IMPACT OF ANTHROPOGENIC CLIMATE CHANGE ON THE VEGETATION OF THE SOUTPANSBERG REGION OF SOUTH AFRICA

BY

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November 2013

Impact of Anthropogenic Climate Change on the Vegetation of the Soutpansberg Region of South Africa

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A dissertation submitted in fulfilment of the requirements of the Masters of Science in Environmental Science and Management

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November 2013

DECLARATION

I, Priscilla Ntuchu Kephe (Student No: 23160802) hereby declare that this dissertation for the award of Masters of Science (Environmental Science and Management) at the North West University, is my own work and that it has not previously been submitted for assessment to another university or for another qualification and that all material contained herein has been duly acknowledged.

Signature .... Date 07/10/2014

ACKNOWLEDGEMENT

I would like to thank my supervisors, Prof. T.A Kabanda and Dr. B.M Petja for their tremendous advice and guidance which has helped in executing this research project. Their valuable support, encouragement and mentorship have enlarged my knowledge in climate change and remote sensing fields. Thanks to the North West University Postgraduate Bursary and the Department of Geography and Environmental Science for making this study possible by providing funding for the field trips.

Special thanks to my family: my husband Lendeu Siewe, the Ntuchu's, Dr and Mrs Bungu without whose love and support none of this would have come to fruition. They gave me the motivation to complete this project. To my daughters Claire and Caidyn for being so understanding during the long hours I worked.

ABSTRACT

The aim of this study was to assess the impact of anthropogenic climate change on the plant biodiversity with a primary focus on the geographical area of the Soutpansberg region of South Africa. It is of primary importance to establish the effects of anthropogenic climate change on the vegetation of Soutpansberg in order to preserve the natural state of vegetation as much as possible. However, it has been noted on several studies that indigenous plant species will not only diminish due to climate change but also due to incorrect forest management

The relevé method was adapted and used to assess the structure and composition of vegetation in each of the delineated areas (North West - NW; North East - NE; South West - SW; South East - SE; Centre - SE) of the Soutpansberg. Geographic Information System (GIS) and remote sensing technology was further utilised to assess the vegetation cover over time in the study area as well as classifying the vegetation change over time into various classes. Climate data; rainfall and temperature were assessed for pattern, distribution, variability and associated them to the occurrence of different plant life forms found across the Soutpansberg Mountain range.

The results obtained indicated that there is a high variation in vegetation composition, density and species richness as the rainfall and temperature varies across the mountain range. Within the delineated areas of the Soutpansberg: NW; NE; SW; SE; Centre, vegetation richness and density were assessed. The richness and density at the Centre was found to be above 80% with forest cover still very much intact. This was followed by the SE with about 75 % of natural forest cover , the SW which is fast making a transition from forest to woodland while the NE has become more of woodland with a scattered forest layer; the NW which is composed of grassland and thickets. Furthermore the Normalized Difference Vegetation Index (NDVI) values from remotely sensed images indicate a change in vegetation vigour across the years and across the mountain from east to west corresponding in line with observed climate variability. A classification of the vegetation of the Soutpansberg using unsupervised classification, categorized the vegetation into 10-13 functional types. The functional type classification provided the opportunity for undertaking analyses to develop an understanding of the vegetation change over time through image to image subtraction (change detection). The results provide evidence of vegetation change in the study area and also that as time passes with little or no actions taken to curb anthropogenic climate change effects on vegetation, indigenous plant species will diminish. Of more significance, is the fact that the richness amongst different life forms in the same mountain range is explained by different climatic factors (rainfall and temperature), indicating that rainfall and temperature affect the coexistence of different vegetation types and have a different effect on different life forms.

Results confirmed that anthropogenic climate change affect the vegetation of the Soutpansberg with such effects varying across the mountain and the magnitude changes over time and space. These effects resulted in decrease in biomass and vigour of indigenous vegetation across the range with time.

Key words: anthropogenic climate change, Normalized Difference Vegetation Index (NDVI), image classification, vegetation status, rainfall and temperature

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AOI:	Area of Interest
A.S.L:	Above Sea Level
COP:	Conference of the Parties
CE:	Centre
CVA:	Change Vector Analysis
DEA:	Department of Environmental Affaires
DN:	Digital Number
DWAF:	Department of Water Affaires
EEA:	European Environmental Agency
ENSO:	El Niño–Southern Oscillation
ERDAS:	Earth Resource Data Analysis System
GCP:	Ground control Point
GIS:	Geographic Information System
GMT:	Global Mean Temperature
IDL:	Interactive Data Language
ISODATA:	Interactive Self –Organizing Data Analysis
IPPC:	Intergovernmental Panel on Climate Change
MAD:	Multivariate Alteration Detection
MID-IR:	Mid Infrared
NIR:	Near Infrared
NDVI:	Normalized Difference Vegetation Index
LCL:	Lifting Condensation Level
NE:	North East
NW:	North West
RMS_{error}:	Root Mean Square Error
SAI:	Standardized Anomaly Index
SANSA:	South African National Space Agency
SAWS:	South African Weather Services
SE:	South East
SPSS:	Statistical Package for the Social Sciences

SW:	South West
TM:	Landsat Thematic Mapper
UTM:	Universal Transverse Mercator System
UNDP:	United Nation Development Programme
UNFCCC:	United Nations Framework Convention on Climate Change
UNFF:	United Nations Forum on Forests
WGS:	World Geographical System
WMO:	World Meteorological Organisation

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CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 Introduction

This research examines the effects of anthropogenic climate change on the vegetation of the Soutpansberg region of South Africa. This chapter introduces anthropogenic climate change and provides the introductory part of the research project. A background section puts the research into context and the objectives provide the goals of this research. The rationale provides the reason d'être of the research while the hypothesis provides the guiding framework of the research. The environmental characteristics of the study area, has also been extensively described.

Vegetation is expected to be exposed to direct effects of climatic variations such as changes in temperature and precipitation variability. Climate change will result in more intense precipitation events causing increased flood, landslide, avalanche and mudslide damages that will cause increased risks to human lives and properties (IPCC, 2001a). Warmer temperatures increase the water-holding capacity of the air and thus increase the potential evapotranspiration, reduce soil moisture and decrease ground water reserves (IPCC, 2001b) which will affect vegetation composition and status.

Studies show that developing countries are more vulnerable to climate change and are expected to suffer more from the adverse climatic impacts than the developed countries (IPCC, 2001a). In a humid climate like that of the Soutpansberg, there will be changes in the spatial and temporal distribution of temperature and precipitation due to anthropogenic climate change, which in turn will increase both the intensity and frequency of extreme events like droughts and floods (Mahtab, 1992).

1.2 Background

Anthropogenic climate change is characterised by changes in climate regime, brought about by the cutting up of vegetation through agricultural practices, urbanisation, deforestation and mining. Climate change is a natural cycle where climate changes to accommodate the energy received from the sun. This definition clearly attributes climate change to natural factors. United Nation's Framework Convention on Climate Change

(UNFCCC) defines climate change as a change of climate attributed directly or indirectly to human activity, which alters the composition of the global atmosphere and in addition to natural climate variability over comparable time periods (Intergovernmental Panel on Climate Change (IPCC), 2001). Comparatively, the IPCC (IPCC, 2001b) defines climate change as a change in the state of the climate which can be identified (for example using statistical tests) by changes in the mean and/or the variability in its properties and is persistent for an extended period, typically decades or longer. The term "anthropogenic" is added to the term "climate change" in this research where human causes are attributable to climate change. The IPCC's definition and that of the UNFCCC is coined to define the anthropogenic climate change observed in this research. Hence anthropogenic climate change as per this research is, changes in climatic state, identified by changes in the mean and / or variability in its properties and persistent over extended periods, typically decades or longer, attributed directly or indirectly to human activity such as persistent changes in land use (urbanisation, agriculture, mining and deforestation) which affect vegetation cover. Therefore the disturbance of vegetation by human activity is responsible for resultant changes in the climate regime. These have impacted the climate regimes of many areas, causing anthropogenic climate changes as reported for the Soutpansberg area (Kabanda & Munyati, 2010). The emerging population growth and status of towns in and around the Soutpansberg is leading to changes in the land use pattern with increase in demand for more land for agriculture and habitats as shown by Appendix 1.1.

Plant diversity underpins all terrestrial ecosystems, and provides the fundamental life-support systems upon which all life depends. Ecosystems are composed of species assemblages, and it is clear that, individual plant species within ecosystems will react differently to changing climatic conditions. Some species will stay in place and adapt to new conditions, others will move to new locations and some species will become extinct. This will result in changes in species compositions and ecosystem structure, and possible loss of essential ecosystem services. Current observations reveal a climate that is more sensitive than anticipated, with changes occurring sooner and more intensely than predicted (Pew Centre, 2007). The impacts of anthropogenic climate change on plant life are of key concern to humankind because plants, apart from their inherent interest, play a vital role in ecosystem function and in food production and security. They also have implication for other groups of organisms which depend on them for habitat and shelter.

1.3 Statement of the problem

South Africa is amongst the countries with a population that is increasingly urbanising, with an urbanisation figure of 53%, which is expected to increase (Cilliers et al., 2004). The local population of Soutpansberg is expanding rapidly. This comes as a result of resettlement policies of the 1960s and the in flock of workers from failed commercial farms in the west (Kabanda & Munyati, 2009). The rapid expansion of towns in the area especially in the eastern part of the Soutpansberg, poses a problem to the environment since the natural woodland and forest cover are cleared away for settlement expansion and agricultural practices. Town such as Thohoyandou, Malamulele, Makhado and others have seen rapid population growth, such that, the urban sprawl demands more land for housing and agriculture. This has inevitably resulted in the encroachment on the forest woodlands in the eastern portion of Soutpansberg Mountain (Munyati & Kabanda, 2008).

As observed (Kabanda & Munyati, 2009), much of the rainfall in the Soutpansberg is generated by the mountain range. This is through the combination of orographic effect and evapo-transpiration from the natural vegetation. But today due to the clearing of the natural vegetation, the extent of evapo-transpiration affecting the formation of rain bearing cloud is diminished. Also the development and construction of concrete structures taking place in the east (particularly Thohoyandou) has enhanced the rate of atmospheric absorption by the earth's surface, thus diminishing moisture availability for deep cloud formation. Human activities taking place in the east is negatively affecting the west because the mountain is aligned in a northeast to southwest direction. Hence most of the precipitation is captured by the mountains along the eastern part with decreasing amounts in the west, even though there are some higher peaks in this area. This has enhanced local anthropogenic climate change which is manifested in the western part of the Soutpansberg. Vegetation is a crucial link in understanding the interaction between plants and climatic conditions. The physical properties and nature of vegetation renders it a very suitable yardstick by which climatic effects on the ecosystem can be measured.

This study looks at the changes in the local climate of the Soutpansberg and how it affects the vegetation of the area. There is a need to assess the impact of anthropogenic climate change on vegetation in order to develop adaptation and mitigation strategies to deal with the resulting impacts.

1.4 Aim

The main aim of this study is to assess the impacts of anthropogenic climate change on the vegetation of the Soutpansberg.

1.5 Specific Objectives

1. To assess the state of vegetation health and status in the light of changing climate.
2. To determine climate variability (rainfall and temperature).
3. To assess the existing forest structure and extension (Spatial and temporal).
4. To establish the relationship between changing vegetation and anthropogenic climate change (Spatial and temporal).
5. To propose ways by which plant communities of the Soutpansberg can be sustained.

1.6 Hypothesis

Research Hypothesis: Anthropogenic climate change impacts on the vegetation of the Soutpansberg.

Null Hypothesis: Anthropogenic climate change does not affect the vegetation of the Soutpansberg.

Specific Hypothesis 1: There is a significant relationship between anthropogenic climate change and vegetation status.

Null Hypothesis1: There is no significant relationship between anthropogenic climate change and vegetation status.

Specific Hypothesis 2: The rate of impact of anthropogenic climate change varies across the range.

Null Hypothesis 2: The rate of impact of anthropogenic climate change does not vary across the range.

Specific Hypothesis 3: The effect of anthropogenic climate change impacts vary across time.

Null Hypothesis 3: The effect of anthropogenic climate change impacts will not vary across time.

1.7 Rationale

There is a need to establish the effect of anthropogenic climate change on the vegetation of Soutpansberg, so as to preserve the natural state of vegetation as much as possible. The structure and species composition of vegetation reflects the sum of all environmental factors within a given environment, thereby acting as living summary of the surrounding environmental factors (Corney et al., 2004). Plant function is inextricably linked to climate and atmospheric carbon dioxide concentration. On the shortest and smallest scales, the climate affects the plants' immediate environment and therefore directly influences physiological processes. At larger scales, the climate influences species distribution and community composition, as well as the viability of different crops in managed ecosystems. Climatic conditions are key determinants of plant growth, whether at the scale of temperature regulation of the cell cycle, or at the scale of the geographic limits for a particular species (James et al., 2006). In the Soutpansberg, the climate is regime is being influenced by human activities like deforestation, urbanisation, mining and agricultural activities resulting in anthropogenic climate change Consequently, the conditions for the establishment, growth, reproduction, survival and distribution of plant species might be affected by anthropogenic climate changes.

Observed changing climate has been found to affect the livelihood of people in a negative way. Loss of vegetation has led to a reduction in soil moisture, thereby affecting agricultural productivity, soil erosion and runoff causing increase in floods and rainfall reduction. This has accelerated the scarcity of natural resources leading to competition of the available resources. Also rural urban migration is also influenced due to lack of job opportunities in rural areas and as a result of this movement from rural areas, urban infrastructure becomes under severe pressure due to over population in urban areas. The scarcity and competition for limited resources is known to trigger conflicts in some of the areas. This will affect the economy of the Soutpansberg area, since given that some of the people of the people generate their income from biodiversity activities in the Soutpansberg areas.

It is of essence to consider the effects of anthropogenic climate change on plant diversity, species composition and extent given that the environment and society coexist as a unit. The knowledge will help in bringing up strategies on how the vegetation can be conserved and maintained so as to improve the quality of the environment and the lives depending on this resource. Without this information, society cannot rationally assess the costs and benefits of policy options. It is thus a possibility that changes in the vegetation of the Soutpansberg, will likely impact on the livelihood of the people of the area and the ecosystem as a whole.

1.8 Description of the study area and its environmental parameters

Soutpansberg region (Figure 1) is found in the Limpopo Province and forms the northernmost mountain range of South Africa. It is located between 23° 05'S & 29° 17'E and 22° 25'S & 31° 20'E. It has a geographical extent of 6800km^2 and spans approximately 210 km from east to west. It is 60 km at its widest and 15 km at its narrowest from north to south.

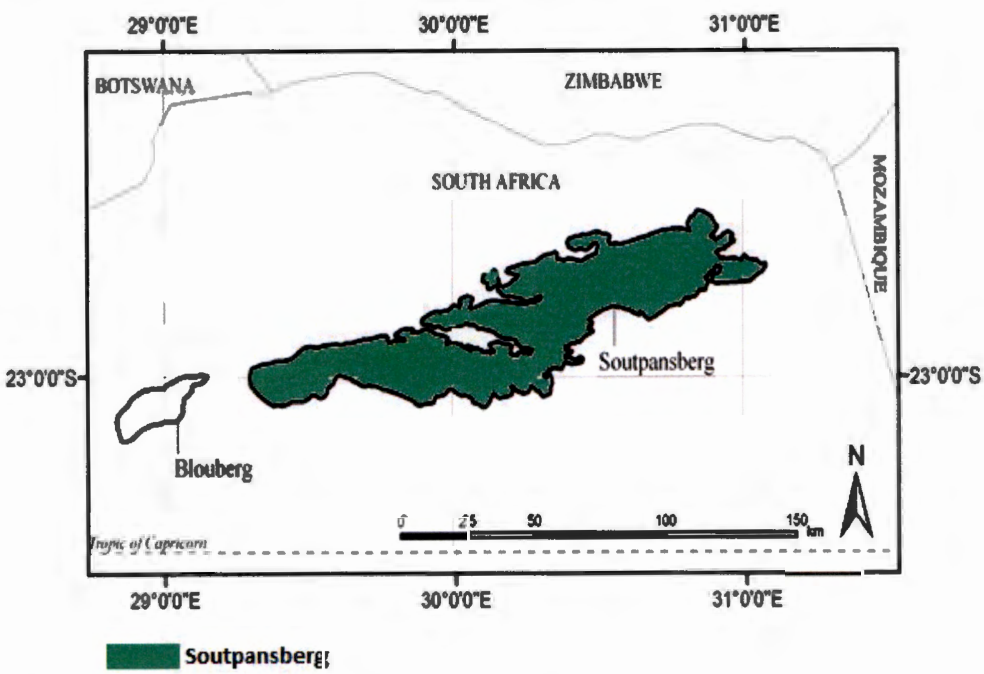


Figure 1.1: Locality map of the Soutpansberg

The approximate boundaries of the Soutpansberg Region include the Tropic of Capricorn to the south, the Limpopo River to the North, the Magolakwena River to the West and the Kruger Park / Mozambique border to the east. The Soutpansberg Mountain range cuts across two districts; Capricon and Vhembe; five municipalities: Thulamela, Makhado, Blouberg, Molemole and Musina in the Limpopo Province. Towns around this range include Alldays, Elim, Louis Trichardt, Mapungubwe, Musina, Schoemansdal, Thohoyandou and Vivo.

1.8.1 Climate

Climate has a very important influence on the vegetation cover of any given area. According to Rutherford and Westfall (1994), temperature and water availability are amongst the most important climatic factors influencing vegetation. The topography of the Soutpansberg gives rise to rainfall and wind patterns that create a diversity of microclimates. There are three distinct climatic regions in the range: the humid on the southern and eastern slopes with the higher peaks, the sub-humid in the south and semi-arid in the north of the mountain (Berger et al., 2003). The Soutpansberg Mountain range represents an effective barrier between the south-easterly maritime climate influences from the Indian Ocean and the continental climate influences which in this case is predominantly the Inter-Tropical Convergence Zone and the Congo Air Mass from the north (Kabanda, 2003; Egan et al., 2005,). This barrier causes the moisture-laden south-easterly winds to empty itself into the southern scarp of the Soutpansberg, creating a rain shadow effect along the northern slopes of the Soutpansberg. The extreme topographic variation and altitude changes over short distances within the Soutpansberg, causes the climate, especially rainfall and mist precipitation to vary considerably.

The amount of orographic rain associated with the southern ridges varies significantly in accordance to the changing landscape. Orographic, anabatic and catabatic winds operating in the area force mist through certain narrow gorges causing a venturi effect which can lead to abnormally high localised rainfall (Hahn, 2002; Matthews, 1991). Orographic mist along this southern slope may increase annual precipitation to 3233mm (Hahn, 2002; Olivier & Rautenbach, 2002). Also areas just below the escarpment crest, where atmospheric moisture can be trapped most effectively against the south facing escarpment, generally yield the highest precipitation (Matthews, 1991). Consequently the mountain influences the reigning climatic conditions for the area. The general climate of the Soutpansberg can be said to be divided into two season .The warm wet season and cool dry season instead of the normal four seasons of spring, autumn, winter and summer as witnessed by other areas in South Africa (Kabanda, 2003).

1.8.1.1 Temperature

Temperature influences the type of plants that grow in an area. In the Soutpansberg, temperature is strongly associated with seasonal conditions and topography of the area (Dzivhani, 1998). Temperatures for the wet warm season which occurs between December and February are from 160°c - 40°c. For the cool dry season: May to August, temperature ranges from 12°c –22°c (Kabanda, 2003). Depletion of vegetation cover and the resulting anthropogenic climate change will change the way in which temperature, evapo-transpiration and plants interact on the local scale of the Soutpansberg. This will have an effect on the plant dynamic of the area as the rainfall pattern.

1.8.1.2 Rainfall

The Soutpansberg Mountain is situated within the summer rainfall region of Southern Africa. The mountain range significantly influences the rainfall distribution in the Vhembe district. Moist winds rise up the eastern slopes of the ridges and creates orographic lifting, which when coupled with convection from daily heating leads to the development of showers and thunderstorms. The mountain range is aligned from the northeast to the South West, with most of the precipitation captured by the mountain along the eastern part. Most of the precipitation in this area can be classified as orographic in nature, because it is the result of moisture-laden air carried by the prevailing south-easterly winds from the Indian Ocean into the southern scarp of the Soutpansberg (Hahn, 2006). Therefore, the higher parts of the Soutpansberg, particularly on the southern and eastern slopes, are characterised by mist belt areas with frequent cloud cover and mist precipitation (Kabanda, 2003).

The annual rainfall averages ranges from around 400 mm on the northern slopes, 550 mm in the east to 1800 mm on the central southern slopes (Schulze, 1997). In the middle of the Soutpansberg annual rainfall can reach 2000 mm (Entabeni) due to the venture effect (Kabanda, 2003) and can be as low as 340 mm (Waterpoort). This has impacted the distribution and appearance of vegetation in the area with the northern slope having stunted trees and sparse vegetation, the southern slope which receives most of the rainfall having a lush vegetation distribution. The area receives one cycle of rainfall that extends from October and ends in March of the following year (approximately 182 days). The dry season runs from April to October. Rainfall peaks during January and February. During the rainy season, rainfall levels vary greatly in different areas of the mountains due to the effects of orography on precipitation levels (Kabanda, 2003).The complex geography of the Soutpansberg acts as a major and constant modifier of the regions climate, which in turn influences the vegetation diversity of the area.

1.8.2 Vegetation

The topological diversity, variation in the geology, soil morphology and the highly localised microclimates of the Soutpansberg Mountain range has created a suitable condition for a wide range of vegetation (Mostert et al., 2008). This diversity is associated to the soil moisture availability and the rate of environmental desiccation (Bond et al., 2003). The degree of moisture availability in the soil goes on to influence the vegetation distribution and species assemblage in the Soutpansberg. Deep rich soils act as sponges and hold more water than rocky and porous soils. The degree of moisture availability determines

The vegetation communities in the Soutpansberg occur as east-west band, following the orientation of the mountain ridges (Mucina & Rutherford, 2006). Higher rainfall on the southern slopes support dense vegetation of deciduous woods, dense evergreen montane forest consisting of small trees and tall trees and small tree species in the northern arid ridges(Mucina & Rutherford, 2006). There are also plantations of softwood forest on the high rainfall southern slopes which forms the non-Conserved area. The North West region is the Conserved area with indigenous forest.

The vegetation of the Soutpansberg has been well studied (e.g., Hahn, 2002, 2006; Mostert 2006, Mostert et al., 2008). There are about 2500- 3000 vascular plant taxa in the Soutpansberg and a large amount of plant species (approximately 3000) representative of the 1066 different genera and 240 families (Hahn, 1997). Mostert et al., (2008) have identified five main vegetation types in the Soutpansberg:

1.8.2.1 Soutpansberg Arid Northern Bushveld

This vegetation type is associated with the clovelly soil form (Mac Vicar et al., 1991). It is derived from sandstone, quartzite and conglomerate of the Wyllies Poort Geological Formation, basalt from the Musekwa Geological Formation and from the narrow diabase intrusions or dykes within the Wyllies Poort Geological Formation (Botha, 2004a; Patterson & Ross, 2004a). Soutpansberg Arid Northern Bushveld Vegetation type is made up of open woodland with a sparse field layer and is confined to the northern ridges of the Soutpansberg Mountains which is dry, hot and rocky, (Low & Rebelo, 1996). Some of the species found in this area includes: *Adansonia digitata, Boscia foetida subsp. rehmanniana, Commiphora glandulosa, Commiphora tenuipetiolata, Cordia monoica, Blepharis diversispina, Grewia flava, Grewia subspathulata.*

1.8.2.2 Soutpansberg Moist Mountain Thickets

The Moist Mountain Thickets are linked with the short lands Soil Storm (Mac Vicar et al. 1991) derived from basalt and tuff associated with the Sibasa Geological Formation and from narrow diabase intrusions or dykes associated with the Land Type of the Wyllies Poort Geological Formation (Botha, 2004b; Patterson & Ross, 2004b). This vegetation type is a mixture of plant communities characterised by closed thickets showing no separation between tree and shrub layers vegetation. Examples of plants found here are: *Catha edulis, Grewia occidentalis, Dovyalis zeyheri, Acalypha glabrata, Dombeya rotundifolia, Rhus pentheri, Carissa edulis, Rhoicissus tridentata subsp. tridentata, Senna petersiana, Diospyros lycioide.*

1.8.2.3 Soutpansberg Leached Sandveld

This vegetation type is confined to the warmer northern slopes of the mountain, some of the more arid southern slopes along the northernmost ridges of the mountain range, which falls within the rain shadow zone of the mountain. The type of soil favourable for these vegetation type are the Mispah and Hutton soil forms (Mac Vicar et al., 1991) derived from sandstone, quartzite and conglomerate associated with Land Types of the Wyllies Poort Geological Formation (Botha, 2004a; Patterson & Ross, 2004a).This plant communities occur on both very shallow and very deep sands of the relatively dry landscapes .The shallow soils are situated on steep rocky inclines, while the deep sands are associated with relatively high-lying flat plateaus. Sandveld is characterised by such species as *Elephantorrhiza burkei, Diplorhynchus condylocarpon, Ochna pulchra, Grewia retinervis and Strychnos pungens, Centropodia glauca, Eragrostis pallens, Selaginella dregei, Cinera.ria parvifolia.*

1.8.2.4 Soutpansberg cool mist belt

This vegetation type is found 1200 m and higher, above sea level (a.s.l) and is limited to the mist belt region of the mountain range. The vegetation type is varied and includes such as peatlands, low open grasslands and small islands of thickets /bush clumps (Edwards 1983). The cool misbelt is associated with Glenrosa and Mispah soil (Mac Vicar et al., 1991) derived from sandstone, quartzite and conglomerate associated with the Wyllies Poort Geological Formation (Botha, 2004b; Patterson & Ross, 2004b). Some of the species include *Rhus rigida var. rigida, Helichrysum kraussii, Olea capensis subsp. enervis, Syzygium legatii, Aloe arborescens, Rotheca myricoides, Euclea linearis, Rhus tumulicolavar. Meeuseana.*

1.8.2.5 Soutpansberg Forest

The forests are confined to the southern slopes of the southernmost ridges of the mountain. It is linked with the Glenrosa, Mispah and Shortlands soil forms (Mac Vicar et al., 1991) derived from basalt, tuff, sandstone, and conglomerate associated with the Sibasa Geological Formation (Botha, 2004b; Patterson & Ross, 2004b).This major vegetation type is reliant on the orographic rain driven onto the southern slopes by a south-easterly wind during summer. The evergreen high forests are confined to the mistbelt of the mountain, which reaches down as far as 1380 m above sea level (Geldenhuys & Murray, 1993). Species include *Xymalos monospora, Zanthoxylum davyi, Celtis africana, Nuxia floribunda, Rhoicissus tomentosa, Kiggelaria africana, Vepris lanceolata, Rapanea melanophloeos, Rothmannia capensis, Brachylaena discolor, Ficus craterostoma, Combretum kraussii.*

The vegetation communities of the Soutpansberg play a great role in the regulation of rainfall in the region. They increase the mountain altitude, thereby lowering the lifting condensation level (LCL) closer to high humidity content (vegetation level). Consequently, it enhances the formation of clouds (Kabanda & Munyati, 2010). The increased evapo-transpiration of the plants also enhances and contributes to cloud formation over the mountains. They also reduce the absorption of atmospheric radiation directed at the earth's surface, in so doing maintain high humidity closer to the ground (Kabanda & Munyati, 2010). The plant distribution helps to enhance the topographic display of the area.

1.8.3 Topography

The topography of the Soutpansberg runs in an east-westerly direction (Figure 1.2). Attitudinally, it is 250 m above sea level (A.S.L) at its lowest and 1748 m at its highest - (Latjuma- western peak) with steep southern slopes and moderate northern slopes. Its highest ridges are found at the western extreme of the range (Mostert et al., 2008). It is surrounded by slightly undulating plains and lowlands of 400 to 900 m A.S.L., including the dry Limpopo River valley in the north.

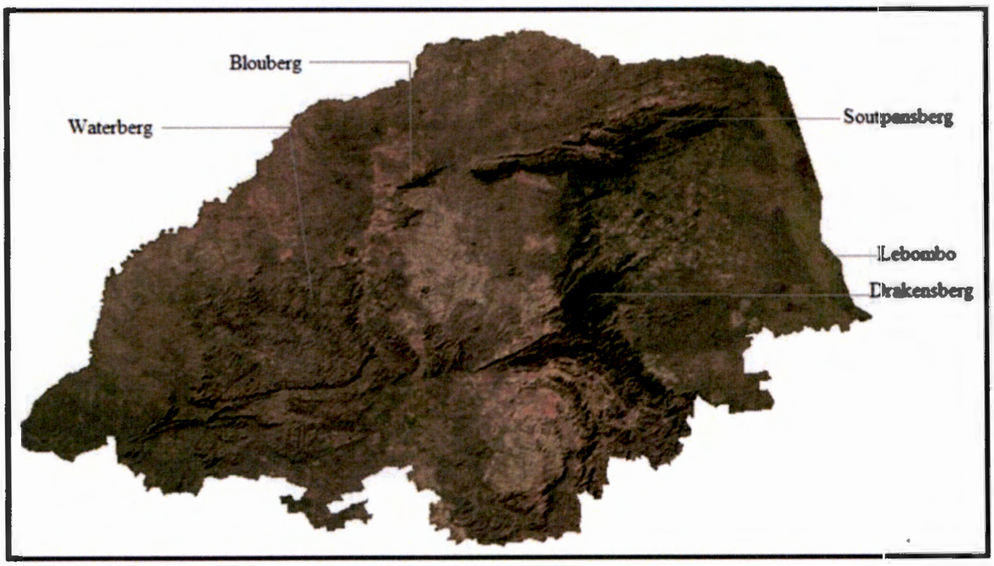


Figure1.2: Topography of Soutpansberg and Surrounding

The Soutpansberg topographical feature most probably has been sculpted by erosion processes (Partridge & Maud, 1987) and has been shown to display the typical characters of an inselberg (Hahn, 2006). Inselbergs often harbour unique species assemblages and like oceanic islands, often stimulate speciation processes and hence can harbour a considerable number of endemic species (e.g. Parmentier, 2003; Parmentier et al., 2005).

1.8.4 Geology

The geological system in the Soutpansberg is approximately 1,800 million years old. This was formed through successive east-west faulting along the Tshamuvhudzi, Nakab, Kranspoort and Zoutpan strike-faults (Brandl, 2003). This faulting was followed by a northward stilting of the area, resulting in the creation of the Soutpansberg Mountain range with its main south facing cliff lines and northern side dipping at an incline of approximately 45° (Mostert et al., 2008). Most of the rock formations in the Soutpansberg Mountain range consist of sandstone, quartz sandstone and pink, erosion resistant quartzite with a few igneous intrusions mainly composed of basalt and dolerite (Brandl, 2003). Geology influences topography as well as in soil formation since it provides the parent material for its development. Climate therefore influences geology because it determines the extent to which weathering and leaching occurs which in turn largely determine the kind of vegetation that will develop on a particular site.

1.8.5 Soils

Most of the rock formations in the Soutpansberg Mountain range are made of sandstone, quartz sandstone and pink, erosion resistant quartzite with a few igneous intrusions mainly made up of basalt and dolerite (Brandl, 2003).The main soil types in the area are shallow, acidic sandy soils. These soils are derived from weathered sandstone and quartzite. The rich clay soils on the other hand are derived from basalt and diabase dykes who are prone to erosion along the southern slope. Other soil types in the area include fine-grained deep sands from the Aeolian Kalahari sands and peat soils that occur along the cooler high wetlands (Mostert et al., 2008).

1.8.6 Fauna

The Soutpansberg Mountain with its micro-habitats is home to highly diverse animal communities. Amongst the total number of species found/recorded in South Africa, 36% of all known reptile species, 56% of bird species and 60% of all mammal have been recorded here (Berger et al., 2003). The Soutpansberg has 145 species of mammals and is especially rich in bat, carnivore and hoofed mammals (Gaigher & Stuart, 2003).Some carnivore species found here such as the leopards, brown hyenas (*Hyena brunnea*) , hyenas (*Crocuta crocuta*) are on the decline. Other animals include African wildcat (*Felis silvestris*), serval (*Leptailurus serval*), honey badger (*Mellivora capensis*), African porcupine (Hystrix africaeaustralis), cane-rat (*Thryonomyidae*) and various species of the Muridae. Twenty five species of the order Artiodactyla also inhabit the Soutpansberg Mountain and these include bushbuck (*Tragelaphus scriptus*), mountain reedbuck (*Redunca fulvorufula*), southern reedbuck (*Redunca arundinum*), klipspringer (Oreotragus oreotragus) (Gaigher & Stuart, 2003). However, the effect of anthropogenic climate change on the vegetation depletion has not been connected to the dwindling of fauna species in the area.

1.8.7 Land Use

The Soutpansberg spread across four municipalities which affects the mountain through the utilisation of the land. The Thulamela municipal area is approximately 2966.4 km in extent comprising 13, 86% of the total area of the Vhembe District Municipal Area. It has an estimated population of 618460 people making up 1.19% of the total population of South Arica (CSIR, Geospatial Analysis Platform, 2013). The annual growth rate stands at 2.26% per annum. This is the highest populated area in the Vhembe district, followed by Makhado.

The Makhado municipal area covers about 754727 square meters with a population of 497090. This population has been recorded as growing at 1.4% per annum (Makhado local municipality multi-year budget, review, 31 March 2011). According to community Survey 2007, the number of household in Thulamela is 137,852, Makhado is 11, 4060, Musina 142,003. The number of household since Census 2001 has risen to 1, 1952 households in Thulamela, 5,082 in Makhado, 2,626 in Musina (Vhembe District Municipality, 2011).

The surface area of the Blouberg municipality is 4,540.84km^2 making up 26.8% of the total land surface of the Capricorn district, with a population of 194,119, and household number of 35598. On the other hand Molemole municipality covers an area of 3,347.25km^2, has a population 100,408 and 27,296 households. The population according to the 2007 household survey has been on a decline, probably due to HIV/AIDS pandemic, migration and low fertility rates (Capricorn District Municipality, 2011).

Land in the Soutpansberg and surrounding area is made up of a patchwork of agricultural practices which vary greatly from crops like potatoes, tomatoes and other vegetables, cotton, paprika, bananas, avocados, mangoes, litchis, papaws, pineapples and various nuts. There are also a number of tea, coffee, pine and eucalyptus plantations. The northern region is mainly cattle and game farming.

Limpopo is the second most woodland abundant with an estimated 105, 632 km2 of broad woodland types and only 17,323 km2 of these woodland types are protected (Lawes, et al., 2004). It was estimated that 59.5% of households in Limpopo use wood as their main source of energy for cooking (DWAF, 2005) and this is likely to increase in spite of the increase in electrification of households. These woodlands are likely to be subjected to extensive clearing or selective cutting in the future as a result of land use pressure and demand for fuel wood increases (Lawes et al, 2004). Fuel wood as a primary energy source for cooking and heating or as a safety-net in times when money is tight will continuously be used for years for affordability reasons .The Soutpansberg Mountain is no exception to this plight given that it is already experiencing depletion of the natural vegetation.

Large scale deforestation in the Soutpansberg began from 1979 and is still continuing to date (Mphaphuli, 1979) as towns such as Thohoyandou, Tshakhuma, Tsianda and Lwamondo continue to grow. This has negatively affected the eastern edge of the Soutpansberg Mountain range, resulting on a localised pressure on woodlands and forest for the purpose of settlement and subsistence agriculture (Munyati C & Kabanda, 2009). The accessible and fertile mountain area has experienced a pole ward movement of people as a result of the increasing pressure from the population growth and shortage of land for cultivation. Consequently forest is fast giving way to agriculture and settlement. The alteration in the land cover has enhanced local anthropogenic climate change which is manifested in the western part of the mountain.

1.9 Layout of Chapters

This study is divided into five chapters. The focus of the first chapter is to provide the background to the research, the research problem, objectives and hypothesis. It also gives a profile of the physical and socio- economic geography of the Soutpansberg area.

The second chapter provides an examination of current literature relating to climate change, causes and terrestrial vegetation response. The review also provides an overview of the significance of climate change for protected areas, biodiversity conservation, including response strategies that can be engaged to address to climate change.

Chapter three describes the methods employed to assess climate variability and the magnitude of vegetation change in the Soutpansberg. It further shows the procedures used to determine the extent of vegetation change in each plot using remotely sensed images.

The fourth chapter presents the results of the analysis carried out in Chapter Three. The final chapter comments on the potential implications of terrestrial vegetation change for management and policy, summarizing the findings of this study and by proposing future research directions.

1.10 Summary

This chapter provides the background, statement of the problem, purpose, rationale and the environment of the study area. The background shows the importance of vegetation in the rainfall and climate patterns in the Soutpansberg. Changes in land use patterns due to urbanisation, agriculture, mining and urban sprawl, depletes the vegetation cover of the area leading to anthropogenic climate change. Given that the vegetation plays a huge role in the climate dynamics of the Soutpansberg, there is a need to investigate the effects of anthropogenic climate change on the vegetation of the area.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The objective of this chapter is to; provide the review of theories and models of past and current literature on anthropogenic climate change effects on vegetation, and how this research fits into that body of knowledge. The research aims at illustrating the impact of anthropogenic climate change on the vegetation of the Soutpansberg, and the importance of incorporating climate change in the policy and management of natural/ indigenous vegetation. Five areas of study used for setting the foundation for this analysis are reviewed. The first section describes past and recent climate change in relation to natural and anthropogenic causes. It also outlines past, current and future vegetation responses to climate change and explains how projected climate change varies across South Africa. It further illustrates the consequences of this change on plant life and the need for these changes to be addressed. The second section provides a global and regional response to climate. The third section seeks to review possible responses in ecosystem management, to adapt and mitigate to the expected impacts of anthropogenic climate. The fourth section looks at methods of assessing vegetation status in the light of climate change. Lastly section five gives an overview of using remote sensing and GIS in assessing the impacts of climate change on vegetation.

2.2 Anthropogenic Climate Change Drivers

A variety of pressures and influences are constantly affecting ecosystems. These shape their biotic and abiotic components at time scales of years, decades or centuries (Shugart, 1998). It is of essence to view the causes of climate change, and changes that have occurred in the earth's climate in the past before moving to anthropogenic causes in the present. In this regard, past climate will help us in placing modern climate observation in context. In order to understand climate change fully, the causes of climate change must first be identified. The causes of climate change are divided into two categories: natural and human causes (anthropogenic).

2.2.1 Natural Causes of Climate Change

The earth's climate has changed throughout geological history as a result of natural factors that affect the radiation balance of the planet, such as changes in earth's orbit, the suns output and volcanic activity (IPCC, 2007a) as well as ocean currents. These natural changes resulted in past ice ages and periods of warming over several thousand years. Changes to the earth's climate over recent geological timeframes brought about by natural factors have resulted in an observed slow rising global temperatures and sea levels since the end of the Pleistocene epoch -10,000 years before present (IPCC, 2007a).

2.3 Anthropogenic Causes

The principle anthropogenic activities responsible for changing climate regimes include changes in land use. These include amongst others deforestation as a result of urbanisation, urban sprawl, agricultural, practices as well as mining activities.

2.3.1 Deforestation

Deforestation is a major contributor to climate change. It accounts for about 20 per cent of human carbon emissions (more than the entire global transport sector produces). Deforestation makes such a huge contribution to carbon emissions because trees absorb CO_2 as they grow. The more trees that are cut down, the fewer there will be left to absorb CO_2, leading to its building up in the atmosphere.

Deforestation has been used to explain observed regional drying in the tropics (Werth & Avissar, 2002) and extra tropics (Pitman et al., 2004). The accelerated shrinking of the glacier atop Mt Kilimanjaro for example is thought to be associated with land use (deforestation) in Africa. Temperatures in that region have been declining for the past 25 years, so the melting of the Kilimanjaro glacier is not related to global warming but to deforestation (Fairman et al, 2011).

2.3.2 Agriculture

Agricultural practices and expansion has been argued to have contributed to northern hemisphere cooling prior to substantial increases in greenhouse gas concentrations (e.g., Govindasamy et al., 2001). Alteration in landscapes, primarily the conversion of forests to agriculture or pasture, changes the partitioning of solar insulation into its sensible and latent turbulent heat forms. Agricultural and pasture regions give out less transpiration and the results are less thunderstorm activity over theses landscapes. Through agricultural activities such as land clearing, cultivation of annual crops, irrigation, grazing of domesticated animals, humans are extensively altering the local, national and global land cover characteristics, by the expansion of agriculture into natural ecosystems which has had a significant climate impact (Lobell et al., 2006).

Over the past century and a half, approximately 40% of the agricultural land in Africa, 40% in Latin America and 70% in Asia has been derived from former tropical forest land. This has provided only two million km^2 of the 15 million km^2 of farmland globally (Pimm, et al., 2001). During this time period, the amount of land converted from forest to agriculture was more than twice all of the land converted from the earliest origins of agriculture to about 1850. Already 23% (4,700,000,000 hectares) of the earth's land area has been converted to agricultural and pastoral use. This represents 45- 60% of the land potentially suitable for agriculture (Dobson, 1995). Agricultural practices, through a modification of the surface energy budget and GHGs emissions can influence the climate of an area. Clearance of vegetation causes less evaporation from the soil and the formation of cloud in the atmosphere. This explains the rise in temperature and a decrease in precipitation at the regional scale.

In considering the role played by agriculture in respect to anthropogenic climate change, it is important to consider the type of vegetation which influences the microclimate and macroclimate either directly or indirectly. These changes can alter the global climate if the energy budget at the earth's surface is significantly changed. Agriculture globally accounts for 13% of the radioactive forcing related to GHGs. Agricultural sources such as animal husbandry, manure management and agricultural soils account for about 52% of global methane (CH_4) and 84% of global nitrous oxide (N_2O) emissions (Smith et al., 2008). Past deforestation and intensive agriculture practices have greatly contributed to the increase in atmospheric carbon dioxide (CO_2). For example, until the 1970s, more CO_2 had been released into the atmosphere from agricultural activities than from fossil fuel burning (Lal et al., 1998).

