

Arable land is very important because it unburdens the load on grazing land. It reduces the pressure exerted on grazing land by providing forage after harvest time. In the study area, each village has arable land partitioned for cultivation, by respective village households. It was found that some villages cultivate their arable land while others do not. Villages that have fenced arable land are those where grazing land is fenced as well, which confirms functionality of their management institutions. Respondents from villages that have fenced arable land reported that they monitor both their grazing camps and arable land to avoid cutting of fences, while respondents from unfenced villages reported that they never attempted to monitor their grazing camps and arable land. Field observation revealed that

only fenced arable land is cultivated whereas unfenced one is abandoned and used as open access grazing land. Table 5.6 depicts the villages with and without fenced arable land.

Table 5.6: Villages with fenced and unfenced arable land

| **ARABLE LANDS** | |
|---|---|
| **FENCED** | **NOT FENCED** |
| Koloni | Kudikidikana |
| Debe Valley | Matsamraleni |
| Qibira | Njwaxa |
| Zihlahleni | Debemarela |
| Tafeni | Mbizana |
| James Mama | Gqadushe |
| Mnqaba James | Mxumbu |
| | Pewuleni |

### 5.5.7. Livestock herding

Respondents reported that livestock herding is only partly practiced some villages, but not in others. The main reason given for practicing herding in some villages is protection from theft from grazing camps and accidents on roads, particularly in villages without fences. Table 5.7 provides information on the number of villages that practice livestock herding and those that do not. In conformity with the chi-squared test results and NDVI image (Figure 5.11), good condition vegetation was found in villages that practice livestock herding.

Table 5.7: Livestock herding practice per village

| LIVESTOCK HERDING | |
|---|---|
| **PRACTICED** | **NOT PRACTICED** |
| Koloni | Kudikidikana |
| Debe Valley | Matsamraleni |
| Qibira | Njwaxa |
| Zihlahleni | Debemarela |
| Tafeni | Mbizana |
| James Mama | |
| Mnqaba James | |
| Gqadushe | |
| Mxumbu | |
| Pewuleni | |

### 5.5.8. Livestock kraaling

It was noted earlier that kraaling is practiced in certain villages, but not in others. Although kraaling is partly practiced to avoid theft, it also assists in vegetation recovery. On the basis of responses obtained from participants, villages were grouped relative to the absence and presence of livestock kraaling practices. Table 5.8 shows villages that practice kraaling and those that don't. It is indeed discernible from the NDVI map (see Figure 5.11) that the villages listed as practicing livestock kraaling have more healthy vegetation than their counterparts where this practice is non-existent.

Table 5.8: Livestock kraaling practice per village

| LIVESTOCK KRAALING | |
|---|---|
| **PRACTICED** | **NOT PRACTICED** |
| Koloni | Kudikidikana |
| Debe Valley | Matsamraleni |
| Qibira | Njwaxa |
| Zihlahleni | Debemarela |
| Tafeni | Mbizana |
| James Mama | |
| Mnqaba James | |
| Gqadushe | |
| Mxumbu | |
| Pewuleni | |

### 5.5.9. Rotational grazing

The importance of rotation grazing was referred to earlier. It was noted earlier that rotational grazing is practiced in certain villages, but not in others. It was gathered from the interview schedule that rotational grazing was practiced in all villages when fencing in the grazing camps was still intact. However, it is currently practiced only in villages that still have fences. Table 5.9 shows absence and presence of rotational grazing practices in the villages. Villages which practice rotational grazing were found to have good condition vegetation, in contrast to the counterpart villages where vegetation degradation is widespread, as borne out by the 2011 NDVI image (Figure 5.11).

Table 5.9: Rotational grazing practice per village

| ROTATIONAL GRAZING | |
|---|---|
| **PRACTICED** | **NOT PRACTICED** |
| Koloni | Kudikidikana |
| Debe Valley | Matsamraleni |
| Qibira | Njwaxa |
| Zihlahleni | Debemarela |
| Tafeni | Mbizana |
| James Mama | Gqadushe |
| Mnqaba James | Mxumbu |
| | Pewuleni |

### 5.5.10. Government support

Based on the responses obtained from the local level headmen and lady chief, there is no support received from Government. This was evident in the failure to replace deteriorated fencing, which was provided by the former Ciskei homeland government. The respondents reported that ever since the provision of fencing by the homeland government, there has been no support received from the current democratic government. The farmer's associations have also not received any funds from the government to implement resource management projects since 1994, in contrast to the homeland government, which used to provide tools for the implementation of natural resource management systems. As already noted, the lack of support in the form of fence rehabilitation has contributed significantly to the deterioration of vegetation condition.

## 5.6. Conclusion

Homogeneity in the spatial distribution of topographic characteristics across the villages of the study area has been established in this chapter. A significant relationship between vegetation condition and a range of grazing management attributes (fencing, rotational grazing, herding, kraaling, conflicts over grazing camps and training) was established by means of the logistic regression. This was supported by the 2011 NDVI image. The functionality or otherwise of local institutions, which was assessed by way of the interview schedule confirmed that villages with functional grazing management local institutions had good condition vegetation. This was also reflected by the 2011 NDVI image. It can therefore be concluded that vegetation condition in the central Keiskamma catchment reflects local level institutional management regimes. Further discussions of these results are provided in Chapter 6.

# CHAPTER 6

# DISCUSSION AND CONCLUSION

## 6.1. Introduction

In this chapter, the results obtained in Chapters 5 (using methods and techniques described in chapter 4) are discussed within the context of the literature reviewed in Chapter 3. The existence and efficacy of local-level institutions responsible for grazing management are reviewed in this chapter. The importance of remote sensing and GIS techniques for vegetation condition analysis, and the relationship with grazing management are discussed. Recommendations concerning the management of vegetation resources are also made. Finally, directions for future research are suggested and conclusions are drawn.

