# Daily Rainfall Variability in Southern Africa

Sabatha Thulane Qwabe

Thesis submitted to the Faculty of Science for the Masters of Science Degree

*University of the Witwatersrand, Johannesburg*
*Department of Geography and Environmental Studies*
*1999*

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I declare that this dissertation is my own, unaided work, and that it has not been submitted previously as a dissertation or thesis for any degree at any other university.

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## Abstract

Clear characterisation of daily rainfall over the southern African continent is necessary for the purpose of achieving sustainable human and agricultural-environmental development.

In this research, daily rainfall variability over southern Africa is investigated to determine the relations between rainfall, rainfall frequency, and amount of rain per rain day. Firstly, the characterisation of daily rainfall over the region from 1950 to 1997 is given. This is followed by the analysis of daily rainfall variability during the 10 wettest and driest years. Thirdly, the influence of Sep-Nov and Dec-Feb seasons on the 10 wettest and driest years is then highlighted. Lastly, to determine whether the relation between the three rainfall parameters determined over the whole southern African region holds true for local areas, daily rainfall variability over Swaziland during the period of meteorological records is discussed.

Analyses of daily rainfall over southern Africa indicate that on scales of days to years, rainfall departures from mean result from changes in both daily rainfall frequency and intensity. Positive rainfall changes are due to an increase in the number of rain days and amount of rainfall falling on those rain days. Negative rainfall changes result from a decrease in rainfall frequency and rain falling on those rain days.

Southern Africa does not show uniform changes in these rainfall variables, but patterns of spatial and temporal variability. This variability increases from the eastern to western regions of the subcontinent (i.e. rainfall variability increases from the eastern humid to the western arid regions of the subcontinent).

The conclusion is that over the whole of southern African region changes in mean rainfall are dependent on the number of rain days and rain per rain day. This result also holds true over smaller areas of the subcontinent, such as Swaziland.

I declare that this dissertation is my own, unaided work, and that it has not been submitted previously as a dissertation or thesis for any degree at any other university.

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Dedicated to my mom, my dad, my special lady, and my uncle Menzi. I would have never come this far had you not been there for me when I needed you. I love you so much.

## Preface

Changes in mean daily rainfall and rainfall variability before and during the period of meteorological records have major implications for human and agricultural-environmental resource development. Rainfall studies over some parts of southern Africa, and other parts of the globe, suggest periods of increasing frequency of rainfall deficiency over the last few decades (Morris and Marsh, 1985; Mason, 1996; others), with increasing frequency of floods (Hecht, 1998).

On global and hemispheric scales, spatial and temporal rainfall variability have been suggested. Their implications for agriculture and hydrology have also been highlighted. Despite of the profound implications of daily rainfall variability for sustainable agricultural-environmental development, little is known about daily rainfall variability over the southern African region of Lesotho, South Africa and Swaziland.

Distinct and important climatological relationships exist between rainfall, rainfall frequency, and rain per rain day. Extreme wet occasions and wet spells may result from greater increases in frequency of rain days and rain per rain day; the opposite may occur during extreme dry conditions. Alternatively, wetter conditions may result from no change in the number of rain days, but simply more rain falling on those days and the opposite for dry conditions. The effects of rainfall frequency and intensity on rainfall are likely to show differential spatial and temporal distribution over the whole of southern Africa.

It is important to determine the differential spatial and temporal influence of daily rainfall variables over southern Africa so to better characterise spatial and temporal daily rainfall variability over the subcontinent. Previously, wetter and drier conditions at individual stations have been characterised by an ambiguity in whether wetter (drier) conditions are caused by an increase (decrease) in rain days or rain falling on those days, or both. No investigation of the relationship between daily rainfall, rainfall frequency, and intensity per day has been undertaken for the region as a whole.

The aim of this study is to investigate the spatial variability of daily rainfall in southern Africa. The hypotheses to be tested are that:

(a) wet (dry) periods are characterised by higher (lower) frequency of rain days,

(b) rainfall amounts per rain day in wet (dry) periods are higher (lower) than in dry (wet) periods, and that

(c) the spatial patterns associated with such changes in variability are distinctive.

To analyse daily rainfall variability of southern Africa, South African Weather Bureau data for 132 stations were used. Data for stations located close to each other were areally averaged using annual rainfall records to produce a single rainfall-mapping unit; 88 such units formed the basis for subsequent analyses.

Annual and seasonal analyses of historical records will be undertaken for southern Africa as a whole from 1950 to 1997, as well as for the Swaziland sub-region.

The dissertation is divided into seven chapters. **Chapter One** introduces the field of rainfall variability both at global and regional scales. **Chapter Two** provides the tools and techniques used to perform daily rainfall analyses. Interpretations of data generated by processes in chapter 2 are presented in **Chapter Three, Four, Five, and Six**. Annual daily rainfall variability during the period of analyses is shown in **Chapter Three**. The influence of rainfall frequency and intensity on daily rainfall variability during the ten wettest and ten driest years is highlighted in **Chapter Four**; summer daily rainfall variability over the period of analysis and during the ten wettest and ten driest years is given in **Chapter Five**. **Chapter Six** presents daily rainfall variability over a local area within southern Africa, and its relation to the whole of southern African daily rainfall variability. Finally, **Chapter Seven** gives the summary and conclusion of the results.

My special thanks to the Swaziland Government, especially the Ministry of Agriculture and Co-operatives, for financing my studies, culminating to this research. My special gratitude to Professor P.D. Tyson, whose devotion, commitment and sterling supervision made me accomplished this kind and quality of work. Erik van Waren, your continuous willingness and unconditional support throughout data analyses made me hold on during the toughest times. Thank you. Coleen Vogel, thank you for everything. My mom, dad, uncle Menzi, relatives, friends, colleagues at work, Swaziland Meteorology Dept. and Climatology Research Group, thank you for all your wonderful support and patience. Lastly, Njabu, though you found me half way through, your moral support was all I needed to finish the research. You are the reason for all that I do. I have no better words to thank you.

Contents

# Chapter 1

## Introduction

Climate is the major determinant of human activities and at the same time it is subjected to changes because of these activities. A reciprocal relationship exists between climate and man. Rainfall is undoubtedly the most determining factor to life's continuity. Global attempts to understand rainfall variability are not new, yet rainfall still remains the most difficult variable of climate to predict and understand despite of its importance in human existence. Rainfall variability, both in space and time is complicated by its association with rainfall change (Tyson, 1981; 1986). Detailed knowledge of rainfall variability is an important prerequisite for sustainable agricultural and hydrological planning in many parts of the world. It is imperative, therefore, to develop *reliable* knowledge of rainfall variability so as to ensure sustainable global and regional economic growth and human-environmental development. Determination of amounts and patterns, especially in developing countries of the tropics and subtropics, is of great importance and should continue to receive priority attention (Odumodu, 1983).

Interest has been focused on global climate variability (Bradley *et al.*, 1987; Diaz *et al.*, 1989; Vines, 1985; Amanatidis, *et al.*, 1993; Segal *et al.*, 1997), because of its possible association with increases in $CO_2$ (Amanatidis *et al.*, 1993; Yu and Neil, 1993). In certain regions studies have shown the existence of decadal oscillations of rainfall over periods of approximately 20 years and shorter. In southern Africa, rainfall studies have indicated the existence of long-term quasi-periodic fluctuations of rainfall of 16-20 years, 10-12 years, 6-7 years and others of shorter periods (Tyson *et al.*, 1975; Dyer and Tyson, 1977; Vines, 1980, Tyson, 1986). Rainfall analyses in south east Australia (Vines, 1981), New Zealand (Vines and Tomlinson, 1980), United States (Vines, 1982) Canada (Armstrong and Vines, 1973), South America (Vines, 1982b), and Europe (Vines, 1985) provided similar results to those observed over southern Africa. Global rainfall variability has pronounced-differential effects on agricultural and hydrological yields and human-economic development. The seriousness of the effect of rainfall variability depends largely, but not wholly, upon whether agriculture and hydrology are marginal or not. Many parts of southern Africa are in marginal rainfall zones, thus agriculture and hydrology are highly sensitive to small variations in rainfall, especially to the occurrence of extreme rainfall events, even for short periods within the growing season.

