THE ESTABLISHMENT OF THE LONG-TERM RAINFALL TRENDS IN THE ANNUAL RAINFALL PATTERNS IN THE JONKERSHOEK VALLEY, WESTERN CAPE, SOUTH AFRICA

by

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DECLARATION

"I declare that the thesis entitled, "*THE ESTABLISHMENT OF THE LONG-TERM RAINFALL TRENDS IN THE ANNUAL RAINFALL PATTERNS IN THE JONKERSHOEK VALLEY, WESTERN CAPE, SOUTH AFRICA"* is my own work, that it has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references."

Godfrey Moses 2008

Signed:…………………………

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ABSTRACT

The objective of this study is to establish whether there is a long –term decline of rainfall in all rainfall gauges within the Jonkershoek Valley. Annual rainfall data from 1945 to 2005 from eight raingauges located in the Jonkershoek Valley were statistically analyzed to detect possible decreases in rainfall over time and to establish rainfall relationships between gauges. The statistical analysis has revealed that despite the short distances between gauges, rainfall discrepancies exist between gauges located in and around the study area. The analysis was mostly based on sequential techniques, which have shown that variability is found in rainfall over time between gauges. The rainfall patterns also demonstrated the spatial variability among gauges topographically and altitudinally, but consistency was found amongst gauges in their annual falls within the catchment area. A further result was that rainfall anomalies were found explaining the discrepancy that exist in the annual rainfall between gauges with distance differences of 16km between each other. The sequential analysis revealed two distinct rainfall weather-driving patterns that approach the Cape and which influences the rainfall there. These patterns might indicate a possible shift of frontal systems from the southern ocean to a more easterly direction. Further exploration of the annual data revealed that rainfall gradients in the Jonkershoek Valley are tightly linked to topography and altitude, and changes in observed rainfall may be the result of orographic rainfall-producing characteristics of the mountains of the Western Cape. The analysis of the sequential differences has showed quite strongly that cyclical patterns in rainfall are small or not existent. Drier periods are becoming more frequent in the Jonkershoek catchments. The effect of these changes is that frontal systems seem to be coming more from the southern oceans from the south west and lesser from the traditional north-westerly side. This analysis has not proven that rainfall is declining with time, but given indications that this may be so. A longer rainfall record may prove to be more definitive.

KEYWORDS: Raingauge, Rainfall gradients, Orographic forcing, Rain shadows, Weather systems, Mesoscale climate, Sequential analysis, Sequential differences.

ABREVIATIONS

MAP: Mean Annual Precipitation

SD: Standard Deviation

Q1: First Quarter

Q2: Second Quarter

Q3: Third Quarter

IQR: Inter Quartile Range

LLJ: Low Level Jet

ARIMA: Autoregressive Integrated Moving Average

Nb: Nuweberg

RER: Radar Estimated Rainfall

GER: Gauge Estimated Rainfall

ACSYS: Autographic Chart Digityzing System

CNC: Cape Nature Conservation

SAWS: South African Weather Services

DWAF: Department of Water and Forestry Affairs

SAS: Statistical Analysis Software

WMO: World Meteorological Organization

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CHAPTER 1

INTRODUCTION

1.1 Introduction

There is a considerable amount of uncertainty of how global climate change will affect the climate of the Western Cape, South Africa. Modellers (Christensen *et al.,* 2007 and Hewitson 2005) have made predictions on these aspects but this need to be verified by reference to observed data. Groups of raingauges with long data sets are useful for undertaking this verification, but the relationship between the gauges within the group also needs to be understood. This study attempts to establish that relationship.

Measurements of rainfall have been undertaken in the Jonkershoek Valley, near Stellenbosch, over a period of 61-years, with different types of raingauges at different locations. Twenty-one rain gauges in the Jonkershoek catchments have long-term rainfall records since 1935. This setup offers a unique opportunity to compare spatial patterns and other rainfall characteristics of these catchments. Preliminary analysis of the data obtained from only a few gauges has shown a decline in rainfall. What is not known is whether this trend is consistent over the remainder of the Jonkershoek Valley, and whether the same trends can be found outside it.

The South African Weather Bureau, now South African Weather Service (SAWS), divided South Africa into 93 rainfall districts, 8 climatic regions and published precipitation data for each district (Weather Bureau, 1972). This finding is at odds with what has been casually observed in the preliminary analysis of data, as explained above. Further research is needed to develop an improved understanding of the rainfall dynamics of this area.

1.2 Background to the study

Mountain catchments are important components in the hydrological cycle in the winter rainfall region of the Western Cape. The demand for water in this region is increasing dramatically within a context of general scarcity, which amplifies the importance of precipitation as a vital resource (Midgley *et al.*, 2005).

Quantification of rainfall depth, coupled with its spatial distribution, is essential to water resource studies and for the development of sustainable water supplies to human settlements and economies, as well as for hazard warnings and forecasting (see Olson *et al*. (1995), and Ebert and McBride (1997) as examples). The question of whether there are any trends in the total rainfall has important implications to everyone, especially because demands for water are rising in the face of a limited supply (Midgley *et al.*, 2005).

The most common method of measuring this rainfall is with standard recording and non-recording raingauges, which are point observations. By taking a fair sample of the rainfall reaching the surface of the earth specifically over the area for which a rainfall measurement is required (like a defined catchment), and using interpolating and spatial averaging techniques, a reasonable spatial estimate of rainfall can be acquired. Therefore, the measurement of rainfall is relatively straightforward but, owing to the random and systematic errors that do occur, exact measurements are impossible to obtain (Schultz, 1985).

1.3 Aims and objectives of the study

The overall aim of this project was to establish whether there is a long-term decline of rainfall collected in rainfall gauges within the Jonkershoek Valley that have the longest and best quality records. The primary objectives of this research were to:

- determine whether the rainfall relationship between the different gauges has changed over time.

- assessment of the nature of possible changes of climate at the mesoscale (sub-continental) level.

- and to reduce uncertainty about the causes of that change.

To achieve the aim and objectives of the project, a study site located in the Jonkershoek Valley, was selected for analysis. Study site selection will be discussed in detail in Chapter 3, Section 3.2.

1.4 Research Outline

The mini dissertation has seven chapters and it unfolds in the following way:

- Chapter 1 presents the context within which the study was undertaken. It also attempts to show that a need exists to explore long-term historical data in a mountainous catchment in the Western Cape of South African in relation to climate change.

- Chapter 2 reviews the literature of weather characteristics of rainfall behavior and outlines the most important processes as well as statistical techniques that influence a catchment. Certain variables over time are exploited with its topographic characteristics in a mountainous area.

- Chapter 3 presents a description of the study area and catchment location. Information is presented on general characteristics such as topography, spatial location of raingauges, vegetation and the geology of the catchment.

- Chapter 4 conveys the sequential methodology and statistical techniques used in generating the data sets for the different procedures (e.g. converting and quality process of data, etc). The research design is also presented in this chapter.

- Chapter 5 presents the results of the statistical exploration and the sequential analysis, sequential differences and the centralised moving medians of the variables.

- Chapter 6 provides a discussion about the relationship between analysed raingauges, seasonal behavior, and distribution patterns of rainfall over time and possible trends in the long-term annual rainfall. It examines the results in the light of the research objectives set out in Chapter 1 and also provides possible explanations for the changes that were observed over the length of the study period.

- Chapter 7 concludes the research with a brief discussion on its implications for catchment rainfall behavior in the Western Cape South African and recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 General introduction

This chapter entails the literature review of weather characteristics of rainfall behavior and outlines the most important processes as well as statistical techniques used that influence rainfall in a catchment. The main objective for the establishment of the Jonkershoek research catchments was to determine how afforestation might impact on the streamflow. The installation of rainfall gauges was to observe quantity of rainfall. The conversion of rainfall into runoff is therefore determined by climate, and catchment characteristics such as topography, geology, soils and land cover.

2.2 Weather characteristics and rainfall

Weather can be described as phenomena which can occur at any place, over a period of time and coupled with atmospheric characteristics. Trewartha and Horn (1980) relates weather as an everyday experience- one talks of “today’s weather”. Schulze (1997), states that climate on the other hand, refers to a more enduring regime of the atmosphere, which is represented by day-to-day weather conditions and elements from the atmosphere within a specific place over a period of time.

The hydrological concepts described by Schulze (1997) on the mean annual precipitation (MAP) characterises the long term quantity of water available to a region for hydrological purposes and serves as a important statistic in its own right. He described the overall feature of MAP distribution over southern Africa as decreasing uniformly westwards across the eastern side of the country. He concluded that the Western Cape experienced the highest variability of MAP amongst any other province with highest point rainfall of 3345mm per annum (Schulze (1997). Mean annual precipitation and the inconsistency thereof also play a large role in determining many aspects of ecosystems behavior of mountain catchments.

Scientific results have shown that there are different opinions about possible causes for decline of rainfall in Mediterranean areas. A statistical study done by Jury (2004) on African rainfall over a period of 31 years linked such declines and variability of rainfall to climate change. His results assumed that El Niño was responsible for the dry years and La Niña for the possible wet phases. These rainfall fluctuations varied between 3-8 years. A technique using moving averages was selected as the best means of extracting meaningful fluctuations found in the highly variable precipitation (Jury, 2004).

For the purpose of this study it was pertinent to look at what has been done elsewhere regarding changing rainfall regimes. In Australia, detailed studies around long-term decreases of precipitation were done by Allan (1992). The purpose of Allan's research was to establish possible causes that have lead to a decline in winter precipitation because of atmospheric and oceanic circulation features. This relationship between rainfall and sea level pressure was accomplished through data smoothing methods to resolve possible fluctuation of precipitation in decadal and multidecadal periods. Most of the variability related to decline in precipitation seems to be coupled with oceanic-atmospheric influences.

Allan (1992) also cites many others who have done similar studies about the long-term decline of precipitation in Australia e.g. Gentilli (1971), Wright (1971), (1974a, 1974b), Broadbridge (1989), Nichols and Lavery (1992). Most of these studies have raised the concern that the recent downward trend in rainfall could lead to the enhancement of the greenhouse effect.

Smith's (2003) assumption that only upslope regions influence precipitation is invalid for areas with a rugged terrain. This theory has led to the studying of the long-term behavior of rainfall in the Jonkershoek catchment. The use of interpolation methods to calculate rainfall correctly seems to propose problems as the mountains are treated the same despite the altitudinal corrections. The alternative was that precipitation data be collected over a period of time in the Jonkershoek Valley.

Rainfall records are available for the last 70 years and certain gauges have been maintained since 1935 in the Jonkershoek Valley. Plummer's (1932: Page 22) description of the Jonkershoek region as "slopes of north–south trending folded mountains" and records that all gauges are below 1,500 feet (457m.) and mostly below 800 feet (244m.). A preliminary account of rainfall in the Jonkershoek was published by Wicht (1940). Based on his research it has lead to the establishment of rain gauges in higher altitudes during 1945 where these data sets are now a valuable source of information.

2.3 Climate: Catchment weather systems

Climatic mesoscale atmospheric circulation systems and surface forcing have an important influence on the weather of the southern parts of South Africa. The steep escarpment of southern and eastern South Africa induces the occurrence of large spatial differences in rainfall totals over relatively short distances (Engelbrecht and Rautenbach, 2000).

The climate of the Western Cape is a typical mesothermal Mediterranean type with dry summers with prevailing south easterly winds and cool wet winters with frequent cyclonic rains. The mean daily maximum temperature for February is 29.7 ºC (the hottest month) while the mean daily minimum temperature for July is 5.9ºC (coldest month), (Versfeld and Donald, 1991).

Wicht (1969) description of the weather in Jonkershoek in summer is affected by high-pressure zones between the 25 and 35ºS latitudes. The high pressure causes anti-cyclonic winds to blow moist air over the Dwarsberg Mountain range south-east into the valley. Orographic cooling, causes condensation and this leads to substantial summer rainfall on high altitudes slopes. The south-easterly winds also caused “berg wind” conditions which are accompanied with recorded high temperatures.

2.4 Rainfall patterns, trends and models

The high variability of Jonkershoek streams according to Wicht (1943) is caused by the heavy winter rains and the steep slopes of the catchments, which cause heavy torrential winter spates, and the recession of base-flow during summer. The rainfall recorded at a limited number of subjectively selected stations, where conditions appeared to be sufficiently uniform to restrict casual errors, should, however, yield acceptable indices of rainfall for the area as a whole, which can be interpreted to judge fluctuations in time, and a relatively reliable pattern of rainfall distribution over the area (Wicht, 1961).

Rainfall is generally accepted as a phenomenon which is associated with highly unpredictability behavior which can be related to processes operating within the ocean-atmosphere systems. This type of behavior is associated with the long-term behavior of seasonal rainfall in catchments. Most of the deviations in the periodicity are related to solar cycles, variations in ocean currents and wind directions, sea surface temperature anomalies, etc. (Bhalme and Mooley, 1981), (Ananthakrishnan and Parthasarathy, 1984).

Ceballos (2003) have done an analysis, looking at rainfall trends and dry periods in a Mediterranean type of climate in Spain. He has found that the number of dry years exceeded the number of wet years for a specific region, which has caused a marked water deficit in the rainfall season. This has lead to an increase in variability in the intra-annual precipitation and more dry period occurrences; and this had a significant impact because more than two thirds of peninsular Spain belongs to the Mediterranean climate. His analysis of the temporal trend of annual rainfall has shown that during the nineties the Periplain has experienced a significant decline in precipitation. In the remaining other two sections, rainfall was more dispersed and no statistically significant trends have been detected.

Smith (2003) has found that there is still a need for simple models of precipitation in complex terrain because it could have broad application to high mountain meteorology and hydrology. Smith (2003) added that information on height seems to contribute little to the statistical skill. His testing of an advection model of orograpic precipitation included critical elements like the conversion of condensed water phases, airflow gradient and the cloud evaporation.

Ronny Berndtsson (1987) showed from his study on patterns of rainfall variability that different delimited rainfall regions are governed mainly by topographical and coastal influences. He continues to say that correlation between rainfall data increases precision among the different measuring points in an area. A similar methodology based on daily and longer durations of rainfall was used by Jackson (1978) in order to study local variability in rainfall patterns and local processes of rainfall generation.

2.5 Rainfall type and its variability

Rainfall in the Jonkershoek catchments area is driven by frontal rain systems (Figure 2.1). These cold fronts normally start over the Atlantic Ocean and move in a west-east direction and are associated with north-westerly winds ahead of them. When they reach the catchment they are driven by orographic forcing up against the mountain ranges. This type of winter storm causes heavy downpours upwind before the mountain range and decreases in magnitude as it reaches the rainshadow part of the catchment. The amount of rainfall is related to the angle of the slope and the wind force which causes increased falls at higher altitudes.