Climate change is influenced by agricultural activities through land use change, which can modify the albedo of the earth's surface. In agricultural context the albedo (α) depends on factors amongst which are: crop type, crop phenology, management practices, surface condition, time of day and time of year. The result of these factors leads to an increased albedo, which means that, less solar energy is absorbed by the earth's surface. Global averaged albedo of the earth's surface is about 0.3 (Bender et al., 2006). The land covers with higher albedo (α = 0.35 to 0.90) lower the air temperature, and land covers with lower albedo (e.g. grasslands and forests, α = 0.05 - 0.20) tend to increase air temperature. From the global annual average incoming shortwave radiation of about 341 Wm−2 (Trenberth et al., 2009), a decrease of 0.005 in global albedo would modify the shortwave radiation forcing by about 1.7 Wm-2 thereby increasing the global air temperature by about 0.9°C (Cess, 1976). These changes in climate regimes will likely have consequences on the vegetation.

2.4 Consequences

Climate change effects are already being observed in a wide range of ecosystems and species in all regions of the world (Rosenzweig et al., 2007), in response to the 0.74°C rise in global mean temperature (GMT) that has been experienced since preindustrial times (Solomon et al; 2007). According to general circulation models, warming across Africa ranges from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario) (Hulme et al., 2001; IPCC, 2001). This warming is likely to alter patterns of global air circulation and hydrologic cycling that will change global and regional precipitation regimes (Houghton et al., 2001). It is suggested that shifts in precipitation regimes may have a greater impact on ecosystem (plants inclusive) than the singular or combined effects of rising Carbon dioxide (CO_2) and temperature, especially in arid and semi-arid environments (Smith et al., 2000).

However, at a local scale, the influence of human on the ecosystem is through the alteration of climate regime through land use and land cover change. In South Africa especially in Soutpansberg area the indigenous vegetation is being depleted (through agricultural practices, wood harvesting, and urban growth) causing interference with the rainfall dynamics of the area. This has set in motion environmental changes causing loss of vegetation cover, reduction of rainfall in some areas and other adverse environmental effects (Munyati & Kabanda, 2009; Kabanda & Munyati, 2010). Changes in the climate dynamics of the Soutpansberg might impact on the plant community of the area. This ties with one of the fundamental assumptions in plant ecology that, climate is a key factor determining different characteristics, distribution and composition of vegetation (Woodward, 1987; Stephenson, 1990). For example, temperature is known to strongly influence the distribution and abundance patterns of both plants and animals, due to the physiological constraints of each species (Parmesan & Yohe, 2003; Thomas et al., 2004).

In the Soutpansberg, vegetation distribution varies across the range as per the climatic condition existing giving rise to the following vegetation types: Soutpansberg Moist Mountain Thickets, Soutpansberg Leached Sandveld, Soutpansberg Cool Mist belt, Soutpansberg Forest, Soutpansberg Arid Northern Bushveld and the Soutpansberg Cool Mist belt. Despite the fast-growing human population in Africa, the associated impacts on natural resources and vegetation, it is one of the least studied continents in terms of ecosystem dynamics and climate variability (Hély et al., 2006) and least of all the effects of anthropogenic climate change (climate change brought about by vegetation depletion) and the Soutpansberg region is no exception to this. Understanding how species respond to on-going climate change is increasingly of importance as the rate of anthropogenic climate change increases (Walther, 2003; IPCC, 2007; Walther, 2010). Plant responses to climatic changes are therefore of enormous importance, since they determine to a large extent primary productivity, ecosystem structure, soil composition and potential carbon sequestration.

Understanding species response to the ongoing climate change is increasingly being important as the rate of anthropogenic climate change increases (Walther 2003, IPCC 2007, Walther, 2010). Studies (such as that of Halpin, 1997; Malcolm & Markham, 2000; Peters & Lovejoy, 1992; Rizzo & Wikken, 1992) have put up supporting evidence that climate change will have mostly negative impact on the biodiversity more especially those within protected areas. An understanding of how plant communities have responded, are responding, and likely to respond to climate change is reported in Holt (1990) and Davies et al. (2005). They are of the opinion that species when faced with the on-going climate change pressure will react in three ways. Firstly they can evade through dispersion to suitable habitats (shifting in abundance and distribution).secondly they can stay put and adjust to the changed condition by means of evolution or lastly become extinct.

These coping mechanisms are likely to vary depending on the time scale, organism's life history, rate and extent of environmental change, availability of alternate habitats and species of environmental dispersal (Holt, 1990; Meyers & Bull, 2002; Sultan & Spencer, 2002; Davis et al., 2005; Kokko & Lopez-Sepulcre, 2006). Nevertheless a combination of these responses is also possible or likely (David & Shaw, 2001) and very essential for those species that are already under stress (Halpin, 1997; Leemans & Eickhout, 2004; Scott et al., 2002).

2.4.1 Species Range (Movement/Shift)

Range shift is defined as changes in the geographic distribution of species (Parmesan & Mathews, 2005). Recent studies have observed that in response to the changing climate, many species have adjusted their inhabited geographical range accordingly, thereby keeping pace with this change (Parmesan & Yohe, 2003; Walther et al., 2005; Parmesan, 2006). Mountains with their distinctive biota are also unfairly exposed to climate change (Beniston et al., 1996; Theurillat & Guisan, 2001; Nogue´s-Bravo et al., 2007). They experience an upward shift in distribution as recorded across a number of mountain ranges: Alps (e.g. Walther et al., 2005; Pauli et al., 2007; Parolo &Rossi, 2008; Vittoz et al., 2008), the Norwegian Scandes (Klanderud & Birks, 2003) Iberian mountain ranges (Pen˜uelas & Boada, 2003; Sanz-Elorza et al., 2003) and the Soutpansberg might not be an exception to this shift. This is of concern as mountain ecosystems represent invaluable resources, both in terms of biodiversity and the ecosystem services they provide (Körner, 2003; Viviroli & Weingartner, 2004).

Bachelet et al. (2001), in a study used Dynamic Global Vegetation Model to show that shifts in vegetation distribution would be a slow expansion process. The processes follow a potentially very rapid decline as a result of changes in climate and episodic disturbances. Some past studies (Easterling, et al., 2000; Inouye, 2000; Kirilenko, et al., 2000) concur with this observation. Each of these studies used empirical evidence to show that changes in yearly climate means did not influence vegetation distributions the most but the climate extremes associated with these changes. It is thus worthwhile to note that with respect to potential future vegetation range shifts, the adaptive response ability of most plant communities in the time frame in which anthropogenic climate change is expected to occur will be limited (Huntley, 2005; Thomas, 2005) .

A species ecological niche remains fairly stable over the course of time (Grinnell, 1917). But thanks to climate change the response of most plants to changing environmental conditions is to alter their range rather than change their ecological niche (Parmesan, 2005). Hence species are more likely to shift their range in order to remain within a suitable climatic condition (Parmesan, 2005).

Rutherford et al. (1999) predicted an almost entire loss of the current distribution of the succulent Karoo biome. Savannah, grasslands, and Nama Karoo are all reduced in total extent, with both the savannah and Nama Karoo invading into some of the previous grassland areas. The fynbos is the only biome to show limited changes in total extent, but there is evidence that many individual species may be impacted. In the forest biome the most likely impacts are in its distribution in the north-eastern part of the country. There might also be an increase in the current desert biodiversity as a result of the increased risk of desertification. Another example of range shift is that of the tree Aleo, Aloe dichotoma, which shifted across its distributional range in Western South Africa and in Namibia (Foden et al., 2007). Several dominant savannah plant species are predicted to undergo dramatic range shifts which will consequently change the plant species composition of an area thereby impacting the assemblages utilising them (Rutherford et al., 1999). An example of such plant species predicted to shift was *Colosphospermum* mopane.

Even though research shows that plant communities are likely to change in distribution in response to changing climates, it should not be viewed as projecting the movement of the entire ecosystem. Ecosystems will not move with each constituent species progressing northward in unison with its contemporary neighbours (Lovejoy & Hannah, 2005). Instead, the responses will be different between individual species as well as individuals within that species (Graham & Grimm, 1990; Overpeck et al., 1992). Species diversity in various regions will change due to the number of species shifting, invading or receding (Tamis et al., 2001; EEA, 2004).

Given the probability that species ranges will not shift in organised and intact units, species units are likely to become more fragmented as they shift in response to changing climate (Channel & Lomolino, 2000a; Root & Schneider, 2002). In fact, up to 66% of species may be lost due to predicted range shifts caused by climate change in South Africa's Kruger National Park (Erasmus et al., 2002). Models suggest a potential 40% reduction in endemic plant species richness even under moderate climate change scenarios (DEA, 2010) in South Africa. These declines in species composition will likely lead to the extinction of specialist species from such compromised biomes (Huntley, 2005). For example, following the biome sensitivity assessments in Africa, deciduous and semi-deciduous closed canopy forests were shown to be very sensitive to small decreases in the amount of precipitation. Thereby illustrating that deciduous forest may be more sensitive than grasslands or savannahs to reduced precipitation (Hély et al., 2006). On the other hand shrub and grassland vegetation types have root systems that are shallow and dense enabling them to draw their moisture from water that is available in upper soil layers. Growth of these species therefore depends highly upon the timing, intensity and duration of rainfall. Climate projections suggest that during already dry months; less precipitation will most likely occur, reducing the resilience of these plants (Vanacker et al., 2005). The availability of rainfall to plant will determine the plant species in the area as well as the abundance and type of specie in an environment.

The degree to which plants will need to respond to present and future anthropogenic climate change or what climate changes are to be expected are uncertain (Huntley, 2005) hence making it possible that rates could be above or below the 100-200m per year predicted. It is thus possible that many species will not be able to keep pace with changes, and in cases where entire biomes are vulnerable, a decline in biodiversity is fairly certain (Kirilenko et al., 2000; Malcolm et al., 2005).Where it is impossible to shift their ranges, species will have to adapt to the climatic condition prevailing at that time.

2.4.2 Species Adaptation

Vegetation adaptation to changes in the environment is an important aspect of biotic response to climate change. In the light of changing climate, species need to adapt to the prevailing climatic conditions. In essence they need to shift their distribution of phenotypes in a manner where the average fitness for the shifted phenotypic distribution becomes higher than that of the original distribution when compared within the current environment. Adaptation can work through a change in the genetic composition of the population. An example is through microevolution (where some genotypes increase while lower fitness genotypes decline) or, through different forms of phenotypic plasticity (when the same genotype gives rise to different phenotypes in different environments) (Pigliucci, 2001). The maintenance of genetic diversity within a species is crucial to its ability to adapt both in the short-term and long term survival (Frankham, et al., 2009; Jump, et al., 2009). A range shift may alter the genetic diversity within species (Phillips et al., 2010), while the range reduction is more likely to cause loss of genetic diversity (Aguilar et al., 2008) and may therefore limit severely the species' ability to adapt to a changing climate.

The basis of expressions of all biological diversity is the genotypic variation found in all populations. The populations comprising each level of ecological organisation are subject to natural selection and contribute to the adaptive capacity or resilience of species (Muller-Starck et al., 2005). Genetic diversity within species is important because, it is the basis for the natural selection of genotypes within species as they respond or adapt to environmental changes. Natural adaptation of plants to changing conditions will range from pre-existing resiliency, to phenological change within individuals, to true adaptation resulting from the recombination of genes (Root & Hughes, 2005; Thomas, 2005). Species may also adapt through phenotypic plasticity, if their genotype enables a range of responses that are suited to the new conditions (Nussey et al., 2005).

Concerns have been raised that predicted climate changes may occur too quickly for species to adapt (Davis & Shaw, 2001; Huntley 1991; Jump & Penuelas 2005). As duly noted, the primary reaction of plants to climate change will instead be niche tracking/ changing location to stay within the same set of prevailing conditions (Holt & Gaines, 1992; Holt & Gomulkiewicz, 1997; Peterson, 2003). Evidence from paleological studies have shown instances in which niche tracking took place due to insufficient time for adaptive or genetic responses to take place (Rousseau, 1997). To iterate, he argues that in the past, genetic response to rapid changes has been limited to microevolution. This is the process in which recombination of the species' genetic material takes place, limiting the adaptive response to environmental conditions in which the species' genetic diversity already enables it to adapt (Rousseau, 1997). But according to Geber and Dawson

(1993), some genetically diverse species are capable of rapid evolution. High genetic diversity increases the induced capacity of plants to respond to climate change.

Resiliency, plasticity and phenological change hinder the necessity, and the likelihood, of genetic adaptation. Plants demonstrating high levels of plastic response to environmental changes put themselves closer to the ideal in terms of natural selection, and thus pass along their genetic traits without changing any genetic adaptation (Price et al., 2003). Hence there is the elimination of the need for genetic change for survival and thus can persist in new environments. For example seasonal botanic phenomena like flowering, leaf development and leaf drop all depend on accumulated temperature-days and thus are able to respond to rapid climate change by advancing or postponing these events (Penuelas & Filella, 2001). With increases in temperatures, flowering and leaf development in plants will occur earlier in the spring, likewise leaf drop will take place later in the autumn, so as to take the greatest advantage of changing conditions (Root & Hughes, 2005).Hence in adaptating to anthropogenic climate change, genetic diversity induces changes in the phenological timings of organisms (Geber & Dawson, 1993).

Despite the fact that genetic adaptation is probably not the main response of plant species to climate change, this does not mean climate change will not have genetic repercussions on plant communities. An overall loss of genetic variation between and within species is expected (Descimon et al., 2001). Hewitt (1999) argues that, most species within their current range have a zone where their glacial and interglacial distributions overlap. This zone is located at the lower latitude extents of their current range. As temperatures rise, areas which have the greatest genetic diversity would be lost as the zone of overlap recedes. Expansion into the higher latitudes would include only those subspecies predisposed to dispersion (Thomas, 2005). Populations which remain stationary in the face of changing abiotic factors (altered temperature, precipitation, and disturbance cycles) as well as biotic factors, (community compositions and competition) will probably result in an evolutionary response (Thomas, 2005).

Although most research on plant responses to climate change focused on plant species range shifts (Baker et al., 2000; McLachlan et al., 2005), given the slow rate of plant migration from one region to another, plus land use patterns which fragment plant populations, adaptation may become the most important factor in plant responses to climate change (Davis & Shaw, 2001; Davis et al, 2003). However some research in plant adaptation to climate change suggests that plant populations will not have sufficient time to adapt to altered climates (Etterson &, Shaw , 2001), hence populations of plant species will be subjected to rapid changes in their genetic structure, most especially plant species with long generation times (Jump & Penuelas , 2005). Even if there is genetic variation in a population for traits that could support adaptation to a location with altered climate, correlations between traits that do not support selection for the new climate may limit adaptive evolution (Etterson &, Shaw, 2001). Also, different populations of the same species may differ in both their genetic structure and the extent to which climate change will push the species to its physiological limits (Etterson, 2004).

Quaternary paleoecologists have regarded evolution as a slow process relative to climate change. They predict that the primary biotic response to a changing climate is not adaptation, but instead a persistence in situ. Therefore if changing climate remains within the species' tolerance limits, species will respond by a range shifts or extinction. Davis et al (2005) argues that all of these three methods of responses involve evolutionary processes. Genetic differentiation within species is ubiquitous, usually through adaptation of populations to differing environmental conditions. Noticeable adaptive divergence evolves on a time scale when compared to change in climate (within decades for herbaceous plant species, centuries or millennia for longer-lived tree). This implies that the biologically significant evolutionary response can accompany temporal change in climate. In instances where species are unable to shift their range or adapt to climate change, then it is forced to extinction.

2.4.3 Species Extinction

Recent studies predict that climate change could result in the extinction of up to half of the world's plant species by the end of the century (Bramwell, 2007). Climate change is increasingly being viewed as a significant threat to African biodiversity, particularly for endemic species (Hannah et al., 2005; Malcom et al., 2006). King identified climate change as a greater risk to society than terrorism (King, 2004). Factors that will accelerate the rate of a species' risk of extinction (global loss of all individuals) or extirpation (loss of a population in a given location) include, a decrease in the size of its range, the density of individuals within the range, and the abundance of its preferred habitat within its range (Wilson et al., 2004).

A reduction in the range of a species is likely to have an increased risk in local extinction (Erasmus et al., 2002). This may be the result of the positive inter-specific relationship between population size and range size (if range size decreases, there is the likelihood that there will be a rapid decline in population size). This relationship could also be exacerbated if climate change restricts the range of species to just few key sites, thereby increasing the risk of extinction (Erasmus et al., 2002). Species found in managed areas will likely face the challenge of shifting to more agreeable climatic envelope, thereby increasing their risk of extinction or change in plant composition and density. These changes in plant species geographic distributions do not result simply from the simultaneous migration of populations throughout the range. They are however, generated by the widespread establishment of new populations at the leading edge of a species distribution, and extinction of populations at the retreating edge (Hampe & Petit 2005, Thuiller et al. 2008). Hence, even those species whose distribution range does not shrink in response to climate change suffer increased rates of population turnover and extinction. If there is a shuffle in species distribution across the globe in response to climate change, there is a risk of tearing apart contemporary natural communities, and most importantly, the beneficially coevolved relationships between species (Root & Schneider, 1993).

It is theorized that such extinctions were from the inability of some species to respond to the rate of change. A relationship formula derived from the observation of such extinction events is as such; where the rate of dispersion required is greater than the achieved rate, then biodiversity will be lost due to population constrictions, extirpation and possibly the extinction of slow responding species (Huntley, 2005; Martin, 1996; Webb, 1997).

New evidence suggests that climate-driven extinctions and range retractions are already widespread. This has been poorly reported due, at least partly, to a failure to survey the distributions of species at a sufficiently fine resolution, to detect declines and to attribute such declines to climate change (Thomas et al., 2006).

2.5 Changes versus Variability

Distribution patterns of natural vegetation are governed above all by climate. This control is expressed in part through the tolerance limits of different plant functional types (PFTs) to climatic extremes at various stages during the growth cycle, e.g. cold tolerance, heat stress, growing-season drought (Woodward, 1987). The recurrent frequency of extreme climate conditions is thus an important control on plant growth, and the long term state of the vegetation must inevitably be determined to some degree by the inter annual variability as well as by the mean climate. It also seems likely that differences in the pattern of variability – especially the tendency for extreme conditions to be repeated in consecutive years could affect vegetation composition.

The basic phenomena associated with precipitation events - interception, infiltration, and runoff rates are driven chiefly by evaporation from soils, transpiration by plants, horizontal and vertical soil water transport, and hydraulic redistribution of soil water. All of these depend in complex ways on vegetation and soil characteristics and on the timing and size of precipitation inputs. There is a good correlation between event size and infiltration depth in ecosystems. Water from larger rainfall events infiltrates more deeply (Sala et al., 1981), but infiltration, storage, and use depend on the season and on patterns of organism activity. In summer, evaporation and transpiration remove nearly all water from shallow soil layers within days of rainfall, so that in the absence of rapid drainage, water does not infiltrate deeply into the soil profile. In winter, evaporation and transpiration are limited, so water can accumulate and infiltrate deeper into the soil profile. This spatial and temporal partitioning of water has been shown to have ecological and evolutionary implications for plant water use strategies.

Early signs of anthropogenic climate change are emerging in Southern Africa (Pollack et al., 1998, Hulme et al., 2001; Schulze, 2005), characterised by climate variability on a range of temporal scales (Tyson & Preston White, 2000). Central and eastern regions are expected to experience increased summer rainfall, with little change projected in the South Western Cape. Up to 10% reductions in runoff and/or stream flow are also expected over the western parts of the country by 2015, with such decline moving gradually from west to east (DWAF, 2004). Projected increase in evaporation due to higher temperatures is expected to increase by 10 - 20% with consequences such as increased evaporation losses from dams and increased irrigation demands for drier soils (Hewitson & Crane, 2006). Hence such increases in temperatures would imply an increase in water requirements for plants, placing higher demands on irrigation (DWAF, 2004). In addition to such decreases in water availability, a decrease in water quality is also expected (DWAF, 2004). Certain parts of the country are expected to have an increase in rainfall in the future while others will experience a decline resulting in lower or higher stress on water resources respectively (Mukheibir & Sparks, 2003).

Africa's rainfall variability is governed by factors such as ENSO, sea surface temperatures and land atmosphere feedbacks. The sea surface temperature is considered to be the primary influence over African rainfall (Nicholson, 2000). The ENSO cycles play a vital role in inter-annual rainfall variability (Ngongondo, 2006). During pacific warm episodes, the rainfall is usually below the normal, while during La Niña or Pacific cold episodes it is above normal (Ngongondo, 2006). During La Niña, rainfall over Africa is usually abnormally high and particularly influences the rainfall over the western parts of South Africa (Nicholson & Selato, 2000). Klopper et al. (1998) found an association between ENSO and seasonal mean maximum temperature over the eastern half of South Africa. Such rainfall changes were also observed in other parts of the world (Ngongondo, 2006) such as in Ireland where substantial rainfall reductions have been recorded from 1975 - 2006 (Dunne et al., 2008). A study using the Mann-Whitney Pettit and Mann-Whitney-Wilcoxon statistics in a river catchment (Malawi), on rainfall variability and trends found that the precipitation pattern followed the ENSO and La Nina episodes (Ngongondo, 2006).

A quasi 18 year oscillation of inter-annual rainfall for 60 and 80 year data using spectral analysis sets, found out that for the subcontinent including South Africa, the majority of 18 year spectral peaks were being statistically significant at the 95% level (Dube, 1999). Another study examining climate variability over southern Africa using wavelet analysis for a 3500 year period revealed a 1500 year oscillation in rainfall variability. Significant increases in extreme rainfall events between 1931, 1960, 1961 and 1990 were found for over 70% of South Africa (Mason et al., 1999). Differences in rainfall patterns were noted in different regions of Africa as well as a change in the seasonality of rainfall from year to year. Southern Africa rainfall trends ranged from dry conditions in the 1910s, 1940s and the 1980s to wetter conditions in the 1950s (Nicholson, 2000). Investigations in the Drakensburg of KwaZulu-Natal on annual and seasonal rainfall trends between 1955 and 2000 found the correlation to be strong between summer rainfall and ENSO events (Nel, 2008).

Kruger (2006) carried out a study for 138 stations in South Africa between 1910 and 2004. He concluded that no change in precipitation occurred over the majority of South Africa but in some areas (i.e., northern Limpopo, north eastern Free State, western KwaZulu-Natal and the south-eastern regions of the Eastern Cape) there was a significant decrease in annual precipitation. On the other hand other areas like the northern Northwest Province and an area over the Northern Cape Province, Western Cape Province and Eastern Cape Province saw significant increases in precipitation during the wet season. New et al., (2006) expanded the study by Kruger (2006) using a longer data set and a larger number of rainfall stations thereby enabling identifications of significant precipitation trends on a regional scale.

Examining temperature and precipitation trends over the period 1956 - 2000 for centres in southern Africa, a small number of statistically significant trends were found for rainfall (New et al., 2006). However, no trends were identified in the mean annual rainfalls over southern Africa between 1900 and 1970 (Nicholson, 1986, 1989), 1931 and 1960 and between 1961 and 1990 (Hulme, 1992). Likewise using 30 southern African station records dating back to the 1880s, similar conclusions were drawn (Tyson, 1986).

Long term meteorological observations and reconstructions of historical climates (e.g. Nicholson, 2000; Hulme et al., 2001; Los et al., 2001), shows that changes in short-term climate variability have occurred over the last few centuries. Although under current climate conditions there is a strong relationship between changes in interannual variability and changes in mean climate conditions (Corti et al., 1999; Monahan et al., 2000; Oba et al., 2001). It is therefore possible that the impacts of climate change on ecosystems could derive as much from changes in variability as from changes in the mean climate (Kutzbach et al., 2001), especially in regions with highly variable climates.

Rainfall across Southern Africa has shown substantial spatial variation in annual precipitation and its variability as well as a quasi-periodic cycle of about 18 years (Tyson

& Preston-Whyte, 2000). It is therefore not surprising that temporal variation in rainfall contributes significantly and often substantially to the population dynamics of a variety of South Africa's species (Radford & du Plessis 2003; Craig et al 2004;Altwegg & Anderson 2009). These changes in regional precipitation regimes are expected to have serious consequences on the distribution, structure, composition, and diversity of plant, animal, microbial populations and communities with their attendant ecosystems (Easterling et al., 2000, Houghton et al., 2001, Weltzin & McPherson, 2003). Consequently changes in the variability of precipitation are likely to affect with ramifications the performance of species and their interactions with other organisms (Houghton et al., 2001).

2.6 The Need for Concern

Society has long been concerned with the major impacts of human activities on natural systems globally as well as locally. Work on species level responses to change factors (e.g. anthropogenic climate change) is lacking in Africa, in spite of its high concentration of endemic species. The few studies that have been carried out focused on plant species and generally confirm findings from other continents. A substantial body of literature shows that the climate is changing at an unprecedented and unnatural rate, and that this is affecting more than simply the surface temperature of the earth. For example eleven of the twelve warmest years on earth between 1850 and 2006 occurred between 1995 and 2006 (IPCC, 2007a). This resulted in an estimated nine fold global increase in economic losses from natural disasters between the 1960s and the 1990s (IPCC, 2007a) .Even though climate change is a global issue, local and regional scale provides a most readily observable arena (Smith & Smith, 2009) for its impact. It is now increasingly appreciated that anthropogenic climate changes are likely to progressively cause impacts on Africa and its biodiversity and these will generally be negative from both ecological and economic perspectives (IPCC, 2007). Though impacts vary in scale and magnitude across global to regional, there are some fundamental impacts that are expected to be experienced in response to anthropogenic climate change, which will definitely affect the local scale. Anthropogenic climate change is exacerbated by alien species of plants which take advantage of the situation.

2. 6.1 Plant Invasion

South Africa has a long history of problems with invasive alien species and has one of the biggest problems than any other country in the world (Van Wilgen et al., 2002). Anthropogenic Climate change could change the relative distribution and importance of invasive alien species in a number of ways. Firstly, changes in climate could result in areas becoming more (or less) suitable for alien species. Thus, species that are currently a problem could expand (or shrink) their distribution ranges as climate changes, with corresponding changes in impacts.

Secondly, alien species that are currently present in the area, but not invasive, could become invasive under altered climatic conditions (Richardson et al, 2000). Climate change is also accompanied by other elements of change, especially changes in the levels of carbon dioxide (CO_2) in the atmosphere, and significantly increased levels of nitrogen deposition. These elements can increase the relative competitive ability of alien species to grow relative to native species. In addition, new alien species are arriving all the time, and some of these may also become invasive. It has been estimated that alien vegetation occupies more than 10 million hectares (i.e. 8%) of the total land surface of South Africa (Ashpole, 2001). These vegetations may cause environmental and ecological threats to natural vegetation, which may eventually have an impact on the economy. For example, alien vegetation is known to use more water than natural vegetation; hence there may be a reduction in water supplies especially in mountain water catchment areas. As a competitor with natural vegetation, they suppress and change the natural landscape resulting in a decrease of natural vegetation of the area. Alien vegetation has a higher biomass (fire load) which increases the intensity and frequency of fire occurrences (Ashpole, 2001). It also causes physical and chemical damages to various plant life forms; and may enhance vegetation diseases together with the action of climate change.

2. 6.2 Risk of diseases

Climatic conditions such as temperature and moisture are most favourable for growth, survival and dissemination of pest and disease outbreak. Changes in such climatic conditions can cause an expansion in the normal range of pest or disease into a new environment, thereby affecting natural plant communities (Rosenzweig et al., 2001). In the case of pole ward distribution of plant species, the prospect is poor for those plants that already inhabit high altitudes or mountains such as the Soutpansberg. Given the new associations of species that could occur as climate changes, many species will face 'exotic' competitors for the first time. Climate change will restructure communities as present geographic ranges of species shift pole ward.

Temperature is one of the dominant factors affecting the growth rate and development of insect pests (Patterson et al., 1999). Many pathogens of terrestrial taxa are sensitive to temperature, rainfall and humidity, creating synergisms that could affect biodiversity. Anthropogenic climate warming can increase pathogen development and survival rates, disease transmission and host susceptibility. Some pests and pathogens are likely to increase their range as a result of the projected changes in climate and, in the case of insects, increase their population densities. This could place at risk the health of ecosystems and thus plays an important role in determining future vegetation (Winget, 1988). The most severe and least predictable disease outbreaks might occur if the anthropogenic climate change alters host or pathogen geographic ranges, causing formerly disjoint species and populations to converge (Davis, 2001).

The rich biodiversity of African biomes is impacted by climate change (Erasmus et al., 2002). Scientists anticipate the effects of climate change based on available data sets on species distributions, vegetation types and ecosystems in South Africa to be significant. Studies carried out (e.g. Peters & Lovejoy, 1992; Rizzo & Wikken, 1992; Halpin, 1997; Malcolm & Markham, 2000) have confirmed that climate change will have mostly negative impact on biodiversity. These effects will be felt most by those within protected areas. There is likely to be an overall shrinkage and shifting of optimal areas for major biomes, a range shifts for many species, especially endemics, as well as an increase in extinctions. In developing reasonable estimation of how plants will respond to anthropogenic climate change, researchers intend to aid in developing strategies to curb the negative impacts of climate change on plants.

2.7 Climate Change Mitigation and Adaptation Approaches

Climate change adaptation is a way of responding to the impacts of climate change by moderating the impacts as well as taking advantage of new opportunities or to cope with the consequences of new conditions. The IPCC defines adaptation as the "adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007). The ability to adapt is reliant on a region's socioeconomic and environmental situation, as well as the availability of information and technology. Mitigation is the measures taken to reduce the depletion of the vegetation cover such as afforestation measures. Vulnerability refers to the "degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Hence vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2007).

Climate change adaptation is increasingly seen as an issue of both human welfare and of security (Müller, 2002)). It has been addressed as such by the UN Security Council, forecasting conflicts over scarce food, water and land as well as unprecedented rates of human migration (Purvis & Busby, 2004). Vulnerability to the impacts of climate change is a function of exposure to climate variables, sensitivity to those variables, and the adaptive capacity of the affected community. In order to conserve ecosystem patterns and processes, even if done for the preservation of humankind, we need to understand the patterns and processes driving vegetation structure and function. By understanding, planning for and adapting to a changing climate, individuals and societies can take advantage of opportunities and reduce risks. Adapting to climate change involves reducing exposure and sensitivity and increasing adaptive capacity. As per the IPCC there are two types of adaptation:

- Anticipatory Adaptation which is an adaptation which takes place before the impacts of climate change are observed also known as proactive adaptation.

- Reactive Adaptation which is adaptation that takes place after impacts of climate change has been observed. For the purpose of this research, recommendation for adaptation will be reactive.

A multi-sectoral approach can be an effective adaptation strategy. This would involve simultaneously addressing a range of objectives, which include climate change adaptation, mitigation of vegetation depletion, biodiversity conservation and sustainable livelihoods. Recently there has been a paradigm shift in conservation towards a more holistic approach to ecosystem conservation (Fairbanks & Grant, 2000). This need for a holistic long term approach to conservation has sparked a renewed international interest in vegetation science particularly phytosociology. The establishment of conservation areas will greatly help to reduce anthropogenic threats to ecosystem form and functions (Margules & Pressey, 2000; Fairbanks et al., 1999). The Soutpansberg conservancy and the Blouberg Nature reserve are examples of such conservation areas. Given the importance of the Soutpansberg range (Van Wyk & Smith, 2001; Hahn, 2002; Berger et al., 2003; Hahn, 2006) there is a need for the conservation of this area.

2.8 Global and Regional Perspectives on Climate Change (Human Face)

There has been concerted international and national efforts to put in place regimes in order to "save the planet" from climate change effects. Such regimes include amongst others the Kyoto Protocol, the UNFCCC, the IPCC and Kyoto's flexible mechanisms are key components of the current climate change regime. Nongovernmental organisations such as the Prototype Carbon Fund, the Global Emissions Fund, and the Climate Action Network are also in the forefront in combating climate change.

South Africa has mapped out a detailed scenario building process on how it can meet its UNFCCC Article 2 commitment to greenhouse gas stabilisation while ensuring its focus on poverty alleviation and job creation. The National Climate Change Response Green Paper 2010 is part of a policy process that builds on the 2004 National Climate Change Strategy. The Green Paper provides an overview of government's proposed policy position on a particular issue served as the basis for a process of consultation that may eventually lead to issuing legislation (Presidency 2009), and precedes the publication of a White Paper.

The White Paper sets out South Africa's climate change response strategy to achieve the National Climate Change Response Objective consistent with those outlined principles and approaches. These are structured around risk reduction and management; mitigation actions with significant outcomes; sectoral responses; policy and regulatory alignment; informed decision making and planning; integrated planning; technology research, development and innovation; facilitated behaviour change; behaviour change through choice; and resource mobilization (White paper, 2011).The Department of Environmental Affairs has developed the Climate Change Adaptation Strategy and the Long Term Adaptation Scenarios with key strategic sectors such as biodiversity,water,agriculture amongst others. These products form part of the National Climate Change Response Policy.

Policy-related quantification of human influences on climate has focused largely on changes in atmospheric composition. One of the reasons for this may be the difficulty in objectively comparing the effects of different local land surface changes with each other and with the effects of changing atmospheric composition. Tropical deforestation was excluded from the Kyoto Protocol due to controversies surrounding sovereignty, scientific uncertainty and implications in efforts to reduce fossil fuel emissions. However, the neglect of land use effects will lead to inaccurate quantification of contributions to climate change, with the danger that some actions may give unintended and counterproductive results. Through initiatives in developing countries discussions on reducing emissions from deforestation in developing countries are presently underway within the UNFCCC.

Deforestation (conversion of forests for agriculture activities) was estimated at the rate of 13 million hectares per year in the period 1990-2005 (UNFCCC, 2011). Deforestation results in the instant release of carbon stored in trees as CO_2 emissions. Estimation of CO_2 emission from deforestation stands at approximately 5.8 GtCO2/yr to global greenhouse gas emissions in the 1990s. A major decision to stimulate action on reducing emissions from deforestation and forest degradation in developing countries was adopted by the Conference of the Parties (COP) in Bali (2008). COP, at its fifteenth session (Copenhagen, 2009), adopted a decision regarding guidance for activities relating to reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries.

COP 13 also saw the adoption of the Bali Action Plan. This decision launched a comprehensive process to enable the full, effective and sustained implementation of the Convention through long term cooperative action up to and beyond 2012. One of the areas being addressed by the process is policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation. In addition to the UNFCCC, the other two Rio Conventions, the Convention on Biological Diversity and United Nations Convention to Combat Desertification also acknowledge the importance of protecting forests and their sustainable use of biodiversity conservation and combating desertification and land degradation. In addition, the United Nations Forum on Forests (UNFF) is starting to implement a new non-legally binding instrument to stop illegal logging and promote sustainable forest management. Cooperation among these international bodies will enhance synergies in promoting sustainable forest management in developing countries.

2.9 Approaches for Assessing Vegetation Change as an Indicator of the Changing Climate.

2.9.1 Field sampling by the relevé method

Most ecological studies involve field sampling or phytosociology which involves the use of methods for recognising and defining plant communities (Kent & Coker, 2002). The relevé method developed by Braun-Blanquet in 1928 hold that species act as indicators of the habitat typical of the community and that patterns in the floristic composition correspond to patterns in the environment (Werger, 1974; Kent & Coker, 2002). This approach is by recording field observation by relevé. A relevé being the list of species observed in a plot together with an estimate of their abundance/dominance and sociability. Every class is fixed to the percentage of cover estimation regardless of the number of individual plants. Sociability or gregariousness is an expression of a horizontal pattern of species. It measures the value of clustering or contagion of the species. In South Africa, numerous vegetation studies based on the Zurich-Montpellier School have been conducted. Examples of such studies include amongst others those carried out:

In the Fynbos Biome: van Wilgen and Kruger (1985), McDonald (1993b), McDonald, Cowling and Boucher (1996) and Cleaver, Brown and Bredenkamp (2004).

In the Savannah Biome: Bredenkamp (1986), Bredenkamp, Deutschlander and Theron (1993), Breebart and Deutschlander (1997), Siebert, Matthee and van Wyk (2003), Pienaar (2006).

In the Forest Biome: Du Preez and Venter (1990a), McDonald (1993a), Matthews, van Wyk and van Rooyen (1999), Matthews, van Wyk, van Rooyen and Botha (2001), Grobler, Bredenkamp and Brown (2002) and, Cleaver, Brown and Bredenkamp (2004), as well as van Staden and Bredenkamp (2006).

In the Grassland Biome: Behr and Bredenkamp (1988), Eckard (1993a), Coetzee, Bredenkamp and van Rooyen (1995), Dingaan (1999), Muller (2002), Siebert, van Wyk, Bredenkamp and du Plessis (2002), Botha (2003).

2.9.2 Satellite Derived and Geoinformatics Methods

Remote sensing provides the capabilities of monitoring vegetation at local to regional scales. Satellites provide data at various spatial (i.e. Fineness of the spatial detail visible in an image) and temporal (time interval between images) scales. Timely and accurate change detection of earth's surface features is extremely important for understanding relationships and interactions between human and natural phenomena in order to promote better decision making (Lu et al. 2004). Detecting and delineating changes in images of the same scene taken at different times, have had interested researchers for many years, owing to a large number of applications in diverse disciplines (Radke et al., 2003). Because of the advantage of repetitive data acquisition, its synoptic view, and digital format suitable for computer processing, remotely sensed data have become the major source of information for different change detection applications during the past decades (Lu et al., 2004). Some aspects that could be monitored using remote sensing technologies for change detection are, for example, land use and land cover, forest or vegetation change, deforestation, wetland, landscape or vegetation change, and crop monitoring.

Despite the numerous benefits of the potential of satellite remote sensing in vegetation, there are some limitations involved. A primary limitation of satellite sensor is that they provide a measure of the amount and type or reflected and emitted electromagnetic energy. This information can be influenced by soil, moisture, substrate, plant structural configuration, topography, atmospheric effects, and the amount of vigour, productivity, structure and floristic composition of the vegetation (Richardson & Wiegand, 1977; Vogelmann & Moss, 1993). It is therefore of critical importance for the researcher to correct images for this nuisance variable to produce accurate and timely results from remotely sensed data.

2.10 Change Detection

Digital change detection is the computerized process of identifying changes in the state of an object, or other earth-surface features, between different dates. As attested by Shaoqing (2008), change detection can be classified into three categories: characteristic analysis of spectral type, vector analysis of spectral changes and time series analysis. The spectral type method is responsible for the distribution and characteristic of changes based on spectral classification and calculation of different phases of remote sensing images. Methods employed include multitemporal images stacking, algebraic change detection - algorithm of image and change detection of the main components of the image, and change detection after classification.

The vector analysis method of spectral changes takes care of the strength and direction characteristics of changes. This is based on radicalization of changes in images at different times, especially analysing the differences of each band. The method of time series analysis, analyses the process and trend of changes of monitoring ground objects based on remote sensing continual observation data. Time series methods include amongst others, image subtraction method, image ratio method and the method of change detection after classification. Currently, there are many change detection methods that have been implemented and their use depends on the application, which in this case is remote sensing. Some of those commonly used with multispectral imagery include image differencing, Change Vector Analysis (CVA), Post Classification Comparison, Multivariate Alteration Detection (MAD) (Toll et al., 1980; Jensen, 1981; Jensen & Toll, 1982; Fung & LeDrew, 1987; Lambin & Strahler, 1994; Sunar, 1998; Mas, 1999; Sohl, 1999).

Post Classification Techniques: Post classification technique deals with independent production and subsequent comparison of spectral classifications for the same area at two different time periods (Mas, 1999). This technique has the advantage of providing direct information on the nature of land cover changes. The classification process employed in the techniques can be either supervised or unsupervised. Since the technique's accuracy depends on the accuracies of the original classifications, the accuracy of the change map will only be as accurate as the classifications. Hence it is essential for the individual classification maps be as accurate as possible. Advantages of these techniques include: types of change classes that appear in the final change classification is controlled by the analyst, the techniques are capable of producing descriptive information on the types of changes that are occurring, and the techniques tend to be less dependent on the co-registration of images and do not require that images be normalized prior to implementing the technique. The major disadvantages of these techniques are: it is time consuming to accurately classify images; errors made in the classification are compounded in the detection of change.

A series of studies have produced good results with post classification techniques. These include that of Riordian (1980), who reported an accuracy of 67 percent for detecting non-urban to urban change using an unsupervised classification. Pilon et al. (1988) used post classification in combination with a simple enhancement technique to differentiate areas of human induced change from areas of natural change. Sohl (1999) reported accuracies of 96 percent for the identification of new forest land and 62 percent for new agricultural land using a post classification technique in a semi-arid environment. Sohl (1999) further compliments the strength of the method for providing users with a complete descriptive comparison between images. Mas (1999) also obtained the highest accuracy with this technique in a study comparing six different techniques.

In spite of a number of studies having positive results with this technique, Toll et al. (1980) reported that the post classification comparison approach produced rather poor results. This according to him was as a result of difficulty in producing comparable classifications for different images. Jensen (1981) asserts to this, saying the technique produced rather poor results unless extremely accurate classifications were made. Jensen in a discussion of change detection techniques for urban mapping attributes the difficulty in producing accurate classifications to the heterogeneity of suburban land use, resulting in many mixed pixels and hence lower accuracies in the individual classifications as well as the subsequent change detection products (Jensen, 1981).