Dependence on agriculture for economic development increases vulnerability of nations to rainfall variability. Underdeveloped countries are particularly vulnerable to rainfall variability in terms of precarious water supplies and non-sustaining agricultural and hydrological management methods. The degree of seasonal rainfall variability, determined by daily rainfall, so conspicuous in semi-arid to arid zones, is an important determinant of the variability of crop yields in any year. Besides agricultural policies and management, rainfall variability is an important determinant of agricultural-economic variability, which often takes a similar pattern to rainfall variability. Spatial and temporal distribution of rainfall is a very important factor in the national economy (Mooly *et al.*, 1981). Changes in the mean climate and variability of climate, particularly in the frequency of the extreme weather events are important determinants of agricultural profitability (Parry, 1990; Rosenzweig and Hillel, 1998). There is uncertainty as to whether presently observed global rainfall variability is an indication of long-term rainfall change or is just a manifestation of short-term natural oscillations. Suggestions indicate that increasing global mean temperature may change the frequency of intense rainfall because of the possible change in the paths and intensities of depressions of storms and the possible increase in convective activity (Gordon *et al.*, 1992; Whetton *et al.*, 1993; Hecht, 1998).

### Rainfall Variability over Southern Africa

Although southern Africa climate variability received increased attention after the devastating drought of 1982-83, the variability of climate over the subcontinent had in fact been investigated previously for many years (Dyer, 1980; Harrison, 1983). Over the subcontinent, meteorological records have been used to study rainfall variability (Tyson *et al.*, 1975; Tyson and Dyer, 1977; Dyer, 1980; Tyson 1981; Miron and Tyson, 1984;

Taljaard, 1986; Matarira and Flocas, 1989; Lyons, 1991; Matarira and Jury, 1992; Levey, 1993, Makarau and Jury, 1997). Despite of the recent indications that global rainfall variability may be associated with climate change resulting from increasing atmospheric greenhouse gases, this is by no means established in southern Africa. Southern African rainfall responds to sea-surface temperature anomalies around the subcontinent, including the equitorial Indian Ocean (Walker, 1990; Jury and Pathack, 1991; Mason, 1995).

A large part of southern Africa is arid to semi-arid, with a high degree of inter-annual rainfall variability (Mason and Joubert, 1995; Onesta and Verhoef, 1976; Tyson, 1986) and intra-annual rainfall variability (Dyer, 1982). The degree of inter-annual rainfall variability is highest from the west to the central interior of the subcontinent and lowest along the eastern escarpment with much rainfall received in summer. Inter-annual rainfall variability over the subcontinent shows statistically significant cyclic variability of different time periods (Tyson and Dyer, 1977; Tyson, 1986). Major annual rainfall oscillations have been used in long-range seasonal rainfall forecasting models (Tyson and Dyer, 1977; Louw, 1982; Currie, 1993).

The 10-12 years rainfall oscillation accounts for more than 30% of the inter-annual rainfall variance along the south coast of the country while the 18-20 years rainfall oscillation is of great significance in the summer rainfall region (Dyer, 1975; 1980; Tyson *et al.*, 1975; Tyson, 1971; 1978; 1980; 1986; van Rooy, 1980; Vines, 1980; Kelbe *et al.,* 1983; Lindesay, 1984; Currie, 1991; 1993). Tyson (1981) suggested that rainfall variations over the subcontinent are explained in terms of variations in pressure and circulation patterns. Mason and Jury (1997) confirmed that inter-annual rainfall variability over southern Africa is largely determined by the preferred longitude of subtropical convection, and by shifts and changes in amplitude of the westerly waves.

Despite the previous work (Tyson *et al*, 1975; Dyer, 1980, 1981a; 1981b; 1982; Tyson, 1986) and intra-annual rainfall records (Dyer, 1982), much remains to be understood about southern African rainfall variability. The debate of whether or not the subcontinent is progressively declining has been going on for over 100 years (Mason and

Jury, 1997). Earlier indications suggested progressive desiccation over the subcontinent (Wilson, 1865; Barber, 1910; Cox, 1926; Schwarz, 1919; Thompson, 1936), which were refuted by recent studies (Tyson *et al.*, 1975; Tyson, 1980; 1986). New evidence suggests an approximately 10% decrease in mid-summer rainfall (December-February) between 1931-1960 and 1961-1990 over some parts of Botswana, Zimbabwe, and South Africa (Hulme, 1992; 1996; Hulme *et al.*, 1996; Mason, 1996; Gondwe *et al.*, 1997). Rainfall records indicate that inter-annual rainfall variability over Zimbabwe, South Africa and other parts of southern Africa is increasing (Unganai, 1992; Mason, 1996; Hulme, 1992). The extreme dry years experienced in most parts of southern Africa in the early 1980s and early 1990s may have further purported the assertion of progressive rainfall decline over the subcontinent. It is of paramount importance to clearly understand the nature of southern African rainfall variability so as to identify and properly manage vulnerable land resources and sustain developmental activities highly sensitive to fluctuations in water supplies.

## Inter-annual Rainfall Extremes and Causes

Increasing inter-annual rainfall variability has major implication for agricultural and hydrological planning and development over southern Africa. Increasing frequency of drought has negative effects to the prospect of achieving sustainable agricultural and hydrological development. The implications of floods for agriculture vary depending on the agricultural water management system. Over southern Africa, the frequency of floods and droughts may be increasing (Mason and Joubert, 1995; Mason and Jury, 1997). Indications suggest indicate that changes in frequency of extreme rainfall events are sensitive to small changes in climate (Means *et al.*, 1984; Wigley, 1985; Rind *et al.*, 1989; Katz and Brown, 1992; Katz and Acero, 1994). This is yet to be established for southern Africa.

Variability of rainfall results from changes in frequency, duration and intensity of large-scale weather events responsible for the number of rain days with significant rainfall (Harrison, 1983; Taljaard, 1986) and amount of rainfall per rain day. The frequency of rain days and the amount of rain per rain day are primary factors responsible for daily, seasonal, annual and decadal rainfall variability. The major weather systems responsible for rainfall are well-understood (Dyer, 1982; Tyson, 1981; 1986) the changing patterns of rain days frequencies and amounts are not. Among the systems responsible for rainfall variability are: (a) tropical-temperate troughs and their associate cloud bands; (b) cut-off lows or deep west-coast troughs and (c) tropical cyclones across the coastal margins of Mozambique and eastern South Africa.

Tropical-temperate troughs are major rainfall contributors over the summer rainfall regions (Harangozo and Harrison, 1983; Harrison, 1984a; 1984b; Tyson, 1986; Lyons, 1991; van den Heever, 1995). These troughs are often responsible for heavy rains during the second half of the summer season (Walker and Lindesay, 1989; Lindesay and Jury, 1991; Jury *et al.*, 1993). Generally, the troughs are shorter lived during early and the late summer season, because of increased westerly shear (Barclay *et al.*, 1993). Van den Heever (1995) has indicated that the total rainfall volume from each trough events depends on the availability of atmospheric moisture, atmospheric stability, the strength of upper-level divergence and the speed of movement of the trough.

Cut-off lows or deep west-coast troughs are often responsible for the heaviest rain falls (Mason and Jury, 1997). Cut-off lows have been responsible for a number of severe floods in southern Africa (Taljaard, 1985; Tyson, 1986; Jury and Levey, 1993). The frequency of cut-off lows producing heavy rains peaks during the transition seasons in March to May and September to November when the meridional temperature and pressure gradient are strongest (van Loon *et al*, 1971; Taljaard, 1982), with lowest frequency between December and February (Taljaard, 1982). Taljaard (1985; 1986) suggested that cut-off lows are important contributors of early and late season rainfall. High inter-annual variability of frequency of cut-off lows is significantly responsible for high variability of rainfall during the transition seasons (Taljaard, 1985).