When someone wants to study the reasons for the uniqueness of the vegetation in an area, the amount of rainfall may be one of he main controls and that is why precipitation and its variability needs to measured more effectively. The ideal place to measure rainfall is on a flat area. In Jonkershoek catchment, a characteristic such as topography is a more deciding factor to the actual rainfall volumes for the specific area.

Reason *et al.,* (2003) in his paper has done an investigation around the variability of the inter-annual precipitation in the Western Cape, in South Africa. His study was based on the atmospheric general circulation model, which was associated with the upstream interaction of the South Atlantic Ocean. His model was run over a 10-year period using mean monthly global sea surface temperature for a winter period between May and September. The results from his study have shown that factors like low and mid level winds, and sea level pressure are indicators that the wet winters are associated with the increased inflow from tropical South America. These factors coupled with the eddying affect, thickness of the lower atmosphere increased storm intensity and enhanced precipitation (Reason *et al.,* 2003). This sort of climatic behavior in the Western Cape could shed some light on the cold fronts approaching the Cape.

In his paper, Muñoz-Diaz and Rodrigo (2006) tested and used statistical models in their study to identify variability in the seasonal precipitation in different regions in Spain. The multi regression analysis included a time span of 88 years of which two periods were identified namely a calibration period for even years and a validation period for uneven years. He concluded that the changes in the precipitation can be attributed to variations in the sea level pressure (SLP) field and alternative effects like topography and sea temperatures should be taken into account when modelling precipitation variability. Orogaphic forcing is a contributor to precipitation variability in climatic zones.

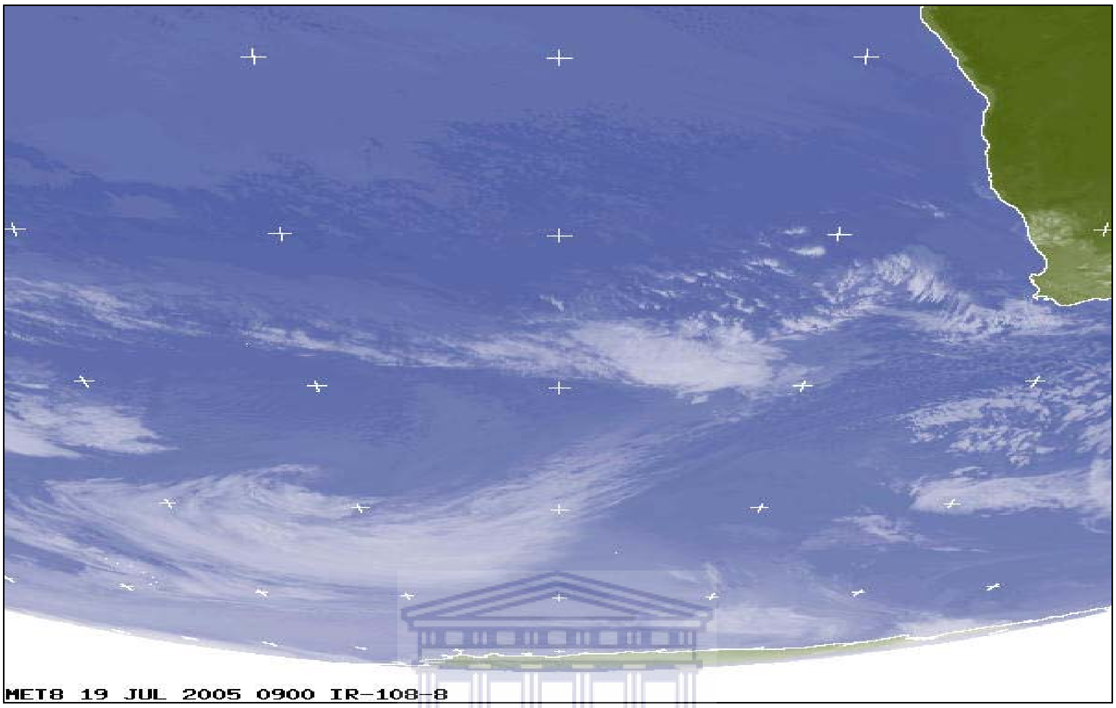


Figure 2.1: **Typical winter cold front approaching the Western Cape.**
Source: Image from South African Weather Services (SAWS), 2005

Research done by Buzzi and Foschini (2000) pointed out that orographic precipitation is generated by different mesoscale features associated with the interaction with topography, such as a moist Low-Level Jet (LLJ) and near-barrier convergence zones. Accurate measurements of global precipitation are very important for the study of the atmospheric circulation and climatic variation (Browning, 1990).

Many authors from different parts of the world have looked at precipitation and analyzed historical time series. In North Carolina (USA), by Hamilton *et al*., (2001) extends their analysis back to the 19th century pointing out how precipitation has a fluctuating behaviour. In Europe, studies on Ireland rainfall series collected from 1940s to 1990s (Hoppe and Kiely, 1999, Kiely, 1999, Kiely *et al*., 1998) confirm the increase in the total annual precipitation.

2.6 Orographic rainfall

Orographic forcing of rainfall has a close association with topography in any mountain catchment and does influence rainfall patterns. It is understandable that mountain barriers can create an impact on rainfall and causes diversion of any rain-bearing clouds.

Most studies on orographic rainfall have shown examples that the wettest regions are found on the windward side of the mountain in relation to a drier lee side of the mountain. These conditions are subjected to wind behavior during the storm. Other processes facilitating the topographic enhancement of rainfall include the formation of orographic wave clouds and induced atmospheric instability resulting from uplift and condensation (Smith 1979).

The study by Sturman *et al.,* (1999) on mesoscale climates in New Zealand focuses on orographic precipitation and its associated climatology. It includes the complex terrain types and the dynamic effects of surface topography. The analysis specifically looked at the wind systems, which integrate with the thermally generated airflows to form a complex interacting environment. The study identifies two major incidents in the behavior of weather patterns of the island. One finding is the orographic blocking by the mountain ranges and lee side trough developments. The second incident is the effect caused by the orographic forcing on the precipitation in the area. The lifting of air over the mountains has led to intense orographic precipitation as a result of thermodynamic processes. Annual totals near the crest of the mountain can exceed more than 12 000 mm (Griffiths and McSaveney, 1983).

2.7 Raingauge technique

In the Western Cape with its Mediterranean climate, rainfall is related to its variation in distribution over the Jonkershoek catchment area. Rainfall seasonality is driven by the frontal systems that approach the Western Cape. Clanwilliam receives a higher rainfall in winter than Cape Town, which is situated more to the south. The further you move to the Southern and Eastern Cape, the more the rainfall is dominated by summer falls.

The installation of raingauges in the Jonkershoek Valley was extensively researched because of site factors such as uniformity, enough large areas and the horizontality of the terrain. The objective for the placement of gauges was therefore that the collection of rainfall should be correct and reliable enough, to be used in mathematical interpretation of the research results. Part of the objective of this study was to test how correct and reliable rainfall data over a 61-year-long period in the Jonkershoek Valley was.

The rainfall recorded at the limited number of subjectively selected stations, where conditions appeared to be sufficiently uniform to restrict casual errors, should however, yield acceptable indices of rainfall for the area as a whole. These can then be inter-correlated to judge fluctuations in time over time, and to indicate a relatively reliable pattern of rainfall distribution over the area (Wicht 1961).

The cold fronts that approach the Jonkershoek narrow valley are accompanied by wind from the north-west or the south east directions. This has lead to the introduction of the shielded raingauge technique to measure rainfall accurately in these windy conditions. In their studies by Pagliucca (1934) and Brooks (Brooks, 1938) showed that the gauge with the windshield attached should be erected perpendicular to the surface of the ground.

Jonkershoek catchments with their mountain faults and steep slopes were taken into account for the erection and location of gauges at specific areas and altitudes. After studying a number of mathematical theories, shielded raingauge orifices were installed relatively parallel with the surface slopes of the higher areas. Tests done by researchers have shown through rainfall evidence that rainfall is measured more accurately with gauges installed parallel with the slope than those who were not (Fourcade 1942 and Horton 1919).

Schulze (1997) has stated possible problems around the collection of precipitation. He has found that the Nipher shielded raingauges recorded an additional 8.1% more than the standard raingauge. In his study of the trend surface analysis he resorted to statistical methods as a result of the complexity of the mountainous terrain.
Marion Clawson (1947) cited that the sequence in which “wet” and “dry” occur may be particularly important. According to her, one should recognize that at present any studies of climatic records are dealing with relatively small samples drawn from a largely unknown universe, the results have unknown validity if extended into some future time period (Marion Clawson, 1947).

2.8 The use of statistical parameters for exploratory analysis

Most mountain catchments encompass a complex relationship between topography and rainfall. The amount of rainfall distributed over an area in a mountain catchment is influenced by winds, type of frontal systems or the currents and the coolness of moist air over the land surfaces. Spreen (1947) developed a multivariate statistical model that predicts mean annual rainfall in the Rocky Mountains (Colorado) from four topographic variables: elevation, slope, aspect, and orientation.

The purpose of this study is to develop a set of topographic variables that influence spatial variation of rainfall and its pattern behavior. Overall, models are used to compare climatic conditions of a mountainous area. Statistical variables like slope and the intercept of equations and the calculated coefficient were used for comparison for its significance.

The use of independent variables by Basist and Bell (1993) such as elevation, slope, exposure, and orientation was to explain the spatial distribution of precipitation in a catchment. The statistical technique was based on linear regression models of mean rainfall for different raingauges and the equation used was:

$P = \alpha + \beta T$

P = Precipitation

α = intercept

β = slope

T = variable (1)

Rainfall due to its variability can be seen as an incident, which will, differ from year to year in its total amount. Rainfall can be linked to dry spells and wet spells, which contributes to its variability and unpredictability during seasons.

Because of the high variability of rainfall in mountain catchments it is a challenge to use different statistical methods to explain these phenomena. The use of variables such as rainfall over time in linear regression models to test the significance of rainfall variability in mountain catchments, form part of this study.

2.9 Statistical correlation technique

Berndtsson (1987) used cross correlation analysis in his study to analyse rainfall patterns to demonstrate rainfall variability. The information available has shown that the use of correlation functions for spatial rainfall variability has been used widely in different studies. This methodology has increased the precision of rainfall measurement at different gauges in measured area. Rodriguez.-Iturbe *et al.,* (1972) precision of estimating a total volume of rainfall over specific area using correlation functions has been well researched. This methodology of transforming point rainfall to areal rainfall is characterised to be used in rainfall-runoff models for catchment areas.

The methodology to use the variation of coefficients to display rainfall variability is one of the procedures used to test the effectiveness of the method. Berndtsson and Niemczynowicz (1986) e.g. found that ten one-hour intensive storms, recorded by a dense network in Northern Tunisia, represented, depending on the gauge, 10-30% of the recorded annual rainfall. The use of the correlation methodology and plotting it over longer periods and over different distances will demonstrate the pattern behavior of precipitation. Schulze (1997) cited that the annual rainfall maps did not show the year- to-year variability but the coefficient of variance (CV) expressed as a percentage was mapped. This statistic can be used for relative rainfall comparisons between regions located next to each other. His results have revealed that on a province by province comparison based on the inter-annual CV of rainfall, the Western Cape showed the least consistency in rainfall from year to year.

The use of the correlation technique can be implemented successfully with a long term annual data record. The variation in the annual rainfall in the Jonkershoek catchment has not shown long periods of dry spells over time and will reduce the possible error in the analysis.

2.10 Statistical sequential analysis

Evidence of variability in mesoscale rainfall behavior between gauges located in mountain catchments is not commonly found in the literature. The comparison of a time variable versus rainfall could exhibit substantial variability amongst gauges. There have been many attempts to reduce variability in rainfall and it can be accepted that variability is an inherent characteristic of rainfall in mountain catchments.

In statistical analysis **sequential estimation** refers to an estimation method where the sample size is not fixed in advance. Instead, data is evaluated as it is collected, and further sampling is stopped in accordance with a pre-defined stopping rule as soon as significant results are observed (WWW.wikipedia.org). The statistical technique known as sequential analysis (Wald, 1947, Wetherill, 1975) provides a strategy that can be used within these constraints. The purpose of this technique provides a means to detect differences between rainfall and time estimates and to distinguish between good wet and dry rainfall years.

In the sequential analysis of rainfall estimates from raingauge data, Cain and Smith (1976) described the ultimate purpose of their analysis to be the identification and adjustment for any shift in the mean value that might be obscured by this variability. Cain and Smith's (1976) application of sequential analysis using key factors to adjust radar rainfall estimates (RER) on the basis of gauge estimated rainfall (GER) was very suitable. They continued to say that this measure was superior to the "factor of difference "often used (e.g., Woodley *et al*., 1974) for various reasons, one being that it preserved the sense of difference with positive values indicating that GER > RER and negative values the converse. Different climatic factors were applied in their study which included rainfall, time and elevation as part of the first stage of the sequential analysis. The second stage in this analysis of the sequential analysis was to measure the response of these factors over time related to climate change.

Wetherhill and Glazebrook (1986) described sequential experiments as a scientific method by its very nature. They continued by citing that firstly there was the sequential choice of the experiment to be performed, in that the factor levels used in the second and succeeding stages depended on the earlier results.

Mori *et al*., (2000) have done studies using sequential differences to determine whether successive events were part of the same bouts. Bouts occurred in animal behavior where a criterion should be chosen to determine whether successive events i.e. bird diving were part of the same bout. They proposed a new method in sequential difference analysis to find the bout-ending criterion for dive bouts analysis. The objective of the dive bout analysis using sequential difference analysis would be useful in dividing sequence of complex behavior with several characteristics into meaningful bouts.

It can therefore be accepted that any annual rainfall events are complex driven by different climatologically characteristics. The using of sequential difference analysis to interpret and describe complex rainfall phenomena would enhance the understanding of rainfall events. Rainfall differs from year to year and the sequential differences would clearly describe the possible trend in cyclical behavior in annual rainfall events. Sequential analysis will therefore contribute to understanding the distribution behavior of these sequential rainfall events.

Different time series techniques have been explored to ascertain the most appropriate statistical methodology for this study. The following statistical techniques were tested on the annual long-term rainfall data from the catchments, namely the SPECTRAL procedure and the Autoregressive Integrated Moving Average (ARIMA) model.