## 6.2. Topographic homogeneity

It is widely known that the landscape or topographic characteristics of an area play a pivotal role in the local distribution of vegetation and its conditions. Mutendeudzi and Thackway (2010) state that vegetation condition may be influenced by natural processes controlled by topographic conditions. A long standing study by Billings (1969) observed that vegetation condition patterns occurring in response to topography may follow divergent, distinct and different trends, compared to those predicted by climate alone. A patchy distribution of vegetation could reflect inconsistently occurring topographic factors (Erich and Ulrike, 2002). In the present study, Aster DEM was used as a source of topographic information. As noted in Chapter 5, there was no statistically significant variability in terms of topographic characteristics across villages of the study area. It could therefore be stated that the variations in vegetation conditions among the villages of the study area are not a product of topographic heterogeneity. The forthcoming sections explore the approaches to assessing vegetation condition and grazing management systems.

## 6.3. Remote sensing, GIS and vegetation analysis techniques

The current study has demonstrated the importance of remote sensing and GIS in assessing vegetation condition at both the spatial and temporal scales. NDVI image for the respective years provided the basis for analysing vegetation condition trends. Given the semi-arid conditions of the study area, the NDVI was found to be the most suitable index due to its ability, under the present vegetation conditions, to separate vegetation from soil and reduce topographic effects. The index reliably helped in identifying areas covered by intact, transformed and degraded vegetation, and bare surfaces.

The use of the object-oriented classification method in the current study eliminated the mixed-pixel effect, which makes the classification approach more suitable for change detection analysis (Mhangara, 2011). It was therefore possible to clearly identify and map the respective vegetation surfaces in a spatial and temporal framework.

## 6.4 Variations in vegetation condition

### 6.4.1 Assessment of vegetation condition trends

Vegetation degradation has received much attention in communal areas (Bruce, 1986). Analyses of vegetation condition trends from satellite images indicate a consistent decline in intact vegetation and an increase in transformed and degraded vegetation, and bare surfaces, from 1984 to 2011, among all village settlements of the study area (see Figure 5.10). This decline in vegetation resource condition coincided with the transition from apartheid to the democratic political dispensation. These trends are in keeping with Mazibuko (2011), who observed that, in the former Ciskei homeland, natural resource conditions became progressively stressed when changes in the management of communal resources were introduced after the 1994 democratic dispensation. Under the new system, tribal authorities were disregarded in favour of municipal council structures and mechanisms of governance. A detailed discussion of the conflicts between traditional and municipal institutions, which gave rise to vegetation deterioration are discussed in section 6.4.2.5.

Analyses of both the 2011 imagery and field observations clearly indicate variations in vegetation condition between villages under different levels of management. Whereas poor vegetation cover was observed in settlements with weak management control, the converse is

true in the villages with functional traditional institutions, despite the relatively homogeneous topographic characteristics of the study area.

### 6.4.2. Relating vegetation condition to grazing management system

The hypothesis that 'different grazing management strategies across the villages of the present study area explain the variations in vegetation condition among them' is clarified in this section. In the central Keiskamma catchment, the existence of local level institutions was explored and their functionalities determined. Ostrom (1990) contends that common resource management can be a reliable, provided there is effective institutional guidance, overseeing and enforcing the adherence to grazing management rules. As noted in Chapter 5, local level institutional structures in the central Keiskamma catchment exist; however, some of these institutions are functional, while others are ineffective. The dysfunctionality of the institutions in some villages to a large extent explains the degradation of vegetation and soils. The mismanagement or malfunction of these structures exposes rangeland to uncontrolled grazing (Alemayehu *et al.* 2008). Benin and Pender (2002) state that good grazing management systems reduce the degradation of vegetation resources by limiting and lessening the overexploitation of vegetation, while improving long term vegetation resource quality and availability. It was evident in Section 5.3 of Chapter 5 that a gradual decline in pristine vegetation was linked to the deterioration of institutional structures. Degraded vegetation was widespread in villages with weak institutional control, as opposed to those with better institutional control.

These observations are in keeping with the findings of Bennett and Barrettt (2007), who noted that variation in vegetation condition in communal areas of the Keiskamma catchment reflects the level of management control. Moyo *et al.* (2008) also found that the efficacy of institutional structures is the principal driving force of vegetation conditions in communal villages.

In the study area, livestock grazing is the primary anthropogenic activity practiced. Grazing management systems are practiced in an attempt to reduce the problem of vegetation degradation caused by livestock grazing. Poteete and Welch (2004) also recommend the development of local institutions for grazing management, as an effective way to improve vegetation resources.

#### *6.4.2.1. Grazing land fencing*

As noted in Chapter 5, fencing proved to be one of the most effective management strategies controlling vegetation condition in the study area. Fencing is considered to be an effective way of restricting unauthorised access to grazing. Field observations as well as image analyses identified a high level of vegetation degradation occurring in grazing lands that were not fenced, in sharp contrast to the good and almost pristine vegetation in fenced rangelands. The first question that may be asked is: why are some grazing lands fenced, while others are not? Understanding the factors influencing the absence of fencing in reverts to Section 3.5.6.1 of Chapter 3. Several studies have recommended fencing as the basis for implementing sustainable grazing management (Bush, 2006; Turner, 2009; Hamilton *et al.* 2008; Gay *et al.* 2009). These observations are in agreement with those by Turner *et al.* (2009) who noted that good vegetation condition is common in fenced rangelands because fencing restricts livestock access to vegetation at any time of a day, and also prevents degradation caused by livestock browsing and trampling.