The infrequent passage of tropical cyclones across the coastal margins of Mozambique and eastern South Africa are often responsible for the heaviest rains over some parts of southern Africa (Mason and Jury, 1997). These tropical cyclones are responsible for a small percentage of total rainfall over southern Africa, and in occasional events can cause severe falls (Kreft, 1953), such as the cyclone Demonia of 1984 over north of Durban (Poolman and Terblanche, 1984). Quite often, tropical cyclones are associated with dry conditions over southern Africa (Matarira, 1990; Matarira and Jury, 1990; Jury and Pathack, 1991; Jury, 1992; 1993).

There are other synoptic systems providing rainfall to southern Africa (Tucker, 1971; Miron and Lindesay, 1983; Mirron and Tyson, 1984; Tyson, 1986; Preston-White *et al.*, 1977), but are responsible for smaller percentages of the total annual rainfall over the subcontinent. The suggested inter-annual rainfall variability over southern Africa, related to changes in incidence, persistence and strength of the important synoptic systems, has been confirmed by the similarity of the atmospheric activity responsible for dry and wet spells at a range of temporal scales (Tyson, 1986).

Despite of the large amount of work done on rainfall over the subcontinent, patterns of variability remain unclear. Harrison (1983) pointed out that much would be gained from determining the form of dependency of rainfall on frequency and intensity of rainfall events. In this dissertation the climatology of changing patterns of daily rainfall variability will be assessed. More specifically, changing patterns of rain day frequency and amount of rain per rain day for wet and dry conditions, and extreme wet and dry conditions, will be determined for southern Africa, in this case defined as Lesotho, South Africa and Swaziland, as a whole. In addition, the extent to which the generalised findings for the wider region hold for a specific sub-region, namely Swaziland, will be investigated.

**Hypotheses**

The aim of this study is to investigate the spatial variability of daily rainfall in southern Africa. The hypotheses to be tested are that:

(a) wet (dry) periods are characterised by higher (lower) frequency of rain days,

(b) rainfall amounts per rain day in wet (dry) periods are higher (lower) than in dry (wet) periods, and that

(c) the spatial patterns associated with such changes in variability are distinctive.

Before testing these notions, it is necessary to discuss the data and methodology to be employed in the study.

# Chapter 2

## Data and methodology

### Introduction

To analyze daily rainfall variability of southern Africa, South African Weather Bureau data for 132 stations were used. Data for stations located close each other were areally averaged using annual rainfall records to produce a single rainfall-mapping unit; 88 such units formed the basis for subsequent analyses. The rainfall mapping units are not equivalent to Weather Bureau rainfall districts. The units were determined by using average annual rainfall for each station (Fig. 2.1).

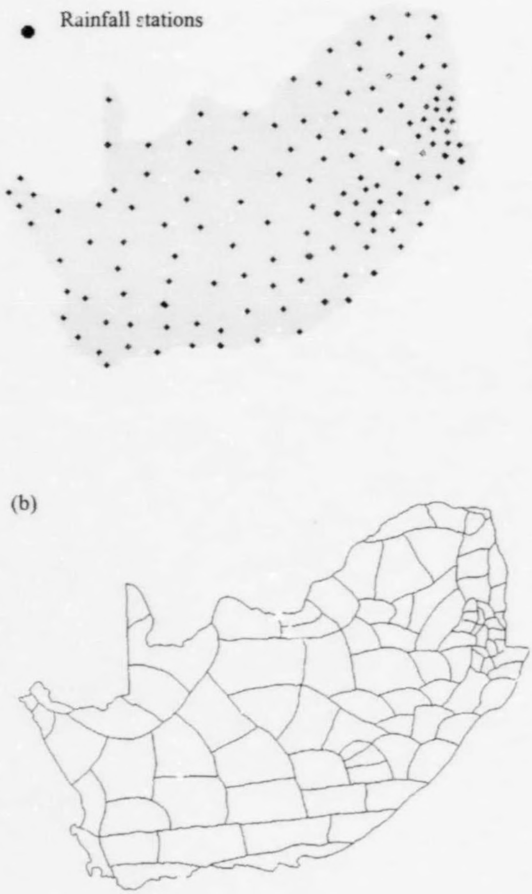
Annual and seasonal analyses of historical records will be for southern Africa as a whole from 1950 to 1997, and for a local based study of the period of meteorological record for stations with reliable data.

### Method of Analysis

Rainfall averages, frequencies of occurrence of rain days (number of rain days), and rainfall intensities (rain per rain day) will be calculated for above- and below-normal rainfall and extreme conditions. The spatial variability during these events will be examined.

Having determined normals for the 1950-1997 period, wet conditions are defined as those above normal; dry conditions as all those below normal. Extreme wet events (years, seasons and months) are defined as all those wet conditions above 150% of normal (i.e. more than 50% above normal). Similarly, extreme wet events are those experiencing 50% or less than normal rainfall. Wet conditions in the 10 wettest years are those years (seasons) experiencing more than 125% of the mean; dry conditions in the 10 driest years are those experiencing less than 75% of the mean. Thus extreme conditions refer to the record as a whole with a cut-off of 50% above and below the mean. Wet and dry conditions in the 10 wettest and driest years use a cut-off of 25% above and below the means of those years.

(a)




(b)

Figure 2.1. (a) Rainfall stations and (b) rainfall mapping units.

For Swaziland, 20 stations were selected based on length and reliability of rainfall records (Fig. 2.2; Table 1).

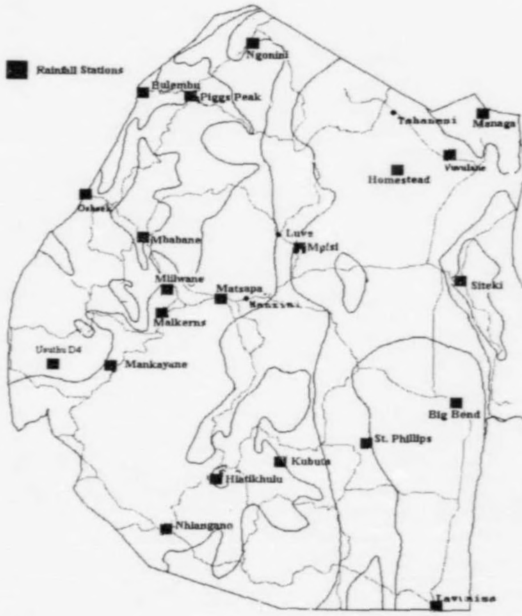



Figure 2.2: Selected rainfall stations

Table 1: Rainfall stations and years of rainfall records.

| Station | Years of Record | Station | Years of Record | Station | Years of Record |
|---|---|---|---|---|---|
| Big Bend | 1929-96 | Steki | 1899-90 | St. Phillips | 1930-88 |
| Bulembu | 1937-96 | Hlatikulu | 1905-90 | Piggs Peak | 1950-97 |
| Homestead | 1916-93 | Lavumisa | 1930-89 | Vuvulane | 1958-1997 |
| Khubuta | 1918-97 | Mankayane | 1909-97 | Usuthu D4 | 1960-1997 |
| Malkerns | 1953-97 | Mananga | 1952-97 | | |
| Mbabane | 1904-97 | Matsapa | 1968-96 | | |
| Mlilwane | 1920-91 | Mpisi | 1920-89 | | |
| Ngonini | 1953-90 | Nhlangano | 1965-97 | | |

Source: Dept. of Meteorology, Mbabane

## Data Sorting

Initial sorting of rainfall data by quartile will be by month, thereafter by season and year.

Daily rainfall, by numbers of rain days and amount of rain per day, will be determined as outlinec in Fig. 2.3. Figure 2.4 outlines the manner by which spatial and temporal quartiles of above- and below normal rainfall will be determined.