The SPECTRAL procedure is based on the statistical testing of data for white noise. It is a test to determine whether a series contains additional information that might be utilized by a more complex model. The determination of white noise is based on the execution different test statistics. If the test statistic exceeded its critical value at 5% or 1% of its significance levels it could lead to either rejecting or accepting the NULL hypothesis of the time series data.
The Null hypothesis theory was not used for this study as the outcome may not be suitable for the purpose of this study.

The SPECTRAL procedure is a complex methodology which includes the estimations and interpretations of statistical periodograms.

The second time series method explored was the ARIMA model. The ARIMA methodology is based on a linear stochastic model suitable for any type of hydrological data. This model was not used for the purpose of the study. The ARIMA model can be applied to time series data for forecasting purposes or predictive performances of the annual rainfall data which did form part of the study.

The second reason for not using the ARIMA model was that it was an economically driven model and more applicable for the financial environment.

The sequential analysis technique was applied for this study on the annual rainfall data collected in a catchment where rainfall is a very highly variable component of the climatic regime.

The main reasons for using the sequential analysis technique were for estimation and interpretation of the complex statistical characteristics of rainfall behavior found in mountain catchments.

CHAPTER 3

STUDY AREA AND STUDY SITE

3.1. *General introduction*

This chapter describes the study area and includes the catchment, general topography, raingauges, climate, vegetation, geology and the data collection sites.

3.2 *Location of the study site*

The Jonkershoek State Forest is approximately 10 930 ha in extent, of which 3000 ha falls in the Eerste River catchment. The Jonkershoek valley is located 10 km south-east of Stellenbosch in the southern western part of the Western Cape, (Figure 3.1). The Jonkershoek catchment has a longitude of 18° 55’E and latitude of 33° 57’S. The narrow valley (Figure 3.2) gives rise to the Eerste Rivier which originates in the Dwarsberg Mountain range and flows through Stellenbosch to False Bay. The catchment area forms part of a range of Quaternary catchments delineated by the Department of Water Affairs and Forestry for South Africa. Tributaries from the sub-catchments on both sides of the Jonkershoek valley flow eventually in the Eerste River (Figure 3.1).

The Jonkershoek Valley, towns, contours and the layout of the catchment area is fully displayed in Figure 3.1.

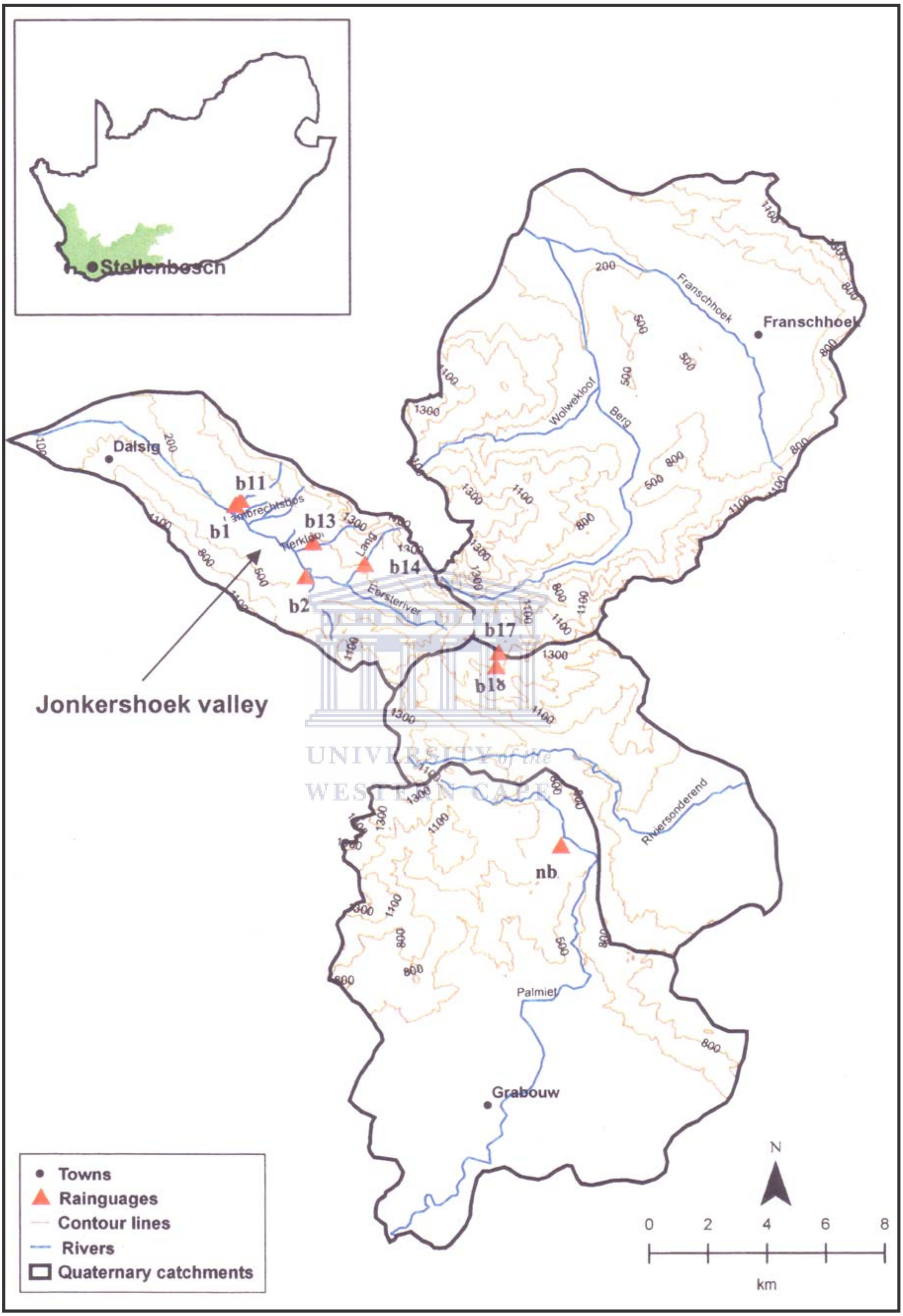


Figure 3.1: **Location map of the Jonkershoek study area and adjacent quaternary catchments within Western Cape of Southern Africa**

Figure 3.2: **View down the Jonkershoek valley, looking north-west. The research catchments are located within the plantations (those dark green patches on the valley floor and lower slopes). Image: Western Cape Nature Conservation, 2002.**

3.2.1 *Description of the sub-catchment area*

The experimental sub-catchments are located in a mountainous region and lie within 8 kilometers from each other, but are hydrographically different from one another. They also differ from each other in relation to size where Swartboskloof occupies an area of about 191 ha where Langrivier covers an area of about 245 ha (Table 3.1). Langrivier and Tierkloof catchments are shaded by large mountain peaks to the northeast, while Swartboskloof with a Northeastern, aspect and Bosboukloof with a southeastern aspect are less steep catchments (Table 3.1 and Table 3.2).

The study-area included five sub-catchments which demonstrate the location of the raingauges with Dalsig as a closely situated suburb. The sub-catchments in the Jonkershoek valley are Bosboubkloof, Tierkloof, Langrivier, Eerste River and

Swartboskloof. Each catchment has its own raingauge (see Table 3.1) measuring all the incoming rainfall entering the catchment area. All these catchments are part of a network of experimental research sites for the area.

Table 3.1: Characteristics of the eight sub-catchments found in Jonkershoek.

Characteristics	Office	Swartbos-kloof	Bosbou-kloof	Tier-kloof	Lang-rivier	Eerste Rivier		Nuwe-Berg
Area (ha)	-	191	200.9	65.5	245.8	-	-	7200
Min. Elevation	244	320	274	280	366	200	200	574
Max. Elevation	-	1100	1067	1530	1460	1237	1219	-
Slope (Horton-1935)	-	-	0.26	0.46	0.4	-	-	-
Aspect	SE	NE	SW	SW	SW	SE	SE	N
Raingauge	**b1**	**b2**	**b11**	**b13**	**b 14**	**b17**	**b18**	**nb**

3.2.2 *Historical background*

The Jonkershoek catchments were established in 1935 to investigate the influence of afforestation on runoff. Concerns had been raised as contradictory evidence from around South Africa showed declining streamflow downstream of new plantations. The catchments, associated research infrastructure, and its water resources became the Jonkershoek Forest Research Station.

3.2.3 *Catchment characteristics and topography*

The Jonkershoek valley has a large altitudinal range from the top ridges (9700 m) to the valley floor as being narrow 4200 m across. The valley is also orientated south-east to north-west in the downstream direction (see Figure 3.2).

The Jonkershoek catchment area have its upper boundaries on the valley ridges and their outlets close to the valley floor, so each catchment is experiencing a very strong rainfall gradient that increasing towards the Dwarsberg mountains. To measure rainfall accurately at a specific site, slope often causes a problem. It is well known that, in general, rainfall increases with elevation in a temperate domain with non-uniform gradients (Barry, 1992), and that mountain ranges trigger contrasts between the windward and the leeward side. The raingauges are located at different altitudes as reflected in Table 3.1 and Figure 3.3.

Hydrological research requires that the rainfall input over the whole catchment is known as accurately as possible. However, access to all parts of the catchments is constrained by the very rugged topography and steep slopes in their upper parts. An additional characteristic of the Jonkershoek sub-catchments is its uneven mountain sides with its changeable slopes and aspects that create a challenge to assessing and interpreting the rainfall under different climatic conditions with its unique topography. In rugged terrain, the inclination and direction of incoming rain are determined by winds and these might be quite unpredictable (Wicht, 1961). Wicht (1944) believed that the satisfactory estimation of the extremely variable rainfall in mountainous areas clearly involves the use of a very large number of gauges.

3.2.4 *Climate and rainfall*

The climate of the Western Cape is Mediterranean with rainfall occurring predominantly in the winter in the form of rainfall. Rainfall also occurs during the summer as a result of high pressure zones, causing winds to blow up in the centre of the valley over the Dwarsberg Mountain to the south east.

Wicht *et al.,* (1969) describes the rainfall as a rainbringing wind blowing from the north-west, forcing the air upwards to spill over the end of the valley in the south-east causing the rainfall to increase over the north-east and south–east. Over a distance of approximately 8km, the moisture laden winds are forced upwards to about 1066 m (3500 ft) towards the end of the valley introducing heavy winter orographic rains.

Most rainfall in Jonkershoek occurs in the winter months when cold fronts move in a general south-easterly direction off the Atlantic Ocean. About 85% of the rain falls in the six months from April to September (van Wyk, 1986).

The annual average rainfall for the Jonkershoek valley is 1390 mm. Raingauge b1 (Mountain to Ocean Forestry Office, Figure 3.3) is situated at the lowest elevation in the catchment (244 meters above sea level) and has a mean annual precipitation (MAP) of 1180mm, whilst raingauge 17b on Dwarsberg (1237 meters above sea level) records the highest annual rainfall (3620 mm) in the country (Wicht, *et al.* 1969).

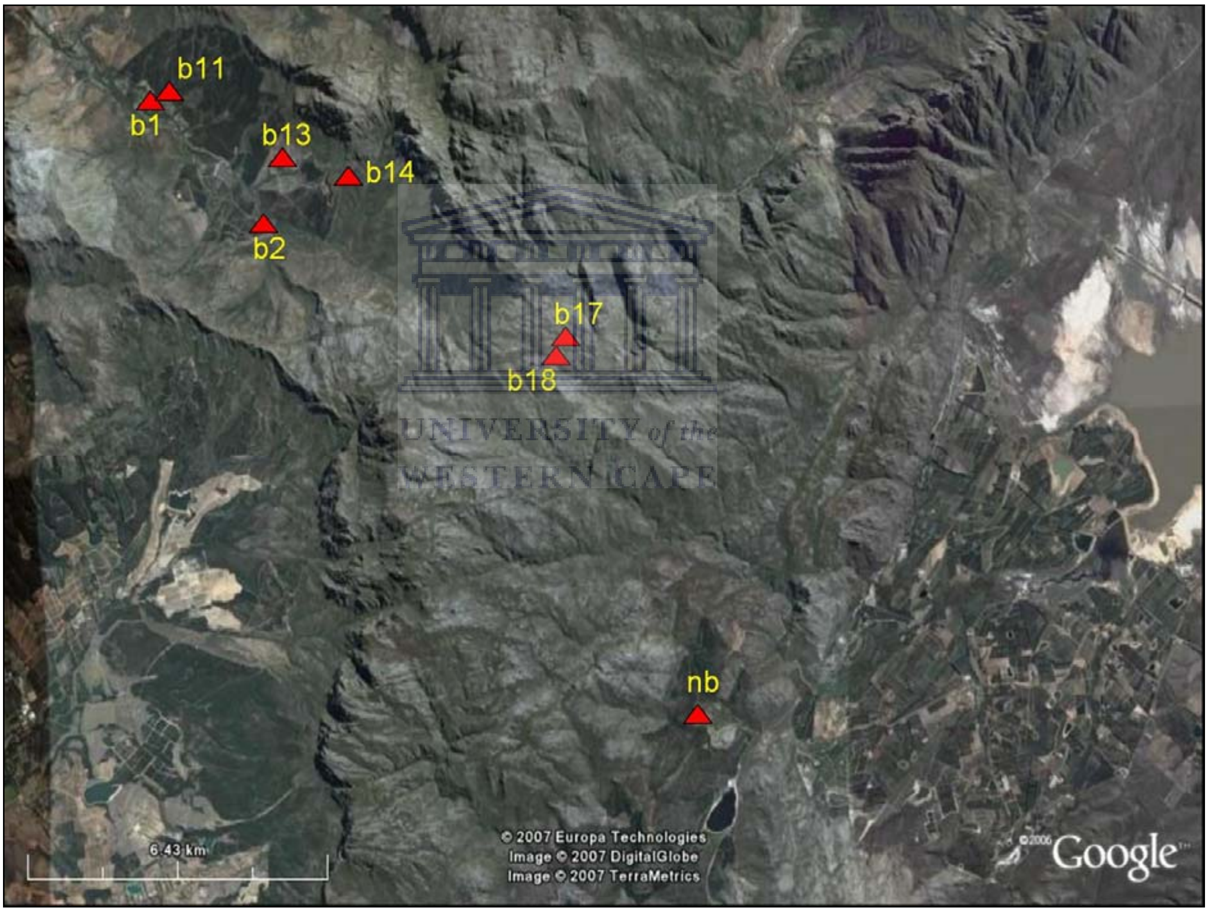


Figure 3.3: Spatial location of the raingauges located in the Jonkershoek valley. Image: Google, DigitalGlobe, 2007

Eight raingauges were selected for the study. Seven of the gauges are found in the Jonkershoek valley of which five are located inside the valley and two on the crest of the Dwarsberg mountain range (Figure 3.3). The five gauges are located in the following sequence based on their elevation are b1, b11, b13, b2, b14, b17, b18 and Nuweberg (nb).