#### *6.4.2.2. Rotational grazing*

It was noted that rotational grazing is important for any pasturage; however, effective implementation of this grazing management system is highly dependent on the availability of effective fencing. If properly practiced, rotational grazing ensures good vegetation condition in communal grazing lands. MacPhail and Kyle (2012) observe that rotational grazing results in healthier vegetation resources, which can sustain livestock over a longer period; however, they maintain that without fencing, rotational grazing is not a simple strategy to implement. The current study explored grazing management systems and determined if, and where, rotational grazing was practiced in the study area. Although all the villages in the study area have a rotational grazing management strategy, it was found that it is not implemented or effective in certain villages, due to the lack of fencing. It was noted that rotational grazing in the study area is only practiced in villages that still have effective fencing. Through field observations, it was noted that degraded vegetation is predominant in villages that do not practice rotational grazing, in contrast to the relatively healthy vegetation in villages where rotational grazing is practiced. Beetz and Reinhart (2010) also point out that, in areas which

have an effective rotational grazing system, vegetation is often in good condition because it has time to regrow and recover.

#### *6.4.2.3. Livestock kraaling and herding*

As noted in Chapter 5, livestock kraaling and herding are among the mechanisms that control vegetation condition. In the study area, it was found through interviews that livestock herding and kraaling practices were not done in all villages. Consequently, high levels of vegetation degradation was observed in villages not practicing kraaling and herding, contrasting with the good vegetation condition in the villages utilising this pasture control strategy. Moyo *et al*. (2012) observe that by practicing kraaling and herding of livestock, communal rangeland vegetation is allowed time to regrow, through the time spent by livestock on the pastureland land being restricted by kraaling and herding. Baars and Ottens (2000) also confirm that vegetation degradation in communal rangelands can be minimised by practicing livestock herding and kraaling.

#### *6.4.2.4 Conflicts over resource access and management*

In section 5.4, it was confirmed that there is a significant relationship between vegetation condition and conflicts over grazing camps. The conflicts were reported to be caused by the redistribution of grazing camps among the village groups. Observations regarding conflicts over grazing camps in the study area revealed high levels of degradation in the villages were conflicts abound; the opposite is true where harmony existed. Conflicts over resource access between village groups are often attributed to inequity in resource distribution (Castro and Nielsen, 2003). Sullivan and Nasrallah (2010) observe that conflicts between village groups often result in environmental destruction and vegetation resource shortages. In the study area, these conflicts have resulted in a land-use shift, from communally managed to open-access land, due to a lack of cooperation among village groups.

#### *6.4.2.5. Conflicts between management institutional committees.*

Many studies focussing on communal grazing management have emphasised the significance of having an institution which implements grazing rules and oversees adherence to these rules. In Chapter 5, it was pointed out that each village is under the management of two institutional structures, *viz*. a traditional leadership institution and a municipal council. The

manner in which these institutions function interactively, determines either the efficient and efficacious operation of the management strategy employed, or its complete ineffectiveness and failure. In section 5.5.1 of Chapter 5, mention was also made of conflicts between the institutional structures responsible for resource management. Bank *et al.* (1996) state that in circumstances where there is more than one institution responsible for resource management, cooperative interaction among the distinct governmental institutions is required. Adams (2001) adds that, in situations where local land management rights and their extent are not clearly defined in communal areas, political conflicts often come into existence. This also leads to confusion among community members, regarding understanding the real extent of power held by each structure. A lack of understanding over the level of authority possessed by each institution has resulted in conflicts between the two institutional management committees.

#### *6.4.2.6. Management training*

Members on some village committees in the study area have reported receiving grazing management knowledge through attending workshops, while others have not. It followed that villages where grazing management committees were functional were those where members attended management training workshops. It was evident that a high degree of vegetation degradation dominated villages where committee members had not received management training, contrasting with the good vegetation observed in villages that attended the training. Schusler *et al.* (2003) emphasise that public participation is important in natural resource management, despite the indigenous knowledge already extant. However, the lack of government support, as pointed out in section 5.5.10 is a major concern, as all the grazing management strategies discussed above can operate smoothly only with the provision of the requisite resources.

## 6.5. Recommendations

The implications of vegetation condition trends in conjunction with grazing management systems were discussed in this chapter. Based on remote sensing techniques, field observations and interviews regarding the existence and effectiveness of local level institutional structures responsible for regulating grazing management systems in the central Keiskamma catchment, the deterioration of grazing resources is attributed to either the

effectiveness or lack of local level institutional management structures. Having determined vegetation condition trends in relation to grazing management systems, recommendations for the reversal of vegetation degradation are provided in this section.

The presence and functionality of local institutional structures in all villages have been assessed. In the light of the loss in institutional functionality in some villages and resultant deterioration of vegetation condition, it would be necessary to revitalise the effectiveness of these institutions. This would be achieved by resolving conflicts between the institutions managing resources, by ensuring that their roles regarding resource management are clearly defined. Matiru *et al.* (2000) observe that conflicts arise when there is no coordination and harmony between legal procedures and bodies of law. The conflicts between village groups regarding ownership of grazing camps must also be resolved. Due to the levels of vegetation degradation in villages without fencing, it is necessary to ensure that effective barriers are reinstated. It was noted that fencing was initially provided by the then Ciskei homeland government. It is suggested that the municipal structures avail resources to the local communities to repair, rebuild or re-erect fencing.

Institutional committee members should be encouraged to attend resource management workshops, to add external management knowledge to the indigenous knowledge possess. There should be regular meetings, with open discussions, which will review management rules, determining their success or efficacy and allow for modification or remedial action. Efforts should be made by agricultural extension officers to educate communities about the best strategies for sustainable vegetation resource management, thereby enabling and empowering local stakeholders in the application of acquired sustainable resource management knowledge, based on resource conditions.

In instances where the state interferes with traditional institutional functionality, collective action rarely succeeds (McCarthy *et al.* 2004). State agencies should find the most appropriate and mutually beneficial methods of working with communities. They should support local level management institutions and allow local decision-making, without exerting other external rules (Meinzen-Dick and Di Gregorio, 2004). Resource management rules should be implemented by local communities, as they are the ones who possess the knowledge about local conditions.