Enhancement Change Detection Techniques: With enhancement techniques, a mathematical method is employed. The method combines images from different dates which, when displayed as a composite image, show changes in distinctive colours (Pilon et al., 1988). These techniques have the advantage of generally being more accurate in identifying areas of spectral change (Singh, 1989). These techniques however, often require additional analysis in order to characterise the nature of the spectral change, and also require more accurate image normalization and co-registration. These techniques are discussed in the subsequent paragraphs.

Multivariate Alteration Detection Transformation: Nielsen et al. (1998) introduced the Multivariate Alteration Detection Transformation, which is based on the canonical correlation analysis. This method mainly finds the difference between linear combinations of the spectral bands from two acquisitions. The produced differences are orthogonal and constructed so as to show maximum variance. The threshold for the generation of a change/no change map is done using the Bayesian approach.

Change Vector analysis (CVA): Borrego et al. (2001) presents the CVA detection method. The CVA generates two variables: the magnitude of variation and the angle of the change vector. The change vector is obtained by subtracting the images represented in vector form. The magnitude of variation between the two vectors is obtained by calculating the Euclidean distance between the differences in positions of the same pixel from different times. The angle of the vector (which indicates the type of change that has occurred) varies according to the number of components used. Each vector is a function of the positive or negative changes through the spectral bands.

A series of studies have used CVA with success. In their study Lambin and Strahler (1994) found that CVA was effective in detecting and categorizing interannual change. Sohl (1999) in a study comparing change detection techniques concluded that CVA produced the best result of all the techniques tested. This was due to its graphically rich content and its ability to detect urban and agricultural change with fairly good locational information. In their study to assess the ability of CVA to monitor land cover change and condition, Johnson and Kasischke (1998) found the CVA to be useful for studies in which changes of interest and their spectral manifestation are not well known. Also in studies where changes of interest are known or thought to have high spectral variability, or changes in both land cover type and condition are of interest.

Image ratio method: With this method, a pixel value of a time image divides the corresponding pixel of another time. The ratio of corresponding pixels in each band from two images of different periods is calculated after image registration. The Equation is given as:

$$Rxk\ ij = xk\ ij(t1)/xkij\ (t2) \qquad 2.1$$

If the corresponding pixels of each image have the same gray value, namely Rxk ij = 1, showing that no change occurred. In the changed region, the ratio will be much greater than 1 or far less than 1 according to the direction of change (Shaoqing, 2008). In most cases, xk ij (t2) may be equal to zero. To overcome this situation, a very small value would be added denominator a (e.g. 0.01) when the denominator is equal to zero on the computer. Because the real ratio is ranging from 1 / 255 to 255, the range of the ratio is usually normalized to 0~255 for display and processing. 1 of the ratio is usually assigned to 128 of brightness. 1 / 255 to 1 of the ratio would be transformed to 1 ~ 128 by the following linear transformation:

$$NRxk\ ij = Int[Rxk\ ij\ x\ 127 + 1] \qquad 2.2$$

1 / 255 to 1 of the ratio would be transformed to 128~ 255 by the following linear transformation:

$$NRxk\ ij = Int[\ 128\ x\ Rxk\ ij/2] \qquad 2.3$$

A threshold value is needed to select outlining significant change region in the ratio image. The ratio image will be converted to a simple change / no change image, or positive change / negative change image. This will reflect distribution and size of the changes. The threshold value choice must be based on the characteristics of the regional research targets and the surrounding environment. A threshold value will vary in different regions, different times and different images. The threshold value border of "change" and "no change" pixels is often chosen from the histogram of the ratio image. The image ratio method is useful for the extraction of vegetation and texture. The influences of the slope and aspect; sun angle, radiation changing caused by strong seasonal variations and multiplicative noise can be eliminated or reduced. It can also highlight different slope features between the bands. This method has a higher accuracy level and can be applied to estimate change detection in cities. A drawback of this method is that the type of feature changes cannot be analysed. The choice of the threshold value is also difficult to attain. Also different features of the same slope are easy to be confused and the ratio synthesized image is often compensated for in the analysis.

Imaging differencing method: The image differencing method of change detection used by Bruzzone et al. (2002) is an automatic approach to unsupervised classification of changes in multi-temporal remote sensing images. It involves the subtraction of the first date image from a second-date image, pixel by pixel (Mas, 1999). Here two bands are subtracted and a threshold is selected so as to generate a binary change or no change map. The bands are the same, differing only to different points in time. Threshold selection is based on the formulation of the unsupervised change detection problem in terms of the Bayesian Approach. The changed region and unchanged region is determined by selecting the appropriate threshold values given by the Equation:

$$Dxk\,ij = xk\,ij\,(t2) - xk\,ij\,(t1) + C \qquad 2.3$$

Where i, j as pixel coordinates, k for the band, xk ij (t1) for the pixel (I, j) value of k-band image, t1, t2 for the time of the first and the second image, C is constant.

For most change detection methods, the choice of the threshold value decides the capability of change detection. The choice of a suitable threshold value can maximize the separation of the areas of real change and the areas of the impact of random factors (Jensen, 1981). The selection of a high threshold value will cause a lot of missed inspecting, and the selection of a low threshold value will cause void inspecting. In the new gained image, positive or negative value of the image denotes the region whose radiation value is changed, and there is no change in the region when the image value is 0. With 8-bit image, the pixel value is ranges from 0 to 255, and its image subtraction value is ranges from -255 to 255. As the subtraction value is often negative, it can add a constant C. The brightness values of subtraction image are often approximated Gaussian distribution. The unchanged pixels are centralizing around average value and the changed pixels are in the distribution of the tail. Hence the statistical terms associated with the gray levels of changed and unchanged pixels in a difference image, are estimated and used to make the decision if change has or has not occurred. The advantages of image subtraction method are that, it reduces the probability of errors. It is accurate for picking-up information such as beach zone, estuaries and underwater channels ditch. It also has a good practical value so it is widely used in detecting coasting environmental changes, tropical forests changes, temperate forest changes, and desertification and crop analysis. The disadvantages of this change detection technique is that it cannot provide a detailed change matrix, thus a selection of a suitable threshold is required in order to produce a change/no change binary map (Bruzzone et al, 2002). It also does not reflect changes in categories. The value of the subtracted images does not always show the change of the objects because of a variety of factors. These include amongst others, atmospheric conditions, the sun illumination, sensor calibration, and ground water conditions. In its actual applications, the choice of threshold is quite difficult and therefore, it is not suitable for change detections of urban areas and natural images, because some information will be lost (Shaoqing, 2008). It is thus difficult to determine the nature of changes and further analysis is needed.

However, Ridd and Liu (1998) employed this method and were of the opinion that it was fairly effective in its ability to detect changes in an urban environment, with TM band 3 producing the highest accuracies. Also Sunar (1998) and Sohl (1999) reported the image differencing technique as being extremely straightforward. But with qualification the technique becomes slightly more complicated when using multiple bands than single bands, due to the difficulty of interpreting the colours of multiband false colour composites. According to Sohl (1999) the simplicity of the technique is its main weakness, because it lacks an explanation with regards to the nature of change. Jensen and Toll (1982) recommend improving by texture information in order to improve the accuracy of the image differencing technique. Besides this several studies have suggested that image differencing cannot adequately deal with the entire range of change that may occur in a single area (Jensen, 1981; Sohl, 1999).

2.11 Geographic Information System (GIS)

Integrated GIS and remote sensing have been successfully applied to map the distribution of several plant species, their ecosystems, landscape, bio-climatic conditions and factors facilitating invasions (Stow et al., 2000; Los et al., 2002). Examples of such works include that Hessburg et al. (2000) who uses aerial photos from 1932-1993 in the interior of northwest forest and found emergent non-native herb lands. Vrindts et al. (2002) distinguished seven weed species with more than 97% accuracy with a limited number of wave band ratios. Stow et al. (2000) have examined the possibility of using colour infrared (CIR) digital camera imagery to discriminate Acacia species from indigenous vegetation (fynbos) in the Cape lowlands.

2.12 Time Series Analysis

Different methods have been used to analyse data in the field of ecology and climatology. The method chosen depends on the purpose or aim of the study. Investigations using either space for time substitutions, or involving time series to show the effects of climate change on vegetation. Such results have shown how vegetation has moved, shrunk, changed in composition or being invaded. Richard and Van Wilgen (2004) and Gaertner et al. (2009), have used this in their studies to show not only how non indigenous species have moved from being alien to invasive, but have also documented a wide range of impacts on biodiversity. Time series analysis accounts for the fact that data points taken over time may have an internal structure (such as autocorrelation, trend or seasonal variation) that should be accounted for. A time series is a series of observations, xi (t); [I = 1, • • • , n; t = 1, • • • , m], made sequentially through time where: I indexes the measurements made at each time point t (Suppiah, R.H & K.J, 1998). Time series concerns the analysis of data collected over time; weekly values, monthly values, quarterly values, yearly values, etc. Usually the intent is to discern whether there is some pattern in the values collected to date.

To achieve a better understanding of the relationships between climate pattern and vegetation dynamics, several studies analysed time series of precipitation data and vegetation indices like Normalized Difference Vegetation Index (NDVI) (e.g. Al-Bakri & Suleiman 2004, Budde et al. 2004). Capodici et al (2008) used a time series analysis on NDVI, precipitation and temperature data sets to study the temporal dynamics of vegetation and to relate vegetation evolution to climate evolution. Precipitation especially in dry areas is one of the major driving forces for vegetation growth and is therefore in general highly correlated with vegetation. Thus, several studies estimated trends in vegetation cover or monitor land performance and land degradation respectively by analysing the relationship between rainfall and vegetation dynamics (Budde et al., 2004; Eklundh & Sjöström, 2005; Li et al., 2004; Vanacker et al., 2005).

Beyond, other studies analysed the correlation between time series of vegetation and precipitation data, considering different time lags and sums. Outcomes for response time maximum correlations range among lags of one and three months (e.g. Davenport et al., 1993; Eklund, 1998; Richard, 1998). Concerning sums, Herrmann et al. (2005) stated that sums of three months produce highest correlations. This seems rather vague and answers to the question which parameters influence this lag are still missing. Others focused on phenology and specific dates within the growing cycle deriving several indicators from the time series (e.g. Reed et al. 1994, White, 1997, Zhang et al. 2005). Spatially, most studies focus on the Sahel region (e.g. Budde et al. 2004, Hermann 2005, Li et al., 2004). However, only few studies, like Vanacker et al. 2005 specify rainfall variability or vegetation dynamics in more detail.

2.13 Summary

This chapter provided a review of climate change and issues pertaining to anthropogenic climate changes. More light is thrown on the difference in definition of climate change and anthropogenic climate change. Anthropogenic is added to climate change to indicate climate forcing influenced by man rather than nature. Differences in the rate and pace of the natural and anthropogenic factors causing climate changes are shown. Deforestation from land use practices such as agriculture account for the major influences on anthropogenic climate change. Literature portrays that though South Africa rainfall is characterised by variability and some planetary forcing such as ENSO, it is exacerbated by anthropogenic climate change since it accelerate and magnify the variability. A series of scenarios are formed as regards the possible reactions of vegetation to anthropogenic climate change. These might include extinction, shrinkage in population size as well as a change in species composition and evolution. With the shifting, adaptation and extinction, plant life is faced with threatening circumstances like risk from diseases and alien species proliferation. Such outcomes are probably going to affect the species composition and status in the Soutpansberg. Even though international and national effects have been put in place to reduce climate change acceleration, there still need more measures to be put in place and work to be done as concerns the effect of anthropogenic climate change on vegetation. The reference of this is on anthropogenic climate change brought about by the depletion of vegetation. This justifies the need for the need of such studies to be done and for mitigation as well as strategies for minimizing future effects of anthropogenic climate change. In order to have a closer look at such outcomes, a series of studies have employed various methods from relevé method for field sampling of vegetation, Geoinformatics for analysing remotely sensed images. Time series analysis is used for analysing information across time. The methods employed by previous researchers help shape a route which the researcher can use to produce better results through, improving and/ or expanding on previously used methods.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The rationale of this chapter was to put forward the decisions that were made in choosing data, data sources and in developing the methodology for the study. In order to assess the possible impacts that anthropogenic climate change will have on the vegetation of the Soutpansberg and to achieve the stated objectives, this study used rainfall and temperature data to establish the variability of the climate. A field sample survey of the vegetation using a modified version of the relevé method, where only functional plant groups were used to assess vegetation status. Also remotely sensed images were used to assess the changing status of vegetation across time frames. An in-depth detail of the processes involved in converting and analysing the collected data in a GIS framework are discussed. Figure 3.1 shows the steps as employed in the research.

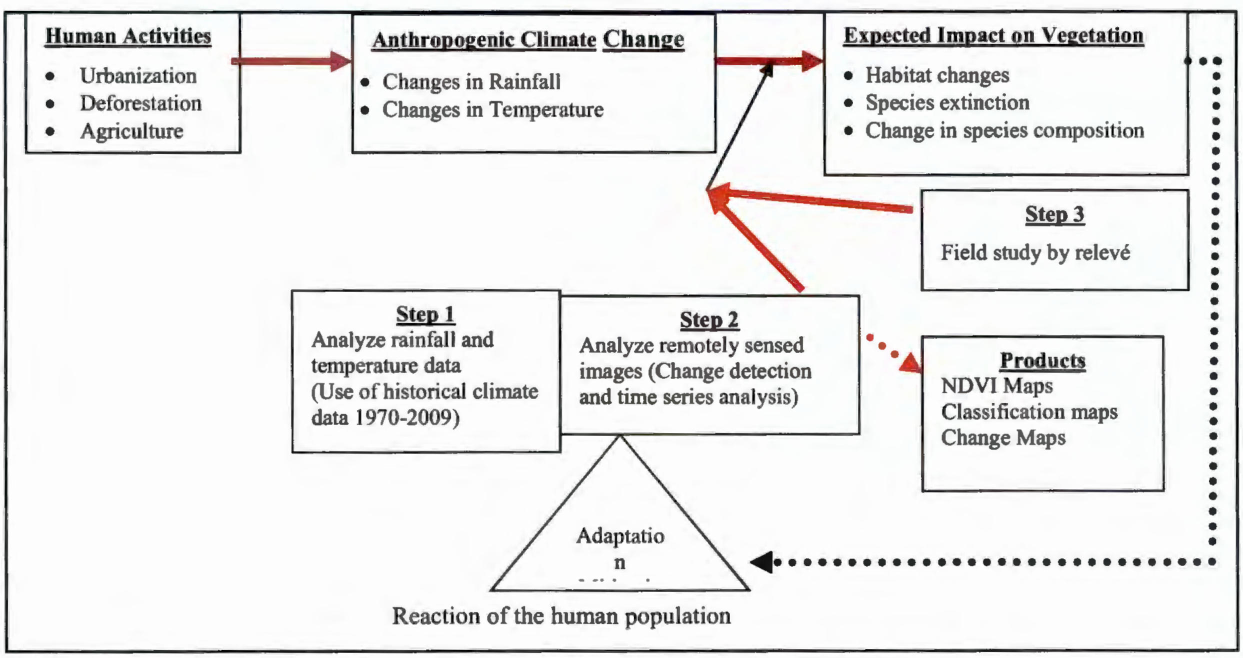


Figure 3.1: Conceptual model of the methodology and impact study of interaction between anthropogenic climate change and vegetation.

3.2 Data and Data Sources

Data used in this research included literature from various sources (journals, books), climate data (temperature and rainfall) maps and remotely sensed images.

3.2.1 Ortho Maps

1:50000 ortho maps from the Department of Rural Development and Land Reform were used to delineate the boundary of the Soutpansberg and various sections of the mountain. The maps aided in defining the confines within which the Soutpansberg Mountain falls and the extent to which sample sites for rainfall stations and vegetation sample sites fall.

3.2.2. Climate Data

Monthly climate data for the period 1970 to 2009 was obtained from the South African Weather Services (SAWS). Climate data include monthly seasonal rainfall data for the period October to March and monthly maximum and minimum temperature from 1970 to 2009 for both the wet and dry seasons. Monthly seasonal rainfall was chosen so as to better understand the characteristics of the rainfall during its peak period of activities as well as alterations within each of the rainfall months across the years. According to Rutherford and Westfall (1994), temperature and water availability are amongst the most important climatic factors influencing vegetation, hence their use in this research.

3.2.3 Relevé Data

Relevé data was obtained from field surveys address the vegetation abundance, distribution and sociability. This data helped in assessing the abundance cover of the vegetation and its distribution in terms of the species in the relevé as well as within each plant life form.

3.2.4 Remotely Sensed Images

Remote sensing data for this research was Landsat Thematic Mapper (TM 5). Images were acquired from the Satellite Application Centre (SANSA). Landsat TM images with its 30m resolution makes the image classification easier because the vegetation covers can easily be assessed with the aid of bands 3, 4 and 5. Band 5 is the mid infrared (Mid-IR) and is sensitive to the amount of water in plants: useful in crop drought studies and in plant health analyses. Band 4 is the near infrared (NIR) and is responsive in determining vegetation types. Band 3 is a visible red band and is very useful in discriminating between plant species (Lillesand & Kiefer, 1994).

3.3. Data Collection

3.3.1 Delineation of Boundaries

Ortho maps were used to stratify the Soutpansberg into eight units forming the boundaries of the Mountain and five units forming the area of interest within the range. The boundary units include Louis Trichardt, Wyliesport, Vivo, Waterpoort, Mara, Vet Fontein, Nzhelele, and Valdezia. This gave the physical boundaries of the study area as used in this study. The five units consist of North West (NW), North East (NE), Centre (CE), South West (SW); South East (SE). With these boundaries set it was easier to set sampling points within the Soutpansberg as well as selecting climate stations within the study area.

3.4 Vegetation Sampling Method

3.4.1 Plot Selection

Plots for sampling were chosen based on a purposive sampling method. Purposive sampling technique is a type of non-probability sampling where the researcher consciously selects particular elements or subjects for addition in a study so as to make sure that the elements will have certain characteristics pertinent to the study. McMillan and Schumacher (2001) recommend purposive sampling because the samples that are chosen are likely to be knowledgeable and informative about the phenomenon the researcher is investigating. The Soutpansberg region was purposively chosen for this study because it is already experiencing anthropogenic climate change and still hosts a distribution of natural vegetation cover. Plots for sampling were purposively selected based on the natural state of vegetation in both the protected and unprotected areas of the mountain. In order to have vegetation in its intactness, natural vegetation from mid slope to summit was chosen to rule out the influence of man on the vegetation. At each of these sample plots, centre of plots location are recorded and measured using global positioning systems (GPS).

3.4.2 Relevé Method

This method was by recording field observation by relevé. A relevé is the list of species observed in a plot together with an estimate of their abundance / dominance or cover.

Every class was fixed to the percentage of cover estimation regardless of the number of individual plants. Abundance was assigned from rare- species to 5 being the most abundant. Abundance was given a value depending on the state of vegetation following the abundance class (Appendix 3.1).

The reason of using estimates is due to habitat types imposing an ordered classification of vegetation, which actually exhibits semi-continuous gradients of structure and composition-layers and species abundance/presence (Jensen, 2000). Sociability or gregariousness values are described as in Appendix 3.1- field data sheet 2.

The relevé method was considered as exceptionally suitable for studying the vegetation of the Soutpansberg, because it is based on the principles that:

- Plant communities can be organised into hierarchical classes based on diagnostic species (Werger, 1974). Therefore in assessing the vegetation cover of the Soutpansberg, vegetation cover can be grouped into various plant life forms. This will make it easier to deal with plant life forms rather than individual plant species within each plant life form.
- Plant species are more sensitive indicators of environmental gradients than others and can be used as diagnostic species in a plant community.
- Plant communities can be recognised by their floristic composition which reflects the best relationship between plants and their environment.
-

In this study, the relevé method has been modified. Wherein species is used broadly to refer to the different plant life forms (trees, shrubs, climber, succulent, herb, grass, lianas) creating forest, woodland, savanna, grassland. In sampling the vegetation each sample plot percentage cover of plants within the community was noted according to the Braun-Blanquet cover abundance scale (Appendix 3.1- field data sheet 1). Due to the large sampling scale and topographic complexities it was decided to restrict mapping resolution to diagnostic vegetation groups identified in each community.

3.4.2.1 Field Survey

Plots were preselected with the aid of a subset image of the Soutpansberg (using ERDAS imagine). Selection was based on the undisturbed vegetation, location (mid slope to summit) accessibility (roads, trials and footpath). The area was divided into five: NW and NE (North facing slope); SW and SE (south facing slope) and Centre (CE) based on homogenous physiographic – physiognomic units. Using the referenced position of the pre - selected plots; sample plots were accessed and sampled. The vegetation study was conducted during the growing period of March 2011 and February 2012. A total of 140 plots were sampled for natural vegetation in unprotected area (uncontrolled sites), 100 for natural vegetation in protected area (controlled sites) (less due to physical constraints and refusal of rights of admission) and 47 for the various land use patterns in the area. The size of sample plots within the controlled and uncontrolled sites was set at $400m^2$ due to the heterogeneity of the area and the size of the survey.

3.5 Data Processing and Analysis

3.5.1 Climate Station Selection

A total of 35 climate stations were selected. Climate data available for each station was analysed for their suitability for the study; stations with data spanning forty years (1970-2009). Using these criteria stations created after 1970 were eliminated from the study. An exception to this rule was Waterpoort because the ratio of rainfall stations concentration on the North as opposed to the rest of the range is about 1:7. Also Waterpoort is the only climate station on the NW facing slope. Hence there is a need for a station to represent the climate dynamics in that area.

The data was further analysed for missing values in the monthly series. But for the case of Waterpoort, it was decided that missing rainfall data must not exceed five per cent (5%) in any selected rainfall station. Missing monthly values were calculated as a percentage of the time span (forty years) of total data collected. All calculations were done in months. The Equation for calculating the percentage of missing data is given as:

$$\frac{\sum x}{N} x \frac{100}{1} \qquad 3.1$$

Where

N = total months of data span

x = months of missing data

$\sum$ = total sum

Thus, span of data collected, N= 40years x 6months = 240 months

*6 because we are dealing with seasonal rainfall which in this case is six months.

The following stations were identified for missing values: Waterpoort, Mara-pol, Palmaryville, Folovhodwe, Mphefu, Levubu, Elim Hosp, Goedehoop, Noitgetdacht, Rampuda (appendix 3.2) and the percentages were calculated as follows. Using data for Waterpoort as an example the calculation was done as thus: Waterpoort with 42 months of missing data

$$= \frac{42}{240} X \frac{100}{1} = \qquad 17.5\%$$

This was done for all the selected stations within the demarcated boundaries of the Soutpansberg with rainfall data fitting the study period. Though Waterpoort station had percentage values more than the stated 5% they were included in the study. After this screening process a total of 23 climate stations were selected.

3.6 Climate Data Sorting

Precipitation data included monthly rainfall for the raining season (October –March) for the period 1970-2009.Temperature data included maximum and minimum temperatures for the wet and dry season for the period 1970-2009. Data is sorted in order to have a complete and orderly distribution of seasonal rainfall across the years. The climate data covered a period of more than thirty years which is considered long enough (that is thirty years) for a valid statistic (Kahya & Kalaycib, 2004). 30 years of historical data is an acceptable period according to World Meteorological Organisation (WMO).

3.6.1 Homogenization of Rainfall Data

Long term climate time series are not free of irregularities (Auer et al. 2005) and hence, it becomes necessary to assess the homogeneity of long term climate records before they can be reliably used. The relative method was used to test for homogeneity. The assumption of this method is that within a geographical region, the climatic patterns will be identical and that the observations from all sites within the region will reflect an identical pattern (Conrad & Pollak, 1950). Hence data collected at all sites within the same climatic region should be highly correlated, have similar variability, and differ only by scaling factors and random sampling variability.

3.6.2.1 Pearson Correlation

Pearson correlation matrices were calculated between the climate station in each of these regions and to take as reference the highest correlated ones (Boissonnade et al., 2002; Tayanç et al., 1998) to test for homogeneity. If X and Y are in the same area with similar characteristics then they should show linearity. r was calculated as seen in Equation 3.2:

$$r = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 (\sum X)^2)(N\sum XY^2) - (\sum Y)^2]}} \qquad 3.2$$

Where:

N = number of pairs of scores

$\sum xy$ = sum of products of paired scores

$\sum x$ = sum of x scores

$\sum y$ = sum of y scores

$\sum x^2$ = sum of squared x scores

$\sum y^2$ = sum of y scores

Correlation matrices were calculated in SPSS and STATISTICA softwares and presented in a table (Appendix3.3). Results show high correlation within rainfall stations within the delineated areas with mark correlation being significant at $p < .05$. Given that from 1970-1976 data was missing for Waterpoort, the correlation between the three northern stations were calculated as from 1977. Reference stations are chosen from the strongly correlated station with complete rainfall data to test for the consistency of the rainfall data. The double mass curve was used to test the homogeneity of the data.

3.6.2.2 Double Mass Analysis for Rainfall data

Double mass analysis is a technique to detect possible inhomogeneity in series by investigating the ratio of accumulated values of two series, through the series to be tested, and the base series. Stations with strong correlation values (Appendix 3.4) were used to test for validity of the rainfall data.

3.7 Missing Rainfall Data

From the visual analysis of rainfall data, it was discovered that a series of the rainfall station had months of missing data. Data for the missing months were filled using the normal ratio method and the arithmetic mean.

3.7.2 Normal Ratio Method

This method is used if any surrounding stations have the normal annual precipitation exceeding 10% of the considered station X. This weighs the effect of each surrounding station (Singh, 1994). The normal ratio is denoted by Equation 3.3:

$$P_x = \frac{1}{m}\left[\frac{N_x}{N_1}P_1 + \frac{N_x}{N_2} + P_2 \ldots + \frac{N_x}{N_n}P_n\right] \qquad 3.3$$

Where:

P_x = Estimate for the station with missing data

P_1 = Rainfall values of rainfall stations used for estimation

N_x = Normal annual precipitation of X station

N_1 = Normal annual precipitation of surrounding stations

m = Number of surrounding stations

Using Mara-pol as an example on how this method was employed, missing rainfall data for the month of Novemebr-1978 for Mara-pol was obtained using Equation 3.3. Surrounding stations used are Mara, UNA –Agric and Hanglip (given that a minimum of 3 stations are normally used in this method).These stations were chosen based on their correlation and proximity to Mara-pol.

Total seasonal rainfall for the year 1978

Mara-pol	=	214.5 mm
Mara	=	441.3 mm
UNA-Agr	=	312.8 mm
Hanglip	=	360.0 mm

Total rainfall for the month of November 1978:

Mara	=	97 mm
UNA-Agr	=	88.1 mm
Hanglip	=	98.5 mm

Therefore rainfall data for the month of Novemebr-1978 for Mara-pol:

$$P_x = \frac{1}{3}\left[\frac{214.5}{441.3}97 + \frac{214.5}{312.8}88.1 + \frac{214.5}{360.7}98.5\right]$$

$P_x = \frac{1}{3}[47.1 + 60.4 + 58.6]$ = 55.4 mm

Therefore rainfall for Mara-pol for November 1978 was 55.4 mm. See Appendix 3.5 for interpolated rainfall data for the rest of the rainfall stations with missing data.

3.8 Average Seasonal Data

The arithmetic mean or average is given by the sum of an array of numbers divided by the total number of observations in that array (Norcliffe, 1977). Seasonal average of rainfall and temperature data for each season of the study period was calculated. The statistical Formula used to calculate the mean was:

$$\bar{x} = \frac{\sum x_i}{n} \qquad 3.4$$

Where:)

$\bar{x}$ = mean

x_i = annual rainfall

n = number of years (40)

3.9 The Standardized Anomaly Index (SAI)

SAI is used to examine the nature of the trends in climate data. It provides an area average index of relative rainfall and temperature yield based on the standardization of rainfall and temperature totals. Given that the index involves a sum and the spatial correlation of precipitation; temperature, the probability distribution of SAI is the dimensional joint distribution of station climate data. If the joint distribution of rainfall and temperature at the stations were multivariate Gaussian, then the probability distribution of the index would also be Gaussian with zero mean and variance that depends on the spatial correlations. Standardization uses the standard deviation so as to allow comparison of rainfall and temperature data for 1970 - 2009 to normal precipitation and temperature (Nyenzi, 1988). This statistic will help in determining the dry, low (-ve values) and wet, high (+ve values) years in the record. This is ideal in determining extreme climatic occurrences such as droughts and floods (Dowdy and Wearden, 1991) and is similar to that used by Kraus (1977); Nicholson (1980); Katz and Glantz, (1986); Delitala et al., (2000).The transformed seasonal rainfall and temperature departure is calculated by:

$$Z = \frac{(xi - x)}{\sigma} \quad 3.5$$

Where;

Z = normalized standardized departure in values

xi = composited data points (total seasonal rainfall for the years)

x = historical seasonal total rainfall

σ = historical standard deviation.

The Z values provide immediate information about the significance of a particular deviation from the mean (Nyenzi, 1988).

3.10 5-Year Moving Average

A 5-year moving average filter was used as a low-pass filter to examine the shape of the trends and long term fluctuations in precipitation index time series (Turkes, 1996). The 5-year moving average was used to filter out planetary forcing. In this case, the El-Niño Southern Oscillation (ENSO) phenomena which occurs in half of a solar cycle, and other effects on the climate which can mask the signal of climate change. Moving averages provided trend information which simple average of all historical data would mask. In studies involving detecting rainfall changes, the moving average is a traditional process that is used for long term trend depiction (Sneyers, 1992).

3.11 Linear Regression

The objective of the regression analysis was to find the nature of the relation between x and y from the data and use the relation to predict the response variable y from the input x. If a linear relation emerges from the plotted data, the calculation of the numerical value of the regression (r) will confirm the strength of the linear relation. This value shows how effectively y can be predicted from x by fitting a straight line to the data. The coefficient of determination (r^2), expresses the strength of the relationship between the X and Y variables. The intercept (height above the origin of a line) and slope (the amount of Y increase whenever X increases by a unit) determines a line. The least square line is close to the points in terms of minimizing the amount of vertical distance. Trends in time series data were analysed using simple linear regression. The slope X indicates the average rate of change in the climatic parameter over the study time period. Equation of the least square line is given by:

$$\mathbf{y = mx + c} \qquad 3.6$$

Where:

y = vertical axis values (rainfall)

x = horizontal values (time in years)

m = gradient of the line (changes of rainfall in a given time i.e. mm/year)

c = vertical axis intercept (constant).

3.12 Significance and Stability Testing

All trends considered in this study were tested for 'significance'. Statistically, a result is called significant when it is unlikely to have occurred by chance. Most often, in statistical hypothesis testing, the significance level of a test is the maximum probability, assuming the null hypothesis, that the statistic would be observed. Therefore the significance level is the probability that the null hypothesis will be rejected in error when it is true (Type I error) or the null hypothesis is accepted in error when it is false (type II error). The significance of a result also called its p-value; is said to be the more significant as the p-value gets smaller. Significance is usually represented by alpha, denoted by the by the Greek symbol, α. The various levels of significance called the p-value, often used are 5%, 1% and 0.1%. If the results of a test of significance give a p-value lower than α -level, the null hypothesis is rejected. Such results are casually referred to as 'statistically significant'.

3.13 Z-Test

Statistical analysis of the difference between rainfall means per rainfall station was carried out. The formular used as expressed by Goddard and Melville (2001):

$$Z = \frac{(x_i - \mu)}{\sigma} \qquad 3.7$$

Where:

z = Standardized value

σ = standard deviation of the probability distribution x_i

μ = long term mean

The standard deviation of the data was calculated using the Equation 3.8:

$$\sigma = \sqrt{\frac{\Sigma(\mu - x_i)^2}{n - 1}} \qquad 3.8$$

Where:

σ = Standard deviation

x_i = annual rainfall total

M = long term mean

N = Number of data

3.13.2 Chi Square

The Chi Square (X^2) test was employed to test the difference between an actual sample and another hypothetical or previously established distribution, such as that which may be expected due to chance or probability. Chi Square can also be used to test differences between two or more actual samples. Computational Equation 3.9:

$$X^2 = \sum \frac{(O - E)^2}{E} \qquad 3.9$$

Where:

χ2 = value for Chi Square.

O = observed frequency

E = expected frequency.

The Equation reads as the value of Chi Square equals the sum of O-E differences squared and divided by E. The more O differs from E, the larger χ^2 is. When χ^2 exceeds the appropriate critical value, it is declared significant.

3.13.3 T-Test

William Seally Gosset (1908) put forward the T-test which involves comparing the means for a group of scores, with focus on the differences between the scores. Computation of t-test is given by Equation 3.10.

$$t = \frac{\sum D}{\sqrt{\frac{n\sum D^2 - (\sum D)^2}{n-1}}} \qquad 3.10$$

Where:

$\sum D$ = sum of all differences between groups

$\sum D^2$ = sum of the differences squared between group scores

N = number of pairs of observation

3.14 Selection of Remotely sensed imagery

The images used for this were cloud free images for the months of March 1989, 1998 and 2008 scenes the period of image acquisition was the raining season, which made it difficult to get 100% cloud free images. The selection of appropriate imagery with similar acquisition dates for change detection is an important element of a project's success. Acquisition dates have become vital in change detection studies for the reason that they lessen discrepancies in reflectance brought on by seasonal vegetation fluxes and sun angle differences (Coppin & Bauer, 1996). Scenes for the growing months were chosen because this will show the full vigour of the vegetation given that it is the period where it receives the most rainfall. Appendix 3.5 shows the specifications of scenes used for the study.

3.14.2 Image Processing

Computer algorithms are used to perform digital image processing on satellite images. Software such as Arc Map and ERDAS imagine written in interactive data language (IDL) are used to retrieve, manipulate and process satellite images. Digital image processing allows a much wider range of algorithms to be applied to the input data and hence avoiding problems such as the build-up of noise and signal distortion during processing.

3.14.2.1 Preprocessing

Pre-processing of satellite images is an essential step before image classification and change detection analysis can be carried out. Raw images with file extension .dat and .fst formats were imported into ERDAS imagine and extracted as .img files.

Radiometric correction: The process of radiometric corrections involved the conversion of digital numbers (DN) to reflectance units (Culf, et al., 1995). The aim here was to minimize variations due to varying solar zenith angles and incident solar radiation. DN values were converted to radiance values (L) using the calibration coefficients "gain" and "bias" supplied in the imagery report file as shown in Equation 3.11 (Culf, et al., 1995).

$$L_\lambda = (gain \times DN) + bias \qquad 3.11$$

Where:

L_λ = satellite radiance

DN = digital number.

Following the calculation of the radiance values, the reflectance (ρ) was calculated using the methods described in Vermote, et al., (1997) for each band. Equation 3.12 shows the Equation for reflectance where the calculation was done on a pixel by pixel basis for each scene using the corner coordinates. The overpass time and acquisition date was contained in the image report file.

$$P\rho = \frac{\pi L_\lambda d^2}{E_{Sun\lambda} \cos\theta_s} \qquad 3.12$$

Where:

$P\rho$ = dimensionless planetary reflectance

L_λ = spectral radiance at the sensor aperture

d = Earth - Sun distance in astronomical units

E_{Sun_λ} = mean solar exo-atmospheric irradiances

θ_s = solar zenith angle.

Source: *NASA Goddard Space Flight Centre,* 2002.

3.14.2.2 Processing

Geometric Correction: Image to image registration is a geometric correction process where, an image is matched to a corresponding coordinate point in a georeferenced image of the same region. Assume A and B are two images to be registered, acquired from the same geographical area on different dates or with different sensors. Here, A is defined as a reference image, and B to match the reference image is defined as a sensed image. Scenes for 1989: 16907619890309 and 1707619890316; 1998: 16907619980318 and 1707619980325; 2008: 16907620080329 and 1707620080329 were the sensed images which were registered to referenced images 169762000109 and 1707620001203. Sensed images were registered to reference images with similar paths and rows. Geometric rectifications of the imagery resampled or changed the pixel grid to fit that of a map projection or another reference image. This is particularly important when scene to scene comparisons of individual pixels in applications such as change detection are being sought as is the case in this study.

Using manual image registration techniques three steps were followed to register the images. Firstly 25 Ground Control points (GCP) were chosen or extracted from the sensed and referenced images indicated above. A GCP is a location on the surface of the earth such as a road intersection that can be spotted on the imagery and located accurately on a map. Two distinct sets of image coordinates (specified in i rows and j columns), and map coordinates (meters in a Universal Transverse Mercator projection) are associated with the GCP. The paired coordinates (i, j and x, y) from 25 GCPs are modelled to derive a geometric transformation coefficients.

The least square criteria is fitted to the GCP data and used to model the correction in the satellite image. Based on the distortion in the figures, the number of GCPs used, and the degree of topographic relief displacement in the area, a first-order polynomial Equation is used to geometrically correct the information. A polynomial Equation is fitted to the GCP data using least-squares criteria so as to model the corrections directly in the image domain. The "mapping polynomial" function is denoted by Equation

$$X' = a0 + a1X + a2Y + a3XY + a4X2 + a5Y2 \quad 3.13$$

$$Y' = b0 + b1X + b2Y + b3XY + b4X2 + b5Y2 \quad 3.14$$

This transformation models six kinds of distortion in the remote sensor data, including translation in x and y, scale changes in x and y, rotation, and skew. With the six coordinate transform coefficients that model distortions in the original scene, the output-to-input (inverse) mapping logic is used to transfer pixel values from the original distorted image x′, y′ to the grid of the rectified output image, x, y. Output-to-input inverse mapping logic is preferred because it results in a rectified output matrix with values at every pixel location.

Root Mean Square Error: In applying the coefficients to create the rectified output image, it is imperative to demonstrate how well the transformation resulting from the least-squares regression of the GCPs account for the geometric distortion in the input image. The method used for this involves computing root mean square error (RMS_{error}) for each GPS using Equation 3.15. RMSerror is the value obtained from the calculated distance between the actual locations on the map coordinate to the transformed position in the raster. This value describes how consistent the transformation is between the different control points. The Equation is:

$$RMS_{error} = \sqrt{(x' - x_{orig})^2 + (y' - y_{orig})^2} \qquad 3.15$$

Where x_{orig} is the original row and y_{orig} the column coordinates of the GCP in the image and x' and y' are the computed/estimated coordinates in the original image when the six coefficients are used. The GCPs plotted are done such that a user-specified threshold of <0.50 pixel error in the x-direction and < 0.50 pixel error in the y-direction for the Root Mean Error (RMS_{error}) is obtained. The RMS_{errors} for the images as shown in Appendix 3.1 are as follows:

16907619890309 = 0.4

17007619890316 = 0.001

16907619980318 = 0.001

17007619980318 = 0.000

16907620080329 = 0.02

16907620080329 = 0.001

RMS_{error} from the geocorrection was within the advisable range of 0.25 - 0.50 pixel (Jensen, 1986). This provided a high quality georeferenced image. Thus, the precision of image registration is controlled by accuracy and veracity of the control points.

Resampling Images: Finally the mapping function was utilised to resample the second image so as to bring it into alignment with the first image. For the original distorted image to be geometrically corrected, the resampling process was used to set the digital values to place in the new pixel locations of the corrected output image. This procedure involved the extrapolation of data values to a new grid, and is the step in rectifying an image that calculates pixel values for the rectified grid from the original data grid. This was done using the nearest neighbour analysis. In the nearest neighbour analysis, the pixel value closest to the predicted x', y' coordinate is assigned to the output x, y coordinate (Jensen, 1986; Lillesand & Kiefer, 1994). This technique of resampling is a computationally efficient procedure, favoured because output values are the original input values, hence it does not alter the pixel brightness values during resampling, whereas other interpolation techniques like bilinear interpolation and cubic convolution use averages to compute the new brightness values, often removing valuable spectral information (Jensen, 1986).

The goal of image rectification is to facilitate the overlay of additional imagery and other geographic datasets. The images were rectified and georeferenced to the Universal Transverse Mercator System (UTM) projection WGS-84 datum (World Geographical System). A standard map area, with boundaries set in UTM, is established for each scene, with each image files in the same region, once rectified, occupying the same map area.

Mosaicking Images: Given that the rectified images are scenes from various section of the Soutpansberg, they need to be merged to form a complete picture of the study area. Mosaicking is the process of combining multiple images into a single seamless composite image. The images of 1989, 1998 and 2008 that were rectified to a standard map projection and datum UTM 86 are mosaicked. Images 16907619890309, 16907619980318, 16907620080329 of the year's 1989, 1998 and 2008 were designated as the base images for each designated year. When mosaicked, the adjacent images 16907619890309 and 1707619980325 overlap about 20% portraying a distinctive overlapping region. This area in the 16907619890309 was contrast stretched. The histogram of the overlapping region in the 16907619890309 image was extracted and applied to image 1707619980325 using a histogram-matching algorithm. This procedure enabled the two images to have approximately the same greyscale characteristics. In order to eliminate the possibility of pixel brightness values in one scene dominating the pixel values in the overlapping scene causing noticeable seams in the final mosaic, feathering is used to blend the seams between mosaicked images.

Subset: The entire scene acquired from the mosaicked scenes display a larger study area than the intended area of interest (AOI) which is the Soutpansberg. In order to focus on the AOI, the images are subsetted. Subsetting is a process where a portion of a larger image is "cropped" or cut out for further processing. This procedure not only eliminates the irrelevant data in the file, but speeds up processing time given that the data to be processed becomes smaller in size. This is important when dealing with multiband data. A vector file defining the boundary of the Soutpansberg with the same georeferenced coordinates as the images is imported into ERDAS to create the AOI and overlaid onto each image scene.

3.14.2.3 Image Enhancement

This operation aimed at enhancing certain characteristics of the soil surface for easy visual interpretation of images. Different bands of a multispectral image were combined to emphasize different land cover areas in the given area. Contrast enhancement techniques were used for each individual image in the study. This extended the range of brightness values in the images enabling discrimination between areas initially having a minor difference in density. This aided in allocating land cover classes.