The eighth gauge namely Nuweberg (nb) is further south and is located in the Riversonderend catchment area.

The distance between the lowest located gauge (b1) in the catchment and Nuweberg (nb) is approximately 16 km apart. The locality of gauges according to altitude varies very widely as the lowest situated gauge is found at a elevation of 244 meters above sea level and the highest gauge (b17) with a height of 1237 meters above sea level over a distance of about 10 km (Table 3.1).

3.2.5 *Measurement, placement and types of raingauges*

The main object of gauging rain in Jonkershoek valley is to obtain reliable, relative measures to be used in the mathematical interpretation of the effects of cathment management on streamflow (Wicht, 1948 & 1967b). The measurement of rainfall and the exact placement for the eight gauges are listed in Table 3.2. The establishment of raingauges in the catchment was complex due to the roughness of the terrain that limits the available open flat plains (Figure 3.3). Raingauges have therefore been placed over an experimental area of 1,619 ha, at various altitudes in the research catchments. Some raingauges were placed in the lower parts near the catchment outlets, in the middle parts where forest roads on the slopes have given access to gauges and on the higher altitudinal areas.

The sequence of the location of the raingauges in the catchment is as follows and starts of with raingauge b1, b11, b2, b13, b14, b17, b18 and Nuweberg (nb). The altitudinal location of the lowest and the highest gauge varies between 220-1560 meters above sea level (m.a.s.l.). Gauges b1, b2, b11, b13 and b14 are all facing south west, to b17 and 18 more to the north-west.

Table 3.2: **Distribution of raingauges located in the Jonkershoek catchments.**

Gauge	Year of erection	Longitude	Latitude	Data collection	Correction factor
b1	1950	18° 56' 50"	33° 57' 50"	Daily	-
b2	1944	18° 57' 30"	33° 59 '15"	Weekly	-
b11	1944	18° 56' 30"	33° 57' 30"	Weekly	1.033
b13	1944	18° 57' 35"	33° 58' 35"	Weekly	1.022
b14	1944	18° 58' 35"	33° 58' 55"	Weekly	1.028
b17	1945	19° 00' 89"	33° 59' 97"	Monthly	1.000
b18	1945	19° 00' 86"	34° 00' 53"	Monthly	1.000
Nb	1945	18° 04' 74"	34° 07' 07"	Daily	-

The layout of the physical features of the sub-catchments with its tributaries is presented in Table 3.1 and in Figure 3.3. Each sub-catchment is equipped with a raingage namely Bosboukloof (b11), Swartboskloof (b2), Tierkloof (b13), Langrivier (b14) and on the crest of the Dwarsberg Mountains (b17 and b18) in the Eersterivier catchment and Nuweberg (nb) which lies in the Riviersonderend catchment area on the lee-ward side of the mountain. The Jonkershoek Valley is therefore enclosed on three sides by mountains as seen in Figure 3.2. Raingauge b1 is located at the foot of the catchment and b2 resided in the middle flatter part of the catchment. The altitudinal difference between raingauge b1 and b17 which is the highest located gauge inside the catchment is 610 meters.

The installation of gauges in the Jonkershoek catchments had to accommodate different factors which might influence rainfall in the area. Factors like wind, sloping and orographic forces were taken into account to record a true catch of rainfall.

Standard (127mm) raingauges of the Snowdon type (Figure 3.4) used by the South African Weather Service (SAWS) were erected at all the gauging stations in the Jonkershoek valley. These gauges are made of copper, with sharp, rigid beveled rims of brass round the aperture, which is vertical on the inside and slopes steeply on the outside (Wicht, 1969). All the raingauges were erected 1.22m above the ground.

Figure 3.4: A standard Snowdon A-type raingauge located at Nuweberg (nb).

A second set of raingauges fitted with a Nipher shield (b-gauges) were installed after 1944 (Figure 3.5). They were placed with their orifices parallel to the slope next to the Snowdon gauges (Figure 3.4). These gauges were installed to limit errors in the rainfall recordings per catchment. A detailed design of a raingauge with a Nipher shield is depicted in Figure 3.6.

Figure 3.5: **A Typical B-type Nipher shield raingauge found in the Jonkershoek Valley.**

Numerous investigations have shown that wind can cause significant errors in the amounts of precipitation (Corbett, 1967; Wicht, 1944). These investigations have lead to the installation of Nipher shields (Figure 3.5) which reduce the wind errors for rainfall for different gauges.

Fourcade (1942) contend that the interception of inclined rain by a raingauge erected on sloping ground, with its orifice horizontal, does not represent the true rainfall. The Nipher shield is, therefore, no more effective if erected horizontally to the ground. These gauges were fitted with a Nipher shield to yield a true interception during windy or any other weather conditions during the four seasons. Wicht (1969) cites various references and mathematical theory that has been experimentally tested showing that raingauges orifices should be parallel to the ground.

All the b-gauges have a correction factor (Table 3.2) which was calculated after the attachment and installation of the Nipher shield on the different slopes. Studies been done by Sevruk (1985) confirms the fact that the rainfall, as measured by the standard raingauge elevated above the ground, is not free from errors and this error needs correction.

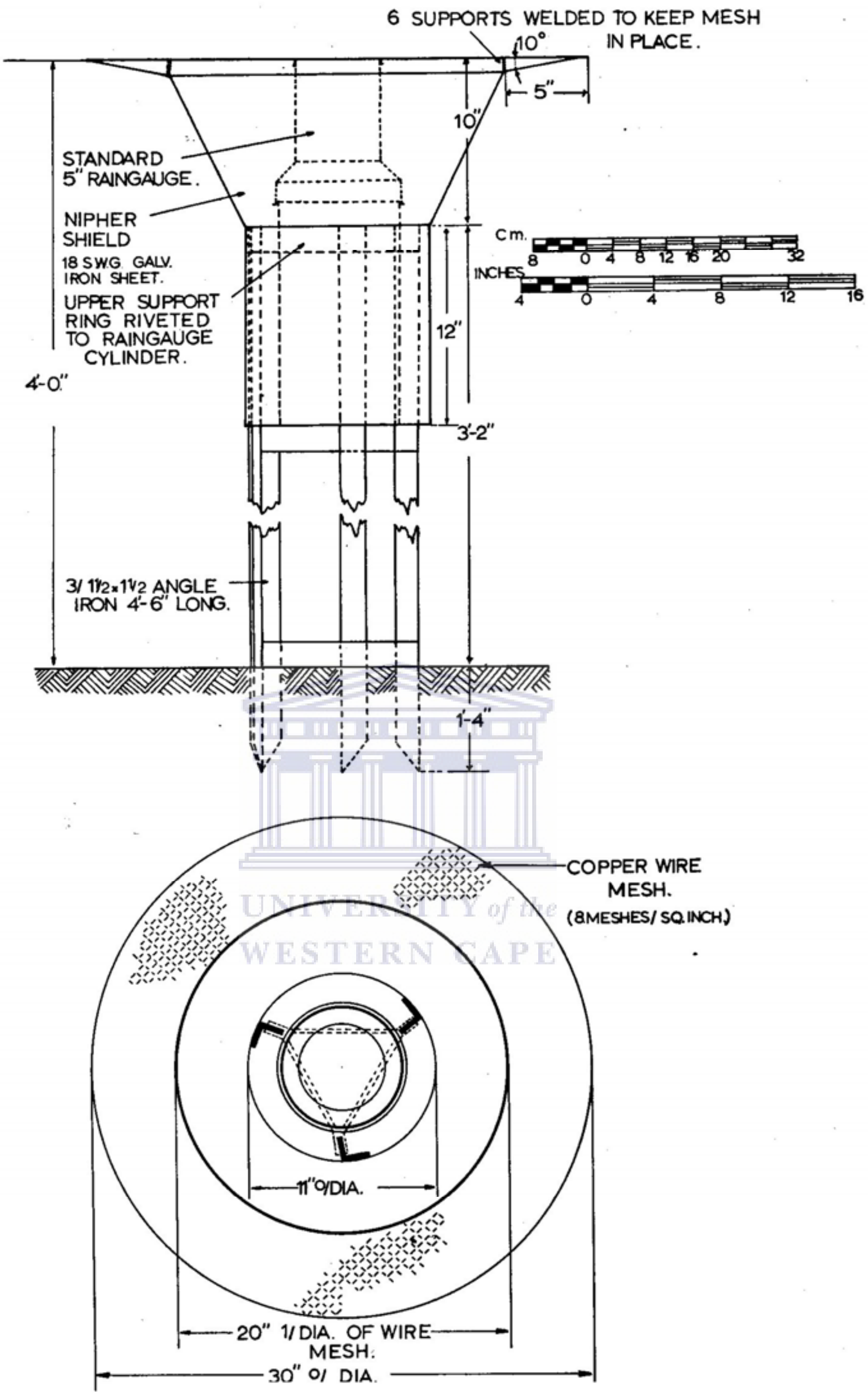


Figure 3.6: **Design of a Snowdon raingauge with a Nipher shield (Wicht, 1969).**

3.2.6 *Vegetation*

The dominant type of vegetation in Jonkershoek is Fynbos which is found in Mediterranean climate areas of the Western Cape. The predominant species are the blue sugarbush *(Protea neriifolia)* and sugarbush *(P. repens)*. Indigenous forest is mostly confined to the riparian zones of the catchment. In addition to the Fynbos, small patches of evergreen forest are found in the kloofs and on scree slopes. The south facing, wetter slopes have been afforested with Pinus Radiata.

3.2.7 *Geology and soils*

The geology of the Jonkershoek catchment consists of sandstone and quartzite with thin shale bands of the Table Mountain Group and appears in the upper slopes and cliffs of the mountains. The Jonkershoek Valley is closed on the South East end by the Dwarsberg mountain range. The soils are complex and of mixed origin, derived primarily of mixed colluvial material from the higher lying geological formations, with major forms being Hutton, Magwa and Nomanci (MacVicar *et al.,* 1977).

3.2.8 *Data collection and quality control of long-term data*

The manual data for most of the standard raingauges were recorded in field books and were entered onto database on a regular basis. Currently the manual data is entered electronically into a spreadsheet. In 1991, Jonkershoek Research Station switched over from a Data General Mainframe computer system to a new pc based system, which has lead to the transfer of data files to the new system. In 1994, the ACSYS (Autographic Chart digitizing SYStem) database was developed to enter and process hydro-meteorological data electronically. The objective of ACSYS was to create a recording station for each catchment, determine where the gaps are, and for processing and storage of data.

The Autographic Chart digitizing SYStem (ACSYS) is a system of programs created to transform analog data on autographic recorder charts to electronic medium data, by means of a digitizer. Autographic recordings are created by instruments placed at strategic positions in the field and consist basically of a continuous trace or traces drawn onto a chart. ACSYS converts these traces to breakpoint data to be stored on computer hard disk in an ordered and meaningful way.

ACSYS was written in the Modula-2[1] programming language and consists of programs: the main program, an auto-install program, a digitizer install program and the programs for the different autographic chart types. The program names are listed in the installation section. ACSYS provides many functions: one can transform autographic chart data to computer records by digitizing the chart, print reports on the stored data, examine a stored record, create text files from the data to use as input for other products and manage the data files.

The autographic rainfall charts from A-gauges were digitized after filling of possible gaps and saved onto the ACSYS database. Error checking of incoming data charts is an important step in the quality process. ACSYS has a built–in error checking system that warns the operator when the data values entered are exceeding it's upper or lower limits and time lags. Data from the A-gauges (Casella) were used to fill up gaps for missing data found in the analyzed b-gauges.

CHAPTER 4

RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

This chapter presents the data collection, capturing and processing of the data from the catchment over a period time. It includes the description of the statistical approaches which entails the sequential approach interpreting the long-term data and the moving median analyses. It can accepted that the Jonkershoek valley is a major contributor and supplier of water resources to the greater Cape Town, Western Cape and any changes in the rainfall pattern will impact on future water demands. This statistical sequential approach intends to provide meaningful insight into catchment rainfall behavior about its annual rainfall patterns for the area.

4.2 Research Design

To test the hypothesis that rainfall is declining over time and to detect possible trend behavior, requires that a reliable data set be used for any further analysis. The rainfall data used for this analysis was extracted from daily, weekly and monthly records which were aggregated in annual values for further analysis. The time range for the analysis of the annual rainfall was taken from year 1945 to 2005. The gauges were distributed all over the catchment area at different altitudes with different topographic characteristics and aspects.

This study intends to address the research objectives as stated in Chapter 1, relating to annual rainfall in a mountainous catchment.

4.3 Methodology

4.3.1 *Selection of gauges and rainfall collection.*

As have been indicated earlier raingauges are implemented and spread over all the catchment area, with some located on the windward and some scattered on the lee-ward side of the Jonkershoek mountain catchments. Most of the raingauges are implemented in the different sub-catchments and were not all initiated at the same time. This has led to the rejection of data starting before year 1945. Eight gauges were randomly selected based on the homogeneity of the rainfall prevailing in the Jonkershoek valley. Five of the gauges (b1, b2, b11, b13 and b14) fall in the Jonkershoek catchment and the rest in adjacent quaternary catchments (Figure 3.3).

The rainfall data was collected manually by observers in the field using a measuring cylinder. As a result of rainfall data collected at different time intervals, the data was summarised into annual totals for each gauge for the purpose of this study. To justify the quality of the annual data records, different processes were introduced specifically looking at data inspection, in order to rectify and clarify possible errors, outliers and to detect possible discrepancy in the rainfall data.

The rainfall (mm) data collected at each gauge was aggregated into calendar year totals starting from January to December for each year. The extracted period of data for all eight 'b' gauges for the analysis of this study extended over a sixty-one year period, starting from 1945 to 2005, the status and locality for each gauge being expressed in Table 4.1. Before furthering to the next phase of the study two quality processes, included the establishment of the missing and the subsequently filling of the missing values for each affected gauge was run.

Table 4.1: Description of raingauge network in the Jonkershoek Valley.