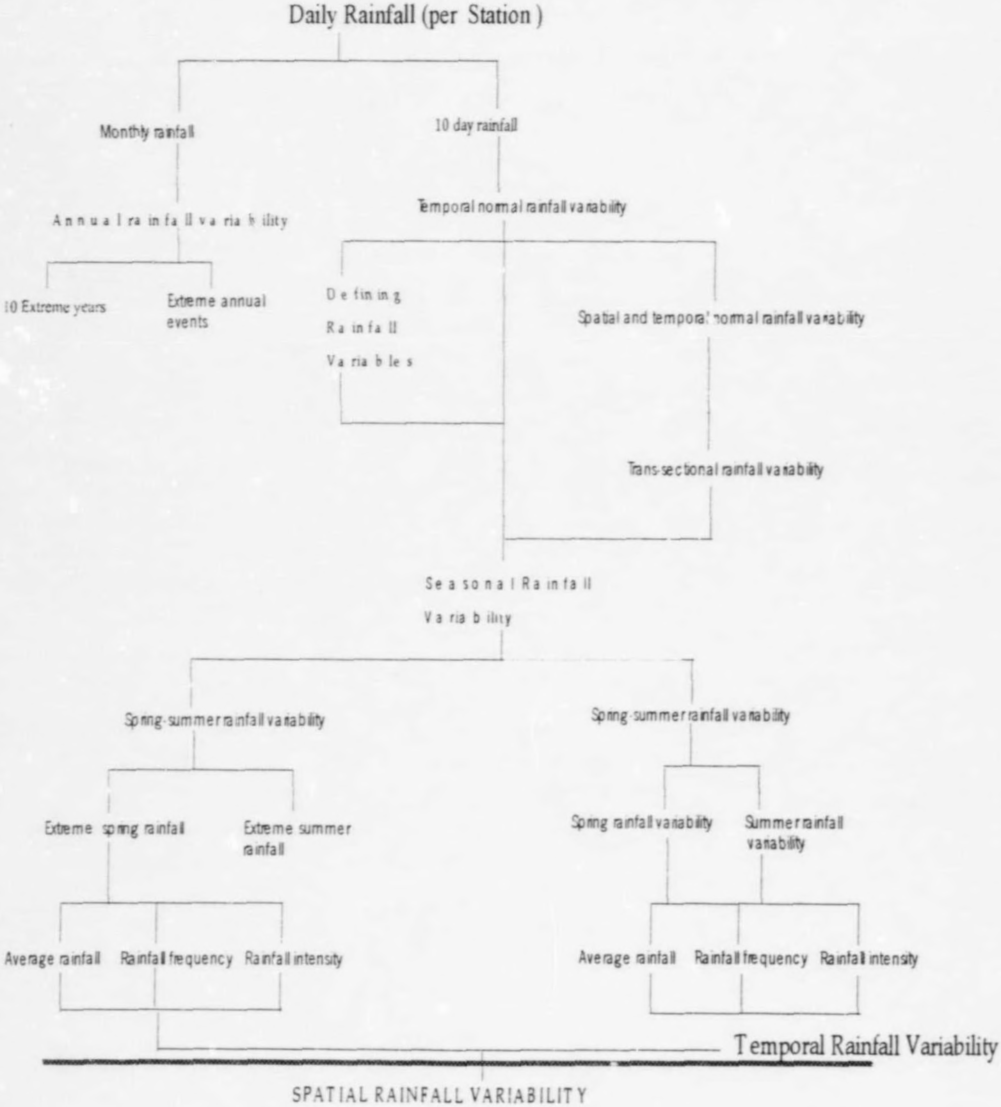



Figure 2.3: Daily rainfall analyses

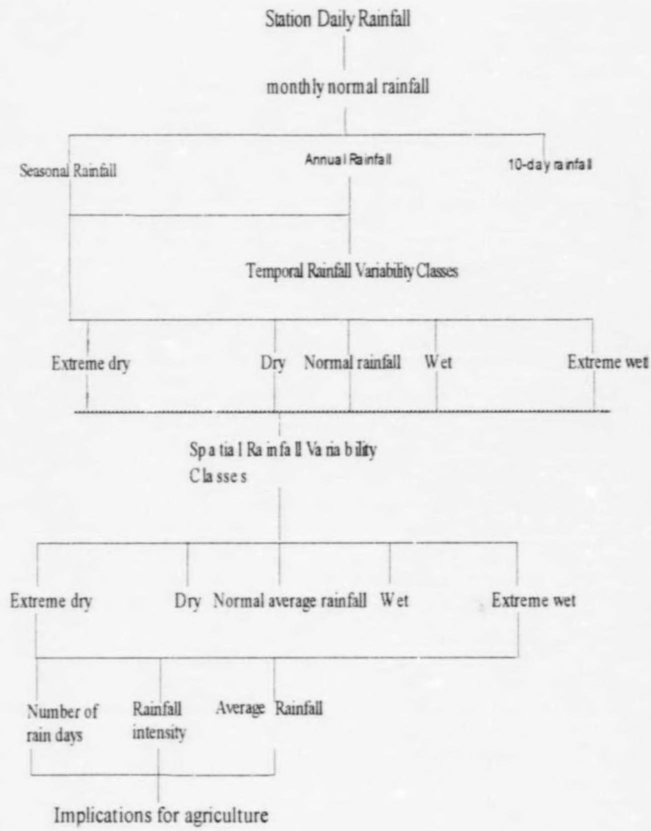



Figure 2 4: rainfall classification

Before discussing the results, highlight limitations of this methodology will be highlighted as indicated below:

(a) it does not statistically show the level of significance between the relationships of the analysed variables for the various stations,

(b) only 132 stations were used over the whole southern African region, thus increasing errors that could be associated with rainfall records of one station representing a larger mapping units, and

(c) not all rainfall stations have complete rainfall records, therefore, missing values had to be calculated from neighboring stations with similar daily rainfall characteristics.

To address limitation (b), local rainfall variability analysis has been undertaken, where the number of rainfall stations over a unit area was much higher, and results much more reliable.

# CHAPTER 3

## Daily Rainfall Departures During Wet and Dry Conditions

### Introduction

Southern Africa is not only characterised by spatial and temporal rainfall variability, but also by a wide rainfall distribution range. There is a significant rainfall increase from the western coastal to the eastern regions of the subcontinent. Areas on the eastern side of the Drakernsburg escarpment are the wettest over the subcontinent, receiving highest rainfall in summer (Dec-Feb) season. In this chapter and the chapters that follow, marginal deviations from mean occurring over small areas have been ignored in the spatial analyses.

To understand the spatial variability of daily rainfall over southern Africa, it is necessary to characterize the subcontinental rainfall into the following categories:

a. mean spatial variability of daily rainfall,
b. spatial variability of daily rainfall in above and below normal conditions and
c. analyses of the spatial variability of daily rainfall in extreme rainfall events over the analyzed period.

Subsequent chapters highlight daily rainfall variability in extreme years and seasons of the extreme years, highlighting the relations between annul rainfall, rainfall frequency and rainfall intensity.

### Mean conditions

Mean annul rainfall decreases over southern Africa from eastern to western regions of the subcontinent, from above 1000 mm to less than 250 mm to (Fig. 3.1.a).

Most of the subcontinent receives less than 500 mm per year, and most of these areas lie in the central interior to the extreme western parts of the subcontinent.

Rainfall frequency, like annual rainfall, decreases from eastern to western parts of southern Africa. Figure 3.1.b illustrates the spatial variability of normal rainfall frequency over the subcontinent. Most of southern Africa experiences fewer than 50 rain days in a year. However, a large part of the subcontinent receives more than 50 days of rain in a year.

Most of southern Africa, largely from central interior to the western regions, receives 6-10 mm per rain day (Fig. 3.1.c). Over most of the summer rainfall regions, rainfall intensity ranges from 11-15 mm per rain day. Only the far-western desert and semi-desert regions receive less than 6 mm per day when it rains.

### Daily Rainfall in Above and Below Normal Conditions

Departures of rainfall features from normal show significant spatial variability over southern Africa. Variability is more pronounced in semi-arid and arid regions.

#### Wet years

Over southern Africa, departures from mean daily rainfall are a function of rainfall sub-regions, the nature of the convective and other rainfall-producing processes and altitude. In general, variability in southern Africa, as elsewhere in the world, increases as annual rainfall decreases, that is, as aridity increases. In above-normal rainfall years, most of the subcontinent's mean daily rainfall shows significant positive departure from normal (from 131 to 160% of the mean) (Fig. 3.2.a.). These are most pronounced over most of the western region and the interior, spreading to the northern semi-arid regions. The winter and all-seasons rainfall regions experience 101 to 130% of rainfall during wet years.