## 6.6. Directions for future research

Against the background of the findings of the current study, the following areas could be considered future research directions in the study area:

- Designing models for conflict resolution between institutional structures, and among village groups.
- Going forward, remote sensing based studies of vegetation condition should be encouraged, particularly as changes in local management institutions are implemented.
- Investigating how differences in resource utilisation interests hinder successful collective actions.
- Determining how the provision of environmental education would promote successful, sustainable environmental management systems.

## 6.7. Conclusion

The current study investigated the extent to which grazing management systems could explain variations in vegetation conditions, within a homogeneous topographic setting in the central Keiskamma catchment. An assessment of the spatial extent of vegetation at given temporal scales, using object-oriented classification, revealed the onset of vegetation degradation among the villages of the study area. Image segmentation made it possible to extract vegetation composition classes, used to assess vegetation condition.

The existence of institutional structures and effectiveness of their grazing management systems were explored and related to vegetation conditions. It was possible to identify issues which may hamper sustainable management systems in the study area, including, inter alia, rangeland fencing; power conflicts between the two primary management structures; and between village groups over resource ownership and access rights. Vegetation condition was associated with fencing in the villages; the lack thereof leading to the abandonment of rotational grazing practices and the inability to restrict outsiders or trespassers from accessing pastoral resources. Fenced grazing lands in the study area have good condition vegetation, while those without, have degraded vegetation.

The conflicts between Municipal structures and local level structures over power have contributed to the deterioration of vegetation condition in the communal grazing lands. These conflicts were reported in specific villages of the study area, resulting in poor service delivery

by local government to the communities under study. Poor service delivery includes the reinforcement or replacing of fences in areas that have deteriorated fences. Also included is the failure of local government to resolve conflicts between villages over grazing resource ownership, which resulted in the cutting of grazing land fences between villages.

Against the background provided above, strengthening the local institutional management regimes, among all the villages of the study area is recommended, as the best remedial path to reversing the current decline in vegetation condition.

In view of the above findings, the primary hypothesis of this study, namely, “the different grazing management strategies across the villages of the present study area explain the variations in vegetation condition among them” is accepted.

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# APPENDIX A

## GEOMETRIC CORRECTION RESULTS AND ERROR MATRICES ASSESSMENT

```
Resample : Summary of Transformation

Computed polynomial surface : Linear     (based on 15 control points)

Coefficient                                X                                Y

         b0              -8.0221699180838186              0.4864794686091045
         b1               0.9105085043730057              0.2280212712843763
         b2              -0.3202841789543527              1.2041557936673257

Note : Figures are carried internally to 20 significant figures.
       Formula shown is the back transformation (new to old).


Control points used in the transformation :

        Old X        Old Y        New X        New Y    Residual
-----------------------------------------------------------------
   27.200570   -32.846040    27.140010   -32.820540     0.000371
   27.185010   -32.859690    27.120230   -32.828040     0.000333
   27.199520   -32.887180    27.127620   -32.852620     0.000534
   27.178380   -32.909010    27.099940   -32.865320     0.000433
   27.189420   -32.947240    27.101320   -32.897340     0.000899
   27.135170   -32.939860    27.046990   -32.880420     0.000543
   27.124350   -32.986550    27.022480   -32.914960     0.000181
   27.087070   -32.857310    27.017720   -32.806820     0.001874
   27.302590   -32.825130    27.250830   -32.824180     0.000421
   27.297630   -32.841740    27.241190   -32.835900     0.000434
   27.398280   -32.880170    27.333590   -32.885400     0.000342
   27.377670   -32.896720    27.307950   -32.894510     0.000177
   27.390510   -32.921770    27.313830   -32.916320     0.000629
   27.392190   -32.964880    27.304220   -32.950330     0.000168
   27.413170   -32.977710    27.322320   -32.964420     0.000158

Overall RMS =     0.000650

Note : RMS Error is expressed in input image units.
With low RMS errors, be careful that an adequate sample exists
(eg. 2-3 times the mathematical min).
```

Figure A1. Resample summary

**ACCURACY ASSESSMENT RESULTS**

Error Matrix Analysis of Ground_truth (columns: truth) against 1984_image (rows: mapped)

| | 1 | 2 | 3 | 4 | 5 | Total | ErrorC |
|---|---|---|---|---|---|---|---|
| 1 \| | 3284 | 113 | 0 | 0 | 0 | 3429 | 0.0423 |
| 2 \| | 27 | 2879 | 15 | 1 | 71 | 4192 | 0.3132 |
| 3 \| | 0 | 2 | 583 | 0 | 0 | 751 | 0.2237 |
| 4 \| | 0 | 8 | 7 | 16108 | 0 | 2046 | 0.2197 |
| 5 \| | 1 | 262 | 39 | 2 | 34103 | 4136 | 0.1746 |
| Total \| | 3372 | 7150 | 1427 | 23140 | 4370650 | 3826 | 0.1548 |
| ErrorO \| | 0.0261 | 0.5973 | 0.5915 | 0.3039 | 0.219 | | |

ErrorO = Errors of Omission (expressed as proportions)

ErrorC = Errors of Commission (expressed as proportions)

90% Confidence Interval = +/- 0.0008 (0.1539 - 0.1556)

95% Confidence Interval = +/- 0.0010 (0.1538 - 0.1558)

99% Confidence Interval = +/- 0.0013 (0.1535 - 0.1561)

KAPPA INDEX OF AGREEMENT (KIA)

Using Ground_truth as the reference image…

| Category | KIA |
|---|---|
| 1 | 0.9574 |
| 2 | 0.6823 |
| 3 | 0.7757 |

| | |
|---|---|
| 4 | 0.7697 |
| 5 | 0.8088 |

1984_image

| Category | KIA |
|---|---|
| 1 | 0.9737 |
| 2 | 0.3976 |
| 3 | 0.4077 |
| 4 | 0.6831 |
| 5 | 0.7607 |