Gauge	Location / Sub -Catchment	Status	Period
b1	Jonkershoek Office	Daily	1945-2005
b2	Swartboskloof	Weekly	1945-2005
b11	Bosboukloof	Weekly	1945-2005
b13	Tierkloof	Weekly	1945-2005
b14	Langrivier	Weekly	1945-2005
b17	Dwarsberg mountains	Monthly	1945-2005
b18	Dwarsberg mountains	Monthly	1945-2005
Nuweberg	Cape Nature Reserve Conservation	Monthly	1945-2005

a. Data quality procedure – Establishment of missing data

Precipitation data in and around the catchments were collected at different times as a result of the layout and accessibility of the gauges. Rainfall data was collected on daily, weekly and monthly rotation rounds (Table 4.1). As a result of operational problems and disfunctioning of the instrumentation, missing data were found in the daily, weekly and monthly recorded rainfall data. Most of the Jonkershoek sub-cathments were equipped with an "a" and a "b" gauge making it easy to impute missing rainfall values for the b-gauges from the records of the "a" gauges (Figures 3.4 & 3.5). The description of the different types of gauges used in the analysis was listed in the site description (Chapter 3).

Raingauge b1 had the longest missing record of five years which started in 1945 and ended in 1949. The gap for the missing data was assigned from the adjacent 'a1' rain

gauge. The daily collection of rainfall data from the ‘b’ gauge was done by the Department of Water Affairs and Forestry (DWAF).
Gauges b11, b13 and b14 had a two year data gap from 1991 to 1992. This was the result of the take over of data collection activities by the Cape Nature Conservation (CNC) from the Department Water Affairs and Forestry (DWAF). Data were imputed from the a11, a13 and a14 orthographic gauges to substitute the missing values for the two year period. Currently the collection of rainfall is done every week by the Council for Scientific and Industrial Research (CSIR).

The selected period of 61-years for the monthly-shielded rainfall stations namely b17, b18 and Nuweberg (nb) had a complete record until year 2000 with minimal missing data. It was possible to impute some data from adjacent surrounding raingauges. The monthly rainfall data for gauges b17 and b18 is currently collected by the Cape Nature Conservation, which falls under the Boland Mountain District and located in the adjacent quaternary catchment (Figure 3.1).

b. Data quality procedure: Filling of missing data

The result of missing data from the rainfall records, has led to an evaluation of rainfall data for reliability and correctness. Irrespective of the time formation, the daily, weekly and monthly data were summarised and output into annual totals. In most of the rainfall data, missing data was not a serious problem, as data was collected regularly and meticulously by the field technicians. In all the rainfall data, the missing values never exceeded a total of more than one percent. Data was re-calculated where the raingauges gave erroneous values especially for monthly gauges after 1995. The final sets of annual data for the 8 gauges were all merged into one set of data and again check for errors, outliers, miscalculations and for data extremes. If outliers were found, errors were identified, checked, and verified with the adjacent gauges from the original field records.

It is crucial for the success of the adjustment that the data from rainfall stations used as reference values are of good quality. Steiner *et al.* (1999: page 2500) points out that “Quality control of all data therefore is the single most important step of any precipitation analysis.… It is very important to check the quality of the rain gauge records and use only those data where the gauge functioned properly.

The Statistical Analysis Software, SAS, Version 6, Fourth Edition was used for the calculation and summarization and merging of the daily, weekly and monthly totals into annual values. The Univariate Procedure (SAS) was applied for error-checking by plotting raingauges against each other without any sequence.

The estimation of the regression coefficient (R^2) was used as an indicator of how paired gauges relate to each other and to establish how good that relationship of the long-term data is between different altitudinal gauges. The regression technique also served to calculate the predicted values to fill up gaps in the rainfall data. Dent *et al.,* (1989) filled in the missing monthly data totals using the regression technique (using surrounding stations described in Zucchini and Hiemstra (1984). The ultimate goal of the data quality process was to use a reliable, continuous long-term set of meteorological data measurements for the study area.

The final representation of annual rainfall for each gauge were graphically depicted on line charts (Figures 4.1-4.8) using the Excel software. A plot for each rainfall station was compiled using both the x (year) and y (rainfall) axis to display the distribution of annual rainfall between two variables over time. The display of the annual rainfall for each gauge is graphical output for each of the eight summarised gauges found in the catchments. The analysis and graphical output of the line plots were prepared.

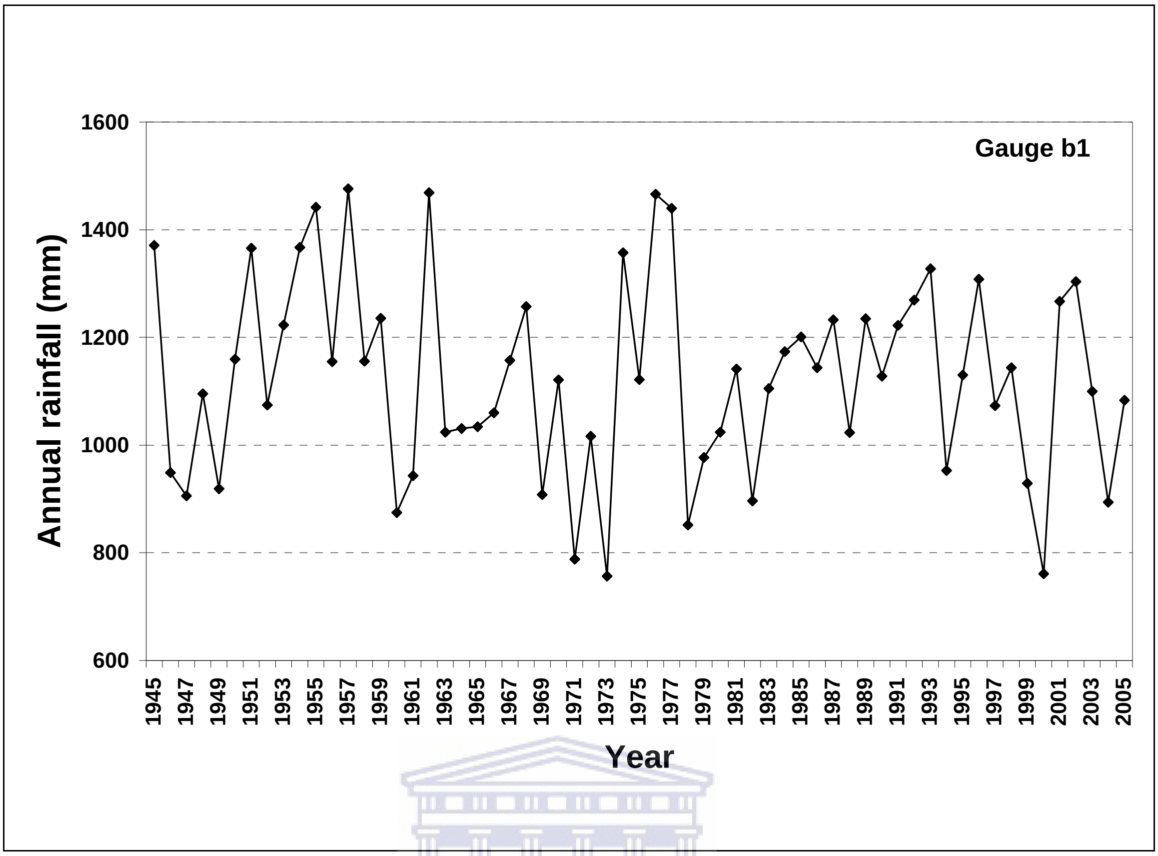


Figure 4.1: **Annual rainfall for gauge b1.**

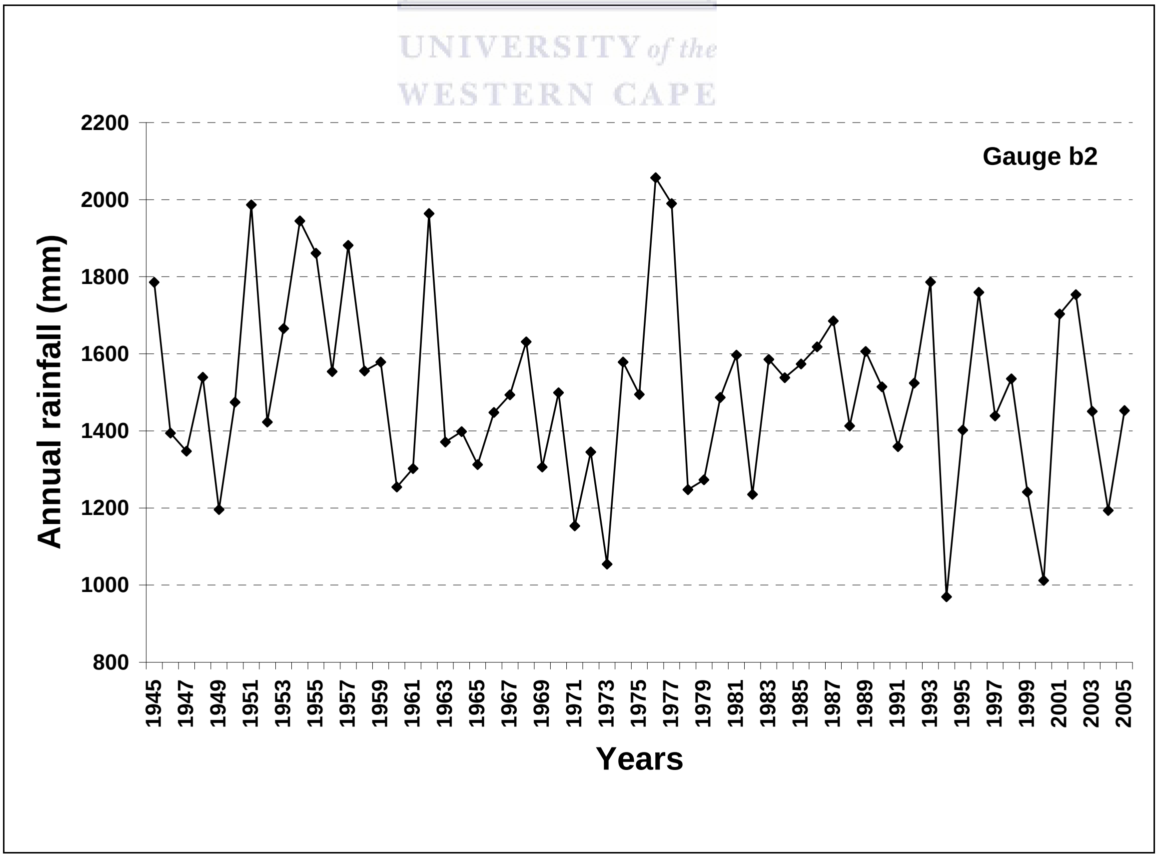


Figure 4.2: **Annual rainfall for gauge b2.**

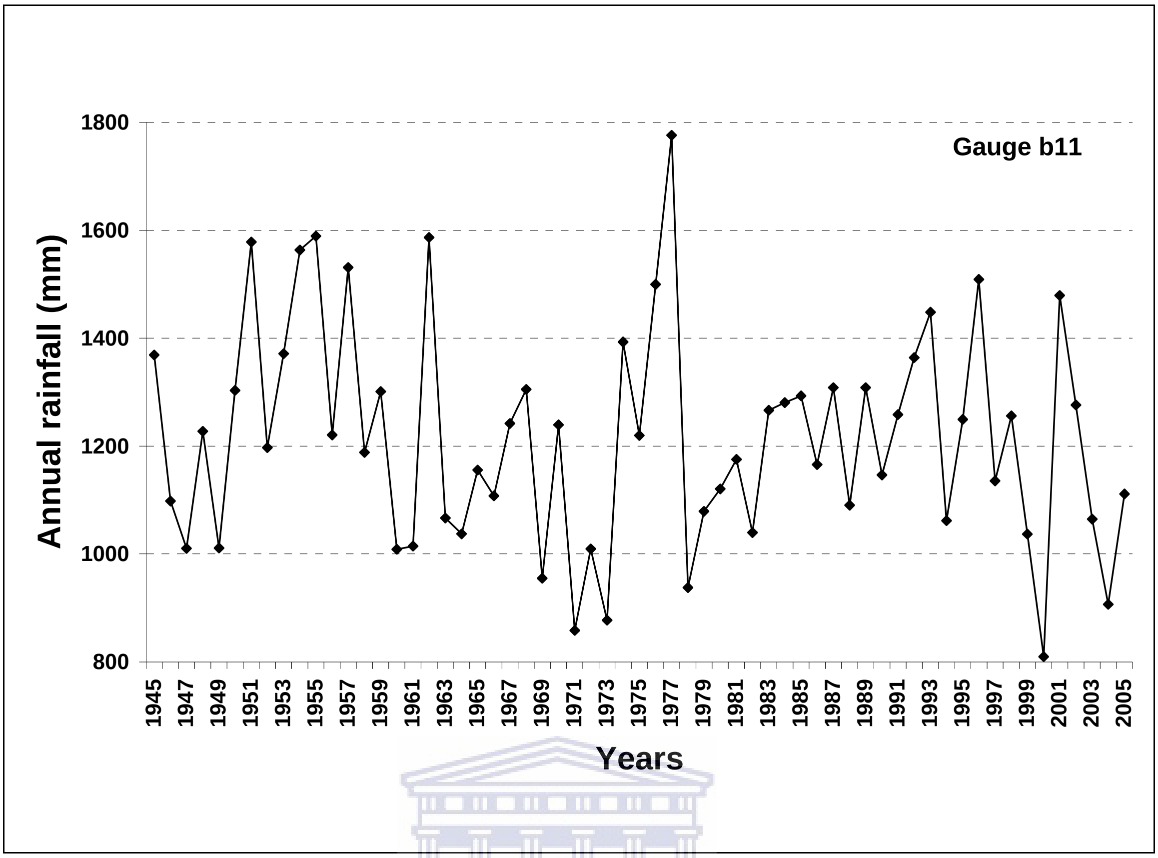


Figure 4.3: Annual rainfall for gauge b11.