Over the whole 1950 to 1997 period, wet years (i.e. above normal years) occur over most of southern Africa in 51-75% of years (Fig. 3.2b). Only in the south-western


Figure 3.1: Normal mean annual (a) rainfall, (b) number of rain days, (c) rain per rain day.


Figure 3.2: Wet conditions: percentage (a) rainfall, (b) frequency, (c) number of rain days, (d) rain per rain day.

region, and in a few other isolated areas to the north-west, does the frequency increase beyond this.

During wet years, the number of rain days increases uniformly over the whole region, even in the arid west (Fig. 3.2.c.). The east-west gradient disappears altogether. In addition to the number of rain days indicated in wet years, the amount of rain per rain day also increases (Fig. 3.2.d.). The increase is up to 25% above normal over most of the southern African subcontinent. In certain areas the increase reaches 150%. For no obvious reason the greater increase in rainfall intensity in wet years shows no coherence in spatial pattern, suggesting the result may be statistical rather than due to a systematic climatological forcing.

**Dry years**

The whole of southern Africa experiences below-normal mean daily rainfall during dry years (Fig. 3.3a). This departure is up to 30% below normal over all but the far north-west, where the diminution reaches 40%. Dry years occur over most of the region with frequencies ranging from 76-90% of normal (Fig. 3.3b).

Except in small areas, the whole of southern Africa experiences far fewer rain days in dry years (Fig. 3.3c). Over most regions, the number of days on which rain falls diminishes to 40-70% of the mean number of rain days in all years. In dry years, not only do the numbers of rain days decrease, but also the amount of rain falling on those days decreases. In no part of the region is this not so (Fig. 3.3d). Most areas experience up to 50% less rain per rain day.

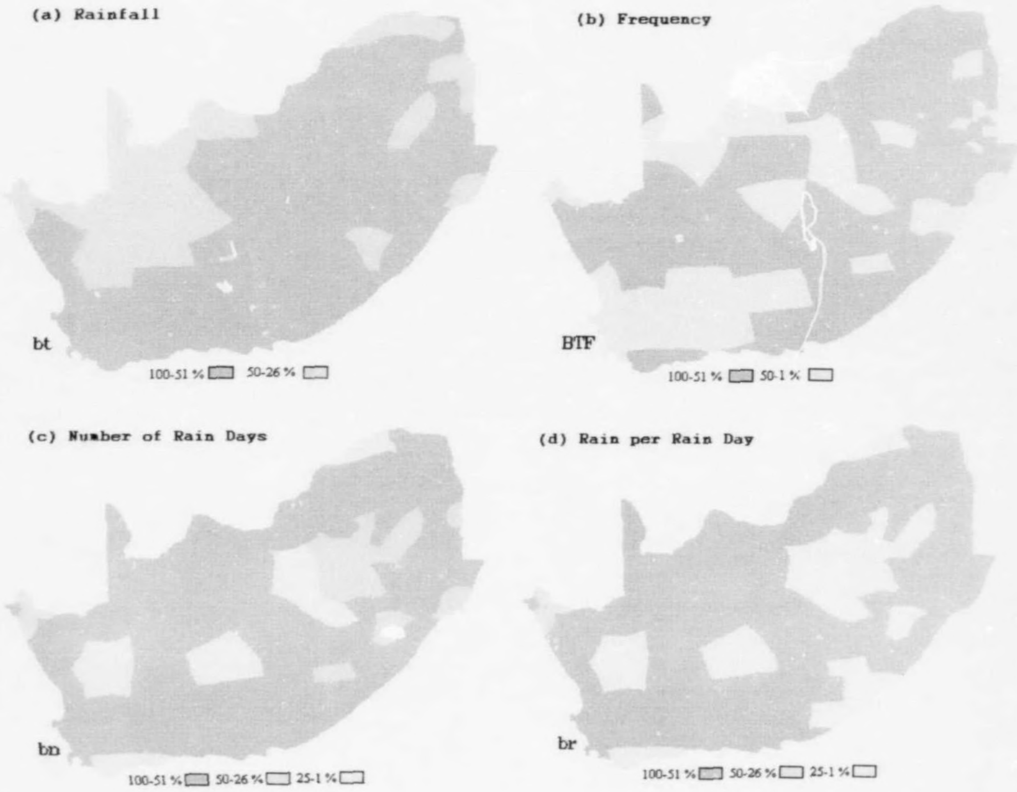



Figure 3.3: Dry years: percentage (a) rainfall, (b) frequency, (c) number of rain days, (d) rain per rain day.

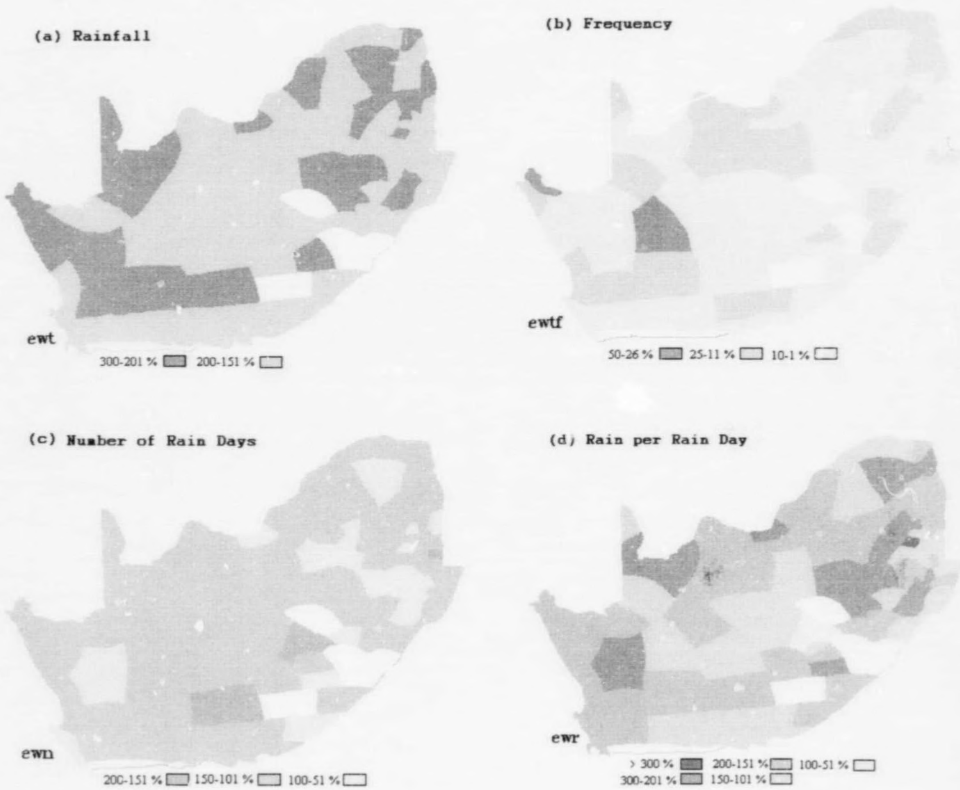



Figure 3.4: Extreme wet years (i.e. rainfall > 150 % of normal): percentage (a) rainfall, (b) frequency, (c) number of rain days, (d) rain per rain day. Blanks on maps indicate areas where criterion is not met.