**Overall Kappa = 0.8054**

Error Matrix Analysis of Ground_truth (columns : truth) 1999_image (rows : mapped)

| | 1 | 2 | 3 | 4 | 5 | Total | ErrorC |
|---|---|---|---|---|---|---|---|
| 1 \| | 3289 | 19 | 0 | 0 | 0 | 3316 | 0.0081 |
| 2 \| | 77 | 5122 | 0 | 0 | 503 | 7848 | 0.1473 |
| 3 \| | 0 | 0 | 1063 | 1 | 0 | 932 | 0.0610 |
| 4 \| | 0 | 0 | 98 | 22556 | 0 | 9733 | 0.2014 |
| 5 \| | 6 | 133 | 0 | 1 | 33145 | 6288 | 0.0884 |
| Total \| | 3372 | 7150 | 1427 | 23140 | 43706 | | |
| ErrorO \| | 0.0246 | 0.2836 | 0.2551 | 0.0252 | 0.2416 | | |

ErrorO = Errors of Omission (expressed as proportions)

ErrorC = Errors of Commission (expressed as proportions)

90% Confidence Interval = +/- 0.0009 (0.2071 - 0.2090)

95% Confidence Interval = +/- 0.0011 (0.2069 - 0.2092)

99% Confidence Interval = +/- 0.0015 (0.2066 - 0.2095)

KAPPA INDEX OF AGREEMENT (KIA)

---

Using Ground_truth as the reference image ...

| Category | KIA |
|---|---|
| 1 | 0.9918 |
| 2 | 0.6477 |
| 3 | 0.9389 |
| 4 | 0.3697 |
| 5 | 0.6842 |

1999_image

| Category | KIA |
|---|---|
| 1 | 0.9752 |
| 2 | 0.7119 |
| 3 | 0.7443 |
| 4 | 0.9716 |
| 5 | 0.7337 |

**Overall Kappa = 0.7797**

Error Matrix Analysis of Ground_truth (columns: truth) 2011_image (rows : mapped)

| | 1 | 2 | 3 | 4 | 5 | Total | ErrorC |
|---|---|---|---|---|---|---|---|
| 1 | 3289 | 19 | 0 | 0 | 0 | 3316 | 0.0081 |
| 2 | 77 | 5122 | 0 | 0 | 503 | 7848 | 0.1473 |
| 3 | 0 | 0 | 1063 | 1 | 0 | 932 | 0.0610 |
| 4 | 0 | 0 | 98 | 22556 | 0 | 9733 | 0.2014 |
| 5 | 6 | 133 | 0 | 1 | 33145 | 6288 | 0.0884 |
| Total | 3372 | 7150 | 1427 | 23140 | 43706 | | |
| ErrorO | 0.0246 | 0.2836 | 0.2551 | 0.0252 | 0.2416 | | |

ErrorO = Errors of Omission (expressed as proportions)

ErrorC = Errors of Commission (expressed as proportions)

90% Confidence Interval = +/- 0.0009 (0.2071 - 0.2090)

95% Confidence Interval = +/- 0.0011 (0.2069 - 0.2092)

99% Confidence Interval = +/- 0.0015 (0.2066 - 0.2095)

KAPPA INDEX OF AGREEMENT (KIA)

---

Using Ground_truth as the reference image ...

| Category | KIA |
|---|---|
| 1 | 0.9812 |
| 2 | 0.6903 |
| 3 | 0.9711 |
| 4 | 0.6203 |
| 5 | 0.7014 |

2011_image

| Category | KIA |
|---|---|
| 1 | 0.9388 |
| 2 | 0.7139 |
| 3 | 0.7729 |
| 4 | 0.9821 |
| 5 | 0.7338 |