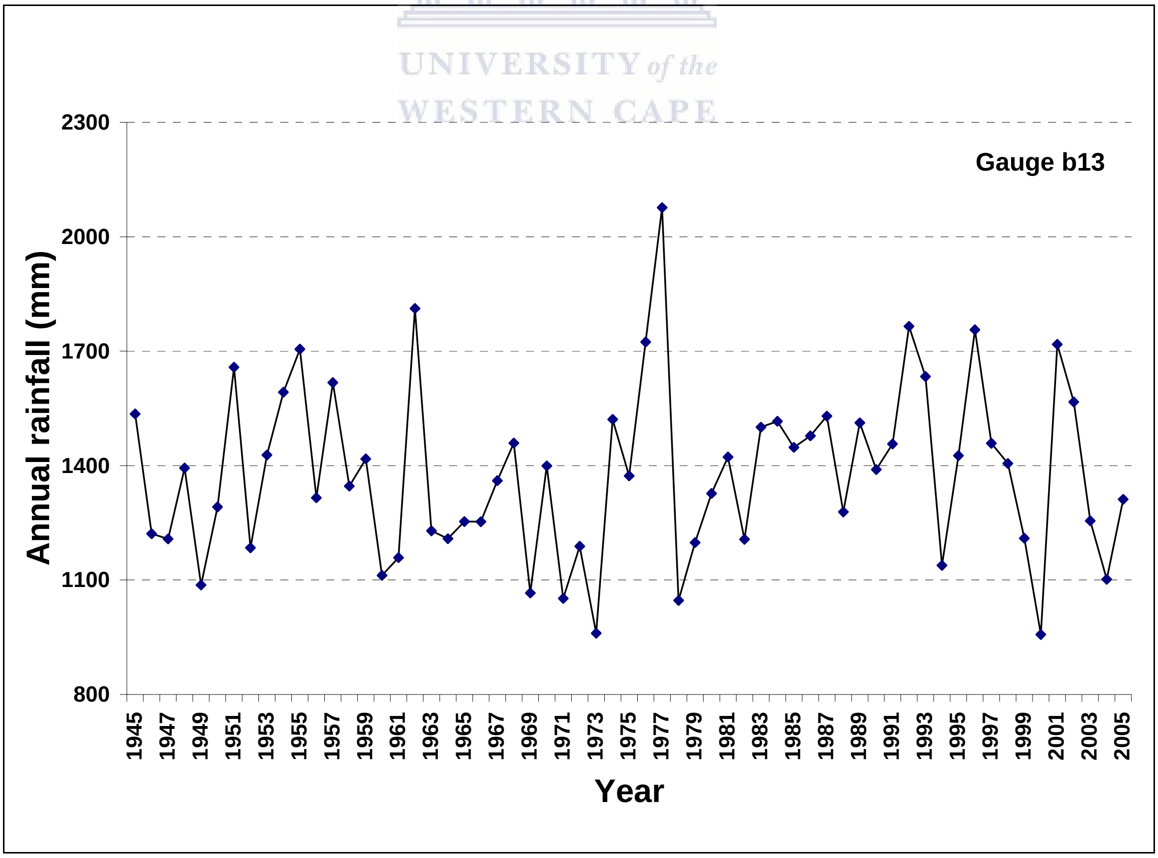


Figure 4.4: Annual rainfall for gauge b13.

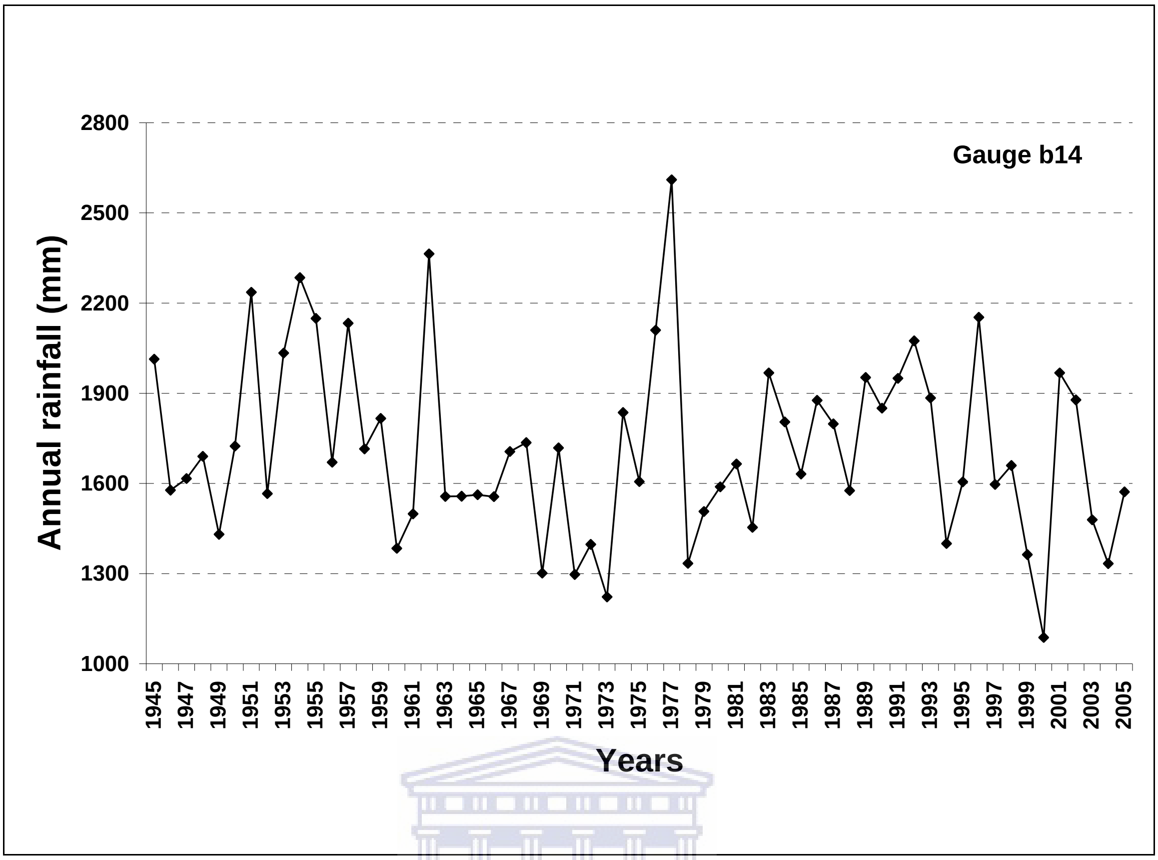


Figure 4.5: **Annual rainfall for gauge b14.**

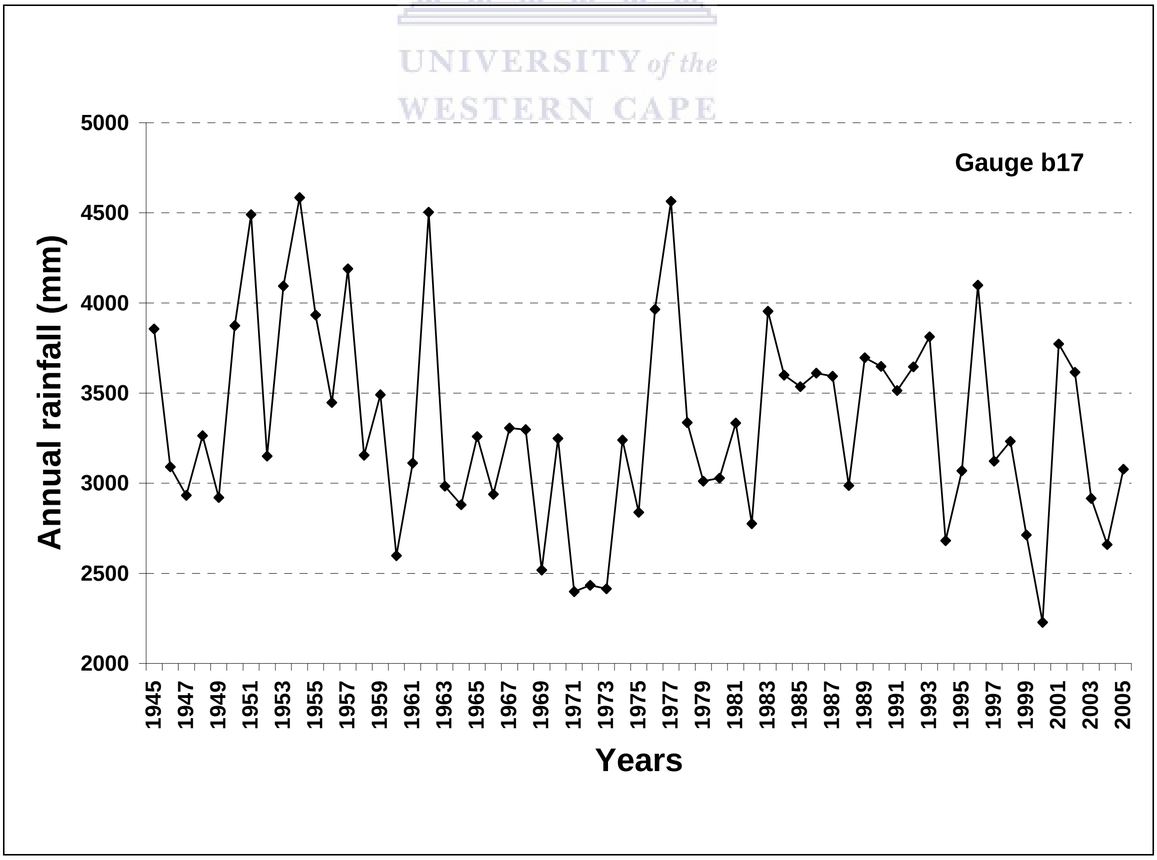


Figure 4.6: **Annual rainfall for gauge b17.**

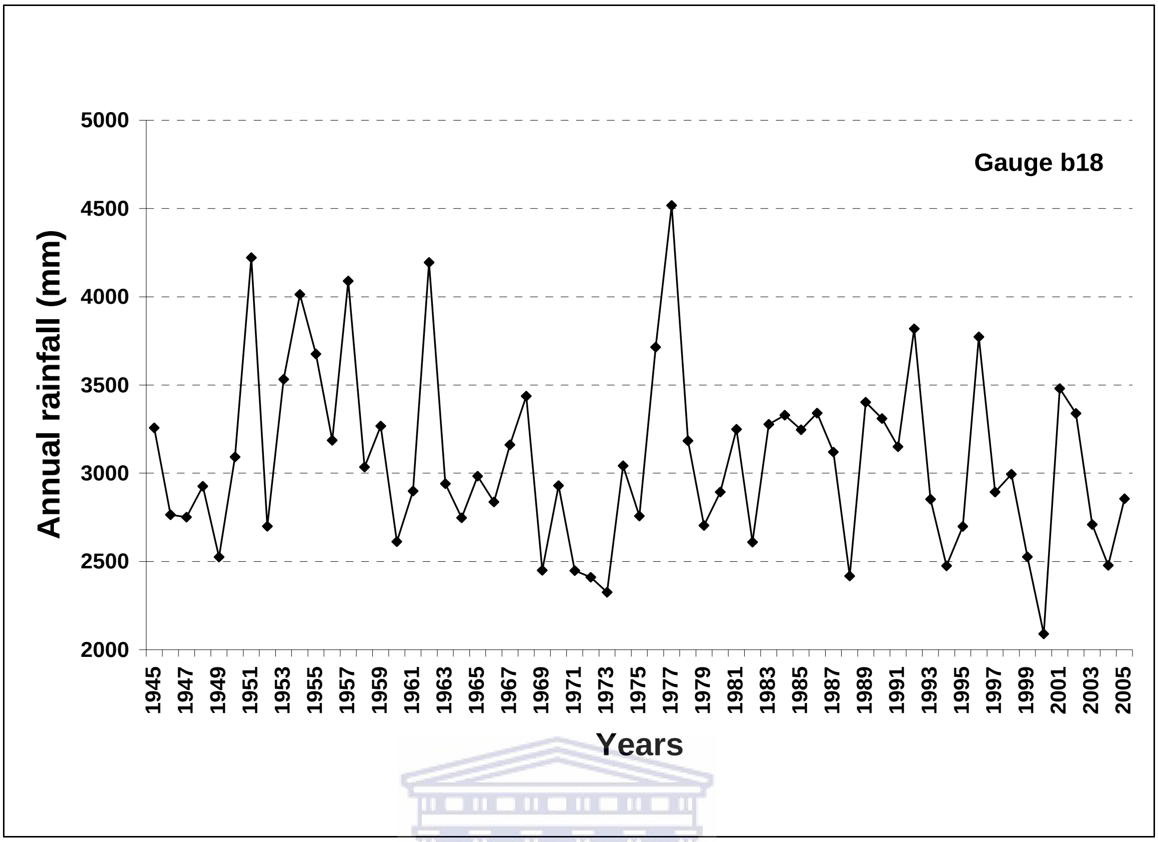


Figure 4.7: Annual rainfall for gauge b18.

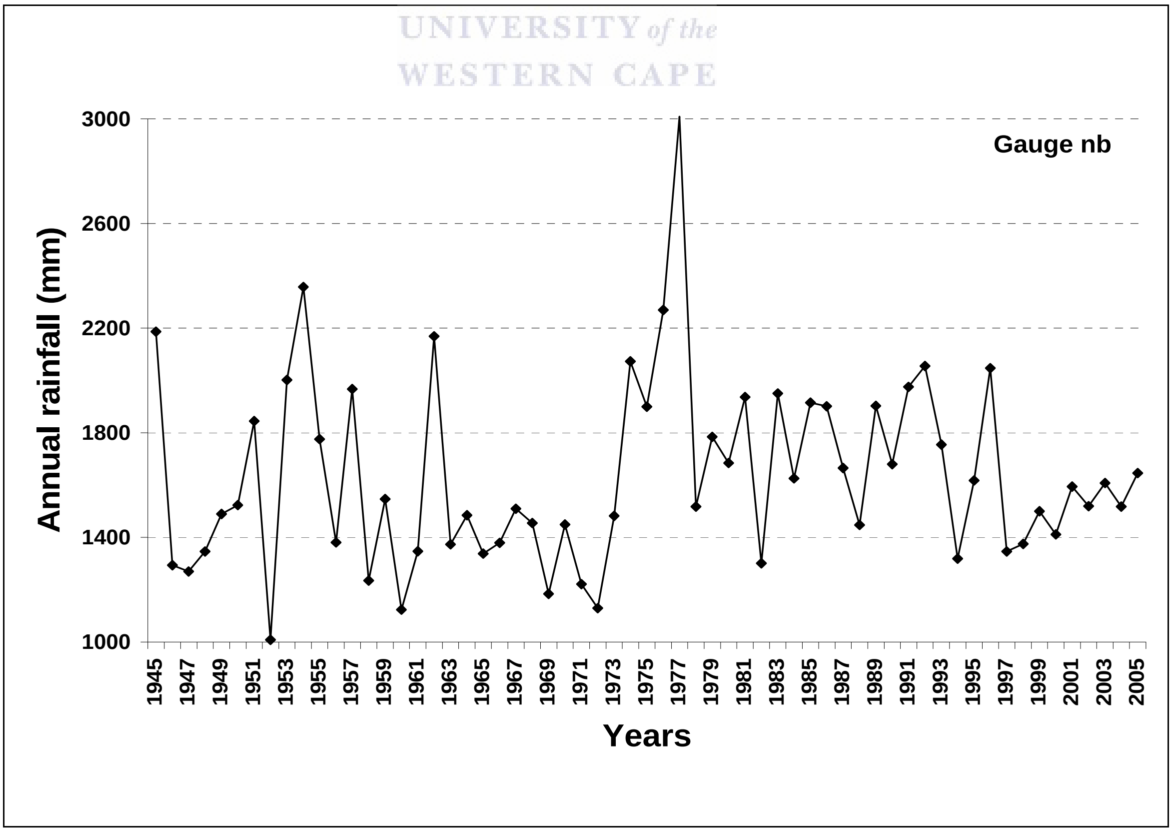


Figure 4.8: Annual rainfall for gauge Nuweberg (nb).