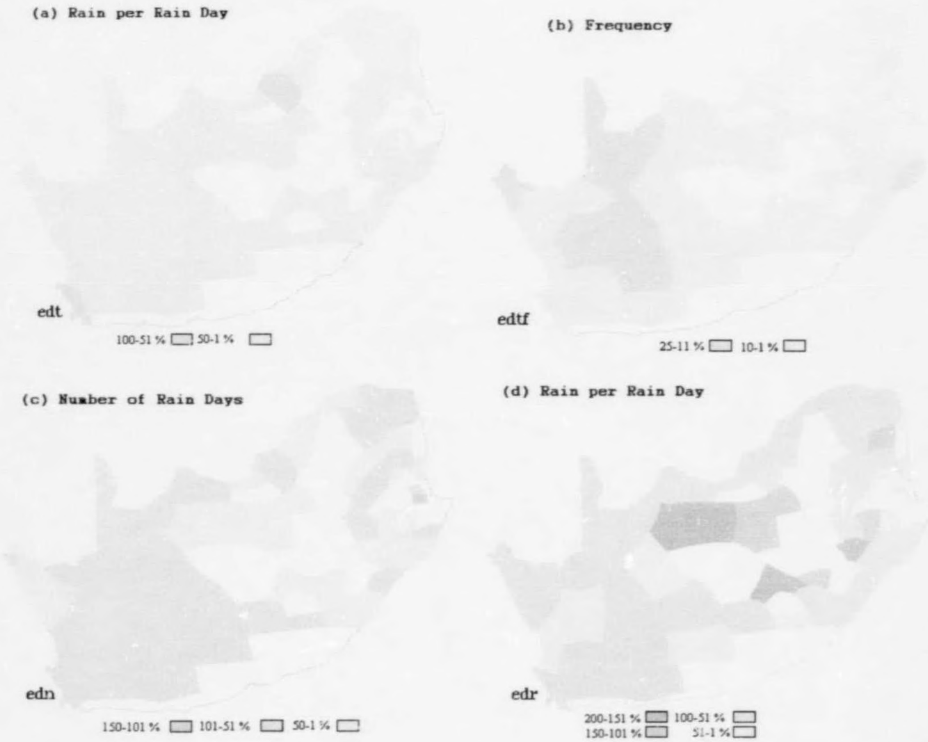



Figure 3.5: Extreme dry years (i.e. rainfall < 50% of normal): percentage (a) rainfall, (b) frequency of occurrence, (c) number of rain days, (d) rain per rain day. Blanks on maps indicate areas where criterion is not met.

## Extreme Wet and Dry Conditions

Given that wet years are characterized by greater numbers of rain days and rain per day, and the opposite occurs in dry years, the question to be answered is whether the same holds for extreme wet and dry conditions. Extreme wet years refer to the 1950-1997 period as a whole and are defined as those years experiencing above 150% annual rainfall of mean; extreme dry years are those with 50% or less of the mean for the entire period.

### Extreme wet years

During extreme wet years, the degree of rainfall excess above the mean varies from 150 to 200% over much of southern Africa. In many regions, the excess exceeds 200% (Fig. 3.4a). The whole of southern Africa shows a low percentage frequency (1 to 26%) of extreme wet years (Fig.3.4b). There is increased frequency of extreme wet rainfall in the northwestern parts of the subcontinent.

In extreme wet years, the number of rain days in such years reaches 300-400% of normal over a wide area; over most of the region rain days exceed 200% of normal (Fig. 3.4c). Even in the driest regions rain days increase. Over most of southern Africa, the amount of rain per rain day during extreme wet years is up to 200% of the mean (Fig. 3.4d).

### Extreme dry years

During extreme dry years, mean annual rainfall is uniformly low over most the subcontinent (Fig. 3.5a). Most commonly it varies from 31 to 50% of normal. Some areas do not show this characteristic. These dominate the south coastal areas of the subcontinent, and the all year-season rainfall region. The frequency of extreme dry years varies between 11 and 30% over most of southern Africa (Fig. 3.5b).

Unlike the situation in extreme wet years, the subcontinent displays significant spatial variability in the number of rain days in extreme dry periods. In extreme dry years, the number of rain days diminishes substantially (Fig. 3.5c). Likewise, a subcontinental decrease in rain per day occurs over southern Africa, most commonly from 71-90% of normal (Fig. 3.5d). Isolated areas show less than 70% of normal rain per day.

Departures of rainfall from mean since 1950 to 1997 are influenced by changes in numbers of rain days and the amount of rainfall received on those rain days. Increases in both variables lead to wetter conditions, while decreases of these variables cause drier conditions. The question that now arises is whether this holds for the rainfall departures during the ten wettest and ten driest years over the analyzed period.

# Chapter Four

## Ten Wettest and Ten Driest Years

### Introduction

Chapter Three highlighted the occurrence of extreme rainfall conditions over southern Africa and the influence of rainfall frequency and rainfall intensity on spatial variability of dry, wet, and extreme events over the subcontinent. In this chapter, an examination of the ten wettest and ten driest years over southern during the period of analysis is presented. A brief discussion of mean conditions in these ten wettest and ten driest years is given first. Thereafter, the relationship between rainfall, rainfall frequency and intensity. Lastly, the spatial nature of rainfall frequency and intensity variability in the single wettest and driest years on record between 1950 and 1997 is considered.

### Mean Conditions

#### Wettest years

In the ten wettest years, mean-annual rainfall shows the same distinctive east-west gradient as all above and below normal years. Rainfall decreases from above 2000 to less than 500 mm per year (Fig. 4.1a). The mean-annual rainfall increases over the whole subcontinent; over most areas mean rainfall ranges from 501 to 1000 mm per year. The lowest increase is experienced over the western arid regions of the subcontinent, where it is less than 500 mm per year.


Figure 4.1: Mean conditions in 10 wettest years: (a) rainfall, (b) number of rain days, (c) rain per rain day.

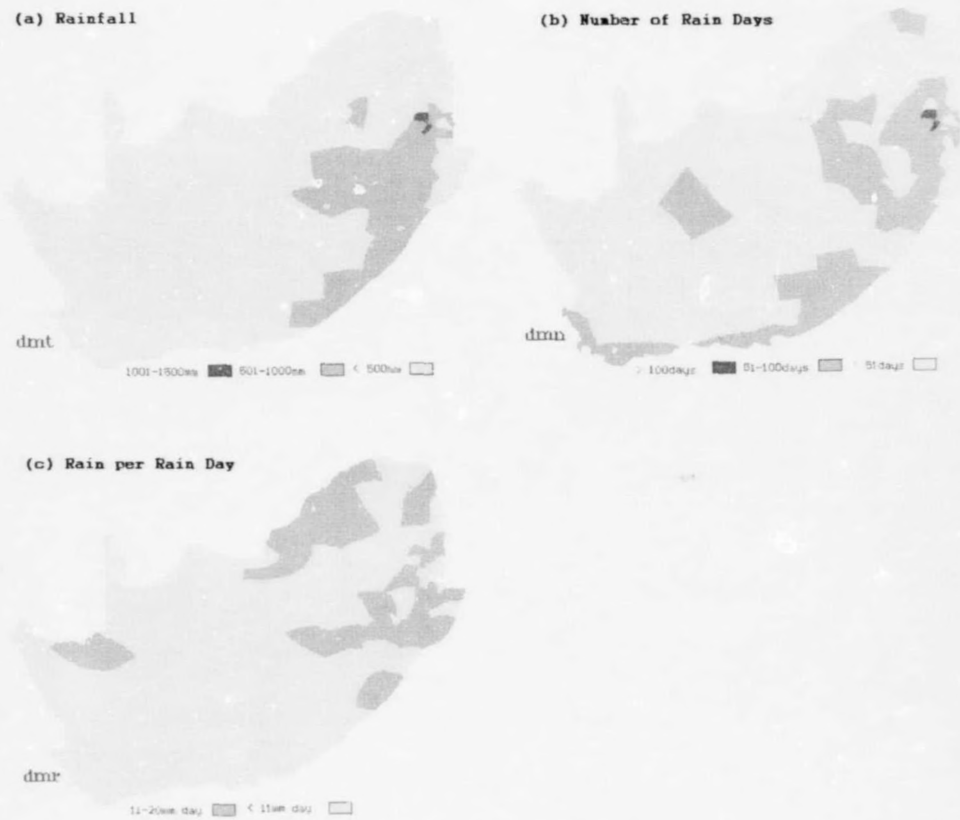



Figure 4.2: Mean conditions in 10 driest years: (a) rainfall, (b) number of rain days, (c) rain per rain day.