3.14.2.4 Image Classification

Classification is the process of identifying pixels in various spectral bands within a satellite image. The process creates clusters of similar pixels into the same informational categories. The main aim of image classification was to automatically categorize all pixels in an image into land cover classes in the study area. The classification method executed for this study was the automated (unsupervised) method. Unsupervised classification identifies natural groups or structures within an image, and detects uniform groupings of pixels that can be clustered into distinct categories in a multidimensional data space. The

Interactive Self-Organizing Data Analysis (ISODATA) technique was chosen to perform the unsupervised classification in ERDAS 10.1. For ISODATA, the maximum number of classes chosen for the vegetation cover was forty. This algorithm generates the clusters; calculates the centroid of each cluster; assigns image pixels into the neighbouring cluster mean using the minimum spectral distance formula. The Recode function in ERDAS was applied to combine the forty five classes generated into ten to thirteen classes and assigned the informational classes based on the field study knowledge. The classification legend was made based on spectral characteristics.

Supervised classification was done after this. Supervised classification was done by following three stages that included training data sets, classification and output. Training samples were taken for each land cover type to be classified in the image. To obtain true representation of the cover classes, training samples were repeatedly selected, assessed and analyzed by either delete or merge. Classification was done by using maximum likelihood classifier (Lillesand and Kiefer, 1994). This option evaluated to which class the pixel most likely belongs, based on the pixel value.

3.15 Normalized Difference Vegetation Index (NDVI)

The NDVI is one of the various numerical indicators in remote sensing measurements used to analyse, and assess if targeted observation contain live green vegetation or not. Given that the remotely sensed data are acquired in the red (R) and near infrared (NIR), it was natural to exploit the strong differences in plant reflectance to determine their spatial distribution in these satellite images using these bands. These spectral reflectance are ratios of the reflected over the incoming radiation in each spectral band individually. It has been shown that NDVI is directly related to the photosynthetic capacity and hence energy absorption of plant canopies (Myneni et al., 1995). NDVI value theoretically, ranges between -1 to +1. Measured value ranges from -0.35 (water) through zero (soil) to +0.6 (dense green vegetation). This corresponds to a DN value of 135 or higher after the NDVI image has been re-scaled to the image domain (0-255). Hence the more positive the NDVI the more green vegetation there is within a pixel. Equation 3.16 shows the mathematical formulae for calculating NDVI.

$$\mathbf{NDVI} = \frac{\mathbf{NIR - R}}{\mathbf{NIR + R}} \qquad 3.16$$

Where:

NIR = spectral reflectance measurements acquired in the near infrared region

R = spectral reflectance measurements acquired in the red region

In the case of the Landsat images:

TM4 = near infrared band

TM3 = red band

With the TM remote sensing data, the Equation is computed thus:

$$\mathbf{NDVI} = \frac{\mathbf{TM4 - TM3}}{\mathbf{TM4 + TM3}} \qquad 3.17$$

3.16 Change Detection

Change detection or Digital change detection is a process that helps in the identification of differences in the state of an object or phenomenon by observing it at different times (Ramachandra & Kumar, 2004). The process involved quantifying multi-date imagery to derive changes over time (Coppin, et al., 2004). Most of the existing change detection algorithms used to analyse spectral data are implemented to detect changes using specific bands for specific applications. In this work a change detection technique based on the Image differencing method was used. Bands 3, 4, 5 of Landsat TM the bands of each multispectral image were used to perform change detection. By using these bands, we expect to maximize the amount of information that can be extracted in relation to vegetation change over the years.

3.17 Accuracy assessment Classification

Accuracy assessment is the comparison of a classification to geographical data assumed to be true. ERDAS accuracy assessment tool was used to conduct an accuracy assessment for this study. The assumed true data were derived from ground truthing during field work. 174 sample points were used for classification accuracy assessment and the remaining 140 points were used as a check. Therefore all map outputs were carried out by using ground reference samples compiled with the satellite image classification. The correctness of classification was evaluated through comparisons to google earth, the interpreter's knowledgeas well as black and white aerial photographs and topographic maps. The overall accuracy derived from the stratified random sampling method for the 1989,1998 and 2008 classified images as shown by appendix 3.8a - 3.10b were 81.32%, 80.83%, and 78.07% with an overall kappa statistic of 0.71, 0.73, and 0.79, respectively. Kappa values of more than 0.80 indicate good classification performance. Kappa values between 0.40 and 0.80 indicate moderate classification performance and Kappa values of less than 0.40 indicate poor classification performance. Given that the kappa value for the study is between 0.71-0.79, the classification performance was moderate.

CHAPTER 4: RESULTS AND DISCUSSIONS

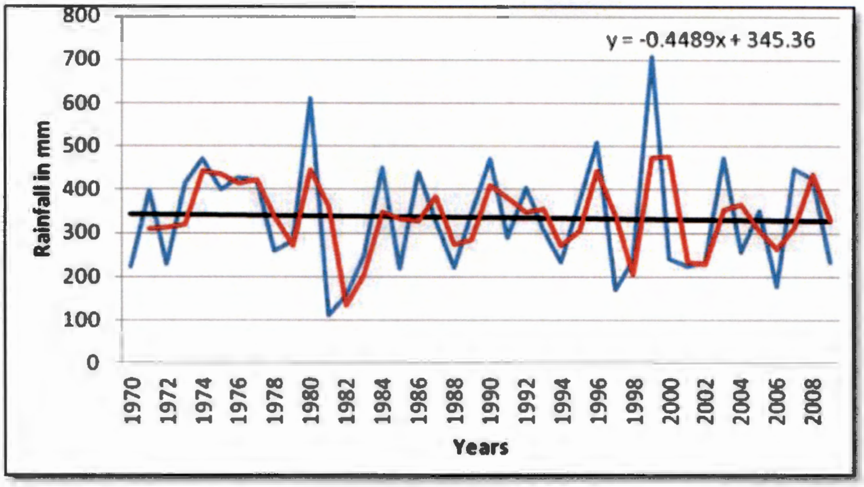
4.1 Introduction

This chapter present result from analysing the various data collected for this study. Vegetation data, rainfall data and remotely sensed data were analysed as per the methodologies that were explained in Chapter Three. The test for homogeneity in rainfall using the double mass curve, showed the southern and northern slopes stations having an almost straight line. This shows that the data from the stations for the study period is reliable. Monthly seasonal rainfall was used in the analysis to establish the variation in the rainfall of the 5 delineated areas of the Soutpansberg Mountains - North West (NW) North East (NE), South West (SW), South East (SE), Centre (CE) and the statistical significance of the variations. Vegetation data were analysed to establish variations in cover and abundance that exist in the mountains and the significance of variation. A correlation was done in order to establish the role of anthropogenic climate change on vegetation status over time.

4.2 Rainfall Results

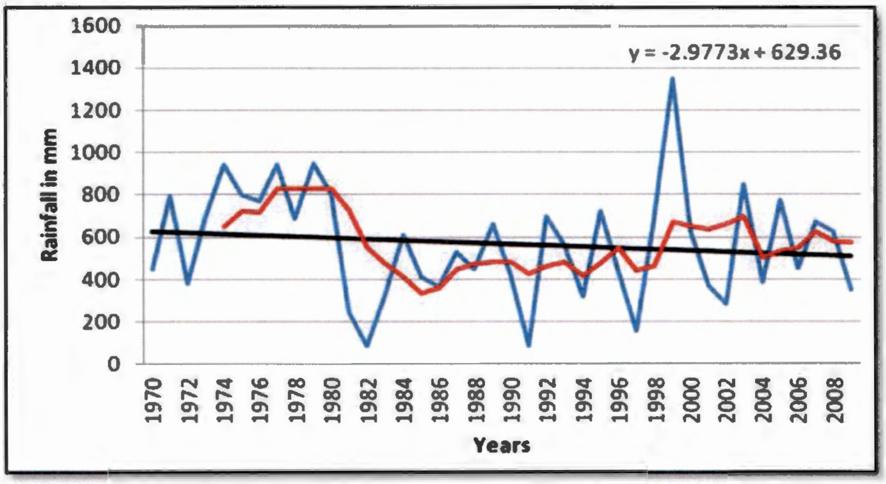
4.2.1 5 Year Moving Mean and Composite Rainfall

Composite rainfall was produced for all five sub-regions of the Soutpansberg by averaging. A 5-year moving average was superimposed to indicate the expected rainfall pattern minus planetary influences. Figures 4.1, 4.2, 4.3, 4.4 and 4.5 indicates that with the elimination of El-Niño Southern Oscillation (ENSO), a quasi- sinusoidal oscillation is observed in the rainfall pattern of the area. This rainfall pattern seen in the Soutpansberg is typical of patterns in Southern Africa rainfall (Preston-Whyte & Tyson, 1988). To further examine the nature of the trends in the rainfall series, a least square trend line (Equation 3.2) was also plotted for the normalized values using the Microsoft Excel statistical tool, and estimation of changes in the rainfall series was determined. In the NW region, the trend line suggests rainfall is decreasing at a rate of -0.45 mm/year starting at 345.36 mm (y- intercept) (Figure 4.1).The area experienced



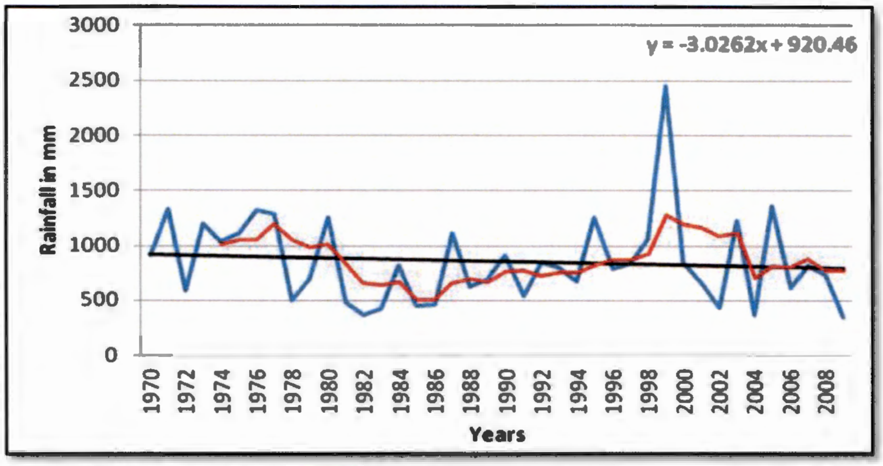
Actual rainfall; 5- year moving average; Trend line
Figure: 4.1: NW composite rainfall, moving average and trend

The NE region exhibits similar rainfall pattern with the NW region. The trend line as seen in Figure 4.2 suggests that rainfall is decreasing at -2.98 mm/year, as from 629.36mm



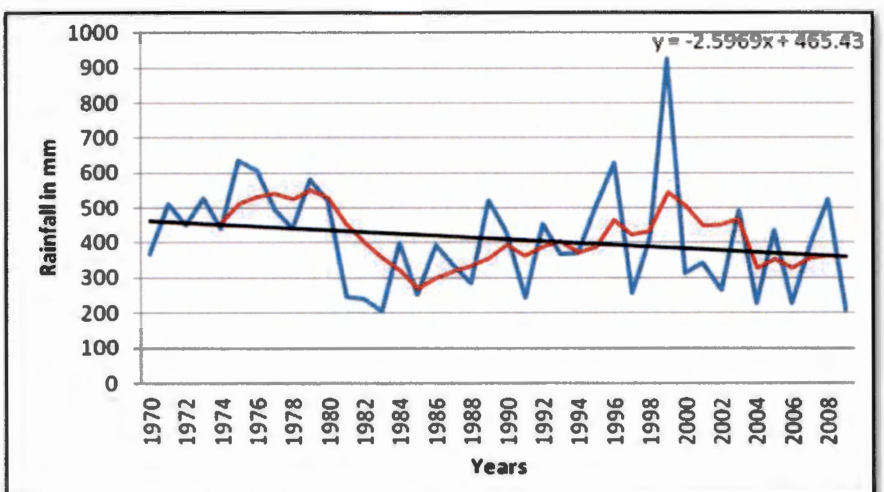
Actual rainfall; 5- year moving average; Trend line
Figure: 4.2: NE Composite Rainfall, Moving Average and Trend

In the South Eastern slope, the trend line indicates a yearly decline of -3.03mm starting at 920.5mm (Figure 4.3).



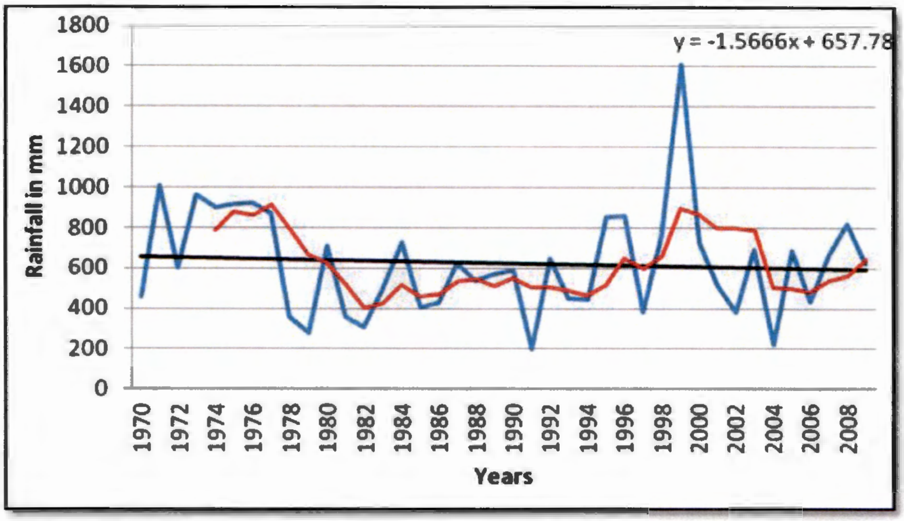
— Actual rainfall; — 5- year moving average; —Trend line
Figure: 4.3: SE composite rainfall, moving average and trend

The SW region exhibits a trend line with a decline in rainfall with a decline rate measured at -2.6 mm/year starting at 465.43mm (Figure 4.4)



Actual rainfall; — 5- year moving average; — Trend line —
Figure: 4.4: SW composite rainfall, moving average and trend

The trend line in the Centre region indicates a decline in rainfall at -1.6mm/year beginning at 657.8 mm (Figure 4.5). The decline is very gradual.



Actual rainfall; ▬ 5- year moving average;▬Trend line ▬
Figure: 4.5: CE composite rainfall, moving average and trend

From the trend line analysis the NW experience more rainfall decline, followed by the NE, SW, SE and lastly the CE sub regions of the Soutpansberg. The high amount of rainfall observed throughout the Soutpansberg in 1999/2000, was due to an abnormal climatic feature, which was caused by the Tropical cyclone Eline, which affected the climate regime of the area during that time (Reason & Keibel, 2004).

4.2.2 Rainfall Anomalies

Rainfall data was composited to produce area rainfall for the 5 divided sections of the Soutpansberg. This was done so as to analyse the variability over time for each section in relation to the whole area. Rainfall data for each station was normalized in order to detect normality in annual rainfall. Any departure from normal would represent either above normal rainfall or below normal rainfall with respect to the area rainfall.

The time variability of the composite time series for the NW region is shown in Figure 4.6. The solid line is the 5-year moving average time series. From the moving average, it can be seen that the region is characterised by three wet periods 1975-1977, 1980, 1990 and a major negative rainfall period 1984-1986. There was an iterative period of negative and positive rainfall 1981-2009. The lowest were 1985, with Standardized Anomaly Index (SAI) of -0.94 and 2004 with SAI of -1.09.

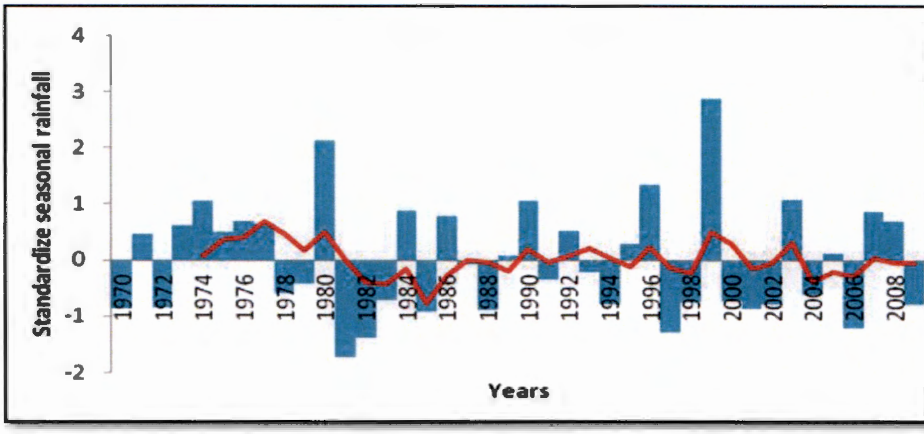


Figure 4.6: Standardized seasonal rainfall for NW

NE rainfall anomalies time series is shown by Figure 4.7. The stations recorded rainfall above normal between the periods 1974-1980 with the highest SAI of 1.43 above normal registered for period 1977 and 1999 as depicted by the departures from mean. These are the major wet periods. A series of below normal rainfall was received from the period 1982-1997. The lowest was in 1985 when the departure from the mean was -0.6.

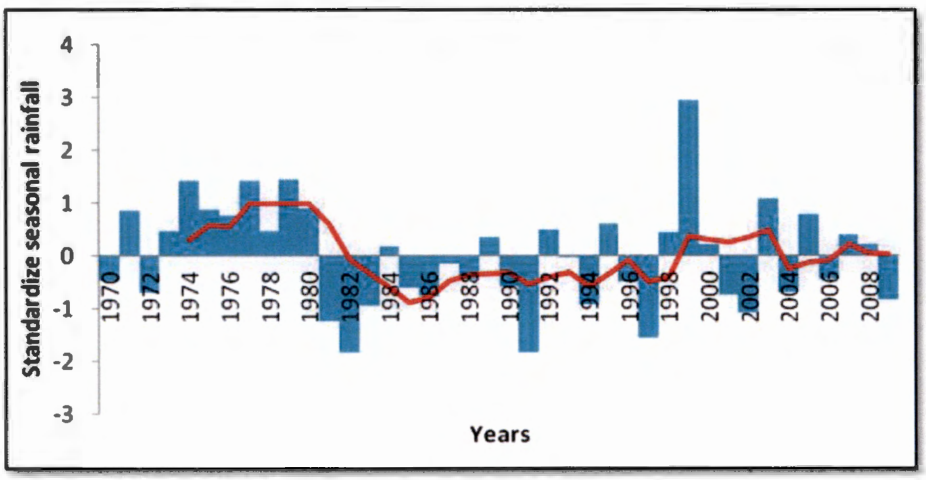


Figure 4.7: Standardized seasonal rainfall for NE

Figure 4.8 represents the rainfall anomalies in the South Western area. The graph shows that the area received significant above mean area rainfall for the period of study in the years1975, 1977, 1995 and 1999.1999 had rainfall 2.1 above the mean. Dry spells were experienced between 1978-1994 and 2001-2008. The lowest year was 1982 with the -1.56 below the mean. This figure shows in 1992, there was a drought which affected the majority of the factors including water, agriculture. The graph shows that in the year 2000, the rainfall distribution was above normal during these periods and floods were experienced in most parts of the country. Infrastructure and human lives were also lost due to floods in most areas.

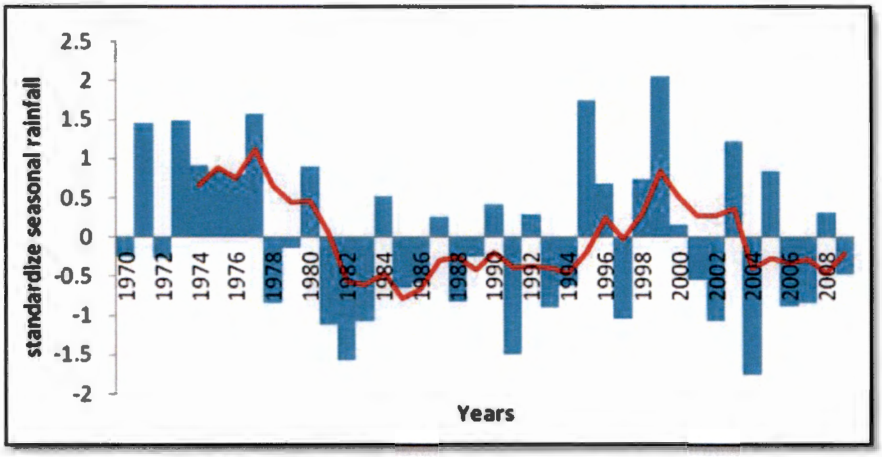


Figure 4.8: Standardized seasonal rainfall for SW

The rainfall for the SE during the period of study had three peak periods of rainfall- 1977, 1980 and 1999. The highest was in 1977 with a standard deviation of 2.2 above average. Extended below normal rainfall was experienced from 1982 -1995. Although, 1987 experienced a slight above normal rainfall it was part of the rainfall season which could not have offset an extended dry season. The driest period with -0.94 below mean was in 1985 (Figure 4.9).

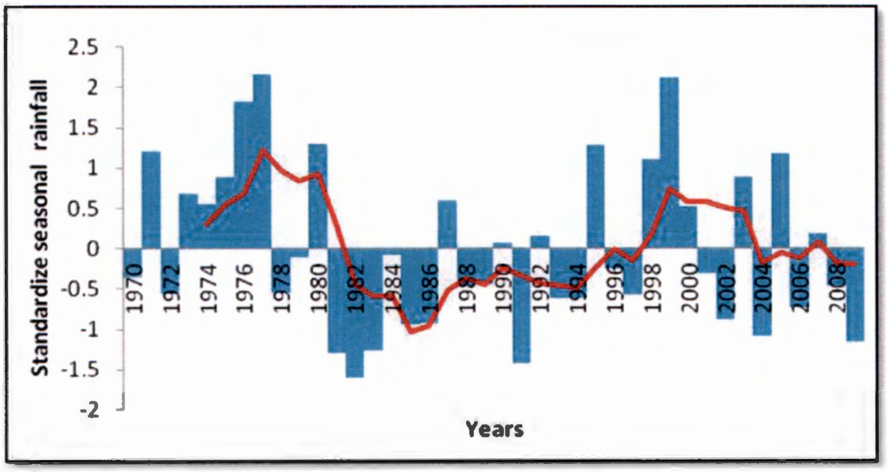


Figure 4.9: Standardized seasonal rainfall for SE

Figure 4.10 represents the rainfall for CE stations. The graph shows that the area received above mean area rainfall for the period of study with the exception for the period 1981-

1994 and 2004-2009. In 1999 the station recorded the highest rainfall with a departure of 2.6 above the mean area rainfall. The lowest rainfall was in 1986 with -1.2 below the mean.

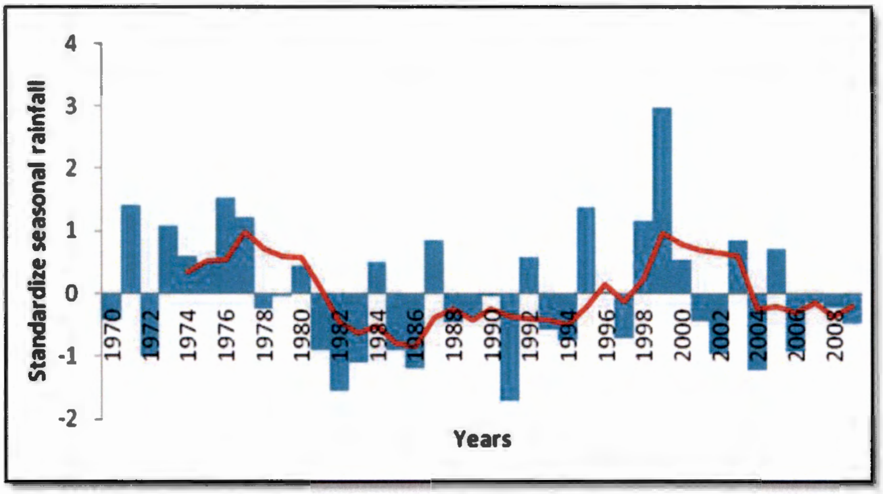


Figure 4.10: Standardized seasonal rainfall for CE

The seasonal rainfall of the areas in the North facing slope is lower than the rainfall in the south facing slope and CE stations as illustrated by the departures from the long term mean. The south facing stations generally receive rainfall above normal whereas all the north facing slope stations receive more of below normal as shown in Figures 4.6, 4.7, 4.8, 4.9 and 4.10.

4.2.3 Seasonal Average Rainfall

The averaged seasonal rainfall for the study period 1970-2009 for each delineated area of the Soutpansberg shows variations across the mountain as evident from the Figure 4.11.

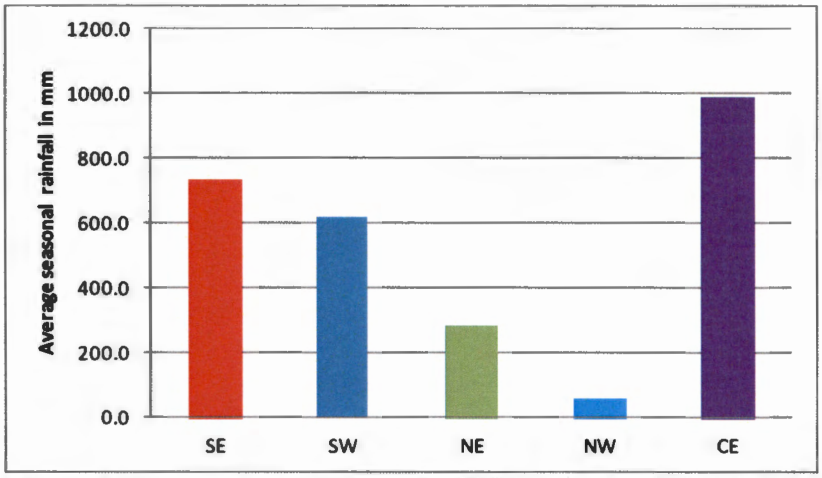


Figure 4.11: Average seasonal rainfall on delineated areas stations (1970-2009)

The S. E stations show accumulated seasonal mean rainfall from 1970-2009 of 734.9 mm, SW - 617.6mm, C.S – 988.9mm, NW - 56.03mm and NE - 284.2mm. From Figure 4.11, it can be deduced that the rainfall stations on the Southern Slope experience more rainfall than those on the Northern Slope. The CE stations experience the most rainfall. It is worth noting that on either slopes the western regions experience lower rainfalls than their eastern counterpart stations. Hence there is a decline in rainfall from east to west direction as observed by Kabanda (2011).

4.2.4 Z- test

In order to establish if the variations in seasonal rainfall totals of the NW, NE, SW, SE and CE are statistically significant, the z-test statistics was computed for the various areas. The test compared the means and determined if there is a significant difference in the composite rainfall in the delineated areas. The significance level was set at 0.05 (5%). Tables 4.1 and 4.2 show the result of the computation.

Table 4.1: Descriptive Statistics group variables

	N	Range	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance
GROUP	5	292620.60	13446.30	306066.90	647533.35	129506.6700	120666.07660	14560302040.990
Valid N (list wise)	5							

Table 4.2: Descriptive Statistics group variables - Z test

	Group
Mean	129506.6700
Known Variance	14560302040.990
Observations	40
Hypothesized Mean Difference	0
Z	4.285
P(Z ≤ z) one-tail	0
z Critical one tail	1.645
P(Z ≤ z) two-tail	0
z Critical two-tail	1.96

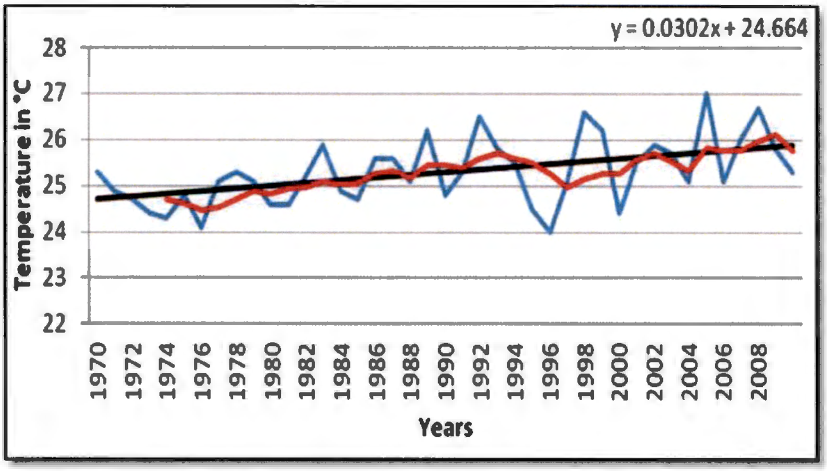
Evidence from Table 4.2 shows z = 4.285 which is greater than z critical value of 1.645. Hence on this basis the null hypothesis was rejected and it was established that the seasonal rainfall within the delineated area were statistically different. To reiterate this p-value for the two-tail-tests is compared with the α-value. Given that the p-value obtained in the analysis is 0 (Table 4.2) which is less than α=0.05, the null hypothesis which states that the means are equal is rejected.

4.3 Temperature Results

4.3.1 5 Year Moving average and Composite Temperature

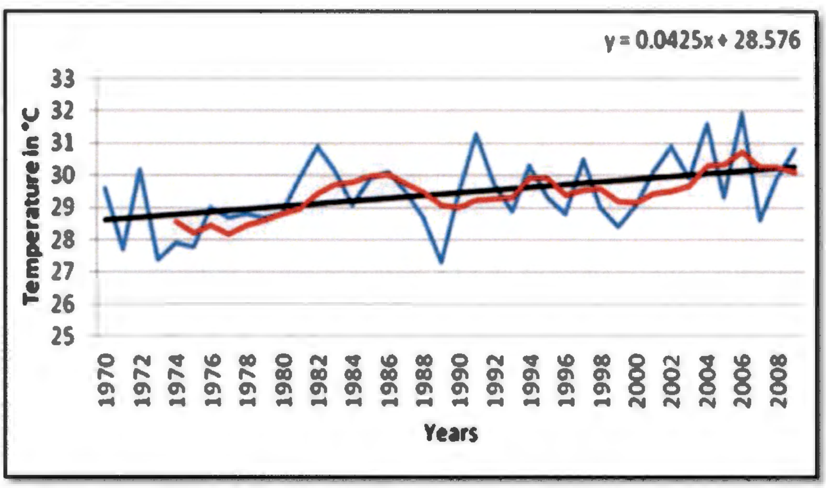
Composite temperature for the five delineated areas of the Soutpansberg was produced and a 5 year moving average was superimposed. A least square trend line was plotted following Equation 3.2 above, to further examine the nature of the trends in the temperature series. The least square trend line was plotted for the normalized values using the Microsoft Excel statistical tool, and estimation of changes in the temperature series determined.

From Figures 4.12.a and 4.12.b, it can be seen that maximum temperatures for Mara in both the dry and the rainy season are on the rise. The dry season experiences an increase in temperature of 0.03°c yearly beginning at 24.65°c and an increase of 0.04 beginning at 28.6°C in the wet season.



Actual temperature ▬ 5- year moving average; ▬ Trend line ▬

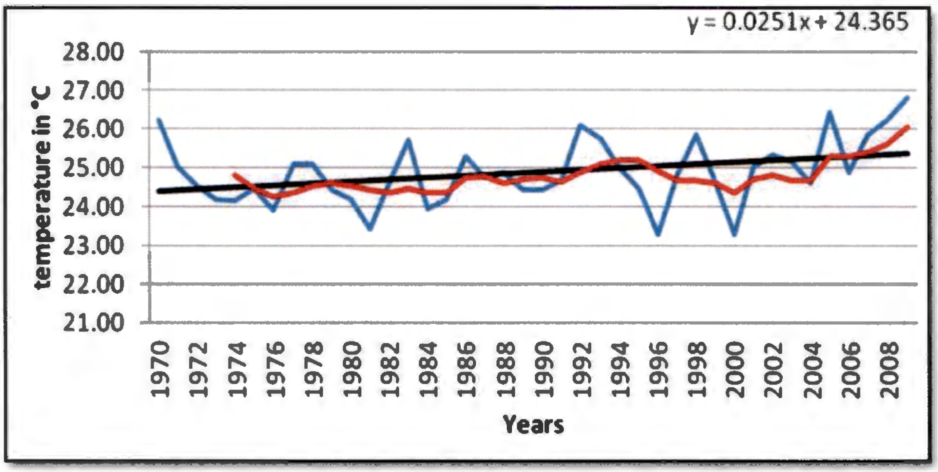
Figure 4.12.a: Mara composite maximum dry seasonal temperature, moving average and trend



Actual temperature ▬ 5 year moving average ▬ Trend line ▬

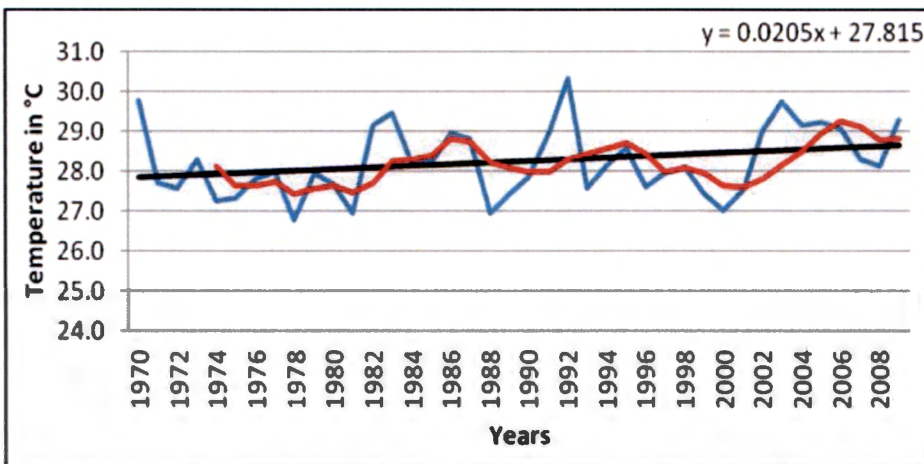
Figure 4.12.b: Mara composite maximum wet seasonal temperature, moving average and trend

Levubu also experiences an increase in temperature with 0.025°c increase beginning at 24.34°c in the dry season and 0.02°c starting at 27.8°c in the wet season as seen in Figures 4.13a and 4.13b.



Actual temperature ▬ 5 year moving average ▬Trend line ▬

Figure 4.13.a: Levubu composite maximum dry seasonal temperature, moving average and trend



Actual temperature ▬5 year moving average▬Trend line ▬

Figure 4.13.b: Levubu composite maximum wet seasonal temperature, moving average and trend

4.3.2 Temperature Anomalies

Temperature data for Mara and Levubu are normalized. Departure from normal would signify either above normal temperature or below normal temperature with respect to the seasonal temperature. The time variability of the composite temperature time series for the Mara is shown in Fig 4.14a and 4.14b. The solid line is the 5-year moving average time series.

Figure 4.14a shows that during the dry season, maximum dry season temperature were below the mean from 1974-1988. This was followed by temperatures above the mean maximum from 1999-2008 except for a dip in 1997.

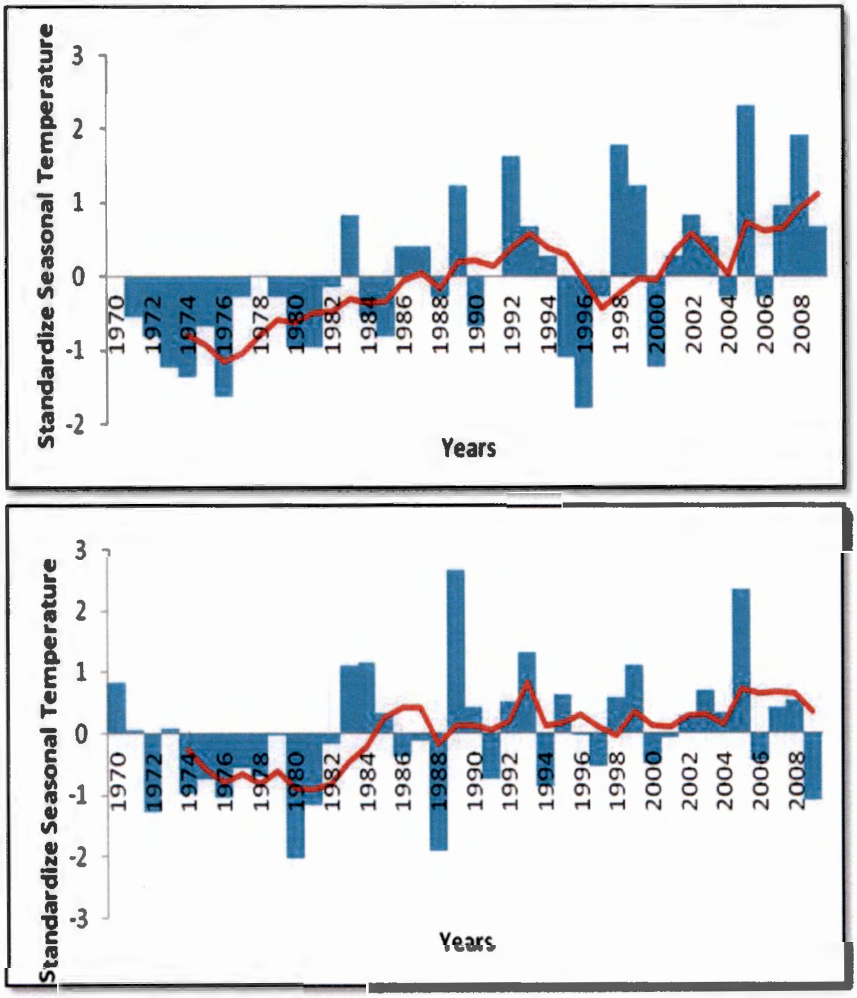


Figure 4.14a: Standardized maximum and minimum dry seasonal temperature for Mara

For minimum temperatures 1974-1985 had below mean minimum temperatures followed by temperature closer to the mean from 1985 onward with a slight dip in 1988.

Figure 4.14b shows the maximum and minimum temperature anomalies during the wet season for Mara. Below mean maximum temperatures prevail from 1974-1981, soared between 1982-1987, dipped and rose between 1988-2002, and had a continual rise from 2000. Minimum temperatures for the wet season were below average from 1974-1984, peaked in 1986-1987, followed by iterative high and lows very close to the means and a sharp peak from 2003. This continues until 2008 where there is a decline, but all this is above mean minimum temperature. The lowest SAI for the maximum dry season was -1.2 in 1976 and the maximum was 1 in 2008, while for the minimum temperature, the lowest SAI was -1.5 in 1981 and the highest above mean was 0.5 in 1993. For the wet season, the minimum SAI for maximum temperature was -1.2 in 1975 and 1977, while the maximum was in 2006. For the minimum wet season temperatures, a SAI of -1.8 was the lowest registered in 1981 and 1.2 for the highest registered in 2008 as shown in Figure 4.14b.

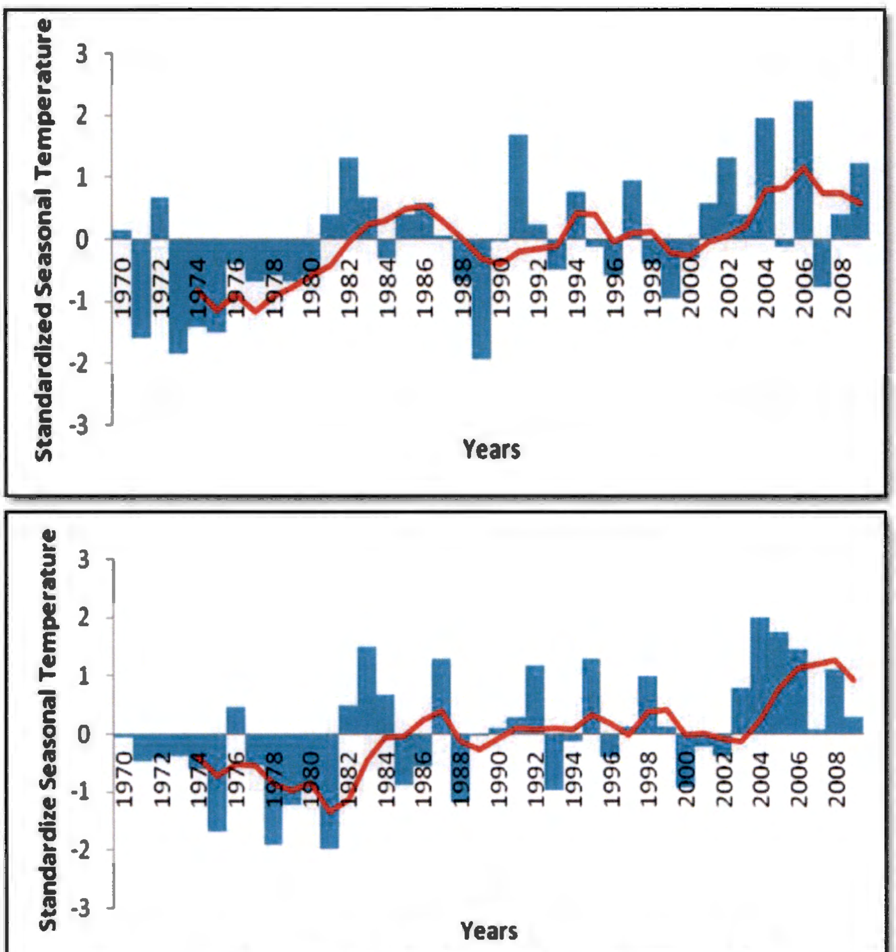
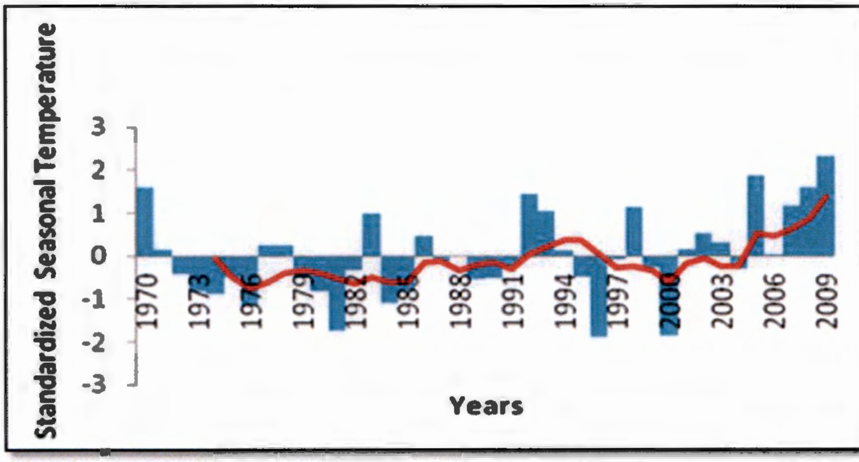


Figure 4.14b: Standardized maximum and minimum wet seasonal temperature for Mara

As shown by Figures 4.15 a and 4.15b, Standardized temperatures for the wet season for Levubu showed that temperatures were below the mean maximum for the period

1974-1982, 1990-1991 and 1997-2003. The lowest SAI was -1.2 in 1978, and the highest was 1.5 in 2006. For the minimum temperature, the period between 1974 -1982, 2001-2005, were below mean minimum temperatures. The lowest SAI was -1 in 1975. The rest of the years during the study period, temperatures were very close to the mean minimum. Below the mean temperatures might be as a result of increasing urbanisation.