**Overall Kappa = 0.7670**

**MAP SHOWING SAMPLING POINTS**

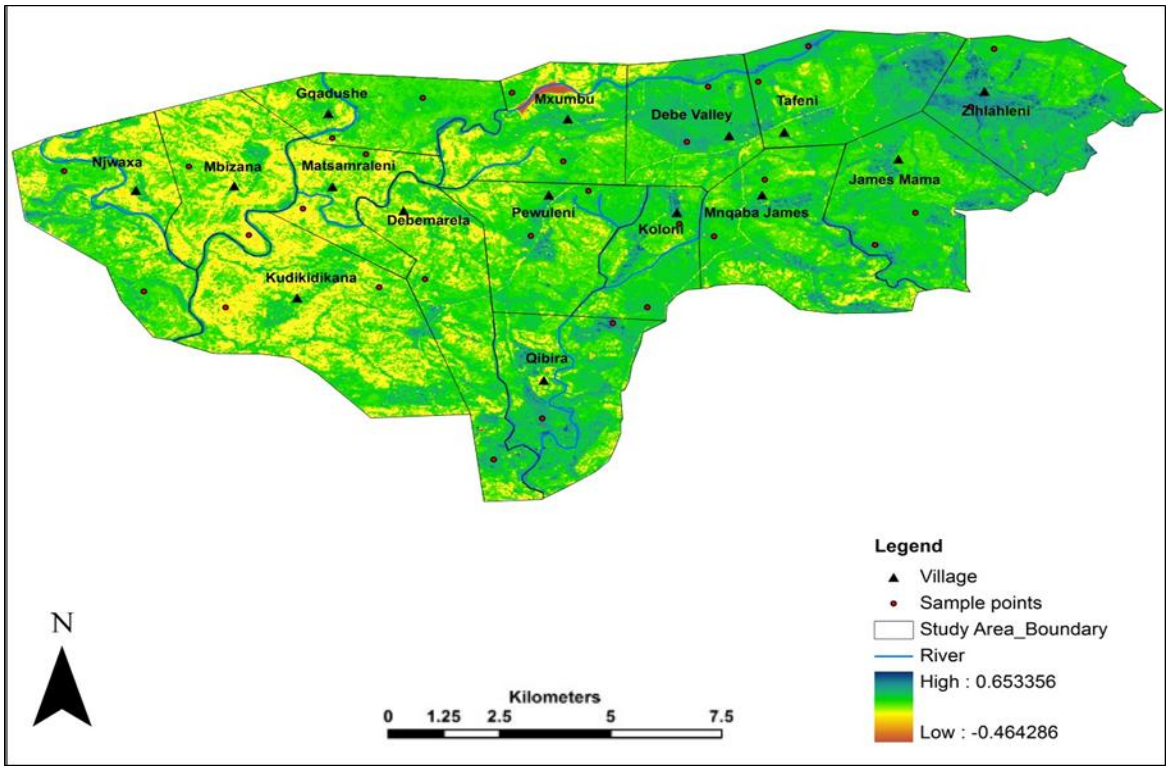


Figure A.2: 2011 NDVI image showing sampling points (Note: these are sampling points visited during field verification. They are not sampling points digitized per village for logistic regression analyses).

# APPENDIX B

## SEMI-STRUCTURED INTERVIEW

Village Name:

| |
|---|
| |

Area coordinates:

| **latitude** | **longitude** |
|---|---|
| | |
| | |

Village committee name:

| |
|---|
| |

**<u>Institutional Committee</u>**

What type of village structure does your committee represent?

| Traditional council | | Municipal council | |
|---|---|---|---|

How was the committee constituted?

| Democratically | | Traditionally | |
|---|---|---|---|

| Yes | | No | |
|---|---|---|---|

Are people aware of the presence of committee?

How many members does the committee have?

| |
|---|
| |

Are the committee members paid?

| Yes | | No | |
|---|---|---|---|
| | | | |

If yes, who is paying the committee?

| |
|---|
| |

Did the committee attend any management training?

| Yes | | No | |
|---|---|---|---|
| | | | |

If yes, provide the aspects which the training was based on:

| |
|---|
| |

Is there any support received from national or provincial government?

| Yes | | No | |
|---|---|---|---|
| | | | |

If yes, what kind of support do you get?

| |
|---|
| |

If no, what support do you think is needed from the government?

| |
|---|
| |

## Grazing management

Do livestock owners practice herding?

| Yes | | No | |
|---|---|---|---|

If yes, how often?

| Always | | Sometimes | |
|---|---|---|---|

Are the animals kraaled during the night?

| Yes | | No | | Sometimes | |
|---|---|---|---|---|---|

Do animals always graze within the village boundary?

| Yes | | No | |
|---|---|---|---|

Are the animals from other villages allowed to graze in your area?

| Yes | | No | | Sometimes | |
|---|---|---|---|---|---|

If no, what happens if they do so?

| |
|---|

Does the committee monitor if the grazing management strategy is followed?

| Yes | | No | |
|---|---|---|---|

Does the committee take a walk around grazing area to check the condition of grazing areas, e.g. fencing condition?

| Yes | | No | |
|---|---|---|---|

Does the committee have the power to penalise those not following the grazing rules?

| Yes | | No | | Sometimes | |
|---|---|---|---|---|---|

Does the committee have the necessary knowledge regarding grazing management system?

| Yes | | Not sure | | No | |
|---|---|---|---|---|---|

If yes, where did the committee obtain grazing management knowledge from?

Describe the grazing management strategy of your committee:

**Fencing**

Is the grazing land fenced?

| Yes | | No | |
|---|---|---|---|

If no, why?

If no, do you see fencing as a necessity?

| Yes | | No | |
|---|---|---|---|

Provide reasons for your answer?

Who erected the fence in your village?

| Traditional committee | | Local government | |
|---|---|---|---|

How does it help in grazing management system?

How would you describe the state of fencing?

| Good | | Bad | |
|---|---|---|---|

If bad, what happened to it?

How does fencing improve grazing management?

**Grazing management conflicts**

Is your committee the only one responsible for grazing management system in your village?

| Yes | | No | |
|---|---|---|---|

If not, which aspects of grazing management is it responsible for?

If fully-responsible, does it operate without any intervention from the other committee?

| Yes | | No | |
|---|---|---|---|

If no, how does the intervention affect grazing management in your village?

| |
|---|
| |

Does the community recognise your committee as the one responsible for grazing management?

| | | | |
|---|---|---|---|
| Yes | | No | |

Do the animals from your village only graze within village boundary?

| | | | |
|---|---|---|---|
| Yes | | No | |

If no, are they allowed to graze in other village camps?

| | | | |
|---|---|---|---|
| Yes | | No | |

If no, why do they graze outside your village boundary?

| |
|---|
| |

**Arable land grazing**

Are the animals allowed to graze in the cropping land?

| | | | |
|---|---|---|---|
| Yes | | No | |

| | |
|---|---|
| If yes, in which time of the year? | |

| | | | | |
|---|---|---|---|---|
| Is cropping land fenced? | Yes | | No | |

## APPENDIX C

## SUMMARY OF LOGISTIC REGRESSION ANALYSIS RESULTS

**The Relationship between Fencing and NDVI Value:**

### Logistic Regression Analysis Summary

**Logistic Regression Results:**

***Regression Equation:***

logit(Fencing_Data) = -2.5685 + 9.400195*Fencing_NDVI

***Individual Regression Coefficient:***

| Variables | Coefficient |
|---|---|
| Intercept | -2.56846874 |
| Fencing_NDVI | 9.40019548 |