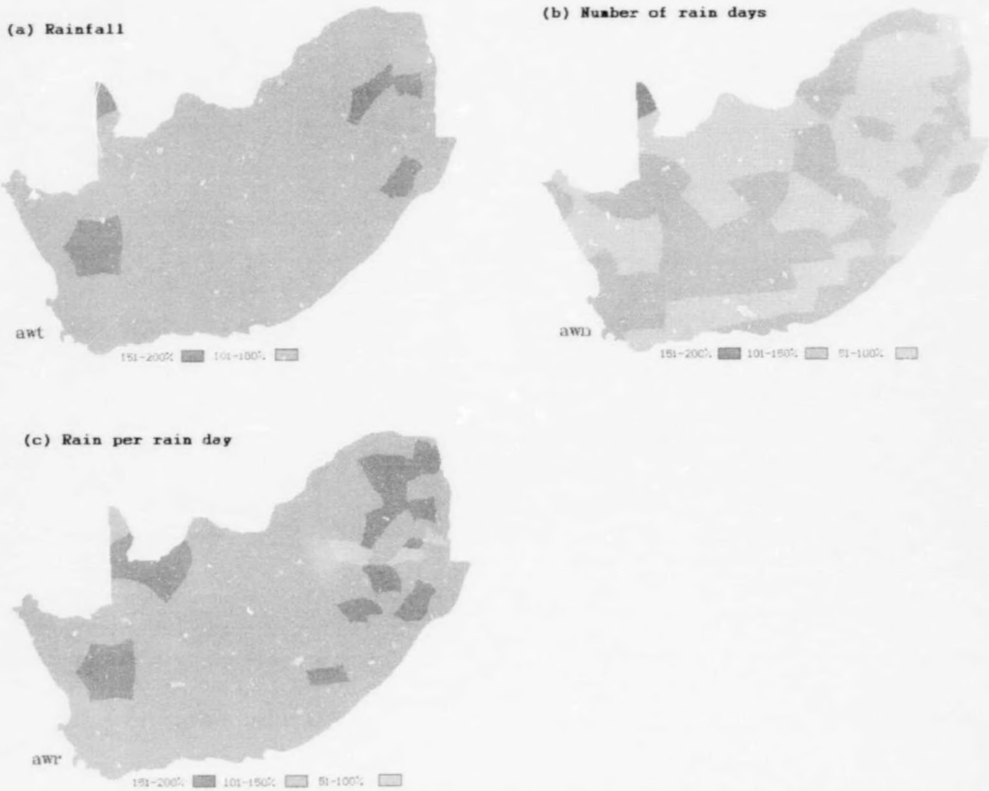



Figure 4.3: Above mean rainfall in 10 wettest years: percentage (a) rainfall, (b) number of rain days, (c) rain per rain day.

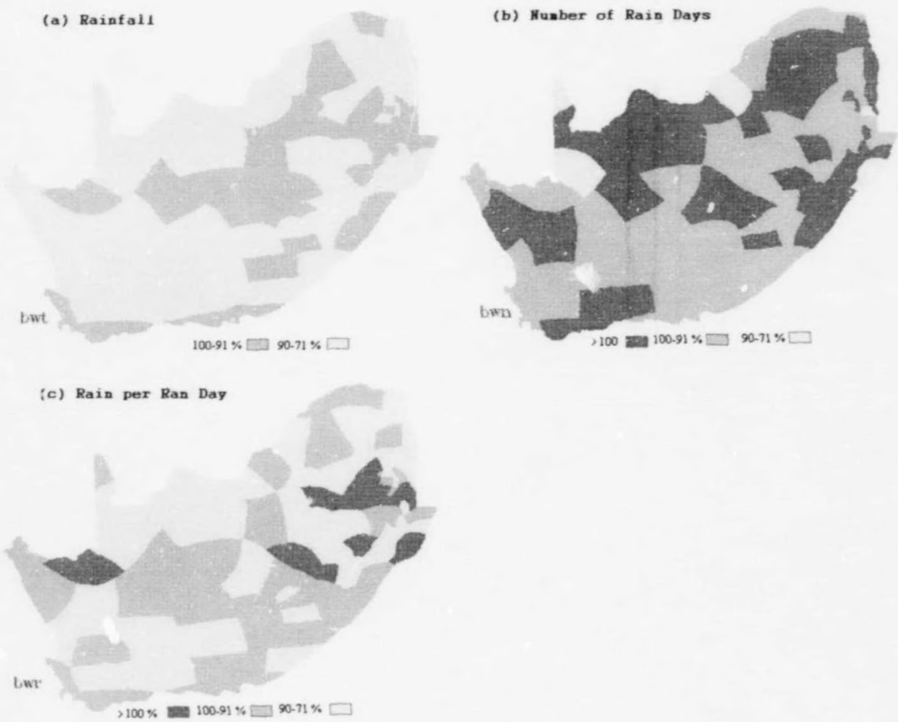



Figure 4.4: Below mean rainfall in 10 wettest years: percentage (a) rainfall (b) number of rain days, (c) rain per rain day

The mean number of rain days decreases from the eastern to western regions of the subcontinent, from above 100 rain days to less than 51 rain days per year (Fig. 4.1b). Over most of the region, the number of rain days ranges from 51 to 100 days per year. Semi-arid and arid regions of the subcontinent show the lowest increase in number of rain days (increases of less than 51% of mean). Most of southern Africa, largely from the central interior to the extreme northeastern areas, receiv. s 11-20 mm per rain day (Fig. 4.1c). The arid regions in southwestern part of the subcontinent receive less that 11 mm per rain day.

**Driest years**

During the ten driest years, rainfall diminishes over the whole of the subcontinent (Fig. 4.2a). Over the whole of the region, rainfall is less than 500 mm per year, except over small areas in the summer rainfall region, where mean rainfall ranges from 501 to 1000 mm per year.

Over the whole southern African region, the number of rain days diminishes during the ten driest years (Fig. 4.2b). Most of the subcontinent is characterized by less than 51 rain days. In isolated areas of the subcontinent, rainfall frequency is more than 100 rain days per year, largely in the summer and all-seasons rainfall regions. Rainfall intensity, like mean rainfall and rain days, diminishes over the whole subcontinent during the driest years (Fig. 4.2c). Most of the subcontinent is characterized by less than 11 mm per rain day.

## Above and Below Mean Conditions in Ten Wettest Years

Wettest years falling above mean of the 10 wettest years are classified here as wet years, while those falling below mean are classified as dry years.

**Wet years**

Wet years, on the ten wettest years, are characterized by increased annual rainfall over the whole of southern Africa (Fig. 4.3a). The whole region shows the range of 101-150% of mean, but in isolated areas, where increase reaches 100% above mean. The spatial pattern of mean rainfall during wet years is not explained by the spatial pattern of the number of rain days. Most of the region experiences a range of 51-100% of mean; increasing to above 150% of mean in the central interior and other isolated areas (Fig. 4.3b). The whole southern African subcontinent, except in isolated areas, experiences from 101 to 150% of mean rain per rain day (Fig. 4.3c). Some of the isolated areas are characterized by more than 150% of mean, while others from 51 to 100%.

**Dry years**

During the dry years in the ten wettest years, mean rainfall does not show the east-west gradient, but a uniform decrease over the whole subcontinent (Fig.4.4a). Most of the region is characterized by a significant decrease below mean, the diminution reaches 30%. Although not in an east-west gradient, the number of rain days decreases differentially over southern Africa (Fig. 4.4b). Over most of the subcontinent, rain days range between 90 and 100% of mean. Over large areas, the number of rain days increases to above mean. The amount of rain per rain day ranges from 71 to 90% of mean, but in some areas, rain per rain day decreases from 91 to 100% of mean (Fig. 4.4c).

## Above and Below Mean Conditions in Ten Driest Years

**Wet years**

In wet conditions occurring during the ten wettest years, the region's daily rainfall shows a significant positive departure from mean (101-150%) (Fig. 4.5a). Most of the subcontinent experiences 25% increase above mean. In wet years, the number of rain days increases uniformly over most of the region, including the arid west (Fig. 4.5b). Not only that the region experiences an increase in number of rain days in wet years, but also the amount of rain falling on those rain days increases (Fig. 4.5c).