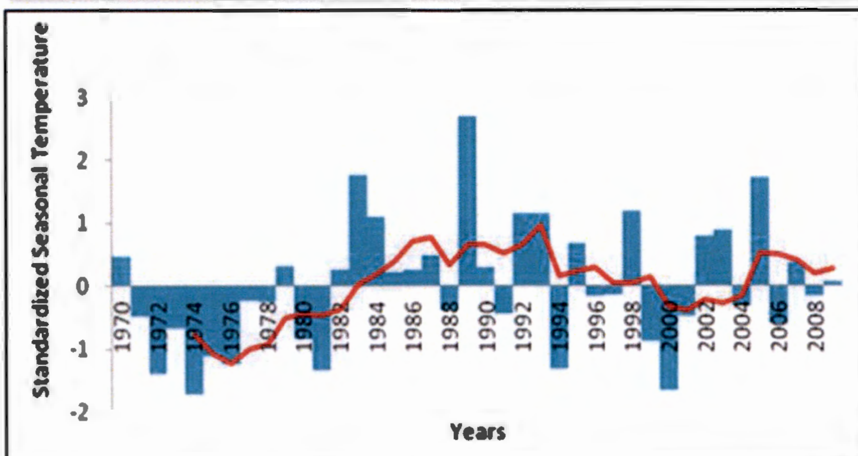


Figure 4.15a: Standardized maximum and minimum dry seasonal temperature for Levubu

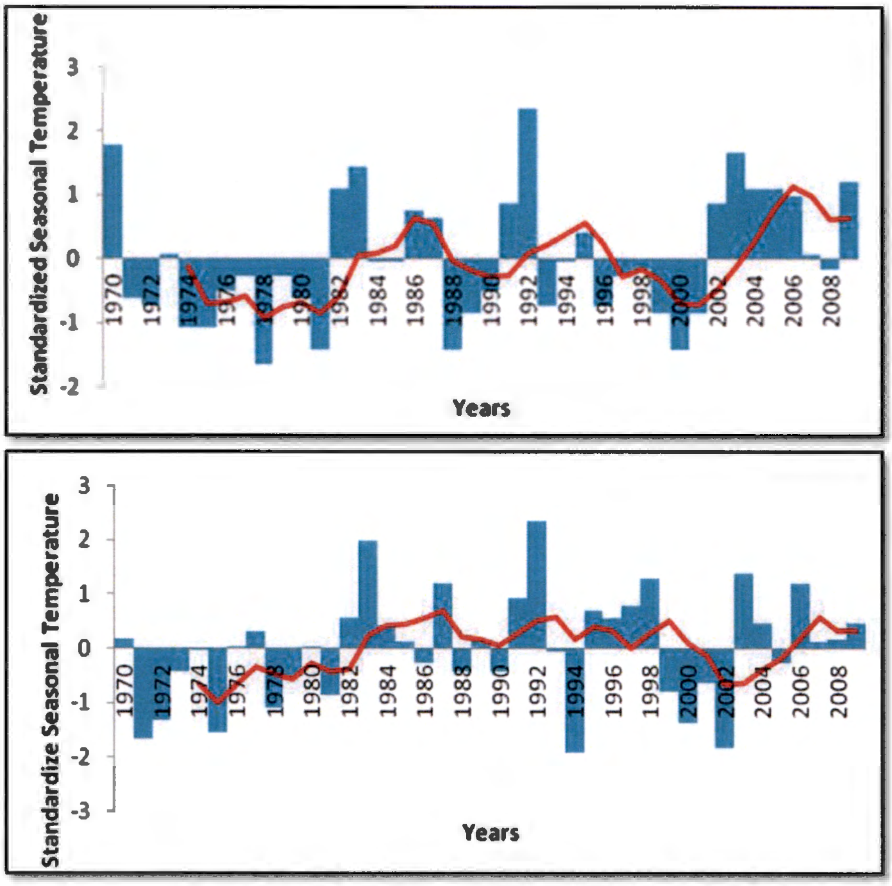


Figure 4.15b: Standardized wet minimum and maximum dry seasonal temperature for Levubu

4.3.3 Seasonal Average Temperature

Average seasonal maximum and minimum temperatures for Mara (representing SW) and Levubu (representing SE) for the study period 1970-2009 indicate temperatures vary between the two stations. As evident from Figure 4.16, Mara station shows an average maximum seasonal mean temperature from 1970-2009 of 24.9°C during the dry season and 29.4°C during the wet season. Levubu on the other hand shows lower mean temperatures when compared with Mara. For the study period 1970-2009, the seasonal mean maximum temperature for the dry season was 24.9°C and the wet season was 28.2°C. Hence it can be deduced that temperature increases from east to west on the Southern slope.

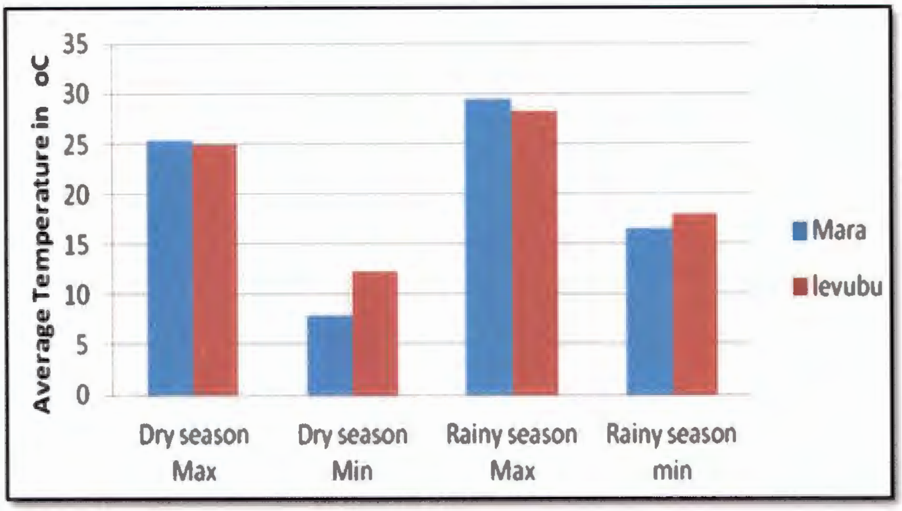


Figure 4.16: Seasonal average temperature- Mara and Levubu

T-Test

In order to establish that differences in the mean temperature for Mara and Levubu did not occur by chance, the T-test was used to compare the means. The significance level was set at 0.05.

Table 4.3: T- test statistic

	Mean	N	Std. Deviation	Std. Error Mean
Mara	151.0308	39	6.09729	.97635
Levubu	148.9795	39	4.68245	.74979

	Paired Differences					T	Df	Sig. (2-Tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval Of The Difference				
				Lower	Upper			
Mara - Levubu	2.051282	5.021893	0.804146	0.423373	3.679191	2.550881	38	0.014895

From the result in Table 4.3, the test revealed a statistically reliable difference between the mean temperature for Mara and Levubu, t= 2.551, $p \leq 0.015$, $\alpha = .05$. Given that the decision rule is given by: If $p \leq \alpha$, then reject H0, the null hypothesis is rejected. Hence the difference in temperature is not by chance.

4.3.4 Rainfall and Temperature Analysis

Table 4.4 shows the results of the correlation between rainfall and temperature at Levubu. The results indicate a weak negative correlation of -.15. The R^2 value indicates 21% of rainfall, can be explained by temperature. The ANOVA table indicates that the regression model predicts the outcome variable significantly. The statistical significance of the regression model that was applied indicates $p < 0.0005$ which is less than 0.05, hence, the model applied is significantly good enough in predicting the outcome variable. The regression Equation is shown on Figure 4.17.

Table 4.4: Simple linear Regression model for Rainfall and temperature at Levubu

		Rainfall	Temperature
Rainfall	Pearson Correlation	1	-.145**
	Sig. (2-tailed)		.000
	N	6766	6766
Temperature	Pearson Correlation	-.145**	1
	Sig. (2-tailed)	.000	
	N	6766	6766

**. Correlation is significant at the 0.01 level (2-tailed)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.145[a]	.022	.022	45.64883

a. Predictors: (Constant), temperature

Analysis of variance (ANOVA)

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	302008.594	1	302008.594	144.931	.000[b]
	Residual	14095971.222	6764	2083.816		
	Total	14397979.816	6765			

a. Dependent Variable: rainfall

b. Predictors: (Constant), temperature

Hence as shown on Figure 4.17, for every increase in temperature, rainfall decreases by .022 mm per season.

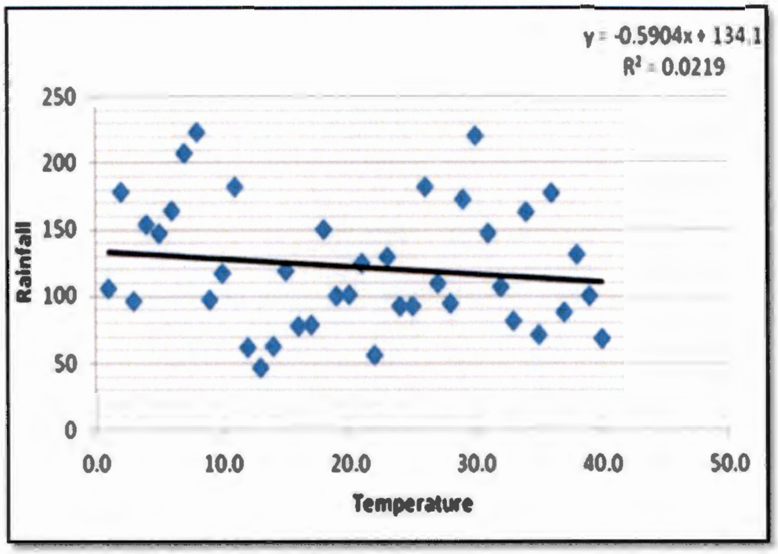


Figure 4.17: Scatter plot and regression analysis of Temperature and Rainfall at Levubu

4.4 Relevé Analysis

Figure 4.18 shows the results from vegetation sampling in unconserved plot. The results indicated that the SW had a high frequency of cover abundance class 3 (vegetation cover is between 25-50) covering 38% of the total SW. This was followed by class 4 (50-75%) with 28%, 5 (75-100%) with 28% and class 2 (5-25%) with 6% of the total land cover. Hence the percentage of cover abundance was between 25-50%. Intra and interspecies association showed the sociability class as class 3, indicating species occur in clusters or small aggregates. In the SE the cover class of abundance 4 covered at 67% of the total land surface, followed by 23% of cover abundance class 5 and 10% of cover class 3. Sociability between the species showed species occurred in large aggregates or carpets (sociability class 4).

In the NW, the vegetation cover fell in class cover 2 having 48% of the total land area, 21% of class cover 3; 15% of class cover 4 and 16% of class cover 5. The sociability class was 2; indicating species occurred in isolated clumps or bunches. The NE had class cover 3 covering 50% of the total land surface; abundance class 4 with 38% and abundance class 5 with 12%. Sociability was class 3 indicating species occur in small aggregates of clusters.

In CE, the abundance class was split between class 4 and 5 each occupying 44% of the land and 12% is covered by abundance class 3. The association between species is shown by class 5, indicating the species occur in large pure stands.

From the dominant cover abundance class of each delineated area, it can be concluded that the vegetation in the Northern portion is on the decline with a class abundance of 2 which signifies very low percentage vegetation cover for NW when compared to the rest of the areas. This is closely followed by NE with cover class 3; SW with abundance class 3; SE with abundance class 4 and the CE with abundance class 5. Also vegetation on the western portions are low when compared to the cover abundance of the eastern portion of the mountain.

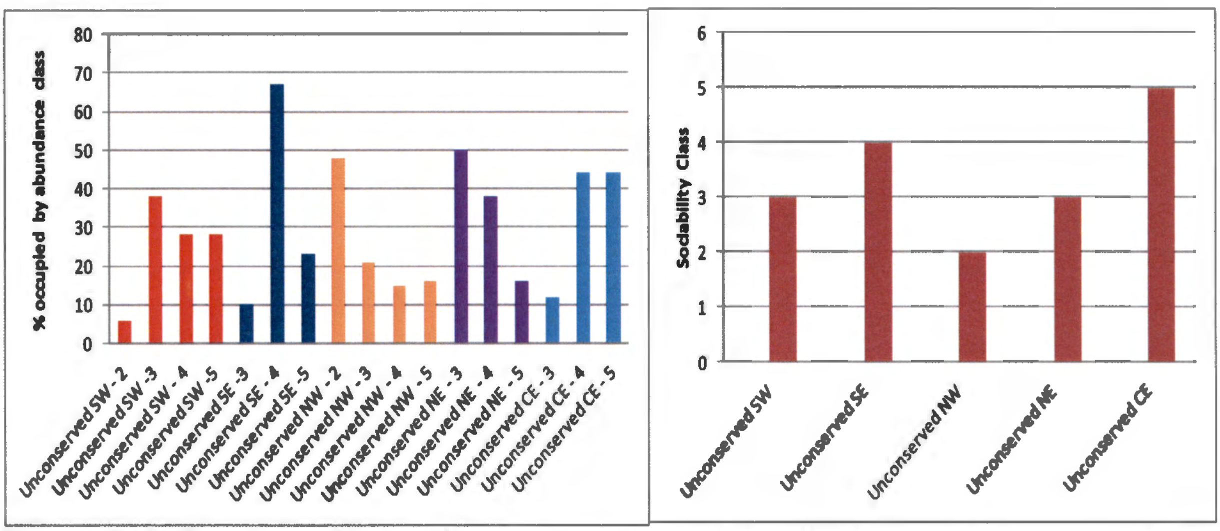


Figure 4.18: Cover abundance class percentage and sociability class in unconserved plots

Sampling results in the Conserved area (Figure 4.19) showed that vegetation in the SW had abundance class 3 with 50% total land cover, class 4 with 35% and class 5 with 15%. The sociability class was 4 indicating the vegetation occurs in aggregates or carpets. In the NW, the vegetation abundance classes 2 occupied 75% of land cover and 35% was occupied by class 3. The sociability class here was 3; species occurring small aggregates or clusters. Variations in vegetation cover abundance from class 2- 5 (5-100%) indicates that at one time the vegetation cover was in cover abundance class 5 (pristine vegetation) which has changed over the years leaving traces of what had once been.

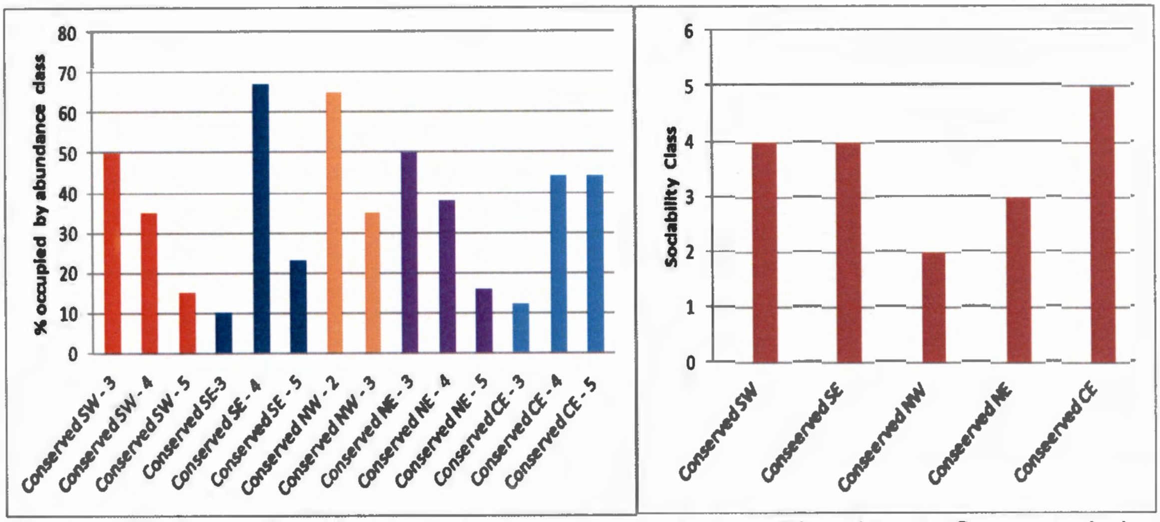


Figure 4.19: Cover abundance class percentage and sociability class in Conserved plots

Figure 4.20 shows the cover class abundance of Conserved areas as well as the unconserved. From the cover class, the unconserved areas- SE, CE, have more vegetation abundance cover of almost pristine nature. SW and the Conserved areas in the SW have the same cover abundance as well as the conserved and unconserved areas in the NE and NW. Paradoxically; the protected areas do not show any advantage in their vegetation status when compared to the unprotected areas. Instead unconserved area shows more abundance and vigour when compared to the Conserved vegetation in the western part of the Soutpansberg.

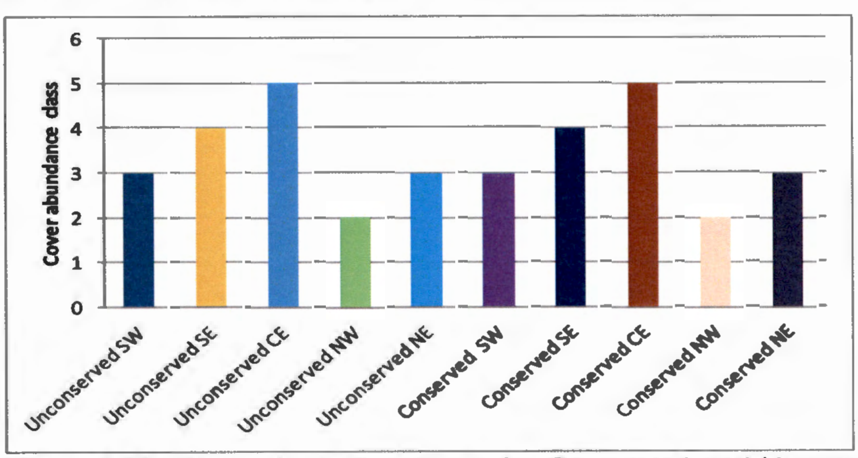


Figure 4.20: Cover class abundance for Conserved and Unconserved sampled plots in the Soutpansberg

From the dominant cover abundance class of each delineated area, it can be concluded that the vegetation in the Northern portion is on the decline with a class abundance of 2 which signifies very low percentage vegetation cover for NW when compared to the rest of the areas. This is closely followed by NE with cover class 3; SW with abundance class 3; SE with abundance class 4 and the CE with abundance class 5. Also vegetation on the western portions are low when compared to the cover abundance of the eastern portion of the mountain.

4.4.1 Chi- Square Analysis

The Chi Square statistic was carried out in SPSS version 20, in order to establish if there is a statistically significant difference in the observed vegetation cover in the various delineated areas (conserved and unconserved). And if so this should not be attributed to a chance occurrence. The results of the test set at significance level 0.05 (5%) is shown in Table 4.5.

Table 4.5: Chi Square results test statistics

	Conserved Veg NW	Conserved Veg SW	Conserved Veg NE	Conserved Veg SW	Conserved Veg SE	Conserved Veg NW	Conserved Veg C.S
Chi Square df Asymp. Sig.	.333[a] 1 .564	1.000[b] 2 .607	4.625[c] 2 .099	6.000[d] 3 .112	19.400[e] 2 .000	4.538[f] 3 .209	12.605[g] 2 .002
$X^2 = 5.417$	df = 6						

From the chi- square analysis (Table 4.5), p= 0.05, X^2=15.417 and the degree of freedom = 6. Based on the level of significance p = 0.05, the table value is 12.592. When the Chi Square value is more than the table value it means the difference is significant. Therefore, at the 5 % level of significance, the data do provide sufficient evidence to conclude that the vegetation density on the Conserved and unconserved is different. The results indicate (95% confidence) that the difference between the data sets cannot be due to chance, rather there is a statistically significant difference in the vegetation density in the conserved and unconserved areas of the mountain.

4.5 Vegetation Structure and response to rainfall

Rainfall values were associated with vegetation cover abundance in the various sites as seen in Table 4.6, in order to see if the conservation status influenced the structure and composition of vegetation. Observation revealed that, in the unconserved areas of the mountain, the vegetation structure of the CE can be termed as a forest with 90% canopy cover. This area harbours an almost pristine forest structure with a well-developed five layers emergent, canopy, understory, shrub layer, herb layer and forest floor and climbers. Describing this area as a forest falls in line of that of Edwards (1983).

The SE area had a dominant cover of trees forming a canopy cover of about 80%. This area too is described as a forest - in agreement with Edwards (1983). The forest here had a three layer structure. The SW had patches of forest cover occurring. Even though with the existence of a forest, it is not as well developed as that in the SE and CE. The vegetation in the SW had a canopy cover of about 50%, a forest 3-layer with no definite separation between the tree and shrub layers.

The vegetation in the NE had a canopy cover of 45% with sparsely populated trees. It is more of a transition between indigenous forest and savannah. The rainfall is low and the lack of multiple strata in the canopy does not warrant its inclusion with forest type (Everard, 1987). The NW had a canopy cover of about 25%, falling under savannah type with low open grassland with patterns of short deciduous trees.

The conserved areas in the SW had a similar canopy cover as the unconserved and the NW Conserved had a similar pattern to the unconserved. Comparing the canopy cover between the Conserved and unconserved areas in the delineated areas, the unconserved areas in the Centre and eastern portions of the mountain showed a canopy cover of 82% while the Conserved areas in the western parts had about 22%. This shows paradoxically, that even though Conserved, the western areas of the mountain show poor vegetation structure when compared to their eastern unconserved sites.

Table 4.6 also indicates that, areas with seasonal average rainfall of about 0-100mm had low canopy covers of about 30%. This is true for areas like the NW Conserved and unconserved areas. Areas with seasonal average rainfall of about 200-350mm had canopy cover of about 45% like the NE. SW Conserved and unconserved areas had seasonal average rainfall of above 500mm and the canopy cover was 50%; SE had seasonal average rainfall of above 700mm with canopy cover of 80% and CE with average seasonal rainfall of above 900mm having canopy cover of 80%. Considering the relationship between rainfall and temperature (Figure: 4.9), it can be said that areas with more rainfall like the CE had lower temperature. The area experiences increase temperature and lower rainfalls as you move from east to west. Hence vegetation decline from east to west following the climatic pattern.

Table 4.6: Vegetation response to rainfall

Area	Rainfall (mm)	Vegetation Density (%) Per Relevé	Forest Structure	% Canopy Cover	Vegetation Class	Description /characteristic
Unconserved SW	~600	25-50	3 layers	50	woodland	No definite separation between tree and shrub layer
Unconserved SE	~800	50-75	4 layers	80	Forest	Moderately closed stands of evergreen trees
Unconserved C.S	~1000	75-100	5 layers	90	Forest	Closed stands of indigenous evergreen trees
Unconserved NW	~ 100	5-25	1 layer	25	Savannah	open grassland with patches of short deciduous trees
Unconserved NE	~400	25-50	2 layers	50	Sub-tropical thicket	Short moderately closed woodland
Conserved SW	~600	25-50	3 layers	50	Woodland	No definite separation between tree and shrub layer
Conserved SE	~800	50-75	4 layers	80	Forest	Moderately closed stands of evergreen trees
Conserved C.S	~1000	75-100	5 layers	90	Forest	Closed stands of indigenous evergreen trees
Conserved NW	~ 100	5-25	1 layer	30	Savannah	open grassland with patches of short deciduous trees
Conserved NE	~400	25-50	2 layers	45	Sub-tropical thicket	Short moderately closed woodland

Appendix 5.2 shows the dominant species for the various plant life forms as observed during the field study. From the distribution of the various plant life forms in each area, there is a decline of vegetation cover from forest to woodland, woodland to shrub and from shrub to grassland as the rainfall decrease towards the west of the Soutpansberg. This is supported by Mucina and Rutherford (2006), who are also of the opinion that the Soutpansberg changes from rainfall gradient distribution of dense deciduous woodlands and evergreen montane forests to a poorly developed grassy layer, and relatively open savannah westward. The existence of patches of forest spread over the mountain

indicates the area at one time hosted mature forests which have degenerated into woodland towards the west. Given that 55% of plants occurring within the Soutpansberg are succulents (Hahn, 2002), it can be deduced that the changing vegetation structure and evolution is related to water stress.

4.6 Results of Image Analysis

4.6.1 Image Classification

The results of the image classification process were obtained using the hybrid classification technique. The 1989 image (Figure 4.21a) showed forest cover of about 50% of the area followed by woodland with 25% and the other vegetation classes 10%. Build up areas and other land uses to cover about 15%. The 1998 image (Figure 4.21b) portrays about 20% vegetation belonging to woodland, 25% of thicket, 10% of shrub, 25% of forest and 20% to other vegetation and land uses.

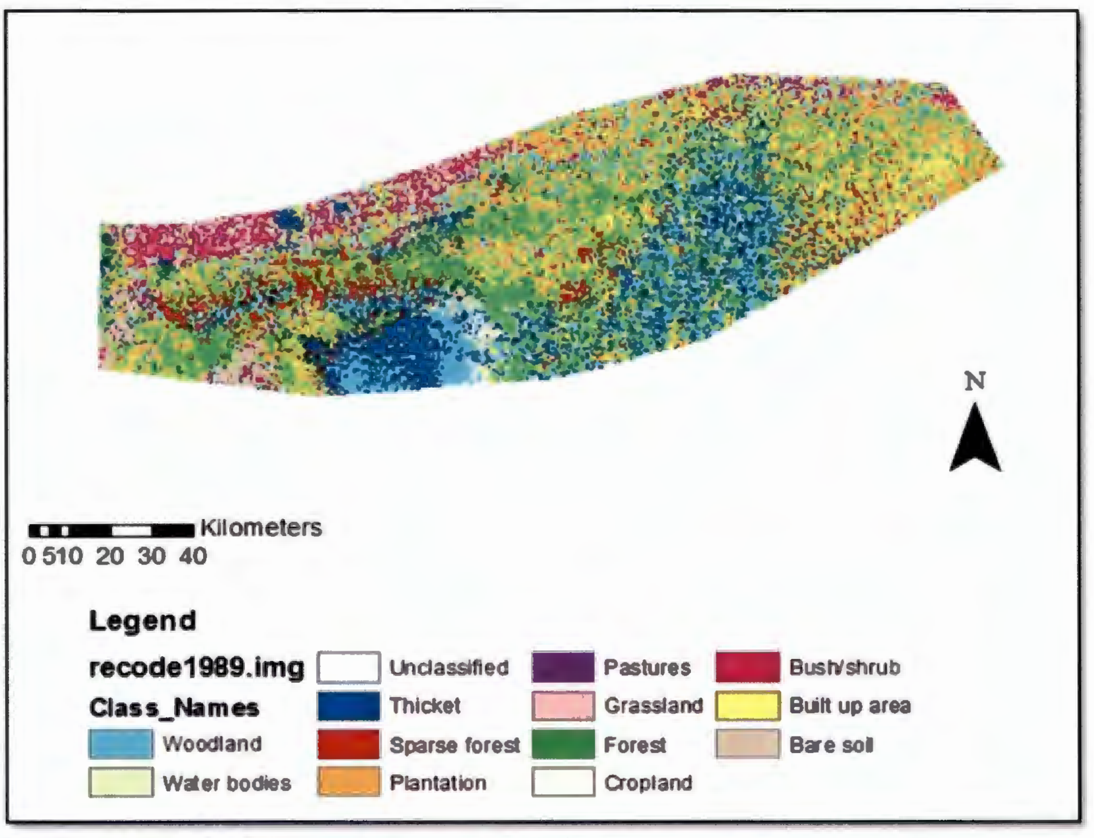


Figure4.21a: Vegetation distribution in 1989-Soutpansberg

From 1989 to 1998 the proportion of forest cover shrinks with an increase in woodland, thicket and sparse forest coverage increasing. In the 2008 image (Figure 4.21c) woodland was the predominant vegetation type, with an increase in plantation and sparse forest cover. The increase in forest cover to the south eastern portion is a result in an increase in pine and eucalyptus plantation which can be confused with indigenous forest.

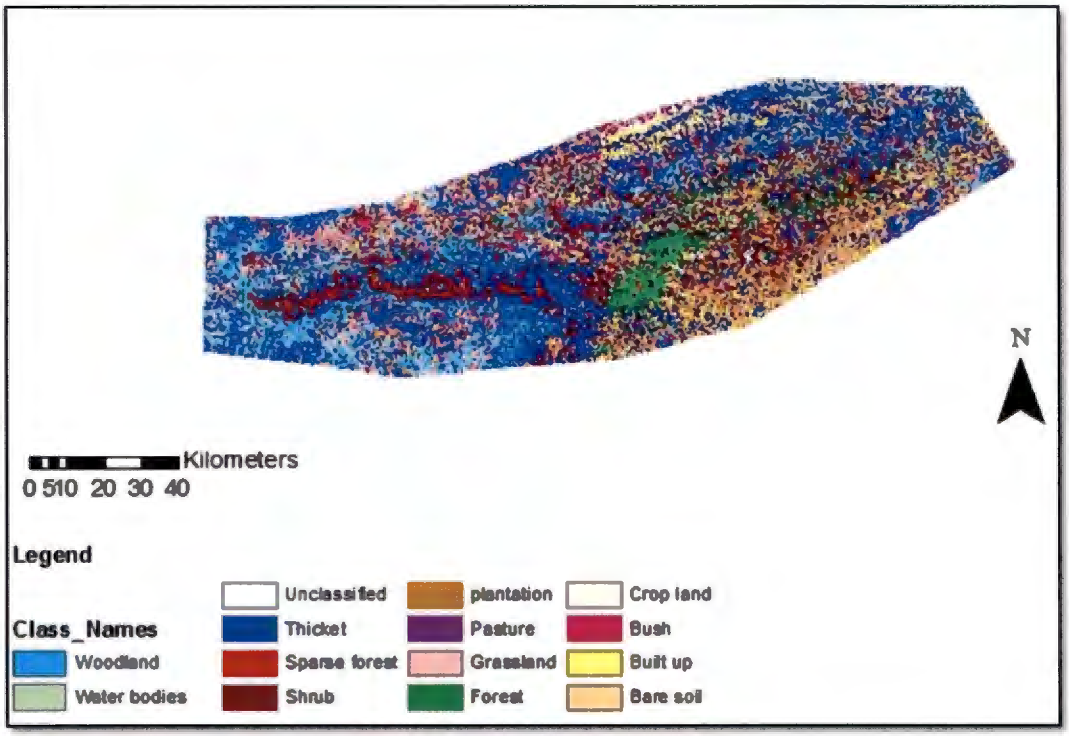


Figure4.21b: Vegetation distribution in 1998-Soutpansberg

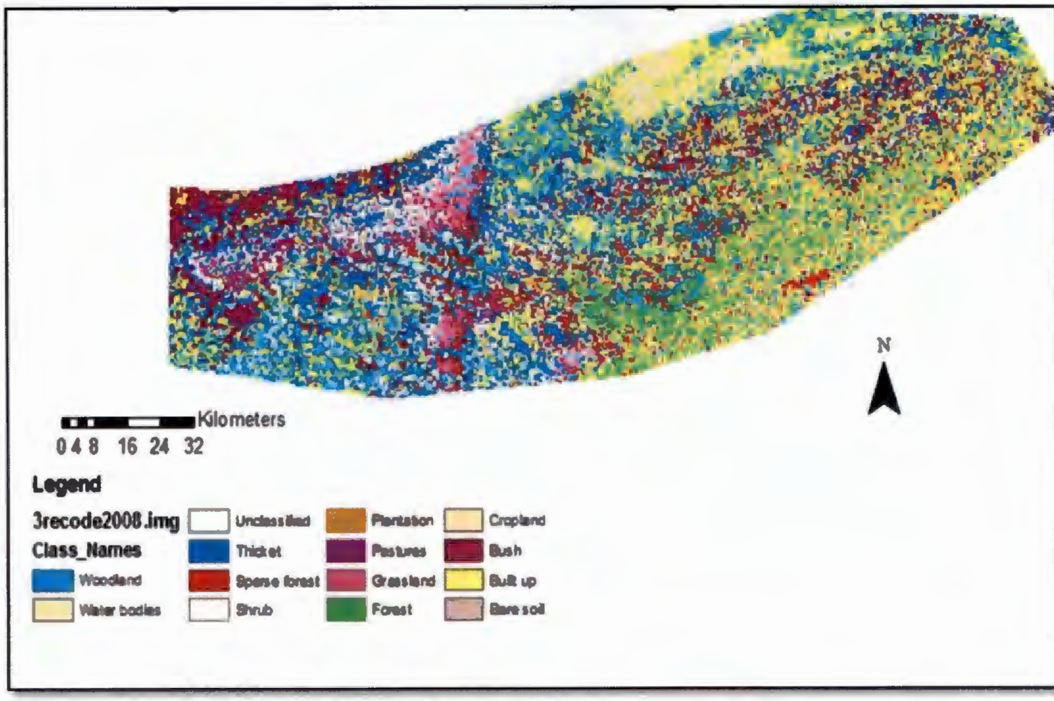


Figure4.21c: Vegetation distribution in 2008-Soutpansberg

Therefore with the passage of time, the vegetation is making a transition from forest to woodland and shrub land.

4.6.2 NDVI

Figures 4.22a, 4.22b and 4.22c showed the NDVI values from the various vegetation cover from the years 1989, 1998 and 2008. NDVI values from the March 1989 image (Figure 4.22a) showed a high reflectance value indicating there was a high vegetal cover for the area in this period. Though there are differences in the values, with vegetation in the CE near rainfall stations, Rambuda shows high NDVI values of between 0.6-0.9; SE stations like Levubu also had high NDVI values of between 0.4-0.6; NE represented by Tshipise had NDVI value of 0.2- 0.4; SW –Mara- 0.2-0.4 and NW-Waterpoort 0.4-0.6. This indicated a high cover abundance and composition of vegetation during this period.

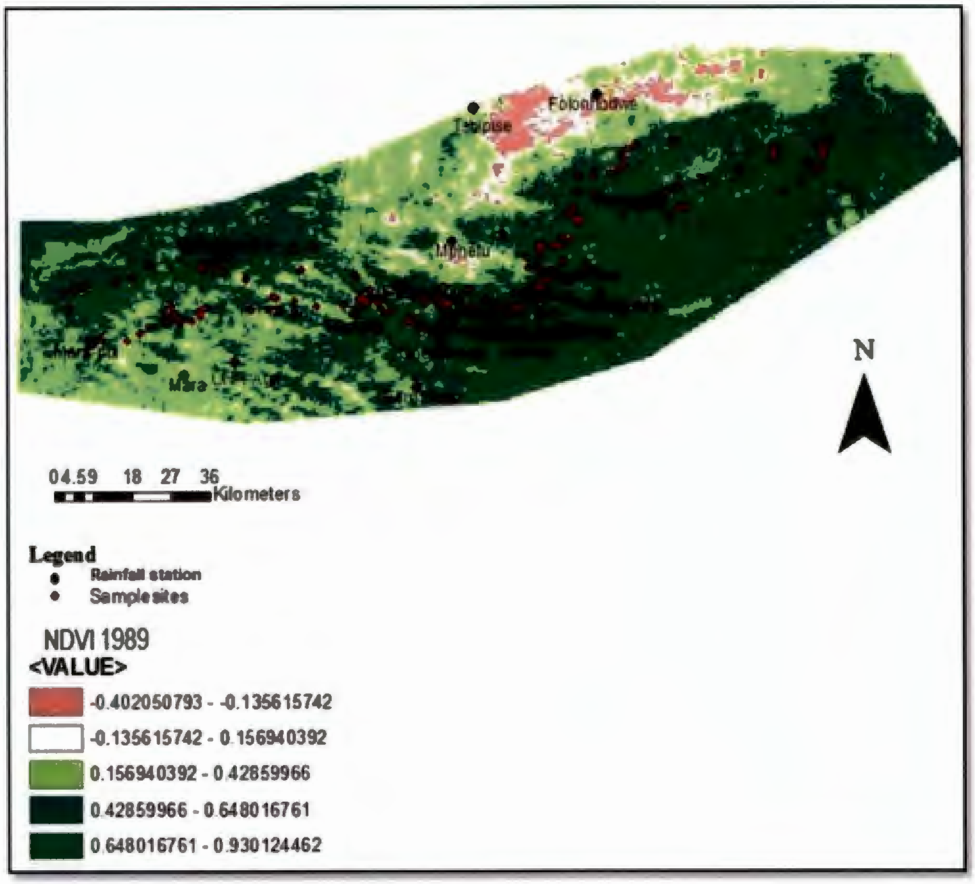


Figure 4.22a: NDVI for March 1989

NDVI values for March 1998 showed a decline in the reflectance value of the vegetation. This was probably due to a decline in composition and biomass. Figure 4.22b showed a decline in reflectance value especially for Waterpoort to 0.3-0.5 from the initial 0.4-0.6 in 1989.

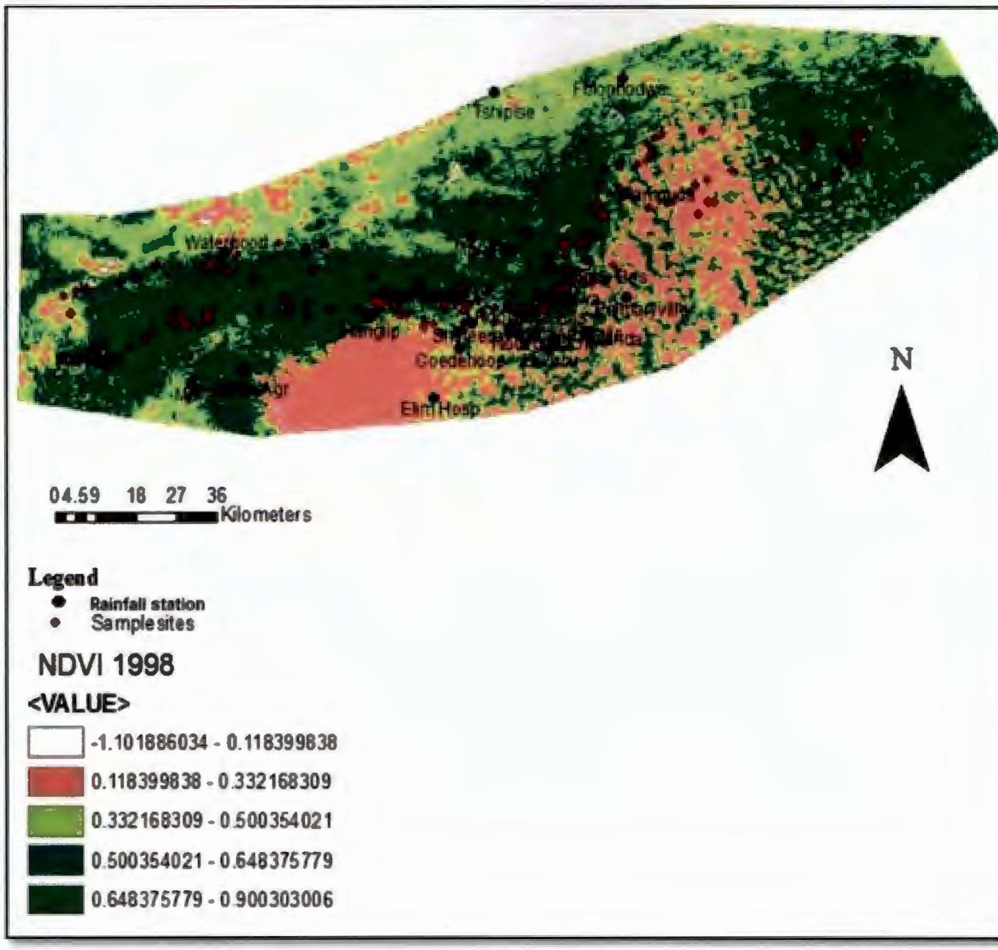


Figure 4.22b: NDVI values – March 1998

The March 2008 NDVI results (Figure 4.22c) showed a decline in the reflectance value of vegetation. Only areas such as Rambuda in the centre maintained the high NDVI value of 0.5-1, followed by the SE area of Palmaryville with 0.3-0.5.