4.3.2 *Statistical analysis of the annual rainfall*

Information regarding hydro-climatologically issues is important within the context of global warming, water and energy cycles and the increasing demand for water due to population and economic growth (Sankarasubramanian and Vogel, 2003). Understanding trends and variations of current and historical hydro-climatic variables is pertinent to the future development and sustainable management of water resources of a region (Oguntunde *et al.,* 2006). These hydroclimatological factors and future demands have steered to a statistical investigation into these phenomena.

Rainfall is influenced by climatologically factors or any rainfall behavior over time needed to be investigated using different statistical techniques. A validated statistical technique might explain cyclical behavior using long-term rainfall data. The statistical techniques used were the linear regression and the sequential analysis. The challenge is similarly to detect whether rainfall is declining over time and whether these changes are consistent over the 61-year period.

The first step in deriving a relationship between gauges was the statistical exploration approach and to describe the basic features of the annual rainfall for each gauge in the catchment. Three statistical techniques were used for the exploratory analysis of the aggregated annual rainfall data over the 61-year period. The statistical exploration of the annual data was to find relationships in rainfall between gauges in and outside the Jonkershoek catchment and to determine the best statistical distribution of the annual data. The graphical expression of the annual rainfall will also test the normality and distributional performance of the long-term data as 5 gauges are located inside the Jonkershoek quaternary catchment, two on the crest of the Dwarsberg mountain range and one further south to the coast. Raingauges, b18 and Nuweberg (nb) are located on the lee-ward side on the Dwarsberg mountain range.

The first statistical attempt was the calculation of the quartiles for the data at each gauge in the catchment. This will include the values of Q1, Q2 and Q3 quartile parameters. The estimation of the quartiles was the first test in understanding the impact of locality features of the raingauges in relation to their annual rainfall in a mountainous catchment. The following quartiles were calculated namely the median (Q2) which refer to 50% of the observations above or below the midpoint, the first quartile (Q1) which is the median of the observations to the left of the midpoint of the rainfall values. The third quartile (Q3) is the median of the observations to the right of the midpoint of the median values (Table 5.2).

The second statistical exploratory effort was the estimation of the inter-quartile ranges (IQR) from the calculated quartiles. The calculation of the quartile ranges was to measure dispersion in the long-term annual data, based on the eight gauges located in and around the catchment area. The results of the inter-quartile range values for different gauges represented the dissimilarities between the calculated quartiles. The computations of the inter-quartile ranges are as follows.

The following inter-quartile ranges (IQR) were defined as follows:

Inter-quartile Q1 = Q2-Q1 (25%)
Inter-quartile Q3 = Q3-Q2 (75%)
Inter-quartile median = Q3-Q1 (50%)
Where Q1 = First quarter
Q2 = Median
Q3 = Third quarter

The final statistical test was the estimation of the coefficient of variance statistic using the parametric and non-parametric methods on the annual rainfall for each gauge. This procedure was followed due to the location of gauges at different heights, distance from one another, different coordinates and each with its own topographic characteristics.

Statistical parameters were calculated from the measured values in mm for each gauge. The calculated quartiles values are displayed in Table 5.2 describing the quartiles for these rainfall values. The graphical display of the quartiles for all the gauges are found in Figure 5.1 representing the locality of the raingauges against the total rainfall for the 61-year period.

Investigations further into the statistical variability and distribution of the annual rainfall data, using the median as a measure of central tendency for the calculation and interpretation of the inter-quartiles parameters. A comparative IQR between the lower and upper mid ranges for each gauge is graphically displayed in a line graph (Figure 5.3) from the calculated parameters found in Table 5.3.

A further parametric statistical measurement of variability is the calculation of the standard deviation (*SD*) and the long-term average ($\bar{x}$) of the annual rainfall for each gauge. The variables used in the linear regression method of graphical tests were the SD against the mean annual rainfall. The SD represented the square root of the variance. The calculation of the SD was used to distinguish how much far the annual values deviate from the mean and to detect possible dispersion in the long-term data. The mean ($\bar{x}$) was computed by adding all the annual data values and dividing them by the number of years. The MAP together with the SD will serve as a good indicator to test rainfall relationships between the analysed gauges.

The objective was to examine the relationship between two variables calculated from the summary statistics. The response variable was the MAP and the independent variable was the SD. This test will also be using the SD variable to explain the heteroscedasticity which means different and greater dispersion from the rainfall coming from the gauges in the catchment.

The formula for calculation of the SD is as follows:

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

n = *Total observations*

x_i = *Annual rainfall*

$\bar{x}$ = *Average* 2.

The results of plotting the calculated the SD and the MAP on a regression line is found in Figure 5.4.

The final statistical exploration measurement for establishing the rainfall relationships between gauges in the valley was the calculation of the parametric and non-parametric coefficient of variance. The coefficient of variance is expressed as a unit of percentage.

The variables used in the parametric calculation were the SD and the average ($\bar{x}$) for each gauge and the calculated inter-quartile variables were used for the determination of the non-parametric parameters. The results of the calculated coefficients of variance are expressed in Figure 5.2 as a graphical expression.

The formulae used to calculate the coefficient of variance for both the parametric and non parametric parameters is as follows:

$$\text{CV (Parametric)} = \frac{SD}{\bar{x}}100$$

SD = Standard deviation

$\bar{x}$ = Average

$$\text{CV (Non-parametric)} = \frac{Inq\_Median}{Q2}$$

Inq_Med = Inter-quartile median

Q2 = median 3.

The calculated quartile values are expressed in Table 5.3 and shown in a line graph in Figure 5.3.

This has lead to further investigation of the long-term data using sequential analysis and sequential differences procedures to describe the annual rainfall patterns in the catchment.

4.3.3 Sequential Analysis

The term "sequential analysis" as cited by Johnson (1961) is expressed as to include all those investigational procedures in which the final pattern of observations is not determined before the start of the investigation, but depends, in some specified way, on the data collected in the course of the investigation.

Different sequential approaches were developed over the time since the inception by Wald (1947) when it was still a military secret during the Second World War. The main objective of the sequential approach was the testing of annual rainfall data and to search that there is enough evidence to reach a proper conclusion.

In order to gain more insight into rainfall variability, based on a network of well distributed meteorological stations located in a mountainous area with frontal rain in the winter, one needs to investigate the rainfall events sequentially for each gauge. Smith (1979) describes intensified frontal rains to a certain extend as a sequential appearance of prefrontal "pure" orographic rain followed by the frontal passage.

The sequential method used in this study was based on a compilation of statistical cross correlations between gauges spatially located in the catchment area. This sequential analysis included the examination of rainfall for each gauge and how it differentiates sequentially between gauges. The first attempt was to divide the 61-year of annual data into different time cycles to establish sequential patterns among the gauges. The objective of the analysis was to look at the pattern behavior of annual rainfall between gauges from year to year. The approach followed was to analyse and interpret the linear sequential linkages between gauges from its annual data also referred as the Snake Trail.

The test to study the spatial rainfall variability experienced in the mountain catchments, will also provide vital information about the possible influence of topographical factors on rainfall. This sequential analysis will also contribute to the explanation of anomalous behavior of rainfall due to mesoscale weather relationships and topographical factors.

The first test was the identification of the variables to be used in the cross correlation procedure for the sequential analysis. The Nuweberg (nb) raingauge represented the independent variable and the dependant variables were the remaining seven gauges, according to the locality sequence found in the catchment. The measuring unit for the annual rainfall data was in millimetres, and Excel Software was used for the calculations and graphical display.

The Excel Software was used to analyse the sequential estimations through using the annual rainfall from the Jonkershoek valley to establish sequential linkages and possible forms of associations between the different gauges.

The process was initiated by dividing the 61-year of annual rainfall data for each gauge into three distinctive cycles. Three time cycles were identified for each gauge, which represented the first 21 years (1945-1965), the middle 20 (1966-1986) and the last 20 years (1987-2005). For each time cycle, three linked spatial scattered diagrams (Snake

Trails) between two gauges with two dependent variables were produced and displayed graphically against the line of equality. The plotted gauges with their annual rainfall were b1, b2, b11, b13, b14, b17 and b18 against Nuweberg. All the spatial graphical results are found in Figures 5.5-5.11. The results displayed in the figures represent all three time cycles for each of the analysed gauges.

4.3.4 Analysis of the Sequential differences

The second attempt based on sequential analysis was the statistical transformation of the annual rainfall data. Sequential differences from the annual rainfall values for each listed rainfall station were calculated over the entire period of 61-years. The ultimate purpose of the sequential differences was to ascertain the annual rainfall relationship of gauges in relation to variability, seasonal behaviour, rainfall spells and trend performance over time. Cain and Smith (1976) explains sequential analysis as follows – This measure is superior to the factor of "difference" often used (e.g., Woodley *et al*., 1974) for various reasons, one being that it preserves the sense of the differences with positive values indicating GER (gauge estimates) > RER (radar estimates) and negative values the converse.

The formula used to determine the sequential differences between gauges was by subtracting the annual rainfall data for the current year for each gauge in the catchment from that of the following year ($\Delta S = \text{Year} - \text{Year}_2$). The calculation of the sequential differences started in year 1945 and ended in year 2005.

After the calculation of the sequential differences a statistical exploratory test was run on the data for each gauge. The variables used in the linear regression were the SD against the MAP. The results (Figure 5.14) from the estimated sequential differences were plotted linearly on the line of equality to reveal discrepancies between gauges in the annual rainfall data in relation to outliers and to reveal any form of heteroscedasticity. The calculated graphical descriptive statistical sequential differences are given in Figure 5.15 which consists of the SD and the mean annual long-term values for all the gauges analysed in the catchment. The calculation of the MAP and SD served as a measure of the distribution reflected in the annual data for each gauge.

The challenge to understand and to interpret winter rainfall data statistically for further forecasting abilities has introduced further calculations. The sequential differences were recalculated to establish rainfall patterns in the annual data. After the calculation of the sequential differences, the data was sorted and only years with rainfall greater and equal to zero were selected for further analysis (Table 5.2). The annual positive rainfall values were used and summed up in total amounts for each gauge. These annual positive totals for each gauge derived from the sequential differences, were used as an indicator to represent good wet years and the rest as dry cycles in the 61-year of data. The results are given in Table 5.4 in the results section.

Additional statistical investigation, using the calculated sequential differences were further tested between gauges around their distribution characteristics and was graphically expressed in Figures 5.16 (a-h) and Figures 5.17(a-h) over the 61-year period.

The first sets of graphical exploratory figures were generated as scatter diagrams, plotting the sequential differences over the time variable for each of the eight gauges (Figures 5.16 (a-h). The second graphical test, using the quadrant correlation was by plotting pairs of raingauges which partitioned the diagram into four quadrants using the sequential differences. The independent paired raingauges included Nuweberg, plotted against the rest of the gauges in the catchment area. The graphical interpretations are found in Figures 5.17(a-h).

The Excel Software was used in the calculation and analysis of the sequential differences estimations.

4.3.5 Centralised moving medians analysis

Moving averages can introduce cycles into a time series that are difficult to analyze (World Meteorological Organization/WMO, **1966).** If a time series with fewer fluctuations is preferable, it is possible to plot different averages in addition to the original time series. This time series comprises different methods and this analysis is an attempt to understand the annual long-term pattern of increasing and decreasing rainfall over time in the Jonkershoek valley. This information will enhance the possibility to forecast future rainfall behavior for the catchment.

Moving medians and moving standard deviations were calculated for all rainfall-gauging stations, using a nine-year interval. The median was calculated by placing all the annual rainfall observations in order and selecting the value that fall in the middle. The centralised median procedure is a measure of central tendency using the median as an indicator of possible patterns, trends, cyclical behavior or irregular variation in the historical data. The time span for the computation of the moving median was from 1945 to 2005, and the first group of 9 years of the record was discarded from the graph for each gauge. The measuring unit for the annual rainfall was in millimetres. The graphical results from the centralised moving deviations plotted against the calendar years are displayed in Figure 5.18.

A further step towards deriving the trend behavior, the moving standard deviation estimations were used to define dispersion in the annual rainfall data. The calendar year served as the independent variable and plotted against the moving standard deviations. The graphical results from the measured moving standard deviations are shown in Figure 5.19.

The final analysis was to compare the moving medians against the standard deviations for each rainfall station. The moving medians were used as the dependant variable against the independent standard deviation. The use of the standard deviation served as a measure of the dispersion in the annual rainfall data. The moving medians served as a smoothing parameter to remove possible random variation of any trends in the long-term annual rainfall between gauges. The median was used in this analysis as it is not sensitive to extremities in the annual rainfall data.

The calculated moving medians and the standard deviations were used in a scatter diagram where the points of the annual data are linked according to the year. This linkage has a starting and an end point which reflect the strength of the linear relationship between gauges. This correlation analysis permits investigation into the characteristics of the annual rainfall and will project whether these linkages are sequentially linked. The number of correlation linkages will demonstrate the strength of association between gauges around their annual rainfall pattern. The results from the comparisons between gauges are graphically displayed in Figures 5.20(a-h) in the results section.

The analysed data was prepared in spreadsheet format and Excel was used to calculate the different centralised medians using the long-term annual rainfall data range and the statistical parameters.

CHAPTER 5

RESULTS

5.1 Introduction

This chapter describes all the results obtained from the analysis from the data collected by applying different methods and statistical techniques that were illustrated in Chapter 4 on the long-term annual rainfall.

The first graphical results from the line graphical diagrams are illustrated in Figures 4.1-4.8 for each gauge demonstrated that annual rainfall values differs from year to year for each gauge located in the catchment. The annual rainfall for each gauge reveals no real trend except for the typical wet and dry spells over the full spectrum of the data and is clearly visible in all the 8 gauges. The graphical representation of the 61-years for each gauge of data disclosed no distinctive pattern that relates to any drastic changes of rainfall over time but fluctuation tendency among the annual rainfall for each gauge.