***Regression Statistics:***

| | | |
|---|---|---|
| Number of observations | = | 300 |
| Number of zeros | = | 160 |
| Number of ones | = | 140 |
| Percentage of zeros | = | 53.3333% |
| Percentage of ones | = | 46.6667% |
| 2logL0 | = | 414.5540 |
| -2log(likelihood) | = | 230.8458 |
| Pseudo R_square | = | 0.4431 |
| Goodness of Fit | = | 344.9977 |
| ChiSquare(1) | = | 183.7082 |

***Means and Standard Deviations:***

| | Mean | Standard Deviation |
|---|---|---|
| Fencing_NDVI | 0.247302 | 0.232423 |
| Fencing_Data | 0.466667 | 0.499721 |

***Classification of Cases & Odds Ratio:***

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 139 | 21 | 86.8750% |
| 1 | 21 | 119 | 85.0000% |

**Odds Ratio = 37.5079**

***Reclassification of Cases & ROC:***

(1) Select a new threshold value such that, after reclassification, the number of fitted ones matches the number of observed oness in the dependent variable:

**New Cutting Threshold for Classification = 0.5152**

*Classification of Cases & Odds Ratio by Using the New Threshold:*

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 139 | 21 | 86.8750% |
| 1 | 21 | 119 | 85.0000% |

**Adjusted Odds Ratio = 37.5079**

True Positive = 85.0000%

False Positive = 13.1250%

(2) ROC* Result with 100 thresholds:

**ROC = 0.8947**

* ROC = 1 indicates a perfect fit; and a ROC = 0.5 denotes a random fit.

## Relationship between Herding Practice and NDVI Value:

### Logistic Regression Analysis Summary

**Logistic Regression Results:**

***Regression Equation:***

logit(Herding_Data) = -1.5437 + 4.341349*Herding_NDVI

***Individual Regression Coefficient:***

| Variables | Coefficient |
|---|---|
| Intercept | -1.54366653 |
| Herding_NDVI | 4.34134853 |

***Regression Statistics:***

| | | |
|---|---|---|
| Number of observations | = | 300 |
| Number of zeros | = | 100 |
| Number of ones | = | 200 |
| Percentage of zeros | = | 33.3333% |
| Percentage of ones | = | 66.6667% |
| 2logL0 | = | 414.5540 |
| -2log(likelihood) | = | 364.8523 |
| Pseudo R_square | = | 0.1199 |
| Goodness of Fit | = | 299.5504 |
| ChiSquare(1) | = | 49.7017 |

***Means and Standard Deviations:***

| | Mean | Standard Deviation |
|---|---|---|
| Herding_NDVI | 0.312563 | 0.213276 |
| Herding _Data | 0.466667 | 0.499721 |

***Classification of Cases & Odds Ratio:***

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 88 | 12 | 67.5000% |
| 1 | 39 | 11 | 72.1429% |

**Odds Ratio** = 5.3787

***Reclassification of Cases & ROC:***

(1) Select a new threshold value such that, after reclassification, the number of fitted ones matches the number of observed oness in the dependent variable:

**New Cutting Threshold for Classification = 0.5294**

*Classification of Cases & Odds Ratio by Using the New Threshold:*

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 114 | 46 | 71.2500% |
| 1 | 46 | 94 | 67.1429% |

**Adjusted Odds Ratio = 5.0643**

True Positive = 81.7391%

False Positive = 28.7500%

(2) ROC* Result with 100 thresholds:

**ROC = 0.7297**

* ROC = 1 indicates a perfect fit; and a ROC = 0.5 denotes a random fit.

## Relationship between Kraaling Practice and NDVI Value:

### Logistic Regression Analysis Summary

**Logistic Regression Results:**

***Regression Equation:***

logit(Kraaling _Data) = -0.5511 + 6.424389* Kraaling_NDVI

***Individual Regression Coefficient:***

| Variables | Coefficient |
|---|---|
| Intercept | -0.55110502 |
| Kraaling _NDVI | 6.42438910 |

***Regression Statistics:***

| | | |
|---|---|---|
| Number of observations | = | 300 |
| Number of zeros | = | 100 |
| Number of ones | = | 200 |
| Percentage of zeros | = | 33.3333% |
| Percentage of ones | = | 66.6667% |
| 2logL0 | = | 381.9085 |
| -2log(likelihood) | = | 285.1277 |
| Pseudo R_square | = | 0.2534 |
| Goodness of Fit | = | 299.5504 |
| ChiSquare(1) | = | 96.7808 |

***Means and Standard Deviations:***

| | Mean | Standard Deviation |
|---|---|---|
| Kraaling_NDVI | 0.247302 | 0.232423 |
| Kraaling_Data | 0.666667 | 0.472192 |

***Classification of Cases & Odds Ratio:***

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 52 | 48 | 52.0000% |
| 1 | 42 | 158 | 79.0000% |

**Odds Ratio = 4.0754**

***Reclassification of Cases & ROC:***

(1) Select a new threshold value such that, after reclassification, the number of fitted ones matches the number of observed oness in the dependent variable:

**New Cutting Threshold for Classification = 0.5254**

*Classification of Cases & Odds Ratio by Using the New Threshold:*

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 57 | 43 | 57.0000% |
| 1 | 43 | 157 | 78.5000% |

**Adjusted Odds Ratio = 4.8399**

True Positive = 88.2022%

False Positive = 43.0000%

(2) ROC* Result with 100 thresholds:

**ROC = 0.8126**

* ROC = 1 indicates a perfect fit; and a ROC = 0.5 denotes a random fit.