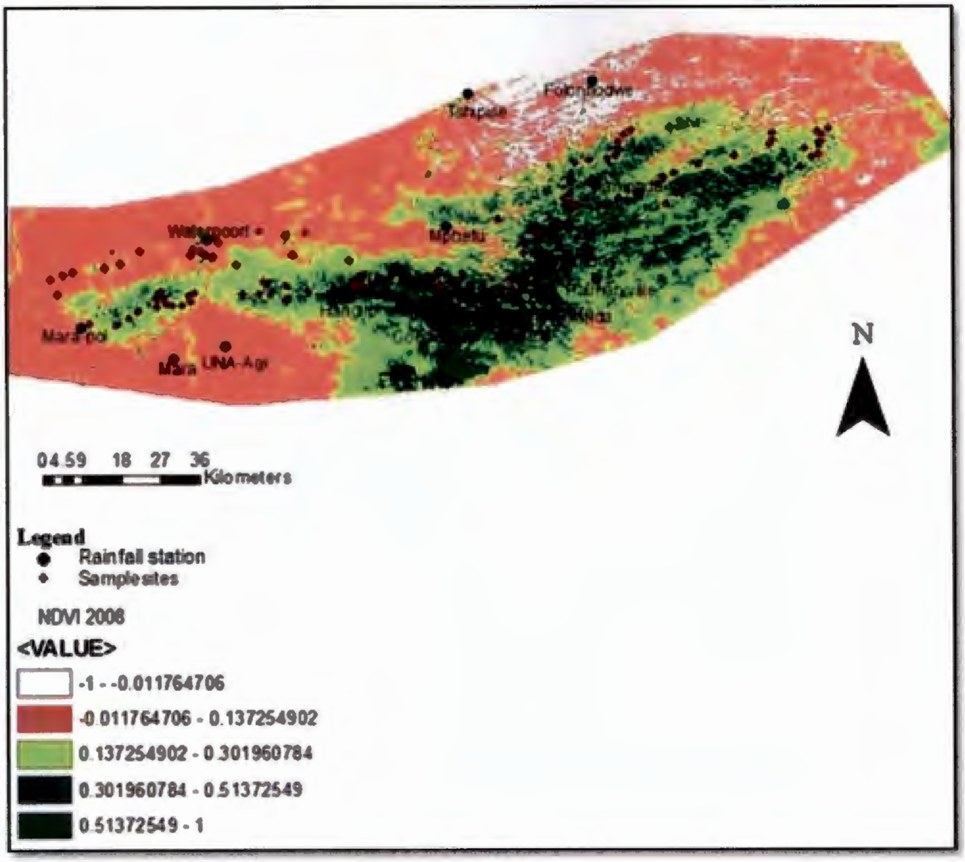


Figure 4.22c: NDVI values- March 2008

4.6.2.1 Rainfall and NDVI

The difference in contrasting rainfall years as shown in Figures 4.22a-c had influenced the vigour and biomass of vegetation. This was seen particularly in the indigenous vegetation of the Soutpansberg. The lush greens found in the eastern part of the NDVI images are mostly plantations. Decline in rainfall and increasing temperatures adds up to decreasing vegetation composition, vigour and status. Figure 4. 23 showed the correlation between rainfall and NDVI for representative stations of the delineated area. The Figure showed that with an increase in rainfall, NDVI values increased or a decline in rainfall resulted in low NDVI.

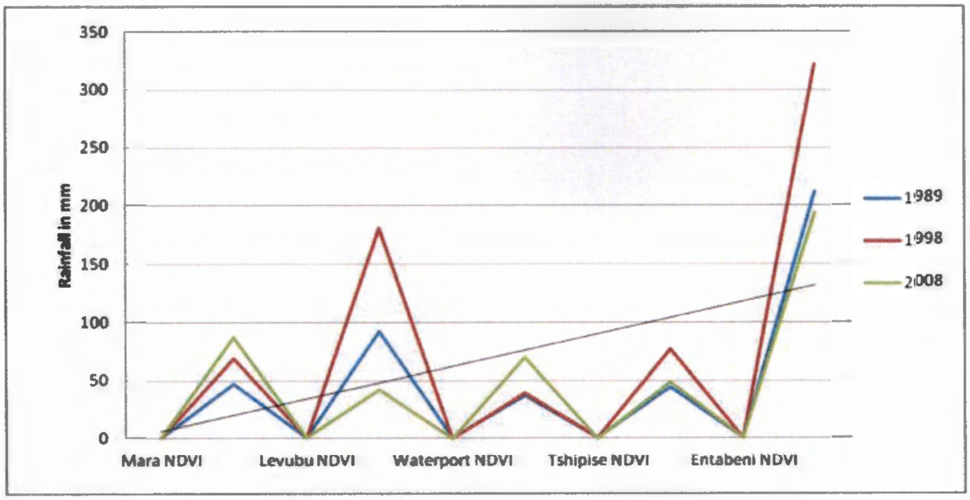


Figure 4.23: Relationship between rainfall and NDVI

4.6.3 Change Detection

The image subtraction method, using NDVI images of 1989, 1998 and 2008, yielded change detection results as seen in Figures 4.22a, 4.22b and 4.22c. Between 1989 and 1998, there was about 98% decline in the vegetation vigour. Probably from the transition of forest to other vegetation classes (Figure 4.23a). Between 1989 and 2008, the decline registered as seen in Figure 4.23b is about 60%, particularly in the western parts and the NE. An increase of 35% was also experienced as well as some increase of about 5% in the northwest. These increases might be as a result in the increase in pine and eucalyptus plantations in the Soutpansberg as shown in the change map of 1998-2008 (Figure4.23c).Figure 4.23c show more increase in vigour and about 35% of decreases

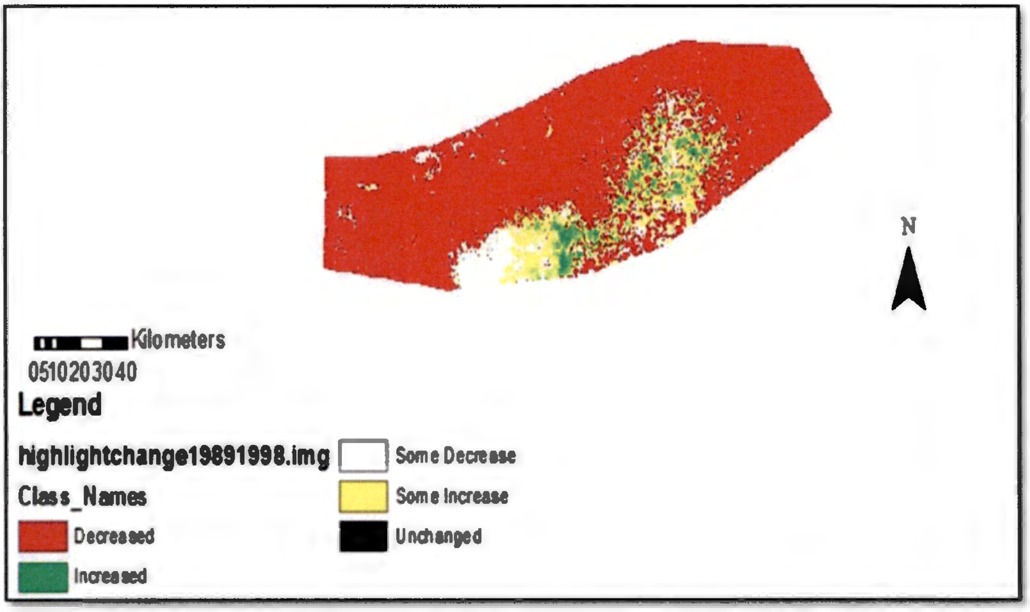


Figure 4.24a: Vegetation change in the Soutpansberg 1989-1998

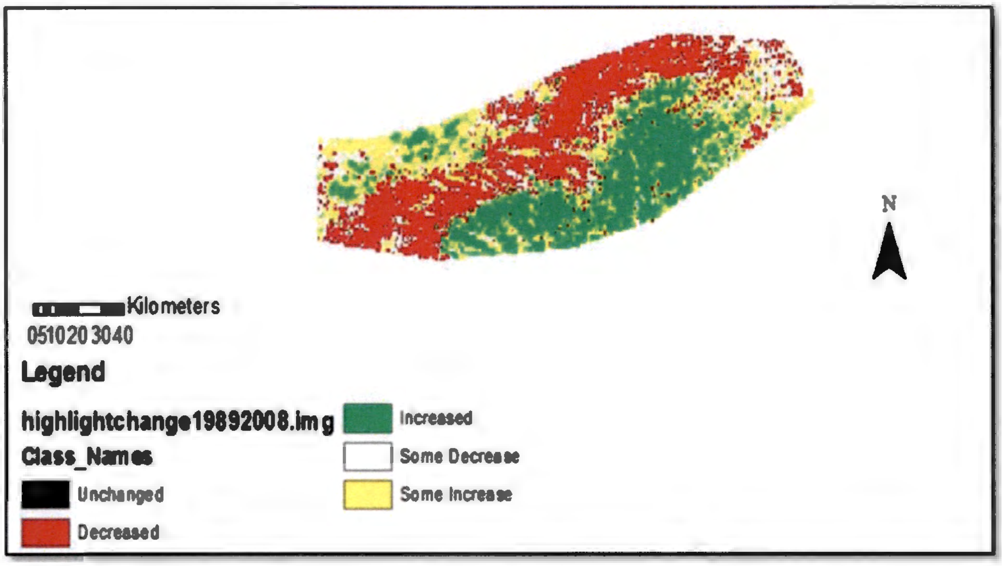


Figure4.22b: Vegetation change in the Soutpansberg 1989-2008

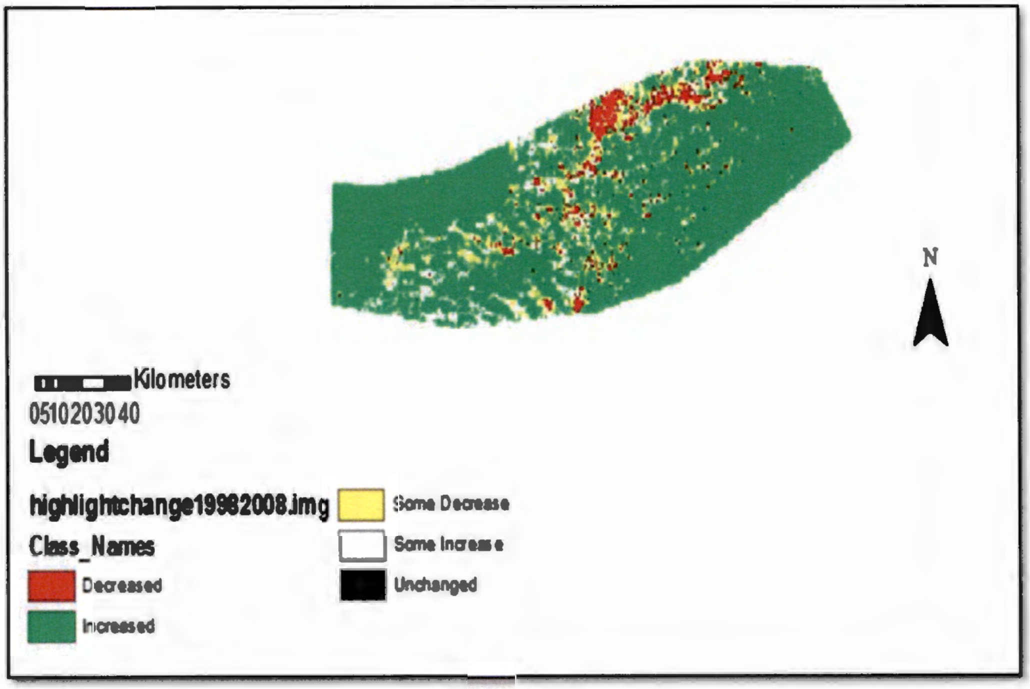


Figure4.24c: Vegetation change in the Soutpansberg 1998-2008

These increases are periodical because these trees are planted not for afforestation purposes but for commercial purposes. This might be misleading in the sense that the vigour shows increase in biomass and composition but in essence this pertains to non-Indigenous vegetation.

4.7 Accuracy Assessment

A classification accuracy assessment was performed on the images for the study area and an assessment report was obtained having an error matrix, accuracy totals and a kappa statistics .To evaluate the accuracy of the classification system, 287 reference test pixels were identified to achieve an accuracy of 70% that with an acceptable error of 5% (McCoy, 2005). The classified image of 1989, 1998 and 2008 were verified with google earth. Stratified random method showed a close percentage of overall classification accuracy for each year. The overall accuracy derived from the sampling method for the 1989, 1998, and 2008 classified images were 81.86%, 78.43%, and 88.00% with an overall kappa statistic of 0.79, 0.75, and 0.86, respectively. A high accuracy assessment was obtained in water bodies, closed canopy forest, and urban and built-up land categories for all three years while the simple random

The overall Kappa statistic indicated that the classification of 2008 image was more accurate than that of the 1998 image, and the classification of 1989 image was more accurate than that of the 1998 image. Tables 4.2 to 4.13. Shows the error matrices and accuracy statistics .The Kappa statistic measures the difference between the true agreement of classified map and chance agreement of random classifier compared to reference data (Lillesand et al., 2004). Kappa values of more than 0.80 indicate good classification performance. Kappa values between 0.40 and 0.80 indicate moderate classification performance and Kappa values of less than 0.40 indicate poor classification performance.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study aimed at assessing the impacts of anthropogenic climate change on the vegetation of the Soutpansberg. This was done by identifying and analysing climate data, as well as change detection of vegetation cover using multitemporal remote sensing (RS) data and GIS based techniques. Rainfall values for each delineated area of the Soutpansberg were analysed and compared to each other. This was to determine dominant local patterns and possible cyclicity of climate change over the past 40 years, as well as vegetation change. Special focus was on the changes in vegetation structure and composition, magnitude and direction of change in the various areas. Vegetation classes were identified and their spatial distribution assessed with the aid of various NDVI maps, and the use of image differencing methods to project areas under risk. The relationship between the vegetation covers and its associated climatic patterns were investigated to account for anthropogenic climate influences on the vegetation structure and composition. With these objectives carried out, the answers to the research questions were provided in the study and the stated hypotheses answered per results presented in Chapter Four. From the results:

The null hypothesis which stated anthropogenic climate change does not affect the vegetation of the Soutpansberg was rejected. Empirical evidences (Section 4.2.2; 4.3.4; 4.5) showed a decline in seasonal rainfall regimes, seasonal increase in temperature like in Levubu. This increasing temperatures and increasing rainfall might be as a result of expansion in urban sprawl. These impacts the distribution of vegetation across the mountain with areas having more rainfall and lower temperatures having abundant vegetation like the Centre and South Eastern regions.

Specific Hypothesis 1 stating a significant relationship between anthropogenic climate change and vegetation status is accepted and the null hypothesis rejected. Results (Section 4.5) showed that areas experiencing more seasonal rainfall had denser and had more species abundance with higher sociability between plant species (Section 4.4).

Specific Hypothesis 2 stating the rate of impact of anthropogenic climate change varies across the range is accepted against the null hypothesis. Climate results (Sections 4.2.2; 4.2.3; 4.2.4; 4.3.2; 4.3.3; 4.3.4) show seasonal rainfall amounts varying between the SW, SE CE, NE and NW. These differences are high especially between the NW and the rest of the regions. The variation in rainfall regimes and temperature results in each area of the mountain experiencing different magnitude of anthropogenic climate change effects.

Specific Hypothesis 3 stating the effects of anthropogenic climate change impacts vary across time is accepted based on visual representation of the vegetation status across the years (Figures 4.21a-4.23c). The calculated NDVI values and change detection confirms that anthropogenic climate change affects vegetation across the years. From 1989-1998, 1998-2008 the vegetation gradually declined following the climate pattern of the mountain.

This study therefore, achieved its objectives by assessing the vegetation of the Soutpansberg in terms of structure and extension in the light of climate change, determining climate variability and established the relationship between changing vegetation and anthropogenic climate change.

5.2 Recommendation

Plants in their various capacities play a crucial role in the ecosystem. It is essential that they are protected or managed in such a way that their very existence is not compromised. Hence there is a need for mitigation and adaptation strategies to be put in place.

5.2.1 Adaptation and Mitigation

It is evident that adaptation is a necessity. Adaptation implies behavioural changes in response to changing/changed conditions. In order for anthropogenic climate change adaptation and mitigation efforts to be successful, anthropogenic climate change adaptation strategies need to be integrated into provincial and municipal development and spatial plans. In doing that, the climate change considerations and response strategy are fully mainstreamed into the work of government and all state owned entities. More policies should be put in place so as to protect areas where a change in vegetation cover is bound to cause a significant effect on climate regimes.

Afforestation projects should be undertaken in areas which had previously hosted forest in the Soutpansberg. Given that the changing climate pattern in the Soutpansberg is caused by depletion in vegetation, more drought resistant species of trees should be planted in the first period of afforestation. This will ensure that the existing water resources are not depleted by the afforestation project and cause further decline in species composition.

Planning and other developmental approval processes should be amended to rezoning processes. Penalties should be simultaneously developed with the legislative process to encourage and facilitate the introduction and formalization of mitigation and adaptation methodologies and technologies. Appropriate measures in development planning will place building restrictions on mountain slopes and tops which will ensure a healthy vegetation health and composition. Also in implementing farming practices which will not involve cutting down of more vegetation in new areas but make the existing land use more productive ensuring that space is appropriately utilised and sprawl into marginal land in avoided.

The municipalities and province should conduct frequent reviews of all policies, strategies, legislation, regulations, and plans falling within its jurisdiction or sphere of influence to ensure full alignment with policies that deal with anthropogenic climate change. By devising a means of monitoring and evaluating government policies, strategies and legislation, loop holes can be found and possible amendments can be done so that the policies achieve the stipulated results.

There should be a capacity for coordinating adaptation and mitigation actions. It is only with proper coordination that the execution of any plan of action can be effective. This can be done by making sure there exist clear links between land stewardship, livelihoods and the economy, effective land use and land care; protection, maintenance and enhancement of natural resources; strengthening vulnerable communities and protecting livelihoods through targeted research and integrating climate risks into development planning.

There should be a system put in place with the capacity for measuring, reporting, and verifying anthropogenic climate change responses. In setting up a focused climate change research and weather information programme, feedbacks on strategies put in place for adaptation and mitigation as well as possible impacts of anthropogenic climate change will be easily made available. Hence making adaptation plans and action for targeted and risk area easy to implement since they have been identified. This will serve to be cost effective because more resources will be channelled into the right adaptation and mitigation practices.

Adaptation cost can be reduced by anticipation, analysis and planning. Adaptation, both anticipatory and reactive, can potentially reduce impacts of climate change, enhance beneficial impacts and produce many immediate secondary benefits. All damages, however, will not be prevented. Even though the potential for adaptation is more limited in developing countries, which are projected to be more adversely affected, climate change effects can be reduced significantly when policies and measures also contribute to other goals of sustainable development.

In ensuring proper coordination on anthropogenic climate change issues, the cooperative structures and mechanisms should involve private and public stakeholders as well as the local population.

5.3 Future Research

Future studies are recommended to predict and assess future loss of forest cover and indigenous vegetation by taking in more factors such as evaporation, evapo-transpiration, soil moisture content, slope and elevation into consideration. Another study can look at the socioeconomic consequences of changing climate regimes in the Soutpansberg in financial terms. Some of the sampled plots at Schoemansdal; SW region showed the vegetation was drying up as if they have been burned or struck by lightning. Further research should be done here to assess if the drying up of the vegetation is more than the effects of anthropogenic climate change.

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Appendix 1.1: Human activities and land uses in the Soutpansberg

A & B= Wood harvesting; C= Agriculture/ranching; D & E= Plantation agriculture F: Tea plantation; G & H= Construction

Appendix 3.1: Field Data sheet 1

Sociability class	Criteria	Percentage (%)
Class 5	Species occur in large, nearly pure stand	75-100
Class 4	Species occurs in large aggregates or carpets	50-74.9
Class 3	Species occurs in small aggregates or clusters	25-49.9
Class 2	Species occurs in isolated clumps or bunches	5-24.9
Class 1	Single occurrence of species in relevé	1-4.9
	+	0.5-0.9
		Observed rare
Abundance Class		
Class 5	75-100 cover of the total area, regardless the numbers of individuals	
Class 4	50-75 cover of the total area, regardless the numbers of individuals	
Class 3	25-50 cover of the total area, regardless the numbers of individuals	
Class 2	5-25 cover of the total area, or usually abundant thought < 5% cover	
Class 1	Covering < 5% the plot are but either abundance with very low cover or < abundant but more cover	
	+ Few individuals, occurring sparsely and covering < 5% of the total plot	

Plot No.	Plot Location	GPS Point Location	Picture No. Of Plot	Cover Class	Sociability Class		Description of plot area (e.g. by stream, slope)
1.	North Slope						
	South Slope						
	Centre						
2.	North Slope						
	South Slope						
	Centre						
3.	North Slope						
	South Slope						
	Centre						
4.	North Slope						
	South Slope						
	Centre						

Vegetation Field Data sheet 2 (Species Identification)

Plot No	Species at forest layers	Picture No.
	Forest floor... Herb layer.. Shrub layer.. Understory... Canopy.. Emergent's..	

Appendix 3.2: Climate station location and % of missing precipitation data.

	Station Name	Station Number	Position	Data Span	Years	Slope	% Of Missing Precipitation Data
1	Mara	0722099 1	Lat -23.15,Lon 29.57	1970-2009	40	South	0.0
2	Mara-Pol	0721665 5	Lat -23.0799, Lon 29.38	1970-2009	40	South	0.8
3	Goedehoop	0723155 X	Lat -23.0798, Lon 30.1	1970-2009	40	South	1.7
4	Vreemdeling	0766028 0	Lat -22.96, Lon 30.02	1970-2009	40	South	0.0
5	Una – Agr	0722277 X	Lat -23.12, Lon 29.67	1970-2009	40	South	0.0
6	Elim Hosp	0723070 7	Lat -23.17, Lon 30.05	1970-2009	40	South	3.3
7	Hanglip	0722721 3	Lat -23.02, Lon 29.92	1970-2009	40	South	0.0
8	Roodewal Bos	0766030 3	Lat -23, Lon 30.02	1970-2009	40	South	0.0
9	Shefeera	0723182 6	Lat -23.03, Lon 30.12	1970-2009	40	South	0.0
10	Levubu	0723485A0	Lat-23.0798, Lon 30.28	1970-2009	40	South	0.4
11	Nooitgedacht	0723334 X	Lat -23.07, Lon 30.2	1970-2009	40	South	0.4
12	Krugerwildtuin	0724790 5	Lat -23.167, Lon 30.95	1970-2009	40	South	0.0
13	Tsianda	0723603 0	Lat -23.05, Lon 30.35	1970-2009	40	South	0.0
14	Klein Australie	0723363 X	Lat -23.05, Lon 30.22	1970-2009	40	South	0.0
15	Waterpoort	0765234A5	Lat -22.9 Lon 29.633	1978-2009	31	North	17.5
16	Tshipise	0766276 X	Lat -22.6, Lon 30.17	1970-2009	40	North	0.0
17	Folonhodwe	0766842 X	Lat -22.5747, Lon 30.4275	1970-2009	40	North	0.4
18	Entabeni Bos	0766480 2	Lat -23, Lon 30.27	1970-2009	40	Centre	0.0
19	Rambuda	0766827 4	Lat -22.7889 Lon 30.4347	1970-2009	40	Centre	0.8
20	Mphefu	0766201 X	Lat -22.8728 Lon 30.1231	1970-2009	40	Centre	3.3
21	Matiwa	0766509 9	Lat -22.98, Lon 30.28	1970-2009	40	Centre	0.0
22	Vondo Bos	0766596 9	Lat -22.933, Lon 30.333	1970-2009	40	Centre	0.0
23	Palmaryville	0766779 6	Lat -22.983 Lon 30.433	1970-2009	40	South	0.4

Appendix 3.3: Correlation Matrices for rainfall stations

Correlations matrices for stations in the South West

Marked correlations are significant at p < .05

	Mara	Mara-pol	UNA-Agr	Roodewal Bos	Goedehoop	Vreemelding
Mara	1	0.568803	0.833112	0.689443	0.386531	0.444202
Mara-pol	0.568803	1	0.540593	0.57997	0.42595	0.278193
UNA-Agr	0.833112	0.540593	1	0.643716	0.537718	0.48605
Roodewal Bos	0.689443	0.57997	0.643716	1	0.516279	0.673593
Goedehoop	0.386531	0.42595	0.537718	0.516279	1	0.413825
Vreemelding	0.444202	0.278193	0.48605	0.673593	0.413825	1

Correlations matrices for South East Stations (SE)

	Levubu	Nooitgedacht	Krugerwild	Tsianda	Klien Australie	Elim Hosp
Levubu	1	0.689148	0.769424	0.724984	0.730651	0.698813
Nooitgedacht	0.689148	1	0.880249	0.738042	0.759768	0.535756
Krugerwild	0.769424	0.880249	1	0.706276	0.727772	0.572588
Tsianda	0.724984	0.738042	0.706276	1	0.691627	0.580228
Klien Australie	0.730651	0.759768	0.727772	0.691627	1	0.721575
Elim Hosp	0.698813	0.535756	0.572588	0.580228	0.721575	1

Correlation matrices for Rainfall Station on the Northern Slope

	Waterpoort	Tshipise	Folonhodwe
Waterpoort	1	0.616156	0.525802
Tshipise	0.616156	1	0.644926
Folonhodwe	0.525802	0.644926	1

Correlation matrices for Rainfall Station in the Centre

	Entabeni	Rampuda	Mphefu	Matiwa	Vondo Bos	Palmaryville	Shefeera	Hanglip
Entabeni	1	0.762176	0.69636	0.75263	0.71104	0.756122	0.71761	0.60834
Rampuda	0.76217	1	0.83114	0.75867	0.66486	0.839062	0.77991	0.65614
Mphefu	0.69636	0.831149	1	0.80906	0.57458	0.867412	0.80140	0.70671
Matiwa	0.75263	0.758675	0.80906	1	0.52950	0.833155	0.82289	0.66847
Vondo Bos	0.71104	0.664864	0.57458	0.52950	1	0.704936	0.50103	0.33505
Palmaryville	0.75612	0.839062	0.86741	0.83315	0.70493	1	0.82502	0.67759
Shefeera	0.71761	0.779913	0.80140	0.82289	0.50103	0.825022	1	0.70913
Hanglip	0.60834	0.656144	0.70671	0.66847	0.33505	0.677593	0.70913	1

Appendix 3.4: Rainfall Stations and Data

Waterpoort (NW) **Tshipise (NE)**

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean	Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	***23.8***	***75.1***	***72.5***	***48.8***	***3.8***	***0***	37.3	**1970**	25.1	107	104.9	66	6.1	0	51.5
1971	***63.2***	***39***	***43.8***	***80.9***	***78.1***	***91.5***	66.1	**1971**	69.4	42.7	50.7	105	73.9	144.5	81.0
1972	***86.3***	***50.8***	***5.5***	***39.3***	***3.5***	***43***	38.1	**1972**	73.5	43	5	47	3	16.5	31.3
1973	***11.5***	***34.6***	***102.3***	***49.5***	***107.2***	***110.2***	69.2	**1973**	16	42.7	148.3	40	53.5	59.5	60.0
1974	***16.7***	***112.8***	***79.2***	***101.1***	***132.5***	***29.8***	78.7	**1974**	33.4	159.5	120.9	95.1	150.5	16.1	95.9
1975	***7***	***41.3***	***140.8***	***78.8***	***92.1***	***41.1***	66.9	**1975**	0	49.5	146	115.5	83	57.3	75.2
1976	***10.7***	***32.2***	***30.8***	***87***	***133***	***133.3***	71.2	**1976**	8.5	42.8	54	73.5	115	95.5	64.9
1977	***17***	***11.8***	***133.5***	64	68.6	125	70.0	**1977**	16	20	110	158	223	24.5	91.9
1978	42	52.5	24	82.5	16	43	43.3	**1978**	76	110.3	16	159	69	2	72.1
1979	66	34	26	62	46	49	47.2	**1979**	136	0	0	187.5	184	52.5	93.3
1980	27.5	85.9	23.8	269.1	57.3	147.5	101.9	**1980**	47	143.1	79	171.4	61.5	60.5	93.8
1981	10.5	28.3	7	34.5	27.3	4.5	18.7	**1981**	21.5	60.7	14	5.5	22.3	0	20.7
1982	39.8	20	21	0	30.5	47.5	26.5	**1982**	7	4.5	20	6	0	6	7.3
1983	0	95	48.5	28.5	8	65.8	41.0	**1983**	14	71	15	16	15.3	104.3	39.3
1984	81	86	26	77.5	145	35.5	75.2	**1984**	0	238	20	55.5	101	0	69.1
1985	63.5	7	87.5	8.5	43	***8.5***	36.3	**1985**	70	39	20	25	69.4	1	37.4
1986	20	50.5	204	64	35.5	65.5	73.3	**1986**	31	29.5	33	44	10	100	41.3
1987	17	6	151	58	31.5	64	54.6	**1987**	52	5.7	78.4	2.1	84.1	37.2	43.3
1988	82.5	36	38	7	21.5	37	37.0	**1988**	132.5	0	73.8	0	46.5	13	44.3
1989	52.5	120	91.5	21	10	51	57.7	**1989**	63.7	174.7	46.9	70.5	32.7	43.8	72.1
1990	1	42.5	112.5	226.9	25	64.5	78.7	**1990**	2.5	25.5	61.2	88.5	34.6	50.6	43.8
1991	0	122.5	34.5	33.5	77	23.5	48.5	**1991**	0	38.1	4.8	16.5	6.8	19.1	14.2
1992	18.5	28.5	210.5	58.5	44.5	44	67.4	**1992**	19.5	71.6	80.9	76.7	110	4	60.5
1993	17	170.5	77.5	23.5	12	8	51.4	**1993**	18	156.3	27	30	2.5	28	43.6
1994	11.5	14.5	39.8	49.7	31	88.3	39.1	**1994**	0	5.5	7	43.4	41.2	37.5	22.4
1995	16.4	20.7	42.8	117.6	150.9	26	62.4	**1995**	7.5	0	61	213	132	23.5	72.8
1996	34.1	106.2	41.8	165.6	31.4	131	85.0	**1996**	37.5	47.5	77.2	74.2	0	69.3	51.0
1997	2.6	53.3	18	82.6	2.6	11.4	28.4	**1997**	9	30.4	13.5	42.9	0.9	2.6	16.6
1998	20.5	73.5	82.7	43.4	12.8	6.4	39.9	**1998**	32.5	144.3	96	41.6	124	26.5	77.5
1999	38.6	75	37.8	66.6	347.8	143.1	118.2	**1999**	48.2	112.7	30.6	233.1	354.5	81.3	143.4
2000	23.9	65.9	43	5.5	77.4	27.2	40.5	**2000**	40	44	119	0	130.6	23	59.4
2001	0.4	87.2	101.5	32.8	0.6	1.5	37.3	**2001**	14	112	54	10	0	0	31.7
2002	11.6	6.3	53.2	89.3	21.5	53.5	39.2	**2002**	11.5	7	97.5	22	23	53.5	35.8
2003	45.3	36.4	34	62.2	147.8	148.7	79.1	**2003**	42	43	46	66	28	107	55.3
2004	34.2	11.7	65	109.4	27.4	8.9	42.8	**2004**	39	20	20	43	21	82	37.5
2005	0	38.5	42	68.3	60	143.4	58.7	**2005**	0	9.4	112.5	75	47	40	47.3
2006	6.6	50.6	40.9	14.6	15.4	50.8	29.8	**2006**	9.5	101	28	47	46	54	47.6
2007	59.1	127.1	112.4	29.5	105	15.2	74.7	**2007**	16	79	126.5	12	6	34	45.6
2008	17.6	151.9	25.4	176	28.9	25.2	70.8	**2008**	0	89.5	55	140	11.5	0	49.3
2009	9.7	113.7	43	35.8	32.9	0	39.2	**2009**	13	107.5	52				57.5

Folovhodwe (NE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	22.4	43.1	40.1	31.5	1.5	0	23.1
1971	57	35.3	36.9	56.9	82.3	38.4	51.1
1972	25.5	58.5	6	31.5	4	69.5	32.5
1973	7	26.5	56.3	59	160.9	23.9	55.6
1974	0	66	37.5	107	114.5	43.5	61.4
1975	14	33	135.5	42	101.2	25	58.5
1976	13	21.5	7.5	13.5	151	171	62.9
1977	18	3.5	157	***70.8***	122	22	65.6
1978	30.5	54.5	17.5	80.1	18	57	42.9
1979	38	55.5	23	60.5	175.5	35	64.6
1980	25	72.5	0	120.5	16.5	9	40.6
1981	15	63.5	0	8.7	31.5	0	19.8
1982	8.5	9.5	1.5	0	22.7	1.5	7.3
1983	3.5	38	0	5.5	20	18	14.2
1984	18.5	59.6	25	35	121.6	40.4	50.0
1985	97	9.1	24	12.5	16	28	31.1
1986	21.3	15.1	8.5	4.6	6.9	64.5	20.2
1987	28	11	150.5	0	59.1	19.5	44.7
1988	80	0.5	36.5	0	67	0	30.7
1989	32	114	38	30	7	7	38.0
1990	0	14	37	40	31	32	25.7
1991	0	0	0	0	0.6	0	0.1
1992	0	28	181	13	114	0	56.0
1993	44	110	38	109	0	0	50.2
1994	0	0	0	19	93	76	31.3
1995	10.5	0	0	124.8	153	0	48.1
1996	30	13	11.6	67.2	0	9	21.8
1997	0	48	0	8	0	0	9.3
1998	30.5	67	6.5	36	68.8	11	36.6
1999	93.7	0	39.7	36	279	39.5	81.3
2000	32	26.9	68.5	11	128.2	2	44.8
2001	2	157	16.5	8	0	0	30.6
2002	2.6	11.1	22	17	15.9	0	11.4
2003	31	193	15	112.1	63.1	107	86.9
2004	21.8	9	11	78	15	28	27.1
2005	0	66.1	124.8	85	114	99	81.5
2006	0	84	9.5	31	0	43.7	28.0
2007	20	151.5	116	60	41	9.1	66.3
2008	0	22.5	90	218	0	0	55.1
2009	0	139	38				59.0

Levubu (SE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	53.8	93.7	136.4	212.8	59.5	46.2	100.4
1971	123.2	203.5	83.9	342.5	321.5	215.7	215.1
1972	80.2	69.4	109.1	75	33.2	216.4	97.2
1973	113.8	50.2	169.5	134.7	325.2	81.8	145.9
1974	44.3	144.7	181.9	253.8	337.6	119.9	180.4
1975	29.6	63.8	374.2	425.9	236.5	209.1	223.2
1976	27	175.3	85	268.6	432.3	449.3	239.6
1977	77.7	72.5	257.1	472.7	379.2	185.1	240.7
1978	53.9	175.8	86.1	165.3	49.6	99.7	105.1
1979	98.2	120.8	126	233.4	172.8	190	156.9
1980	45.4	258.8	101.3	452	417.9	223.3	249.8
1981	62.3	183.8	35.9	50.5	43.8	31.4	68.0
1982	89.4	18.1	24.7	65.4	17	106.1	53.5
1983	57.7	81	46.4	42.6	46.6	142.1	69.4
1984	157.5	238.9	55.5	119.1	153.1	99.1	137.2
1985	73.4	24.5	270.5	36	18	12	72.4
1986	82	152.3	63.3	81.7	117.4	91.7	98.1
1987	140	55	359.6	138.1	284.4	150.3	187.9
1988	261.1	40.5	66.7	4.7	176.1	7.8	92.8
1989	144.1	97.5	160.4	177.5	44.9	115.1	123.3
1990	26.7	55.1	147.8	327.7	107.2	286.8	158.6
1991	37.2	49.1	***44.2***	20.6	57.6	45.1	42.3
1992	24.3	107	386.4	71.1	226	31.1	141.0
1993	35.5	206.5	136.9	190.2	53.7	29.8	108.8
1994	38.9	84.6	72.9	143.3	279.1	98.5	119.6
1995	19.2	175.9	141.2	375.8	623.2	46.6	230.3
1996	79.8	89.3	79.2	236.8	124.2	183.3	132.1
1997	85.9	117.8	54.4	276	28	31.3	98.9
1998	146.5	142.3	317.7	133.5	228.1	119.6	181.3
1999	30.1	232.1	117.1	133.5	228.1	119.6	143.4
2000	30.1	232.1	117.1	11.5	421.9	156.3	161.5
2001	45.9	267.7	252.7	176.6	16.1	23.5	130.4
2002	122.2	49.6	147.5	97.2	57.4	81.3	92.5
2003	172.2	44.3	42.6	139.2	191.9	406.4	166.1
2004	44.4	25.4	153.7	80.9	50.8	89.2	74.1
2005	33	121.4	227.2	309.3	192.6	236	186.6
2006	3.9	61.1	103.9	80	7.5	87.3	57.3
2007	124.6	146.4	238.5	245.6	128.2	152.6	172.7
2008	14.4	74.5	66.6	87.6	10.4	0	42.3
2009	12.8	60.8	18.8				30.8

Nooitgedacht (SE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	80.5	168	130.3	402.4	68.3	64.5	152.3
1971	92.7	161	95.9	379	300	309.1	152.3
1972	189.7	59	81.5	69.4	76	118.5	223.0
1973	117.5	59.5	176.5	330.8	422.5	92.5	99.0
1974	26.7	189.5	137	225.5	368	90	199.9
1975	20.7	76.6	373.5	272.5	229.3	144.8	172.8
1976	25.3	118.5	91.5	334.6	436.6	316.3	186.2
1977	42.5	76.5	242.3	376.1	361.7	187.9	220.5
1978	32.5	163.1	128.1	78.9	39.6	65	214.5
1979	84.9	54.7	98.9	179.4	141.8	131.4	84.5
1980	45.5	228.5	102	492	163.5	230.5	115.2
1981	67.5	173.5	49.5	95	76	26	210.3
1982	78	0.8	47	101	8	131.5	81.3
1983	53.5	59	43.5	35.5	69.3	161.9	61.1
1984	141.9	217.8	70.9	174.2	158.8	56.2	70.5
1985	79.7	28.8	247.5	32.4	59.4	12	136.6
1986	77.9	124	97	42.4	75.6	52.5	76.6
1987	82	75	402.5	70.8	312.8	170.3	78.2
1988	266.5	75.4	57.7	10.4	207.6	5.8	185.6
1989	108.6	94.1	183.3	168.5	53.1	91.5	103.9
1990	40.9	71.1	125.3	322.5	104.5	246.4	116.5
1991	65.2	86.7	**67.2**	180.7	88.8	54.2	151.8
1992	29.9	117.1	239	54.7	344	59.8	90.5
1993	76.7	202	242.1	183.3	41.8	57.8	140.8
1994	39.6	76.4	109.9	85.4	262.8	97.9	134.0
1995	40	121.9	120	502.1	436.5	35.5	112.0
1996	50.3	105.1	117	275.4	111.9	134.9	209.3
1997	84	114	77	424.7	43.9	99	132.4
1998	136	173.5	262.8	189	177.8	125.9	140.4
1999	67	187.2	171	428.5	1364.1	237.5	177.5
2000	100.7	131.7	92.5	20.5	366.5	131.4	409.2
2001	29.4	210.8	194.2	189.8	16.5	14.6	140.6
2002	108.1	40.3	86.5	64.5	63.7	75.5	109.2
2003	132.1	61.3	173.4	168.5	91.5	603	73.1
2004	56.7	22.9	98	98.9	29.5	64.2	205.0
2005	38	216.5	191	254.3	220.6	440	61.7
2006	5.5	140.5	96	74	64.5	240	226.7
2007	120	158.5	276.5	144.5	68.5	51.5	103.4
2008	10	86	73.9	213.8	137	211.5	136.6
2009	0	231.5	117.5				122.0

Krugerwild (SE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	49.5	12	51.5	261	29	9	68.7
1971	57	37	124.5	222	172	145.5	126.3
1972	35	42	82	63.4	9	69	50.1
1973	66.2	31.7	219.6	69	221.1	41.3	108.2
1974	1.9	178.5	41.6	81.6	179.9	18.7	83.7
1975	1.6	122.8	140.2	158.8	57.5	190.1	111.8
1976	55.9	57	47.5	181.3	438.1	218.5	166.4
1977	16.5	88	97	170.1	195.1	119.4	114.4
1978	33	94.5	94.5	108.8	50	5	64.3
1979	34.1	62	97.8	40.5	210.7	86.5	88.6
1980	42.7	118	157.4	254	100.8	43.2	119.4
1981	45.7	100	8.8	51.5	84	0.5	48.4
1982	19.6	10	38.6	19.5	36	76	33.3
1983	35.5	49.2	12.5	43.5	29.7	51.7	37.0
1984	50.5	169.5	43.4	163.5	171.1	6.5	100.8
1985	57.5	43.5	86.5	15	48	0	41.8
1986	17.1	57.8	69.4	12.1	93.5	55	50.8
1987	36.3	22.8	224.7	15	48	0	57.8
1988	17.1	57.8	69.4	23.5	112.5	0	46.7
1989	30.4	85.6	88.7	121	16.4	35.6	63.0
1990	83	31.8	100.7	170	70.5	80	89.3
1991	0	31	7.3	61.5	4.5	16.6	20.2
1992	0	52.5	209.4	112	82	10	77.7
1993	17.2	130	29.1	65.9	5.8	29.8	46.3
1994	44.6	24.2	65.6	96.8	166.5	57.4	75.9
1995	16.3	45.5	51.6	276.6	201	3	99.0
1996	60	28.4	51.2	174.5	39.6	30	64.0
1997	13	74.7	38.5	43.8	6.5	0	29.4
1998	109	60	132.7	128.5	253.8	49	122.2
1999	0	143.7	84.3	338.6	485.1	147.7	199.9
2000	18.6	140.8	28.4	3.2	129.7	115.3	72.7
2001	12.9	190.4	183.3	98.7	2.5	18.2	84.3
2002	31.8	21.5	51.8	91.4	69.5	49	52.5
2003	57.6	45.7	44.9	74.3	166.9	154.3	90.6
2004	14.4	12.6	32.8	41	49.8	9.5	26.7
2005	0	68.5	185.7	275.7	79.3	97.8	117.8
2006	0	4.6	33.5	21.5	53.4	157.5	45.1
2007	22.5	106.2	181.5	63	37.1	44	75.7
2008	0	41	88.5	47	120.7	8.5	51.0
2009	0	52.6	30.4				27.7