Figure 4.5: Above mean rainfall in 10 driest years: percentage (a) rainfall, (b) number of rain days, (c) rain per rain day. Blanks on maps show areas where criterion is not met.

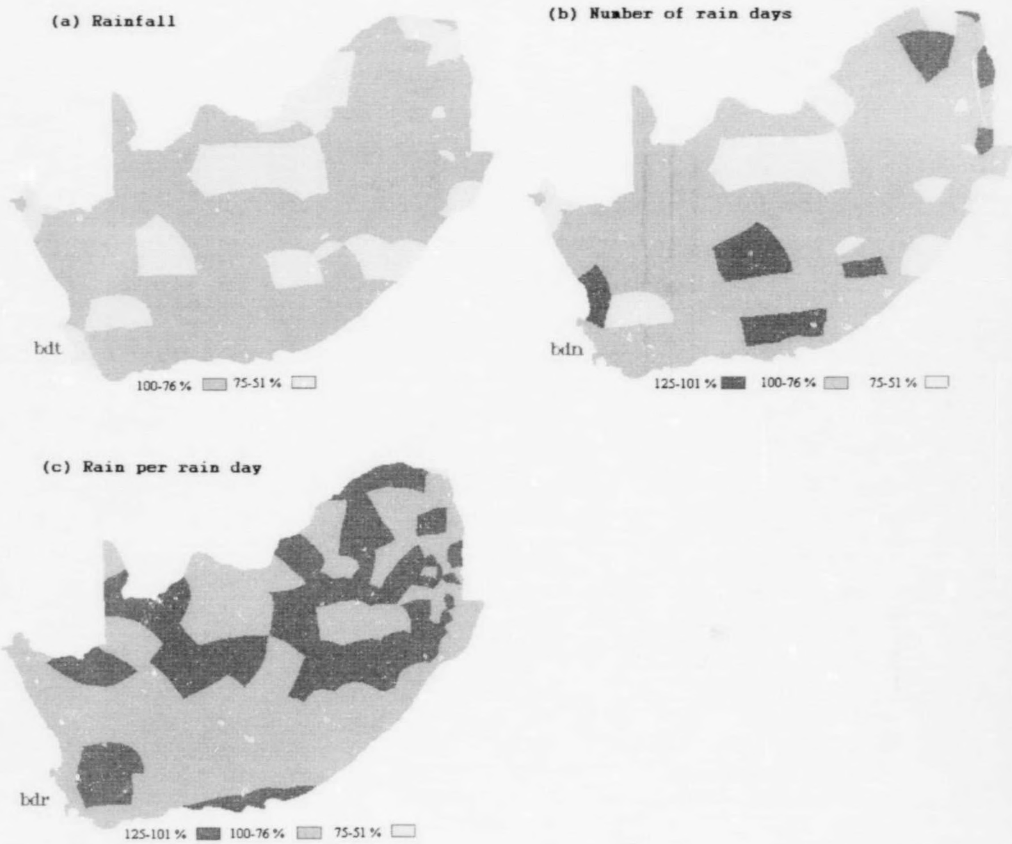



Figure 4.6: Below mean rainfall in 10 driest years: percentage (a) rainfall, (b) number of rain days, (c) rain per rain day.

**Dry years**

With dry conditions during the ten driest years, the whole of southern Africa experiences below-mean rainfall (Fig.4.6a). The departure is up to 25% below mean, in isolated areas the diminution reaches 50%. Except in small areas, the whole of the region experiences far fewer rain days during dry years (Fig. 4.6b). In driest years, not only do the number of rain days diminish, but also the amount of rainfall falling on those rain days decreases (Fig. 4.6c). Most areas experience up to 25% below mean rain per rain day.

## Conditions During Excessively Wet and Dry Years

Having shown that wet years are characterized by increased number of rain days and rainfall intensity and the opposite occurs in dry years, it is necessary to show whether the same holds for average extreme wet and extreme dry conditions over the subcontinent during the ten wettest and ten driest years. It should be recalled that in considering these wettest and driest years that extreme is defined as 25% above and below normal.

**Extreme wet years**

In the ten wettest years, in those years where mean annual rainfall exceeds 125 % of mean, rainfall excess is up to 50 % of normal over many areas (Fig. 4.7a). In some areas, it ranges from 50 to 75%, especially over large areas of the arid west. The blank areas on the maps in Fig. 4.7 indicate areas where the extreme rainfall criterion as not met.

Over much of southern Africa, the number of rain days producing the extreme wet conditions is below average (ranging from 51-100% of mean) (Fig.4.7b). However, this is not everywhere the case and many areas experience extreme rainfall from daily rainfall on a larger number of days (where the number of rain days ranges from 101 to 150 % of mean). This is especially so over the semi-arid western interior. Rainfall intensity shows a significant increase above mean conditions over most of the southern African region, ranging from 101 to 150% of mean. Over a large part of the region, rainfall intensity is 100% above mean (Fig.4.7c).

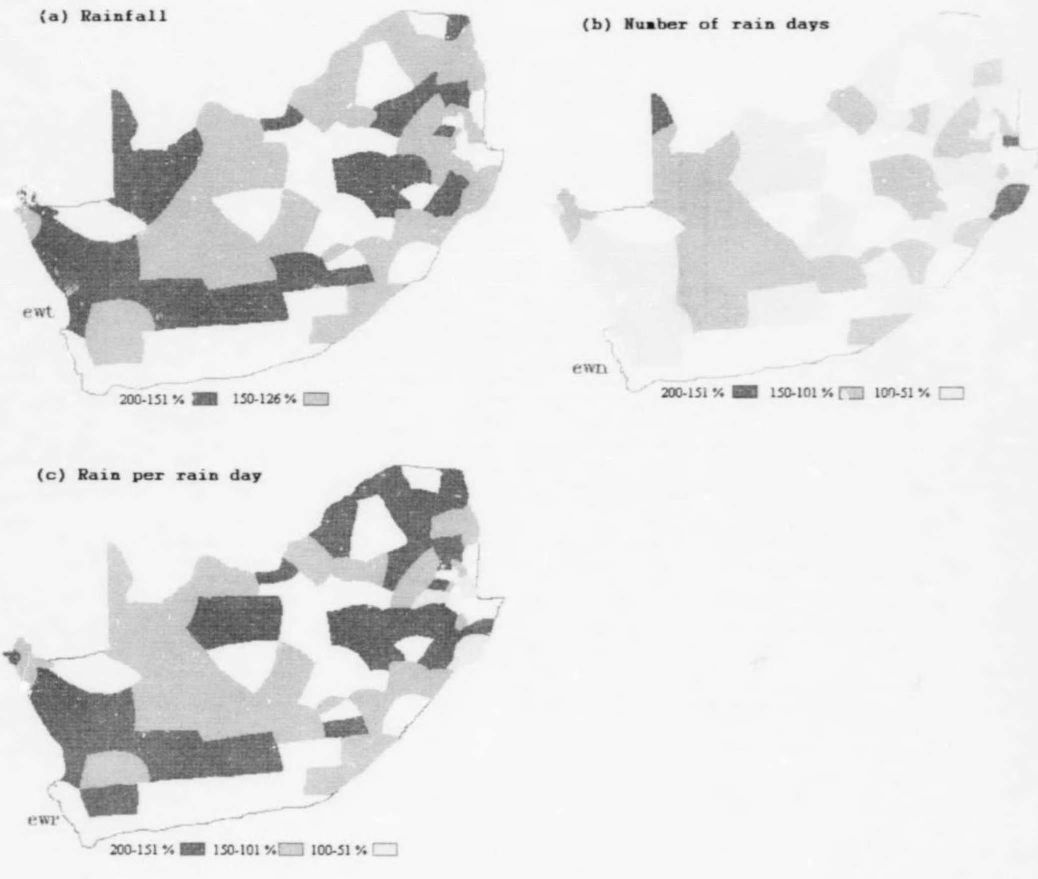



Figure 4.7: Extreme wet conditions (i.e. rainfall > 125% of mean) in 10 wettest years: percentage (a) rainfall, (b) number of rain days, (c) rain per rain days. Blanks on maps show areas where criterion is not met.