## Relationship between Rotational Grazing and NDVI Value:

### Logistic Regression Analysis Summary

**Logistic Regression Results:**

***Regression Equation:***

logit(Fencing_Data) = -2.5685 + 9.400195*Fencing_NDVI

***Individual Regression Coefficient:***

| Variables | Coefficient |
|---|---|
| Intercept | -2.56846874 |
| Fencing_NDVI | 9.40019548 |

***Regression Statistics:***

| | | |
|---|---|---|
| Number of observations | = | 300 |
| Number of zeros | = | 160 |
| Number of ones | = | 140 |
| Percentage of zeros | = | 53.3333% |
| Percentage of ones | = | 46.6667% |
| 2logL0 | = | 414.5540 |
| -2log(likelihood) | = | 230.8458 |
| Pseudo R_square | = | 0.4431 |
| Goodness of Fit | = | 344.9977 |
| ChiSquare(1) | = | 183.7082 |

***Means and Standard Deviations:***

| | Mean | Standard Deviation |
|---|---|---|
| Fencing_NDVI | 0.247302 | 0.232423 |
| Fencing_Data | 0.466667 | 0.499721 |

***Classification of Cases & Odds Ratio:***

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 139 | 21 | 86.8750% |
| 1 | 21 | 119 | 85.0000% |

**Odds Ratio = 37.5079**

***Reclassification of Cases & ROC:***

(1) Select a new threshold value such that, after reclassification, the number of fitted ones matches the number of observed ones in the dependent variable:

**New Cutting Threshold for Classification = 0.5152**

*Classification of Cases & Odds Ratio by Using the New Threshold:*

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 139 | 21 | 86.8750% |
| 1 | 21 | 119 | 85.0000% |

**Adjusted Odds Ratio = 37.5079**

True Positive = 85.0000%

False Positive = 13.1250%

(2) ROC* Result with 100 thresholds:

**ROC = 0.8947**

* ROC = 1 indicates a perfect fit; and a ROC = 0.5 denotes a random fit.

**<u>Relationship between Grazing Camp Conflicts and NDVI Value:</u>**

**Logistic Regression Analysis Summary**

**<u>Logistic Regression Results</u>:**

***Regression Equation:***

logit(Conflict _Data) = -1.5425 + 7.166874* Conflict_NDVI

***Individual Regression Coefficient:***

| **Variables** | **Coefficient** |
|---|---|
| Intercept | -1.54247282 |
| Conflict _NDVI | 7.16687424 |

***Regression Statistics:***

| | | |
|---|---|---|
| Number of observations | = | 300 |
| Number of zeros | = | 100 |
| Number of ones | = | 200 |
| Percentage of zeros | = | 34.2193 % |
| Percentage of ones | = | 269.9016% |
| 2logL0 | = | 386.7725 |
| -2log(likelihood) | = | 230.8458 |
| Pseudo R_square | = | 03022 |
| Goodness of Fit | = | 310.9656 |
| ChiSquare(1) | = | 116.8708 |

***Means and Standard Deviations:***

| | **Mean** | **Standard Deviation** |
|---|---|---|
| Conflict_NDVI | 0.341091 | 0.217861 |
| Conflict_Data | 0.657807 | 0.475234 |

***Classification of Cases & Odds Ratio:***

| **Observed** | **Fitted_0** | **Fitted_1** | **Percent Correct** |
|---|---|---|---|
| 0 | 73 | 30 | 70.8738% |

| | | | |
|---|---|---|---|
| 1 | 22 | 176 | 88.8889% |

**Odds Ratio = 19.4667**

***Reclassification of Cases & ROC:***

(1) Select a new threshold value such that, after reclassification, the number of fitted ones matches the number of observed ones in the dependent variable:

**New Cutting Threshold for Classification = 0.5152**

*Classification of Cases & Odds Ratio by Using the New Threshold:*

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 76 | 27 | 73.7864% |
| 1 | 27 | 171 | 86.3636% |

**Adjusted Odds Ratio = 17.8272**

True Positive = 89.0625%

False Positive = 26.2136%

(2) ROC* Result with 100 thresholds:

**ROC = 0.8387**

* ROC = 1 indicates a perfect fit; and a ROC = 0.5 denotes a random fit.

## Relationship between Management Training and NDVI Value:

### Logistic Regression Analysis Summary

**Logistic Regression Results:**

***Regression Equation:***

logit(Training_Data) = -3.0250 + 5.132780* Training_NDVI

***Individual Regression Coefficient:***

| Variables | Coefficient |
|---|---|
| Intercept | -3.02495013 |
| Training_NDVI | 5.13277960 |

***Regression Statistics:***

| | | |
|---|---|---|
| Number of observations | = | 300 |
| Number of zeros | = | 160 |
| Number of ones | = | 140 |
| Percentage of zeros | = | 76.6667 % |
| Percentage of ones | = | 23.3333 % |
| 2logL0 | = | 325.9637 |
| -2log(likelihood) | = | 276.5736 |
| Pseudo R_square | = | 0.1515 |
| Goodness of Fit | = | 261.7423 |
| ChiSquare(1) | = | 49.3901 |

***Means and Standard Deviations:***

| | Mean | Standard Deviation |
|---|---|---|
| Training_NDVI | 0.294105 | 0.225846 |
| Training_Data | 0.233333 | 0.423659 |

***Classification of Cases & Odds Ratio:***

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 214 | 16 | 90.4167% |
| 1 | 57 | 13 | 18.5714% |

**Odds Ratio = 3.0504**

***Reclassification of Cases & ROC:***

(1) Select a new threshold value such that, after reclassification, the number of fitted ones matches the number of observed ones in the dependent variable:

**New Cutting Threshold for Classification = 0.3746**

*Classification of Cases & Odds Ratio by Using the New Threshold:*

| Observed | Fitted_0 | Fitted_1 | Percent Correct |
|---|---|---|---|
| 0 | 187 | 43 | 81.3043% |
| 1 | 43 | 27 | 38.5714% |

**Adjusted Odds Ratio = 2.7307**

True Positive = 56.2500%

False Positive = 18.6957%

(2) ROC* Result with 100 thresholds:

**ROC = 0.7579**

* ROC = 1 indicates a perfect fit; and a ROC = 0.5 denotes a random fit.