Tsianda (SE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	67.2	81	137.5	217.1	61.8	3.5	94.7
1971	102.4	172	64.5	450	295.8	38	187.1
1972	84.5	98.5	118.5	126	60.5	229.4	119.6
1973	105.5	62	214	114	232	44	128.6
1974	9	155.5	155.5	179	417.5	74.1	165.1
1975	26.9	62	249.5	182.6	358	94.5	162.3
1976	28	170.5	135	115.5	507	177	188.8
1977	56.3	111	296.5	384	417	634.5	316.6
1978	56.2	165.5	122.5	107.3	46.7	213.5	118.6
1979	97	113.2	117.5	163.3	163	81.5	122.6
1980	38.4	247	103.5	371.1	266.6	244.5	211.9
1981	16.5	95	0	4.5	27.1	165	51.4
1982	0	0	0	19	12	0	5.2
1983	17.5	30.5	26	22.8	58	136	48.5
1984	68.5	112.6	55.5	95	114	138.5	97.4
1985	70.5	11	237.5	34	43.1	104.5	83.4
1986	53	97.2	143.2	34.5	90.2	0	69.7
1987	77.5	68	402.6	31.7	325.6	125	171.7
1988	265.4	117.9	21.7	32	239.1	187.9	144.0
1989	128.9	68.1	131	157.4	0	33.7	86.5
1990	37.5	39	44.2	191.3	36.2	88.3	72.8
1991	0	45.35	40	0	35	215.3	55.9
1992	13.4	51.7	379.2	53.4	182.4	96.5	129.4
1993	23.5	191	123.5	153	16.5	69.3	96.1
1994	67.5	57	43.5	0	0	0	28.0
1995	14	148.6	130	341.5	44.5	60.5	123.2
1996	58.5	65.5	97	261	128	5.5	102.6
1997	65.1	69.9	25.8	244	44.7	78	87.9
1998	192.9	180.5	298.4	217.9	228.5	70.6	198.1
1999	71.8	0	68	493	799.5	59	248.6
2000	87.5	106.4	84.5	22.5	481.4	220.9	167.2
2001	8	326.5	272.5	134	8.6	127	146.1
2002	109	58.5	183.2	103	8	24.5	81.0
2003	145.3	92.9	143.2	229	199.7	127	156.2
2004	44.6	15.4	170.5	74.4	30.7	436.7	128.7
2005	24.4	198	224.6	319.7	295.2	90.9	192.1
2006	4.4	120	43.7	172.8	49.3	187.2	96.2
2007	74.1	133	365.3	209.6	105.2	112	166.5
2008	8.5	299.1	33.1	356.7	96.5	91.6	147.6
2009	4	0	0	0	0	178	30.3

Klein Australie (SE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	63.5	152.3	166	283.5	78.3	48.5	132.0
1971	81.1	152.5	75.9	295.3	216.3	243	177.4
1972	140	71.8	134.5	54	124.2	130	109.1
1973	100.7	43.5	150.5	373.6	382.5	100.2	191.8
1974	44.7	117.6	98.5	229	386.5	111.6	164.7
1975	15	51	357.5	327.5	279	129.5	193.3
1976	27	120.5	116	361	558.5	434	269.5
1977	51	76	240.7	648	575	151.5	290.4
1978	72	214.5	220	178.4	52.8	62.2	133.3
1979	61.5	49.5	117	211	121.8	159.2	120.0
1980	23	126	18.5	490	255.4	190.5	183.9
1981	27	201.8	56.1	85.5	104	31.5	84.3
1982	118.6	28	56.5	115.2	29	114.7	77.0
1983	65.1	94	45	51.1	70.1	226.8	92.0
1984	173.2	316.7	103.4	168.8	190.6	112.1	177.5
1985	85.5	40.4	275.5	27.2	259.6	79.7	128.0
1986	87.7	242.2	138.1	27.5	93.5	87.3	112.7
1987	83.9	87.2	411.4	87.5	349.7	265	214.1
1988	297.6	84.9	122	23.5	272.7	14.3	135.8
1989	151.1	79.6	254.3	206.1	50.9	101	140.5
1990	36.3	64	186.7	381.8	182.7	280.5	188.7
1991	10.4	60.1	74.5	46.6	48.7	60.8	50.2
1992	25.4	100.5	345.1	102.2	471	67.1	185.2
1993	28.1	218	244.1	108.4	119.1	62.9	130.1
1994	30	57.9	109	118.3	344	140.7	133.3
1995	15.2	117.4	148.2	612.3	643	58.1	265.7
1996	61	128.1	115	262.8	211	204.2	163.7
1997	116	110	59.5	354.2	47.1	114.1	133.5
1998	179.9	173.2	397.5	199.9	282.1	150.3	230.5
1999	45	180.5	160.4	601.1	1 483.5	506.4	298.7
2000	106.5	120.5	103.5	20.9	485.2	284.3	186.8
2001	41.5	273.5	192.3	207.8	21	31.5	127.9
2002	138.5	60.5	155.3	96.5	105	118.5	112.4
2003	161	67	204.6	236.5	110.8	724.6	250.8
2004	61.5	35	132.5	142.8	17	108	82.8
2005	58.7	140.6	126.7	326.1	356	389.6	233.0
2006	14.4	151.4	204	82.3	64.9	253	128.3
2007	131	134.7	343.2	183.1	83.1	63.6	156.5
2008	23	36.3	133.8	209	158	336.5	149.4
2009	60	284	378.5	245.1	201	60	204.8

Elim Hosp (SE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	70.9	118	42.9	242.5	***36.8***	***22.4***	88.9
1971	112.8	65.9	66.7	224.6	210.8	179.9	143.5
1972	120	50.8	250.8	45.8	60.8	96.9	104.2
1973	5.8	187.1	86.8	188.6	291.3	153.1	152.1
1974	10.9	34.5	184.8	144.2	251	98.9	120.7
1975	55	63.5	66.1	216.7	163	82.4	107.8
1976	72.6	41	127.5	290.6	240.5	199	161.9
1977	48.2	121.1	51.7	414.7	254	98.1	164.6
1978	52.4	40.4	95.8	94.5	71.7	105.5	76.7
1979	34.2	159.7	73.1	111.1	156.3	68.8	100.5
1980	27	67.8	67.3	245.3	196	123.7	121.2
1981	31.2	8.6	53.7	82.2	67.5	5.3	41.4
1982	36.8	86.1	25.5	120.4	6.3	68.4	57.3
1983	80.8	89.3	29	46.4	56.5	84.1	64.4
1984	47.3	22.9	110	68.4	114.4	120.9	80.7
1985	84.7	99.7	74.6	51.4	90.3	7.6	68.1
1986	22.5	58.5	205.3	49.1	35	23.9	65.7
1987	145	23.4	39.3	46	192.9	67	85.6
1988	104.2	135.1	113.7	4	106	2.5	77.6
1989	41.1	57.7	71.4	201.9	55.2	48	79.2
1990	0	64	69	188.2	96.1	145.8	93.9
1991	12.8	90	198.5	56	48.3	59.6	77.5
1992	22.4	135.9	97.9	59.5	263	39.6	103.1
1993	0	85.5	67.5	73.1	29.1	31	47.7
1994	31	61	47.5	81.3	224.7	103	91.4
1995	51	***92.4***	***108***	313.5	394.8	44.9	167.4
1996	***24.5***	***28.6***	12.7	***92.1***	125.5	119.5	67.2
1997	45.5	73	142.7	***150.2***	44	48.9	84.1
1998	41.4	133.7	136.5	185.5	136.3	167	133.4
1999	4.1	91	98.5	283	1 173.5	0	95.3
2000	9	133.1	224.5	***180.1***	279	94.5	153.4
2001	43.5	***64.2***	***56.1***	107	13.5	15	49.9
2002	86.5	0	188.5	64	53	55.5	74.6
2003	24.6	20.7	87	114.5	46	390.5	113.9
2004	4.5	111	114.1	54.6	15.5	29.5	54.9
2005	15.9	64.3	24.5	180.5	210.5	168.8	110.8
2006	65.5	82.5	134.5	146.5	41.7	124.1	99.1
2007	8.5	97	148	68	101	61.5	80.7
2008	20	105.4	74.8	117.5	131	110	93.1
2009	20	105.4	74.8	148.5	99	77	87.5

Mara (SW)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	38	33.1	101.8	150.2	2.9	41.4	61.2
1971	60.4	114.5	28.5	119.3	101.9	87.5	85.4
1972	88.2	93.8	35.5	97.9	37.9	97.7	75.2
1973	97	65	175.1	82.9	94.4	11.9	87.7
1974	2.2	103.6	79.2	166.1	83.1	7.6	73.6
1975	1.5	44	189.3	214.3	110.1	76	105.9
1976	39.1	97.3	41.7	110.6	81.2	236.3	101.0
1977	22	6.6	137.8	190.8	74.3	65.5	82.8
1978	27.5	97	148.5	97.1	24.7	46.5	73.6
1979	51	32.2	72	215.5	191.3	18.5	96.8
1980	34.5	136.2	27.9	236.7	27.8	57.9	86.8
1981	25.8	102.2	55.2	36.3	24.3	2.6	41.1
1982	38.6	32.6	44.1	13.8	43.6	69.3	40.3
1983	5.2	65.7	43.6	21	2.1	66.6	34.0
1984	51.5	98.8	10.7	89.9	132.1	18.1	66.9
1985	62.2	14.1	136.9	3.9	24.4	11.5	42.2
1986	34.1	58.3	133	75.4	21.3	70.8	65.5
1987	37.6	63.6	100	38.1	48.2	49.7	56.2
1988	129.4	9.2	56.3	3	57.6	29.7	47.5
1989	70.8	107.4	179	49.6	15.1	99.9	87.0
1990	24.8	95.6	33	144.8	65.8	66.8	71.8
1991	0.3	91.1	48.4	70.4	24.4	7.7	40.4
1992	18.6	53.2	184.8	101.3	80.4	17.3	75.9
1993	20.5	158.2	123.9	34.5	11	18.4	61.1
1994	30.3	16	50.2	30.2	75.2	169.1	61.8
1995	18.9	45.4	66.7	95.2	213.7	61.3	83.5
1996	10	96.6	42.6	156.4	183.4	140.2	104.9
1997	84.4	47.8	3	106.9	4.4	9	42.6
1998	20	52.1	120.8	163	38.3	19.6	69.0
1999	99.7	176.2	130.5	125.2	315.6	77.2	154.1
2000	34.2	87.8	38.8	17.4	103	33.9	52.5
2001	29.8	149.4	80.4	40.3	1.9	39.7	56.9
2002	11.4	18.9	97.9	66.2	39.6	31.4	44.2
2003	70.6	52	72.6	11.7	134.8	150.2	82.0
2004	32	46.7	79.5	6.9	35.5	25.6	37.7
2005	0	74.7	63.6	74.2	119.3	104.6	72.7
2006	6.3	51.8	86.6	20.6	17	46.4	38.1
2007	68.2	115.3	98.2	50.3	53.1	12.8	66.3
2008	26.8	194.6	25.8	265.7	10.9	0	87.3
2009	15.1	67.6	0	61.2	39.4	23.8	34.5

Mara-Pol (SW)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	11.3	8.4	43.4	165	6.5	28	43.8
1971	70	97.2	52	189.5	83.5	68.5	93.5
1972	26.5	57.5	36.9	22	46.5	44	38.9
1973	103.5	42	133.5	82.5	119.8	41.5	87.1
1974	0	123	85	127	103.5	24	77.1
1975	0	42	190	235.5	116.5	78.5	110.4
1976	49	60	27.5	72	64	43	52.6
1977	17.5	0	180.5	179.8	77.5	74	88.2
1978	34	***55.4***	0	130	14.5	70	50.7
1979	56.5	36.5	39	167.5	135.6	54	81.5
1980	21	193.4	27.5	309.5	35	73	109.9
1981	51.2	73	60	31.5	10	0	37.6
1982	24.5	36	36	0	17	73	31.1
1983	0	39	50	80.5	32.5	121.5	53.9
1984	28	187.9	0	96.5	83	0	65.9
1985	111	10.5	108	0	32.5	6.5	44.8
1986	14.5	107.5	87	82.5	27.5	85.5	67.4
1987	33.5	43.5	183.5	82.5	125.5	58	87.8
1988	96.5	32.5	29	7	105.5	23	48.9
1989	7.5	91	73	36	63.5	56.5	54.6
1990	22	98	91.5	216	59.5	116.5	100.6
1991	0	47.3	24.5	64.5	21	35	32.1
1992	21.8	69.5	71	36	59.5	0	43.0
1993	98	89	134	119	70	17	87.8
1994	21	13	40	74.5	69	76.5	49.0
1995	22.5	80	15	104.5	242	38.5	83.8
1996	11.5	91.5	13	0	***23.7***	***27.6***	27.9
1997	41.6	30.5	0	69	18.5	29	31.4
1998	44	39	62	90.5	49.8	43.4	54.8
1999	47.9	62.7	62.2	114.5	322.2	46.6	109.4
2000	43.5	118.5	44	0	91.5	26.7	54.0
2001	8.8	94.6	123.9	56.1	0	10	48.9
2002	15.5	0	46.5	49.3	55	35.8	33.7
2003	51.7	3.6	62	200.5	263	151.5	122.1
2004	34.5	23	58.5	51.5	28	14	34.9
2005	0	46	43	116	124	145	79.0
2006	9	88.8	67	31	10.8	110	52.8
2007	58.5	189	152.3	60	13.5	11.5	80.8
2008	53	119.5	37	135.5	45	34.4	70.7
2009	22.5	121	26.5	29	83.5	76.5	59.8

Una –Agr (SW)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	31	13	73	107.5	0	21.5	41
1971	78.1	106.3	20.5	131.5	78	122	89.4
1972	132.7	97.5	65	80	31	79	80.9
1973	98	45	75.8	67.5	132.5	9	71.3
1974	4	75.5	106.5	150.5	105.5	0	73.7
1975	0	37.5	134.3	140	103.5	63.1	79.7
1976	27.7	93.7	27	116.5	65.7	107.2	73.0
1977	26.3	10.1	105.4	139.7	109.1	40.1	71.8
1978	44.3	88.1	26.9	113.5	9.5	30.5	52.1
1979	47	26.5	45.5	109.5	73.8	26.5	54.8
1980	17.6	90.7	25.4	248.1	30	42.8	75.8
1981	23.8	54.8	40.9	25.7	21.7	14	30.2
1982	36.1	49.6	15.5	26.5	19.5	75	37.0
1983	3.1	84.1	49	23.1	17.2	64.6	40.2
1984	47	77.9	24	77.5	115.8	34.9	62.9
1985	58.6	29.8	149.8	4.2	11.9	7.5	43.6
1986	36.5	64	88.8	119.3	19.4	55.3	63.9
1987	39.2	25.1	214.6	45.9	54.5	39	69.7
1988	93.7	31	46.7	0.8	88.7	34.8	49.3
1989	52.5	66.7	140.7	27.3	54.5	70.9	68.8
1990	29.2	108.6	58.7	100.5	39.5	69.7	67.7
1991	0	51.9	51.2	58.1	16.8	12.2	31.7
1992	17.7	58.6	261.4	66.3	59.5	12.1	79.3
1993	16.8	132.1	50	28.5	9.2	30	44.4
1994	21.5	9.4	64	36.8	70.4	126.2	54.7
1995	15.6	44.4	53.8	67.7	223.7	59.2	77.4
1996	72.1	80.2	98.5	80.3	88.9	106.9	87.8
1997	72	42.5	0	83.7	0	8.5	34.5
1998	17.9	78	85.3	112.5	6.8	18.6	53.2
1999	58.1	76.7	44.3	117.2	345.5	95	122.8
2000	28	88.9	61.7	5.5	89	23.2	49.4
2001	7.2	96.1	65.6	48.2	4	20.6	40.3
2002	6.5	10.6	88.5	100.5	21.3	19.3	41.1
2003	23	53.4	40.9	25.3	99.9	105.	58.0

Vreemelding (SW)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	91.5	45.2	207	107.2	295.5	35	130.2
1971	11.5	127	79	196.5	291	122	137.8
1972	5.5	30.5	150.7	345	140.5	115.5	131.3
1973	19	86.1	110.5	142.5	522.5	214.5	182.5
1974	29	56.5	149	267.5	301.5	109	152.1
1975	47	153	140.5	109	50.5	88	98.0
1976	49.5	46	194.7	161.5	91	100.5	107.2
1977	34.5	220.5	48	451	244.5	174	195.4
1978	49	62.5	61.5	50.5	152	5	63.4
1979	43	61.5	32	184.5	39.5	145.5	84.3
1980	24.7	82.4	46	42	65	187	74.5
1981	99.5	167	68.5	199.5	79.5	115.8	121.6
1982	70.5	9	216.5	94	117	31	89.7
1983	95.5	134.5	86	37.5	27.7	50	71.9
1984	57	17	269.5	63	151.5	105.5	110.6
1985	169.5	39.5	82	7	233	30	93.5
1986	57	135	107	73.5	85	108	94.3
1987	15	55	65	91.5	133	138	82.9
1988	9.5	56.5	25.5	0	53.7	181	65.2
1989	37.5	96.5	20	80	263	34.5	88.6
1990	33.5	201	139.5	72	41	29	86.0
1991	44	32	32	64	177.5	74.5	70.7
1992	41	60	151	80	263	34.5	104.9
1993	33.5	201	139.5	72	41	29	86.0
1994	44	32	32	64	177.5	74.5	70.7
1995	41	60	151	323.5	299.5	44	153.2
1996	43	76	62.5	322	179	113	132.6
1997	37.5	20.5	25	305.5	25	39	75.4
1998	94	116	222.5	128.5	187	85.5	138.9
1999	57	118	122	280	1 135.0	232.5	161.9
2000	60	98.5	84	40	203.5	196	113.7
2001	19.5	183	75.5	74	13	37.5	67.1
2002	24	35	125.5	93	86	157	86.8
2003	96.5	63	0	95	93	301	129.7

Continued **Una –Agr (SW)** **Vreemelding (SW)**

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean	Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
2004	33	64	43.3	0	32.3	28.4	33.5	**2004**	31.5	14	130	61	68.5	122	71.2
2005	0	71.5	53	58.4	118.6	92.3	65.6	**2005**	9	104	79	161	295	177	137.5
2006	41.5	44.1	76.7	55.3	1	73.2	48.6	**2006**	21	93.5	74	102	66	183	89.9
2007	60	108.5	60	60.5	43.5	5.6	56.4	**2007**	87	106	189	75	64.5	46	94.6
2008	17	124	10	228.5	24.4	0	67.3	**2008**	10	115	28.7	212.8	138.5	153	109.7
2009	14.1	156.3	87.5	84	79.5	13	72.4	**2009**	22.5	145	100	70	158.5	38	89.0

Roodewal Bos (SW) / Geodehoop (SW)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean	Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	149	171	271	492.5	187.5	174.5	240.9	**1970**	76.5	97.5	112.7	208	48.5	98.5	107.0
1971	183.5	352	198.5	738	488.5	395.5	392.7	**1971**	65.5	162	43.5	228.5	114.5	221	139.2
1972	163	195	154	177	195	210	182.3	**1972**	75.5	30	28	73.8	69.5	51	54.6
1973	275.5	128.5	630.5	373.5	740.5	176.5	387.5	**1973**	83	51	175	215	347.5	107	163.1
1974	19.3	172.1	48.2	0	0	94.1	55.6	**1974**	15	179.5	63	163	266	60	124.4
1975	0	0	40.1	70.5	31.5	25.2	27.9	**1975**	21.5	51	135	190	149	132	113.1
1976	6.3	58.4	121	483.1	699.1	390.6	293.1	**1976**	28.7	55.2	59	268.5	302.4	224.7	156.4
1977	57.5	123.2	463.1	405.4	473.2	179	283.6	**1977**	23	44.5	185.5	253	198.5	150.9	142.6
1978	40.6	215.3	311.5	195.8	132.5	246.2	190.3	**1978**	16.4	109.3	105	48.1	24.5	62	60.9
1979	86.1	121.5	192.9	220.6	227.7	193.4	173.7	**1979**	34.5	42.2	40.7	76	99.1	125.3	69.6
1980	52.1	186.5	68	515.9	347.1	265	239.1	**1980**	14.6	93	91	392.5	150	144.5	147.6
1981	111.8	144.3	64.4	86.8	263.2	18	114.8	**1981**	37	94.1	16.6	84	84	0.2	52.7
1982	64.1	33.7	44.2	101.7	68.9	87.5	66.7	**1982**	33.5	2.5	12	104.5	0	47.8	33.4
1983	58	90.9	75.9	58.3	119.5	302.5	117.5	**1983**	0	***364.8***	***21.7***	0	0.5	131.5	86.4
1984	172.7	279.5	108.8	314.7	217.9	147.6	206.9	**1984**	217	266.5	20.5	199	250	64.5	169.6
1985	67.9	60.8	249.8	139.2	180	51.7	124.9	**1985**	37.5	24.3	303	29	143	23.5	93.4
1986	100	179.8	148.5	69.7	50.3	53.5	100.3	**1986**	70	101	131.7	46.5	64	29.5	73.8
1987	98.3	78.4	448.1	128	363.3	251.2	227.9	**1987**	27.1	86.8	379	74	319.1	128	169.0
1988	271.3	109.2	128	31.9	253.4	21.3	135.9	**1988**	212	70	47.5	15.5	184.8	52.4	97.0
1989	122.7	112.4	161.3	148.5	107.4	70.7	120.5	**1989**	89.1	67	143.4	152.8	39.2	116.8	101.4
1990	49.7	60.9	137.5	232.5	183.9	317.6	163.7	**1990**	70.4	67.5	133.4	330.5	154.2	273.9	171.7
1991	10.7	93.3	105.3	110.8	61	127.7	84.8	**1991**	8.7	89	92.5	179	65	64.5	83.1
1992	46.7	92	251.5	107.8	529.9	68.8	182.8	**1992**	19.8	48.5	174	89.3	586	80.1	166.3
1993	62.6	231	227.2	245.4	77.9	59.5	150.6	**1993**	16	0	0	0	81.5	49.3	24.5
1994	109.3	100.6	69.3	50.5	288.9	112.7	121.9	**1994**	58.5	82.5	121.5	59	322	98	123.6
1995	28.6	88.8	163.9	691.9	478.7	60.2	252.0	**1995**	51.5	129.5	169	545	432.5	***98***	237.6
1996	37.3	133.6	113	445.6	211.6	209	191.7	**1996**	8	108.5	20.4	291.1	97	188.7	119.0
1997	121.3	116.4	53.6	246.4	77.4	77.2	115.4	**1997**	97	75	54	323.5	46.6	69.5	110.9
1998	161.8	116.5	357.7	154.5	356.9	201.4	224.8	**1998**	135	136	340.8	202	230.5	109.5	192.3
1999	67.5	142	198	375	1785.3	255.9	470.6	**1999**	67	165	85	411.5	1 388.0	366	218.9
2000	114.8	122.8	100.8	73.4	447.1	173.5	172.1	**2000**	182.3	120.5	97	28	451.3	177.3	176.1
2001	51.8	215.9	161	154	57.5	10.7	108.5	**2001**	41	293	187	192.8	18	27	126.5
2002	106.9	50.4	116.5	109.8	97.8	166.6	108.0	**2002**	101.7	49	126.5	86.5	70.5	88	87.0
2003	135.8	62.7	189.1	276.7	147.5	640.7	242.1	**2003**	144.5	92	234.5	163.5	127.5	453.4	202.6
2004	50.1	32.9	184.3	171.2	43.2	152.8	105.8	**2004**	0	0	118.5	0	28	0	24.4
2005	46.6	124.8	280.5	304.4	279.7	440.7	246.1	**2005**	2.5	15.3	103.3	280.7	254	201	142.8
2006	21.4	210.3	152.9	45.2	90.6	157.4	113.0	**2006**	17	166.9	71.5	108	54.1	65.1	80.4
2007	135.8	94.2	321.6	165.9	47.1	140.4	150.8	**2007**	0	0	0	0	0	60	10.0
2008	37.7	109.9	202.8	364	329.8	272	219.4	**2008**	0	62.6	103	188.8	151	200	117.6
2009	60	396.6	195.2	10.1	147.2	248.6	176.3	2009	62.5	178.5	236.5	310.5	177	29.5	165.8

Entabeni (CE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	72	169.7	215.6	411.9	197.4	97.3	194.0
1971	136.1	236.1	106.7	629.3	569.2	429.6	351.2
1972	129.5	174.7	152.8	151.7	84.5	169.3	143.8
1973	227.5	140.7	743.7	419.1	669.5	150.1	391.8
1974	83.3	307.3	193.3	432.7	838.9	244	349.9
1975	58.9	109.5	437.5	630.9	440	251.1	321.3
1976	81.7	177.6	210.5	523.5	1 274.5	743	347.3
1977	90	228.5	523.5	896.3	200.3	201.3	356.7
1978	87	288	282.9	234.5	229.5	351.5	245.6
1979	133	175.8	241.4	282.5	304.2	286.7	237.3
1980	66.5	304.5	85.5	248.3	468.5	317.2	248.4
1981	155.3	244.5	132.3	196.1	225.5	117.5	178.5
1982	114	54.9	106.6	114.5	80.1	131.3	100.2
1983	121.7	112	97.7	149.3	185.1	373.5	173.2
1984	262.8	379.3	156.9	357.4	271.9	182.6	268.5
1985	115.3	45.6	316.5	153.9	318.6	42.8	165.5
1986	91.1	182.7	201.9	64.7	99.2	95	122.4
1987	107.7	138.8	451.9	136.6	573	439.2	307.9
1988	332.2	117.5	159.4	58.3	559	47.5	212.3
1989	167.9	153.3	380.5	367.6	147.6	144.9	227.0
1990	50	60.6	267.7	245.2	249.9	468	223.6
1991	32	84.5	217.5	150.7	90	67.5	107.0
1992	63.5	205.5	435	190	543.5	128.5	261.0
1993	5	215.9	86.9	275	409.5	46	173.1
1994	61.5	76	191	174.5	472.5	162	189.6
1995	22.5	120.5	79.5	952	769	102	340.9
1996	73	134.1	110	471.7	270.5	284	223.9
1997	151.5	172	113.5	421.6	90	131	179.9
1998	234.4	142.6	424.5	297.3	551	285.5	322.6
1999	39.5	228.5	197.5	711	1 844.5	619	359.1
2000	178.5	172.5	79	72.1	819.4	445.4	294.5
2001	55.2	323	240.5	334.5	102	76.5	188.6
2002	204.5	98.5	235	82.1	110.5	115.6	141.0
2003	120	96	168.3	372.2	232.1	857.5	307.7
2004	68.9	38.5	162.5	239.5	66	171.5	124.5
2005	77.2	193.6	395.5	393.8	315.1	567.5	323.8
2006	0.5	200	168.5	150	64.5	266.5	141.7
2007	0	16.5	520.7	275.5	0	110.3	153.8
2008	43.1	109.5	127.8	366.5	253.5	264.5	194.2
2009	56.8	312.5	140.9	264.7	281	104.5	193.4

Rampuda (CE)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	24.5	96	184.5	178.5	48	37.5	94.8
1971	106	150.5	73.5	442.5	212	251.5	206.0
1972	41	65.6	37	53.5	42.5	28	44.6
1973	53	13	408	131	292.5	104.5	167.0
1974	11	174.5	149.2	214	347.5	68.5	160.8
1975	10	51.7	160.5	334	276.5	123.8	159.4
1976	53.5	133.5	80	94.5	443	321	187.6
1977	45.5	76.5	249.5	385.5	397.5	177.5	222.0
1978	27.2	158.5	91.5	122	53	0	75.4
1979	46	141	56	118	191	115.5	111.3
1980	61	89.5	210.7	381.3	191	105	173.1
1981	0	95.5	8.5	90	***38***	0	38.7
1982	28.2	***10.7***	0	42.5	4	93.5	29.8
1983	0	4.2	4	3.7	0	16	4.7
1984	99.6	139.4	146.7	219.6	224.6	97.8	154.6
1985	51.5	36.9	109.4	51	104.4	46	66.5
1986	46.9	46.5	112.4	61.8	41.7	94.1	67.2
1987	46.5	65.6	253.9	19.4	314	96.9	132.7
1988	141.2	91.5	49.6	12	148.8	53.6	82.8
1989	76.1	100.3	155.4	182.8	34.9	110.8	110.1
1990	20.1	57	115.5	242.3	98.8	131	110.8
1991	0	35.5	10	35.5	71	18	28.3
1992	9.2	257.5	810	160.5	363.5	35	272.6
1993	45.4	152.2	97	126.8	30	19	78.4
1994	11	19	43.5	66	161	75	62.6
1995	42.1	48	69.1	434.6	355	48	166.1
1996	38	58	94.5	183.5	175	91	106.7
1997	26.2	79.6	88.2	72.2	28	28.7	53.8
1998	111	96	218	196	196	330	191.2
1999	54	0	61.4	471.4	990.2	281.1	309.7
2000	32.1	127.3	127	18	365	218	147.9
2001	5.1	280.4	211.1	120.4	11.2	44	112.0
2002	39.1	32.2	88.2	46.3	57.2	209.5	78.8
2003	151	38.5	35	123	141.5	525	169.0
2004	29.5	11.5	117	167.2	17.5	38.7	63.6
2005	0	35.3	93.8	203.2	237.4	83	108.8
2006	0	160.3	10	34.1	45	103	58.7
2007	47.2	155	338	52.9	16.4	51	110.1
2008	5	105	147.2	109.4	47	34	74.6
2009	0	20	5.8	12	44.5	74	26.1

Mphefu(CE)								Palmaryville (CE)							
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Mean**	**Year**	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	15	24.5	130.5	88	11	52	53.5	**1970**	52.5	88.5	98	253.5	49	19	93.42
1971	94.5	68	41	150	85	143.5	97.0	**1971**	61.4	163.5	91	439	234	271	209.98
1972	54	71	0	28.5	4	10	27.9	**1972**	60.9	99	61	21	51	113	67.65
1973	54	46	68.5	129.5	61.5	18.5	63.0	**1973**	98	33.5	258	110	208.6	48.7	126.13
1974	4	120	47.5	94	144	27	72.8	**1974**	13.4	249.8	182.5	159.8	349.5	88.1	173.85
1975	0	49	150.5	***104.4***	172.1	***56.5***	88.8	**1975**	24.5	69.5	283.5	223	196	214	168.42
1976	23	59	***40.4***	181	206	132	106.9	**1976**	23	178.5	76.6	142.8	421.5	618.9	243.55
1977	31	81.5	80	137	249	19.2	99.6	**1977**	52.9	93	346.3	256.1	357.4	176	213.62
1978	46	75.5	74.5	104.6	10.8	59.5	61.8	**1978**	58.2	192.8	120.4	81	31	0	80.57
1979	54.5	59	31	99.6	79	16	56.5	**1979**	58.2	170	145	165	123	82	123.87
1980	45	205.5	159.5	***99.3***	***89.7***	***68.9***	111.3	**1980**	75	115	0	205	157	281.5	138.92
1981	15	60.9	10	29	69	8.7	32.1	**1981**	51.6	220	34.5	140	63	0	84.85
1982	12	24	10	50	***14.7***	35	24.3	**1982**	40.8	0	30	39	42	141	48.80
1983	3	21	4	1.5	18.2	155.5	33.9	**1983**	52.5	10	19	41	68.5	2.5	32.25
1984	182.5	19	53.5	95	85	60	82.5	**1984**	155.2	167.3	3.1	111.6	206.5	148.4	132.02
1985	25	4.5	84.9	122.1	70	0	51.1	**1985**	57.5	0	267.5	77.1	49.2	8	76.55
1986	50.7	58	8.8	82.5	28.5	57	47.6	**1986**	50.2	22.6	57.6	41	94.2	95.5	60.18
1987	26	6.5	212	75.5	150	32	83.7	**1987**	70.8	42	341.1	0.5	268.9	196.8	153.35
1988	97.5	15	38.4	0	84.5	0	39.2	**1988**	260.4	86.7	32.2	8.9	230.8	0	103.17
1989	28.5	65	0	40	105.5	37	46.0	**1989**	104	89.5	146.5	0	54	83.2	79.53
1990	0	17	0	121.5	47	83.5	44.8	**1990**	21	20.5	110	366.4	***170.2***	0	114.68
1991	0	51	0	76	0	14.3	23.6	**1991**	7	31.5	60.8	52	14	85	41.72
1992	3	136	146.4	44	106.5	0	72.7	**1992**	12	84.5	300	80	203	102.7	130.37
1993	29.6	97.8	72	5.5	0	22.5	37.9	**1993**	28	270.5	116	203.8	69.8	24.2	118.72
1994	0	43	44	37	28	38	31.7	**1994**	65.7	52.5	73.5	234.5	106.5	95.4	104.68
1995	6	18.5	***116.5***	134	231.3	15	86.9	**1995**	12	167.8	76	333	481.5	51.5	186.97
1996	91.4	49.5	28	153.9	92	59	79.0	**1996**	17.5	26	89	216	159.7	83.3	98.58
1997	0	72.3	22	204.1	0	17	52.6	**1997**	51.5	146.3	93.5	203	53.6	19.3	94.53
1998	34	103	169.6	49	112	60.4	88.0	**1998**	178.1	116.2	293.8	215.5	209	137.5	191.68
1999	74	0	33.6	192	586.9	237.5	187.3	**1999**	52.1	0	66.2	736.5	846.9	191.9	315.60
2000	22.5	78	43	61.5	83.5	108	66.1	**2000**	25	184.6	90.5	32.5	443	128.3	150.65
2001	6	169.5	123	0	39	8.5	57.7	**2001**	12.8	355.5	255.4	130.5	6	23.4	130.60
2002	4	36.4	139.5	0	15	57.5	42.1	**2002**	116.7	32.2	88.2	91	80.9	69.5	79.75
2003	35	11	104	123.5	34.8	253.5	93.6	**2003**	148.5	65.9	91.5	262.5	223	348.5	189.98
2004	22.1	23.9	142	103.7	41.5	5	56.4	**2004**	35.5	19.7	145.5	66.7	6.5	60.5	55.73
2005	0	51.5	114.1	228.3	209.8	85.5	114.9	**2005**	26	82.7	237.2	303.9	283.1	193.5	187.73
2006	0	14.2	72	43	13	112	42.4	**2006**	6.1	173.6	39.4	179.5	61.3	82.3	90.37
2007	87	62.3	71.9	41.1	25.4	0	48.0	**2007**	65.1	128.1	397.9	216.7	68.4	98.5	162.45
2008	0	119	16	164.7	0	0	50.0	**2008**	11.7	58.2	179	123.9	90.3	106	94.85
2009	0	54.4	135.7	29.1	33.6	0	42.1	**2009**	10	205.9	157.8	72.7	189	100.3	122.62

Matiwa (CE)							Vondo Bos (CE)						
Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean	**Year**	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	98.5	182.5	272	518.5	215.5	80	227.8	**1970**	43.5	59.7	172.5	212	60.5	43	98.5
1971	156.4	266.5	78	773.5	569.6	439.5	380.6	**1971**	53.9	42.5	75	268.8	182	241.5	144.0
1972	116	199	164.7	173.9	153.7	168.5	162.6	**1972**	41.8	61	22.5	44.3	36	191.9	66.3
1973	258.5	127.8	508.7	454.9	646.5	142.7	356.5	**1973**	79.7	21.5	295.9	177.7	226	63.5	144.1
1974	83.6	368.6	198.6	425.1	827.3	233.3	356.1	**1974**	6	220.7	153	345.8	535.3	179.5	240.1
1975	81.2	142.4	571.5	595.5	429.2	278.7	349.8	**1975**	38	32	415.2	406.7	347	229.8	244.8
1976	74.4	204.2	265.5	773.5	569.6	439.5	387.8	**1976**	60.3	130.7	175.3	395.8	674	634.7	345.1
1977	116	199	164.7	173.9	153.7	168.5	162.6	**1977**	78	127.2	603.4	631	534.9	293.2	378.0
1978	258.5	127.8	508.7	263.5	242.5	375.5	296.1	**1978**	71.6	297.5	70.2	246.1	124.1	87.5	149.5
1979	167.5	243.5	298.6	268.2	334.7	324.1	272.8	**1979**	96.5	278.5	232.2	238.2	338.9	215	233.2
1980	103.5	292.5	97.5	229.5	391.5	340.3	242.5	**1980**	68.5	262.5	74.1	388	391.5	115.5	216.7
1981	204.5	272	94.1	223.6	284	98	196.0	**1981**	107.7	204	63.5	234	188.1	36.4	139.0
1982	142	67.2	152.8	110.2	93.7	151.4	119.6	**1982**	79.8	39.9	162.2	111.3	74.3	91.1	93.1
1983	130.6	109.2	97.1	117	209.4	378.2	173.6	**1983**	84.1	94.1	57.5	132.1	144.2	268.1	130.0
1984	274.2	429.8	164	356.7	298.9	184.7	284.7	**1984**	292.4	462.6	110.9	271.7	245.1	214.4	266.2
1985	115.4	50.4	327.9	130.1	333.5	41.1	166.4	**1985**	94.2	43	245.3	168.7	123.1	44	119.7
1986	112.9	201.5	199	76.7	107.5	100.5	133.0	**1986**	69.4	133.1	130.8	56	88.8	132.9	101.8
1987	142.2	187.9	536	207.7	646.2	529.8	375.0	**1987**	95.7	123.8	485.5	103.5	574	398	296.8
1988	414.5	176.5	179.4	75.5	607.4	58	251.9	**1988**	0	175.5	124	100.3	419.6	15.5	139.2
1989	165.4	165.6	391.4	426.2	172.8	194.6	252.7	**1989**	138.4	145.4	302.9	256	37.5	90.2	161.7
1990	101.7	156.1	247.1	540.9	210.3	423.4	279.9	**1990**	29	93.8	219.1	420.3	208.5	350.7	220.2
1991	53.4	90.6	157.5	133.7	113.5	85.5	105.7	**1991**	12.1	18.5	0	86.6	0	64.5	30.3
1992	77.5	268.5	452	191.5	613.5	176.5	296.6	**1992**	28	231.3	254.1	106	622.8	143.7	231.0
1993	6.7	225.3	109.4	272	332	60	167.6	**1993**	83.5	251.9	552	307.9	0	16.3	201.9
1994	65.5	79	217	264	478.5	171.5	212.6	**1994**	45.7	62.6	42	358.3	72	157.4	123.0
1995	40	167.5	87.7	1107	776.5	113.7	382.1	**1995**	32.5	210.8	294.2	859.5	782.5	106.2	381.0
1996	103	224.5	137.5	610.5	281	370	287.8	**1996**	83.3	105.8	168.7	359.2	65	184.9	161.2
1997	215.5	230.5	164.5	445	112	158	220.9	**1997**	121.7	147.2	66.9	395.7	60.4	114.5	151.1
1998	321	194.1	590.5	373	581.5	405	410.9	**1998**	213.3	143.3	420.5	300.2	303.5	244.3	270.9
1999	55	275.5	212	814.5	1803	662	637.0	**1999**	38.7	0	125.2	609.6	1 742.9	490.6	252.8
2000	256.5	193.5	116.5	67.5	780.7	419	305.6	**2000**	91.5	191.5	147.5	45.5	781.5	386.1	273.9
2001	64	391.5	293.4	382	121	64.5	219.4	**2001**	39	330.8	245.4	263.9	32.9	79	165.2
2002	233	108	242	81.5	125	180	161.6	**2002**	82.6	105.5	201.7	14	211.8	196.9	135.4
2003	185	165.5	173	382	239	868.9	335.6	**2003**	143.5	71.8	155	186	173	627.7	226.2
2004	119.4	52.7	203.7	243.9	73.8	210	150.6	**2004**	45.4	39.2	182	111.1	99.6	133.5	101.8
2005	111.3	141.3	551.4	469.2	339	474.9	347.9	**2005**	51.5	96.8	334	248.5	183.6	139.9	175.7
2006	47.1	246.1	209.4	193.7	93.4	273.7	177.2	**2006**	13	246.5	162.5	136	60.8	228.1	141.2
2007	273.3	217	710.6	367.9	41.4	104.4	285.8	**2007**	148.5	99	424	245	50.5	135	183.7
2008	73	176.2	328	409.8	263.2	279.5	255.0	**2008**	20.7	117	88	201	196.5	228	141.9
2009	39.3	371.8	214.5	352.5	297.6	108	230.6	**2009**	26.8	285.5	172.5	121	213	77	149.3

Shefeera (CE)								Hanglip (CE)							
Year	Oct	Nov	Dec	Jan	Feb	Mar	Mean	**Year**	Oct	Nov	Dec	Jan	Feb	Mar	Mean
1970	43.8	46.5	119.1	108.7	76.9	61.5	76.1	**1970**	47	48.6	188.2	222.7	53.6	121.7	113.6
1971	87.8	168	61.1	280	203.8	206.5	167.9	**1971**	100	221.8	59.8	388.1	335.5	207.7	218.8
1972	164	127.3	45	84.7	101.4	80.4	100.5	**1972**	124.4	175.5	54.6	86.7	128	119.7	114.8
1973	115.5	58	205.5	226.5	309.2	46.8	160.3	**1973**	111.1	69.6	274.7	179.5	358.5	60	175.6
1974	3	188.1	96.2	175	356.5	82.7	150.3	**1974**	11.3	146.1	77.8	320.8	378	130.7	177.5
1975	9.2	57	128.8	410.2	176	133.2	152.4	**1975**	18	76	140.7	427.8	138	162.5	160.5
1976	33	137.8	115.2	241.5	241	153	153.6	**1976**	24	75	60.8	319	369.6	231.6	203.8
1977	22	66.5	167.5	266	251.5	99	145.4	**1977**	33.5	65.5	205.7	342.2	396.1	158.8	200.3
1978	34	98.5	70.1	81.3	23.3	53.5	60.1	**1978**	29.8	166.1	154.5	116.8	60	106.5	105.6
1979	32.2	22.2	59.2	85.3	53.4	27	46.6	**1979**	55.7	68.5	197	184.5	149.5	112.1	127.9
1980	22.3	128.1	44.2	279	94.1	141.5	118.2	**1980**	48	194.5	38.5	378.5	228	207.3	182.5
1981	46	82.2	28.5	68.4	132.5	0	59.6	**1981**	52.5	98	74	75.7	168	10	79.7
1982	31.1	8.5	32.5	127	36	72.5	51.3	**1982**	45.1	28	28	136.5	28	110	62.6
1983	14.5	149.8	57.6	32.5	76	162.1	82.1	**1983**	32	81	58	34.5	95	208	84.8
1984	119.5	142	62.1	144.1	164.2	96.1	121.3	**1984**	OCT	226.6	77.6	252.1	201.5	102.3	172.0
1985	80.1	23.5	115.3	74.7	84	30.2	68.0	**1985**	94.3	14	264.2	104.7	203.6	32.7	118.9
1986	79.7	112	68	80	39	52.6	71.9	**1986**	88	157	90.8	74	28.5	40.6	79.8
1987	59	18.5	170.4	81.9	179.4	115	104.0	**1987**	63.9	31.3	257.8	44.7	112	165.4	112.5
1988	174.5	18.4	92.8	6	194.5	50	89.4	**1988**	216.5	32.3	127	17.5	224.9	51.9	111.7
1989	79	97.7	130.5	96.4	95	71.8	95.1	**1989**	77.7	107.1	117.8	110.3	91	81.5	97.6
1990	13.2	47.1	86.7	129.7	101.7	211.4	98.3	**1990**	29	71.5	82.9	148.3	107.3	191.2	105.0
1991	0	46.6	35.2	43.4	57.6	19.8	33.8	**1991**	0	59.8	23.5	119.2	43.9	31.8	46.4
1992	40.9	70.7	209.1	74.7	195.6	56.3	107.9	**1992**	39.6	38.2	134.7	109.7	329.3	26.5	113.0
1993	34	206	90.5	72	19	29.5	75.2	**1993**	57.5	205.2	76.5	145.9	27.9	52.4	94.2
1994	47.5	21.5	57	63.5	175.2	80.5	74.2	**1994**	55.6	31.5	49.5	60.9	201.4	85.2	80.7
1995	29	90	106.5	270.1	315.2	43.4	142.4	**1995**	39.2	78.6	152.7	352.5	368.2	54.4	174.3
1996	60	118	60	284.7	147	189.3	143.2	**1996**	58.7	100.8	96.1	383.5	147.5	237.7	170.7
1997	46	88.5	14.5	202.5	20.4	10.2	63.7	**1997**	68	63.9	56.8	207.4	66.7	23.5	81.1
1998	71.2	111.2	210.7	102	179	90.5	127.4	**1998**	111.5	97.1	193.8	178	176.2	101.2	143.0
1999	83.5	100.2	85	309.5	836.4	199	268.9	**1999**	70	104.5	122.3	328.5	1 172.2	289.5	183.0
2000	52	121	83.9	11	324.5	133.5	121.0	**2000**	82	114.5	80.8	22.5	278	120	116.3
2001	27.5	203	168.5	71.5	14	32	86.1	**2001**	32.5	204.6	185.7	209	19.5	28.5	113.3
2002	35.5	24.5	52.5	139	34	100	64.3	**2002**	50.5	32.5	69	82	105	129.7	78.1
2003	58	33.3	84.5	64.5	75	377.5	115.5	**2003**	89	46.5	100	117.5	76	491.5	153.4
2004	22.5	9	82	61.5	10	40	37.5	**2004**	34.6	24	116	97.6	15.5	89	62.8
2005	7.5	72	117.7	151	197	140.5	114.3	**2005**	15.5	130.5	97.5	271.5	305.5	197	169.6
2006	6	121.5	94	62.1	39	110.5	72.2	**2006**	8.1	115	139.5	65	70	179.5	96.2
2007	107	127.5	230.5	113.6	27	59	110.8	**2007**	99.5	82	246	125.1	35.5	67.5	109.3
2008	8	136.6	130.2	295.2	147.5	101.5	136.5	**2008**	22	106.6	81.5	222	267.5	123	137.1
2009	33	304.5	88.9	64	110	26	104.4	**2009**	11	24.8	64.6	84.6	66.4	10.2	43.6

** Figures in bold and italic shows calculated missing values*

Appendix 3.5 Average Seasonal Temperature for Mara and Levubu

Mara					Levubu				
Year	Max-Dry season	Min-Dry Season	Max-wet season	Min-Wet season	Year	Max-Dry Season	Min-Dry Season	Max-Wet Season	Min-Wet Season
1970	25.3	8.7	29.6	16.6	1970	26.2	12.7	29.8	18.1
1971	24.9	8.1	27.7	16.4	1971	25.0	12.1	27.7	17.2
1972	24.7	6.9	30.2	16.4	1972	24.5	11.4	27.6	17.4
1973	24.4	8.1	27.4	16.5	1973	24.2	11.9	28.3	17.8
1974	24.3	7.2	27.9	16.3	1974	24.2	11.2	27.3	18.0
1975	24.8	7.4	27.8	15.8	1975	24.5	11.6	27.3	17.3
1976	24.1	7.1	29	16.9	1976	23.9	11.5	27.8	18.1
1977	25.1	7.5	28.7	16.4	1977	25.1	12.2	28.0	18.2
1978	25.3	7.4	28.8	15.7	1978	25.1	12.2	26.8	17.5
1979	25.1	8.0	28.7	16.0	1979	24.5	12.6	28.0	17.8
1980	24.6	6.3	28.8	16.2	1980	24.2	11.8	27.7	18.0
1981	24.6	7.0	29.9	15.7	1981	23.4	11.5	27.0	17.6
1982	25.2	7.9	30.9	16.9	1982	24.6	12.6	29.2	18.3
1983	25.9	9.0	30.2	17.4	1983	25.7	13.6	29.5	19.0
1984	24.9	9.0	29.1	17.0	1984	24.0	13.2	28.2	18.3
1985	24.7	8.3	29.9	16.2	1985	24.2	12.6	28.2	18.1
1986	25.6	7.7	30.1	16.4	1986	25.3	12.6	28.9	17.9
1987	25.6	7.9	29.5	17.3	1987	24.8	12.7	28.8	18.6
1988	25.1	6.3	28.7	16.1	1988	24.9	12.1	27.0	17.8
1989	26.2	10.3	27.3	16.6	1989	24.4	14.3	27.5	18.1
1990	24.8	8.4	29.4	16.7	1990	24.5	12.6	27.8	17.8
1991	25.3	7.4	31.3	16.8	1991	24.7	12.1	29.0	18.5
1992	26.5	8.5	29.7	17.2	1992	26.1	13.2	30.3	19.2
1993	25.8	9.2	28.9	16.2	1993	25.8	13.2	27.6	18.0
1994	25.5	7.3	30.3	16.6	1994	25.0	11.5	28.2	17.1
1995	24.5	8.6	29.3	17.3	1995	24.5	12.9	28.6	18.4
1996	24	8.0	28.8	16.4	1996	23.3	12.3	27.6	18.3
1997	25.1	7.5	30.5	16.7	1997	24.8	12.3	28.0	18.4
1998	26.6	8.5	29	17.1	1998	25.8	13.2	28.1	18.7
1999	26.2	9.0	28.4	16.7	1999	24.7	11.8	27.5	17.6
2000	24.4	7.6	29.1	16.2	2000	23.3	11.2	27.0	17.4
2002	25.5	7.9	30.1	16.5	2002	25.0	12.1	27.5	17.7
2003	25.9	8.3	30.9	16.5	2003	25.3	13.0	29.0	17.1
2004	25.7	8.6	29.9	17.0	2004	25.2	13.0	29.7	18.7
2005	25.1	8.3	31.6	17.6	2005	24.6	12.2	29.2	18.3
2006	27	10.1	29.3	17.5	2006	26.4	13.6	29.2	17.9
2007	25.1	7.6	31.9	17.4	2007	24.9	12.0	29.1	18.6
2008	26	8.4	28.6	16.7	2008	25.9	12.7	28.3	18.1
2009	26.7	8.5	29.9	17.2	2009	26.2	12.3	28.1	18.1

Appendix 3.6: Scene Specification of Landsat TM images

Date And Time	Satellite	Sensor	Path	Row	Resolution
1989-03-09 07:24:52	Landsat 5	TM	169	76	30 m
1989-03-16 07:30:43	Landsat 5	TM	170	76	30 m
1998-03-18 07:32:22	Landsat 5	TM	169	76	30 m
1998-03-25 07:38:20	Landsat 5	TM	170	76	30 m
2008-03-29 07:45:15	Landsat 5	TM	169	76	30 m
2008-03-29 07:44:51	Landsat 5	TM	170	76	30 m

Appendix 3.7: Root Mean Error (RMS_{error})

16907619890309									
Point No	X Input	Y Input	X Ref	Y Ref	X Residual	Y Residual	RMS Error	Contrib.	Match
GCP #1	205494.5	7517919	30.13	-22.412	-0.317	-0.291	0.4	0.932	
GCP #2	209606.4	7515045	30.171	-22.438	-0.584	-0.858	1.0	2.251	
GCP #3	210717.4	7511766	30.181	-22.468	0.211	-0.253	0.3	0.715	
GCP #4	214174.9	7507337	30.215	-22.509	0.357	0.789	0.9	1.878	0.943
GCP #5	199262	7503400	30.064	-22.544	0.352	0.837	0.9	1.97	0.23
GCP #6	195294.1	7489218	30.021	-22.674	0.174	-0.026	0.2	0.382	0.21
GCP #7	327324.1	7504718	31.348	-22.537	-0.178	0.278	0.3	0.717	0.099
GCP #8	332696	7488468	31.398	-22.686	0.007	-0.632	0.6	1.371	0.636
GCP #9	345681.4	7448707	31.519	-23.05	0.191	0.416	0.5	0.992	0.225
GCP #10	237787	7396353	30.424	-23.524	0.264	-0.382	0.5	1.007	0.876
GCP #11	231318.2	7389505	30.357	-23.587	-0.196	-0.415	0.5	0.995	0.418
GCP #12	232241	7381147	30.364	-23.663	0.123	0.27	0.3	0.643	0.546
GCP #13	238382.8	7380712	30.426	-23.667	-0.166	-0.252	0.3	0.655	0.586
GCP #14	238921.8	7378454	30.431	-23.688	0.138	-0.067	0.2	0.332	0.509
GCP #15	248175.2	7368907	30.521	-23.775	0.167	-0.088	0.2	0.41	0.365
GCP #16	254893.1	7361307	30.587	-23.845	-0.299	0.223	0.4	0.808	0.033
GCP #17	232074.1	7430161	30.375	-23.215	-0.125	0.387	0.4	0.883	0.344
GCP #18	166902.8	7391618	29.712	-23.565	0.136	-0.084	0.2	0.347	0.071
GCP #19	170362.9	7393714	29.747	-23.546	-0.052	-0.18	0.2	0.406	0.43
GCP #20	175436.2	7394707	29.798	-23.537	0.028	0.132	0.1	0.292	-0.179
GCP #21	182514.1	7383640	29.866	-23.638	0.072	0.067	0.1	0.214	-0.023
GCP #22	176769.1	7400570	29.813	-23.483	-0.295	0.453	0.5	1.174	-0.215
GCP #23	181526.4	7432562	29.869	-23.191	-0.039	0.13	0.1	0.295	0.528
GCP #24	183626.3	7440147	29.892	-23.122	0.06	-0.495	0.5	1.081	0.483
GCP #25	236294.4	7434046	30.418	-23.18	-0.03	0.039	0.0	0.106	0.179
RMS							**0.4**		

Continued **Appendix 3.7: Root Mean Error (RMS_{error})**

17007619890316									
Point No	X Input	Y input	X ref	Y ref	X residual	Y residual	RMS error	contrib.	Match
GCP #1	737680.8	7360143	29.326	-23.843	-0.054	0.754	0.8	2.344	
GCP #2	751136.6	7359841	29.458	-23.844	-0.284	0.122	0.3	0.957	
GCP #3	749959.6	7358400	29.446	-23.857	0.021	0.006	0.0	0.066	
GCP #4	753535.8	7357096	29.481	-23.868	0.62	-0.48	0.8	2.43	0.877
GCP #5	756472.8	7353885	29.509	-23.897	-0.616	-0.41	0.7	2.293	0.737
GCP #6	792586.9	7343908	29.861	-23.984	-0.159	0.426	0.5	1.409	0.114
GCP #7	776479.1	7347461	29.704	-23.953	0.426	-0.188	0.5	1.442	0.328
GCP #8	759621.1	7412221	29.548	-23.367	-0.021	-0.142	0.1	0.445	0.166
GCP #9	748358.2	7411773	29.438	-23.373	0.051	-0.173	0.2	0.56	0.47
GCP #10	744759	7416224	29.404	-23.333	-0.039	-0.146	0.2	0.469	0.333
GCP #11	740120.2	7417900	29.359	-23.318	0.167	0.36	0.4	1.229	0.859
GCP #12	735559.3	7419165	29.314	-23.307	0.033	0.001	0.0	0.101	0.555
GCP #13	655363.1	7389453	28.526	-23.586	-0.009	-0.098	0.1	0.306	0.457
GCP #14	642587.5	7384015	28.401	-23.637	0.108	-0.039	0.1	0.356	0.18
GCP #15	619451.3	7375203	28.173	-23.72	-0.063	-0.094	0.1	0.351	0
GCP #16	643066.9	7389324	28.406	-23.589	0.041	0.058	0.1	0.222	0.469
GCP #17	655156.7	7453586	28.534	-23.004	-0.042	0.05	0.1	0.202	0.678
GCP #18	650755.7	7470033	28.493	-22.856	-0.159	0.102	0.2	0.584	0.477
GCP #19	652451.9	7497663	28.514	-22.605	0.095	-0.04	0.1	0.319	0.157
GCP #20	688245.6	7507802	28.865	-22.509	0.032	0.019	0.0	0.114	0.19
GCP #21	781909.7	7410789	29.766	-23.378	0.001	-0.013	0.0	0.041	0.107
GCP #22	759226.9	7419960	29.546	-23.297	-0.061	0.052	0.1	0.249	0.043
GCP #23	771987.3	7421913	29.671	-23.278	-0.078	-0.025	0.1	0.253	0.444
GCP #24	777082.4	7421659	29.72	-23.28	-0.005	-0.097	0.1	0.3	0.217
GCP #25	780370.1	7420206	29.752	-23.293	-0.003	-0.004	0.0	0.015	0.097
RMS							**0.2**		

Continued Appendix 3.7: Root Mean Error (RMS_{error})

1690761998									
Point No	X Input	Y input	X ref	Y ref	X residual	Y residual	RMS error	Contrib.	Match
GCP #1	202055.8	-2475599	30.10473	-22.3085	-8.29E-05	0.000368	0.000	0.540817	
GCP #2	198772	-2477721	30.07155	-22.3276	0.000129	-0.00055	0.001	0.806894	
GCP #3	200821	-2474697	30.09241	-22.3	-0.00049	-0.00044	0.001	0.940355	
GCP #4	203940	-2476470	30.12358	-22.3168	0.000464	-0.00046	0.001	0.935596	-0.55814
GCP #5	209280	-2474455	30.17741	-22.299	-0.00054	-0.00024	0.001	0.848715	0.135214
GCP #6	215310	-2476598	30.23779	-22.3197	0.000236	0.00018	0.000	0.424894	0.594967
GCP #7	277462.9	-2523510	30.85779	-22.7614	0.000203	0.000494	0.001	0.765164	-0.10292
GCP #8	270150	-2527370	30.78396	-22.796	0.000411	1.75E-05	0.000	0.589221	0.365589
GCP #9	254340	-2534006	30.62452	-22.8549	-4.69E-05	-0.00044	0.000	0.635288	-0.24053
GCP #10	247273.9	-2540823	30.55289	-22.9167	-0.00021	-2.40E-05	0.000	0.296904	0.64929
GCP #11	256420.3	-2550138	30.64391	-23.0039	-0.00022	0.000348	0.000	0.5931	0.892296
GCP #12	262811.7	-2548650	30.70825	-22.9912	-0.00073	8.82E-05	0.001	1.055331	0.297197
GCP #13	279759.1	-2550600	30.87832	-23.0116	-7.95E-05	0.000365	0.000	0.534791	0.313009
GCP #14	266735.6	-2579910	30.74475	-23.2801	0.000926	0.001292	0.002	2.277276	0.309479
GCP #15	236252	-2627353	30.43408	-23.7132	-9.44E-07	0.000839	0.001	1.201879	0.792246
GCP #16	241086	-2623786	30.48298	-23.681	-0.00025	-0.00108	0.001	1.5928	0.517491
GCP #17	242673.6	-2584394	30.50261	-23.3179	4.68E-05	5.03E-05	0.000	0.098366	0.310592
GCP #18	229770	-2589870	30.37247	-23.3665	-3.32E-05	-0.00056	0.001	0.798325	0.415364
GCP #19	214948.2	-2572680	30.22518	-23.2058	0.000658	0.00072	0.001	1.397543	0.403057
GCP #20	292230	-2630734	30.99612	-23.7525	-0.00016	-0.00126	0.001	1.813178	-0.47198
GCP #21	248040	-2618135	30.55336	-23.6299	2.00E-05	-0.00042	0.000	0.597911	-0.02007
GCP #22	261539.4	-2619008	30.6889	-23.6399	-0.00027	0.000102	0.000	0.409693	0.307542
GCP #23	183553.3	-2601025	29.90714	-23.4627	-0.00052	-0.00021	0.001	0.796142	0.651558
GCP #24	188010	-2599237	29.95207	-23.4469	-0.00023	0.000288	0.000	0.52413	0.208304
GCP #25	186052	-2591100	29.93316	-23.3715	0.000755	0.000524	0.001	1.31565	-0.30405
RMS							**0.001**		

Continued Appendix 3.7: Root Mean Error (RMS_{error})

1700761998									
Point No	X Input	Y input	X ref	Y ref	X residual	Y residual	RMS error	Contrib.	Match
GCP #1	692759.2	-2490509	28.86526	-22.5084	-0.00032	0.000123	0.000	0.820616	
GCP #2	695611.7	-2490113	28.89323	-22.5045	0.000722	-0.00022	0.001	1.805342	
GCP #3	693869.7	-2488144	28.8759	-22.4865	-0.00019	-0.00027	0.000	0.775393	
GCP #4	690173.3	-2487740	28.83955	-22.4832	0.000463	0.000275	0.001	1.289318	0.695534
GCP #5	699650.6	-2491420	28.93304	-22.516	-0.00038	0.00017	0.000	1.005118	0.849567
GCP #6	706312.6	-2497312	28.99912	-22.5696	0.000301	0.0003	0.000	1.017531	0.291204
GCP #7	709588.2	-2503197	29.03193	-22.6234	-0.00017	-0.00049	0.001	1.239628	0.781129
GCP #8	756880	-2521238	29.49839	-22.7843	-0.00037	-5.36E-06	0.000	0.89504	0.522663
GCP #9	770545.9	-2532810	29.63387	-22.8893	-0.00011	-8.19E-05	0.000	0.334709	0.214248
GCP #10	773124.6	-2529623	29.65885	-22.8597	0.000125	-0.00025	0.000	0.661451	-0.00068
GCP #11	772260	-2521766	29.6495	-22.7875	-3.17E-05	-6.14E-05	0.000	0.165557	-0.13989
GCP #12	732140	-2593920	29.26334	-23.4558	-0.00037	-0.00014	0.000	0.939403	0.674722
GCP #13	733890	-2593306	29.28046	-23.45	0.000489	-3.54E-05	0.000	1.173957	-0.13517
GCP #14	737573.7	-2598780	29.31724	-23.5	0.000235	6.23E-05	0.000	0.581413	0.009959
GCP #15	749480.7	-2602443	29.43459	-23.5324	-0.00018	0.000142	0.000	0.544002	0.488557
GCP #16	762830	-2592545	29.56462	-23.4399	5.43E-05	9.92E-05	0.000	0.270797	0.66397
GCP #17	780750	-2592949	29.74067	-23.4417	-8.67E-05	0.000545	0.001	1.322805	0.387741
GCP #18	785110.6	-2583724	29.78249	-23.3563	0.000162	-6.16E-05	0.000	0.415787	0.375562
GCP #19	732104.2	-2557170	29.25898	-23.1176	-5.15E-05	-0.00026	0.000	0.637089	0.240687
GCP #20	631140	-2618276	28.27402	-23.6909	6.54E-06	-0.00051	0.001	1.225025	0.286136
GCP #21	653490	-2598766	28.4914	-23.5089	0.00063	-5.39E-05	0.001	1.515443	-0.11007
GCP #22	659722.2	-2590635	28.55172	-23.4334	-0.00024	-1.25E-06	0.000	0.582716	0.173451
GCP #23	658890	-2580628	28.54245	-23.3414	-0.00042	-2.99E-05	0.000	1.019866	0.209065
GCP #24	647461.2	-2571964	28.42926	-23.2629	-0.00013	4.62E-06	0.000	0.312466	0.709535
GCP #25	637263.1	-2551925	28.3269	-23.0796	-0.00014	0.000743	0.001	1.808944	0.555495
RMS							**0.000**		

Continued Appendix 3.7: Root Mean Error (RMS_{error})

1690762008									
Point No	X Input	Y input	X ref	Y ref	X residual	Y residual	RMS error	Contrib	Match
GCP #1	209398.1	-2468515	30.17844	-22.2994	0.001698	-0.00077	0.002	0.696476	
GCP #2	213301.4	-2468307	30.21662	-22.2976	-0.00022	0.000119	0.000	0.093182	
GCP #3	213631.9	-2469567	30.22072	-22.3094	0.002329	0.000271	0.002	0.875462	
GCP #4	215392.5	-2471900	30.23958	-22.3313	0.001187	0.000569	0.001	0.491246	0.504191
GCP #5	214663.1	-2476343	30.23543	-22.3728	0.000863	-0.00041	0.001	0.356706	0.669138
GCP #6	227906.9	-2528152	30.4005	-22.8578	-0.00054	0.000241	0.001	0.219997	0.464292
GCP #7	225840.3	-2542081	30.38964	-22.988	0.000453	0.000241	0.001	0.191636	0.250447
GCP #8	224932.2	-2545425	30.38299	-23.0192	0.001582	-0.0003	0.002	0.601342	0.376058
GCP #9	239130	-2545025	30.52211	-23.0161	-0.00264	0.000437	0.003	0.997401	0.52554
GCP #10	246314.7	-2545016	30.59264	-23.0163	-0.00538	-4.97E-05	0.005	2.007302	0.469082
GCP #11	252105.2	-2543522	30.64847	-23.0026	-0.00786	-0.00084	0.008	2.950433	0.1294
GCP #12	279034.6	-2598086	30.94977	-23.5139	0.007997	0.000278	0.008	2.98727	0.591347
GCP #13	263433.3	-2591730	30.79231	-23.4538	0.000176	-0.0002	0.000	0.100731	-0.09491
GCP #14	219812.6	-2603910	30.3723	-23.5659	5.62E-05	-6.67E-05	0.000	0.032571	0.626899
GCP #15	226800	-2599029	30.43759	-23.5206	-0.00021	-0.00028	0.000	0.132067	-0.28831
GCP #16	230837.6	-2601247	30.47873	-23.5415	0.000364	1.83E-05	0.000	0.136059	0.758943
GCP #17	233435.9	-2600310	30.50361	-23.5328	-0.00036	0.000163	0.000	0.148998	-0.09473
GCP #18	244491.4	-2605863	30.6159	-23.5852	-0.00042	0.000292	0.001	0.190806	0.246191
GCP #19	256350	-2603270	30.73057	-23.5615	0.000232	0.000408	0.000	0.175357	-0.20611
GCP #20	279450	-2640441	30.98251	-23.91	2.51E-05	-0.00047	0.000	0.176286	-0.06107
GCP #21	167198.9	-2571845	29.83406	-23.2639	0.000187	0.000455	0.000	0.183755	0.307748
GCP #22	175227.4	-2568495	29.91061	-23.2329	0.000395	-4.40E-05	0.000	0.148228	0.406267
GCP #23	183904.5	-2564280	29.99295	-23.1938	0.000194	-0.0003	0.000	0.133786	0.326304
GCP #24	189172.7	-2562349	30.04337	-23.176	-0.00035	4.63E-05	0.000	0.129991	0.343966
GCP #25	333312.6	-2490192	31.40965	-22.5073	0.000232	0.000207	0.000	0.116051	0.244689
RMS							**0.002**		

Continued Appendix 3.7: Root Mean Error (RMS_{error})

1700762008									
Point No	X Input	Y input	X ref	Y ref	X residual	Y residual	RMS error	Contrib	Match
GCP #1	704776.7	7512506	28.86538	-22.5084	0.029842	0.022856	0.037589	0.552341	
GCP #2	707654.9	7512902	28.89299	-22.5045	0.022571	0.014805	0.026993	0.396642	
GCP #3	709155.6	7513469	28.90756	-22.4995	0.018952	0.011336	0.022083	0.324499	
GCP #4	711972.3	7511459	28.93341	-22.5153	0.004189	0.002256	0.004758	0.069916	0.483
GCP #5	715585.8	7508840	28.96656	-22.5359	-0.0153	-0.01088	0.018775	0.275885	-0.285
GCP #6	714952.9	7505939	28.95911	-22.5599	-0.02103	-0.01319	0.024823	0.364749	0.51
GCP #7	709063.8	7502871	28.9015	-22.5864	-0.0076	-0.00478	0.008975	0.131885	0.24
GCP #8	693921.1	7484960	28.74848	-22.7368	6.70E-05	0.001133	0.001135	0.016675	-0.481
GCP #9	697598.4	7483924	28.78301	-22.7445	-0.01625	-0.01161	0.019973	0.293483	0.193
GCP #10	673081.9	7451939	28.5338	-23.0125	-0.00979	-0.00672	0.011869	0.17441	0.316
GCP #11	663616.6	7421713	28.42884	-23.2625	-0.05132	-0.0376	0.063622	0.934885	0.671
GCP #12	677203.8	7394854	28.54514	-23.4796	-0.16568	-0.11882	0.203881	2.995875	0.617
GCP #13	671806.6	7391460	28.49206	-23.5087	0.209142	0.148893	0.256728	3.772434	-0.146
GCP #14	670770.5	7389509	28.48124	-23.525	0.001739	0.001396	0.00223	0.032761	0.345
GCP #15	675886.6	7381797	28.5262	-23.587	-0.00075	0.0003	0.000808	0.011869	0.027
GCP #16	745726.6	7420241	29.21035	-23.2555	0.000759	0.000959	0.001223	0.017969	0.353
GCP #17	750616.6	7414534	29.25414	-23.3011	-0.00062	0.000324	0.0007	0.01029	0.528
GCP #18	770357	7405287	29.43767	-23.3723	-0.0009	0.00012	0.000907	0.01333	0.157
GCP #19	774929.1	7406369	29.48176	-23.3624	-0.00048	-9.26E-05	0.00049	0.007195	0.178
GCP #20	815397.7	7479972	29.9033	-22.7494	0.000446	-0.00013	0.000465	0.006835	0.376
GCP #21	804871.2	7488054	29.80697	-22.6856	-0.00055	8.43E-05	0.000552	0.008108	0.384
GCP #22	804510.1	7487309	29.80316	-22.6918	0.001326	-8.13E-05	0.001329	0.019521	-0.09
GCP #23	796726.6	7491705	29.73117	-22.6575	-0.00101	0.000284	0.00105	0.015436	0.737
GCP #24	758327.7	7427390	29.33389	-23.1939	0.000717	-0.0011	0.001312	0.019275	0.575
GCP #25	755476.6	7427133	29.3066	-23.1967	0.001524	0.000252	0.001545	0.022702	0.642
RMS							**0.03**		

Appendix 3.8 a: Error Matrix of 1989 TM Image using stratified random method

Class name	Wood land	Water bodies	Thicket	Sparse forest	Plantation	Pasture	Grassland	Forest	Crop land	Bush/ shrub	Built up area	Bare soil	Total
Woodland	10	0	0	0	0	0	0	0	0	1	0	0	11
Water bodies	0	8	0	0	0	0	0	0	2	0	0	0	10
Thicket	1	0	8	0	0	0	0	0	0	0	0	0	9
Sparse forest	0	0	0	10	0	0	0	4	0	0	0	0	14
Plantation	0	1	0	0	15	0	0	0	0	0	0	2	18
Pasture	0	0	0	0	0	12	0	0	0	0	0	0	12
Grassland	0	0	2	0	0	0	12	1	0	0	0	0	15
Forest	0	0	0	0	0	0	0	18	0	0	0	0	18
Cropland	0	2	0	0	4	0	0	0	12	0	1	3	22
Bush/ Shrub	0	0	0	0	0	0	0	0	0	9	0	0	9
Built up area	1	0	3	0	0	0	0	0	0	0	20	0	24
Bare soil	2	0	0	0	0	0	0	0	0	0	0	10	12
Column total	14	11	13	10	19	12	12	23	14	10	21	15	174

Appendix 3.8 b: Accuracy Statistics for 1989 classified Image

Class name	Reference Total	Classified Total	Number correct	Producer Accuracy	User Accuracy	Kappa
Woodland	22	20	15	65.25	75.18	0.85
Water bodies	4	4	2	50.55	85.35	0.55
Thicket	20	18	15	75.35	85.35	0.78
Sparse forest	18	20	16	85.55	90.13	0.78
Plantation	15	18	10	56.56	87.65	0.7
Pasture	6	6	6	98.55	74.15	0.8
Grassland	18	15	13	87.56	68.14	0.84
forest	9	9	9	98.55	75.45	0.55
Cropland	18	20	17	87.34	85.9	0.65
Bush/Shrub	17	17	15	88.05	67.05	0.63
Built up area	8	10	8	75.35	95.55	0.65
Bare soil	19	17	18	95.25	85.95	0.68
Column total	174	174	144			0.705

Overall Classification Accuracy = 81.32%

Appendix 3.9 a: Error Matrix of 1998 TM Image using stratified random method

Class name	Wood land	Water bodies	Thicket	Sparse forest	Plantation	Pasture	Grass land	Forest	Crop land	Bush / shrub	Built up area	Bare soil	Total
Woodland	20	0	0	0	0	0	0	0	0	1	0	0	21
Water bodies	0	14	0	0	0	0	0	0	2	0	0	0	16
Thicket	1	0	8	0	0	0	0	0	0	0	0	0	9
Sparse forest	0	0	0	8	0	0	0	4	0	0	0	0	12
Plantation	0	1	0	0	14	0	0	0	0	0	0	2	17
Pasture	0	0	0	0	0	18	0	0	0	0	0	0	18
Grassland	0	0	2	0	0	0	8	1	0	0	0	0	11
forest	0	0	0	0	0	0	0	20	0	0	0	0	20
Cropland	0	2	0	0	4	0	0	0	6	0	1	3	16
Bush/Shrub	0	0	0	0	0	0	0	0	0	4	0	0	4
Built up area	1	0	6	0	0	0	0	0	0	0	11	0	18
Bare soil	2	0	0	0	0	0	0	0	0	0	0	10	12
Column total	24	17	19	8	18	18	8	25	8	5	12	15	174

Appendix 3.9 b: Accuracy Statistics for 1998 classified Image

Class name	Reference Total	Classified Total	Number correct	Producer Accuracy	User Accuracy	Kappa
Woodland	15	20	18	72.05	85.18	0.85
Water bodies	8	6	4	58.55	65.35	0.65
Thicket	11	12	10	85.35	90.35	0.78
Sparse forest	14	20	16	75.55	80.13	0.75
Plantation	9	10	6	76.56	87.65	0.7
Pasture	12	6	8	68.05	84.15	0.75
Grassland	12	15	10	77.56	78.14	0.75
forest	22	10	8	58.82	85.45	0.85
Cropland	20	10	16	77.25	75.09	0.75
Bush/Shrub	12	19	15	87.05	77.05	0.63
Built up area	22	28	18	67.35	85.55	0.65
Bare soil	15	17	13	85.25	75.95	0.67
Column total	174	174	142			0.731

Overall Classification Accuracy = 80.83%

Appendix 3.10 a: Error Matrix of 2008 TM Image using stratified random method

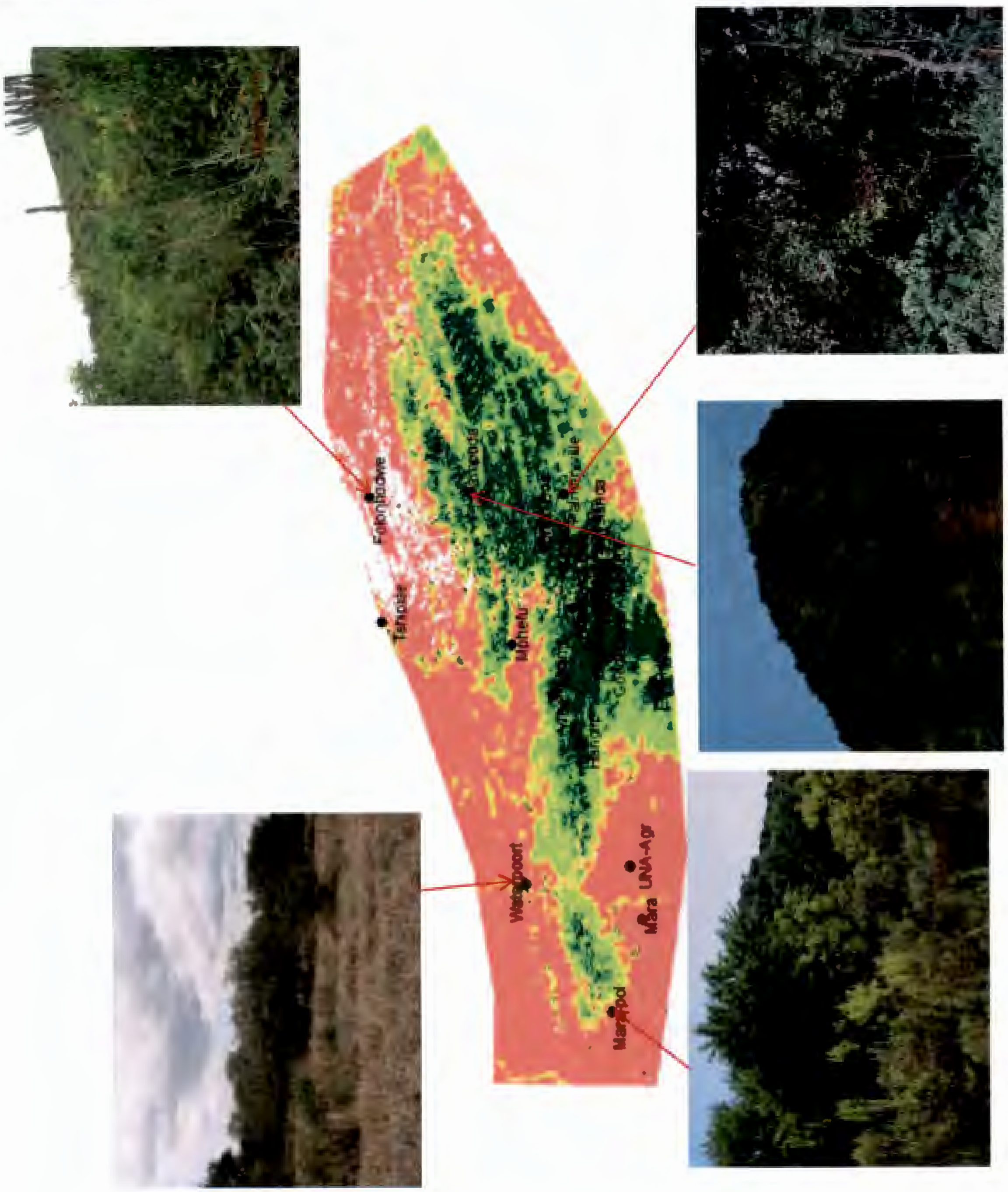
Class name	Woodland	Water bodies	Thicket	Sparse forest	Plantation	Pastures	Grass Land	Forest	Crop Land	Bush / shrub	Built up area	Bare soil	Total
Woodland	20	0	1	0	1	0	0	0	0	1	0	0	23
Water bodies	0	11	0	0	0	0	0	0	2	0	0	0	13
Thicket	1	0	8	0	0	0	0	0	0	0	0	0	9
Sparse forest	2	0	0	8	0	0	0	4	0	1	0	0	15
Plantation	0	1	0	0	10	0	0	0	0	0	0	2	13
Pasture	0	0	0	0	0	8	0	0	0	0	0	0	8
Grassland	1	0	1	0	0	0	12	1	0	0	0	0	15
Forest	0	0	0	0	0	0	0	5	0	0	0	0	5
Cropland	1	1	0	1	3	0	0	0	13	0	1	3	23
Bush/Shrub	0	0	0	0	0	0	0	0	0	17	0	0	17
Built up area	1	0	0	0	0	0	0	0	0	0	19	0	20
Bare soil	2	0	0	0	0	0	0	0	0	0	0	11	13
Column total	28	13	10	9	14	8	12	10	15	19	20	16	174

Appendix 3.10 b: Accuracy Statistics for 1989 classified Image

Class name	Reference Total	Classified Total	Number correct	Producer Accuracy	User Accuracy	kappa
Woodland	15	17	15	72.05	90.28	0.9
Water bodies	8	12	4	58.55	65.85	0.75
Thicket	16	12	10	85.35	80.345	0.85
Sparse forest	14	20	16	75.55	80.93	0.67
Plantation	12	14	6	76.56	77.35	0.75
Pasture	12	7	8	68.05	84.15	0.85
Grassland	12	14	10	77.56	88.15	0.75
forest	22	12	8	58.82	65.25	0.9
Cropland	20	10	16	77.25	75.29	0.85
Bush/Shrub	10	17	15	87.05	77.65	0.75
Built up area	18	22	18	67.35	75.85	0.8
Bare soil	15	17	13	85.25	75.75	0.67
Column total	174	174	139			0.790

Overall Classification Accuracy = 78.07

Appendix 5.1: Vegetation distribution at delineated area rainfall stations of the Soutpansberg



Appendix 5.2: Diagnostic species at sampled plots

Location	Specie Group	Diagnostic Specie	Local Name	Vegetation Description
SW	Tree :Acacia Rhus	A.ataxancantha R.*magalismontana* subsp *magalismontana*	English:Flame thorn Venda:Muluwa Afirkaans: kaffer-wag-n-bietjie	Forest (Edward,1983)
	Shrubs: Blepharies	B. Sinipes		
	Succulents: Aloe			
	Lianas: Ipeoma	I.*bisavium*		
	Herb:Commelina	C.*benghalensis*		
SE	Trees			Forest (Edward,1983)
	Shrub: Rhus	R. *magalismontana* subsp *magalismontana*		
	Succulents: Eurphobia	E.*aeruginosa*		
	Lianas: Ipeoma	I.*bisavium*		
	Herb			
	Grass:Brachiaria	B.*serratta*		
CS	Trees: Xymalos	X.*monospora*	English:Lemon wood,Bog-a-bog Venda:Mutekere,Tshipengo Afirkaans: Borriehout,	Forest (Edward,1983;Gelden huys &Murray,1993)
	Shrub: Podocarpus	P.*falactus*	English:Common yellow wood, Outeniqua yellow Venda:Mufhanza Afirkaans: Blougeelhout,Gewone geelhout	
	Succulents: Huernia	H.*whitesloaneana*		
	Lianas:Ipomoea	*I.bisavium*		
	Herb:streptocarpus	*Streptocarpus subs. parviflorus*		
	Epiphyte:Mystaciduim	*M.brayboniae*		
	Creeper: Orbeanthhus	O.*conjuctus*		
NW	Trees: Adansonia :Albizia	A.*digitata* A.*anthelmintica*	English:Baobab Venda: Muvhuyu Afirkaans: Kremetart English:cherry-blossom tree Venda: Muime,Mupula Khwali Afirkaans: Bonthout	Woodland (Edward 1883)
	Shrubs: Acacia	A.*nigrescens*	English:knobthorn Venda: Mudhaya, Munanga Afirkaans: Merrietiet	
	Succulents:Eurphobia : Aleoe	E.*guerichiana* A. *littoralis*	English:Mopane aloe Venda: Tshikhopha Afirkaans: Mopanie-aalwyn	
	Herb: Centropodia	C.*glauca*		
	Grass: Aristida	A. *stiptata* subsp. *graciliflora*		

Continued **Appendix 5.2: Diagnostic species at sampled plots**

Location	Specie Group	Diagnostic Specie	Local Name	Vegetation Description

NE	Tree: Combretum	C.*apiculatum*	English:Mopane aloe Venda: Tshikhopha Afirkaans: Mopanie-aalwyn	Woodland (Edward 1983)
	Shrubs: Rhus	R.*magalismontana s\subsp codii*		
	Succulents:Apocynaceae Duvalia	D.*procumbens*		
	Eurphobia	E.ingens	English:Cactus euphorbia Venda: Mukonde Afirkaans: kankerbos,Naboom	
	Herb:Commelina	C.*benhalensis*		
	Grass:Brachuaria	B.*deflexa*		