The second changeability found in the annual line diagrams is that gauges experience different mean annual precipitation (MAP) totals, between the lowest located gauge (b1) and the highest located gauge (b17) in the catchment (Table 5.1). This increasing pattern of rainfall with elevation is found in all the gauges except for b2, b18 and Nuweberg. The latter two gauges of which b18, is located on the lee-ward side of the Dwarsberg Mountain range and coincide with the decreasing elevation. Raingauge b2 located in the flatter part of the valley and facing southwest towards the mountain barrier, receives a higher rainfall than its immediate neighbouring gauges (Table 5.1).

The annual rainfall extremes listed in Table 5.1 for each gauge is subjected to slight variability despite the locality of gauges found in a 3000 meter (m) radius of the catchment. The dominant wettest year of 1977 is designated to five gauges namely b11, b13, b14, b18 and Nuweberg. Raingauge b1 had its wettest year in 1957, b2 in 1976 and b17 in year 1954. The driest years for 5 of the gauges was in year 2000 which included b11, b13, b14, b17 and b18 (Table 5.1).

The results in Table 5.1 also exemplify the statistical testing of the annual data for normality, indicated both in the upper and lower boundaries of the 95% confidence limits for each gauge for the 61-years of annual rainfall data. Dispersion from the mean and median is a measure of rainfall variability in the data set and are reflected in the lower and upper confidence limits in which the annual values are lying (Table 5.1). The rainfall differences of the MAP and the median also revealed the increasing trend in rainfall between gauges as elevation increases. Rainfall is measured in millimetres (mm).

Table 5.1: Descriptive Statistics for each gauge from the univariate analysis.

Gauge	N	MAP / Median	Elevation (m)	Extreme High (Year)	Extreme Low (Year)	95 % Confidence limits (lower)	95% Confidence limits (upper)
b1	61	1128.1 1129.9	244	1476.0 (1957)	756.5 (1973)	1081	1175
b2	61	1509.8 1498.9	305	2056.7 (1976)	969.7 (1994)	1447	1573
b11	61	1214.5 1219.6	396	1775.7 **(1977)**	858.2 **(2000)**	1162	1267
b13	61	1380.7 1389.6	427	2076.1 **(1977)**	957.2 **(2000)**	1322	1439
b14	61	1716.1 1664.6	465	2610.2 **(1977)**	1087.4 **(2000)**	1639	1794
b17	61	3331.7 3259.5	1234	4584.1 (1954)	2228.3 **(2000)**	3188	3476
b18	61	3076.6 2994.1	1219	4516.9 **(1977)**	2090.8 **(2000)**	2946	3208
Nuweberg	61	1634.9 1523.2	452	3008.7 **(1977)**	1009.1 (1952)	1543	1727

5.2 Statistical exploration analysis of the annual rainfall.

The statistical exploratory output reflected in Table 5.2 represented by the descriptive statistics and graphically displayed in Figure 5.1 indicated that great statistical skewness exists between certain gauges found in the catchments. Table 5.2 reveals that the aggregated maximum value for Nuweberg (nb) differs from the values from the other gauges. The calculated value for Nuweberg is bigger as expected and further away, compared to the rest of the gauges (Figure 5.1). There is a statistical resemblance between the two calculated quartiles and the median for all the gauges (Table 5.2 and Figure 5.1).

Table 5.2: Descriptive statistics for the 8 gauges in the catchments.

Statistic	**b1**	**b2**	**b11**	**b13**	**b14**	**b17**	**b18**	**Nuweberg**
Min	756.5	969.7	809.7	957.2	1087.4	2228.3	2090.8	1009.1
Q1	1016.4	1347.7	1064.7	1208.4	1555.9	2938.5	2709.0	1375.5
Q2_Median	1129.9	1498.9	1219.6	1389.6	1664.6	3259.5	2994.1	1523.2
Q3	1257.3	1631.3	1308.1	1516.2	1884.3	3647.8	3328.7	1901.0
Max	1476.0	2056.7	1775.7	2076.1	2610.2	4584.1	4516.9	**3008.7**
S D	184.4	245.1	204.8	227.4	302.4	562.9	511.0	358.4

It is also clear from the graphically locality Figure 5.1 that raingauge b2 receives higher rainfall compared to gauge b11 and b13 which is located at a higher elevation in the catchment. The distances between rainfall stations b2 and b11 is approximately 3.4 km and from b2 to b13 is about 1.2km apart, but despite these gaps and altitudinal differences, gauge b2 seems more exposed to climatic behavioral patterns.

Finally from the inserted graphical display of Figure 5.1 the five gauges located in the sequence b1, b2, b11, b13 and b14 show some resemblance related to the same rainfall pattern around their annual totals.

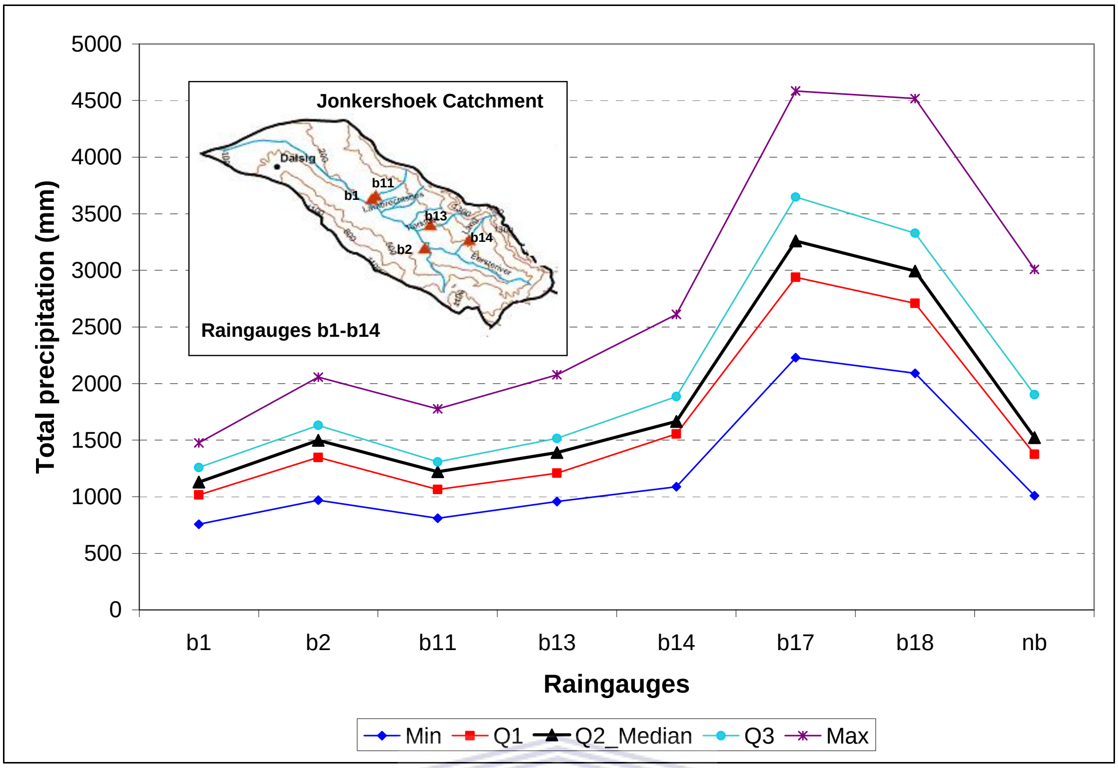
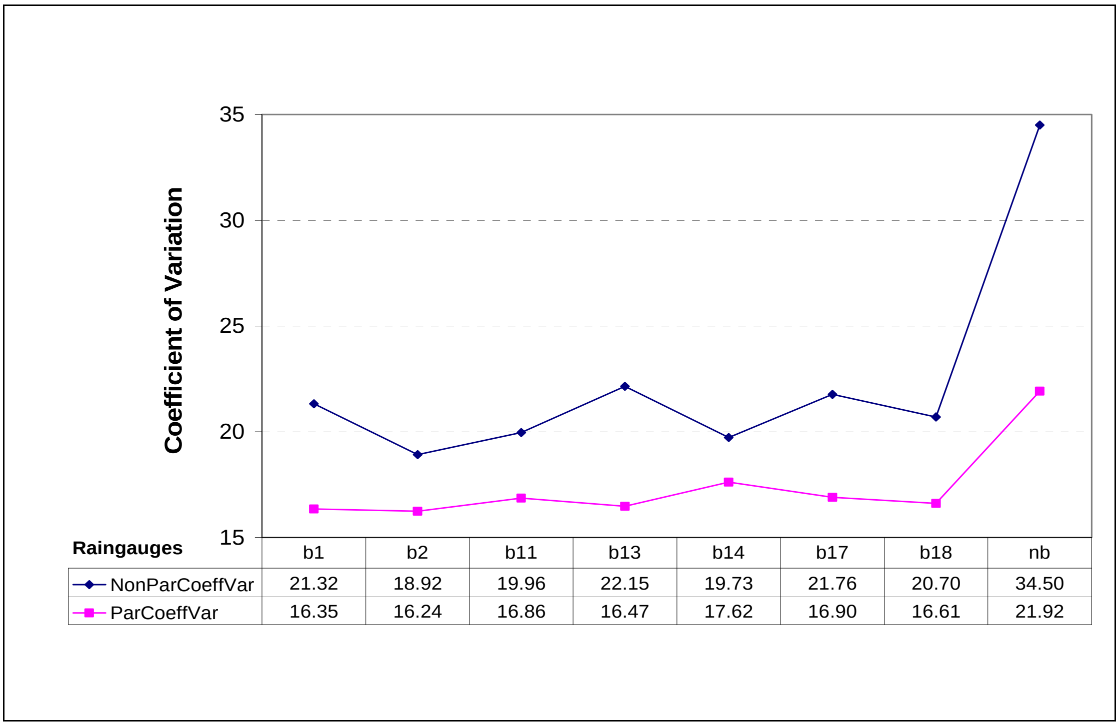


Figure 5.1: Descriptive statistics about the location of gauges in the catchment.

An additional objective was to establish relationships between gauges in a group in the catchment. Results from the analysis of variance, through the statistical comparison of the parametric and non-parametric tests are illustrated in Figure 5.2. Coefficients of variance were determined in both estimations.

Both parametric and non-parametric estimations showed that seven of the raingauges in the catchment are statistically linked, showing the same trend and behavior except for Nuweberg (nb). Figure 5.2 further showed that Nuweberg (nb) raingauge diverges statistically from all the other raingauges in the catchment. Nuweberg (nb) showed more dispersion in relation to the remaining gauges after its rainfall records were standardised for locality.



Raingauges	b1	b2	b11	b13	b14	b17	b18	nb
NonParCoeffVar	21.32	18.92	19.96	22.15	19.73	21.76	20.70	34.50
ParCoeffVar	16.35	16.24	16.86	16.47	17.62	16.90	16.61	21.92

Figure 5.2: Calculated coefficients of variance for the 8 gauges.

The results from Figure 5.3 of the statistical quartiles also indicated two definite clusters around the spread of raingauges in the catchment. The lower located gauges in the catchment are more closely spaced but lose their spread with higher elevations.

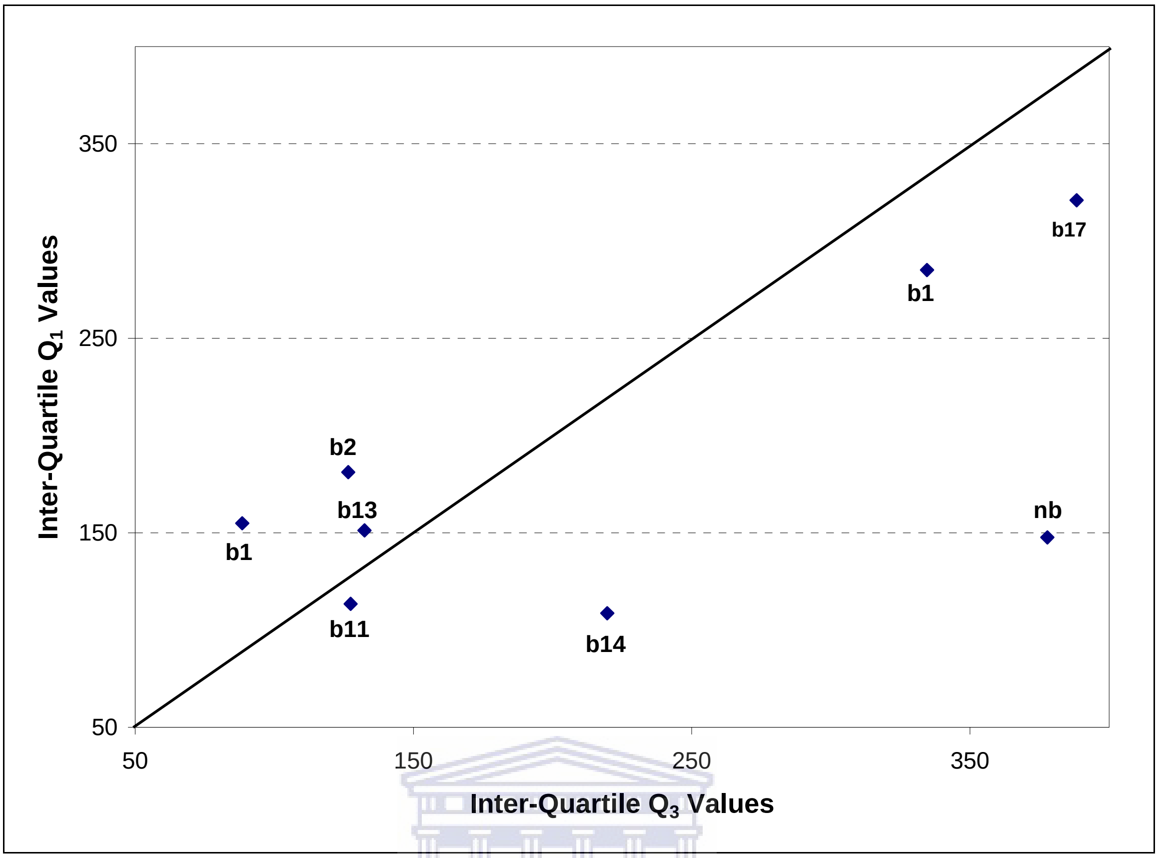


Figure 5.3: Upper and lower inter-quartile ranges for the 8 gauges.

The results are also explained in both the linear inter-quartile ranges (Figure 5.3) and the parametric descriptive statistics found in Table 5.3 where Nuweberg demonstrate a high value in the upper 75% midpoint seems to be out of sequence with the rest of the other gauges. The gauge not falling close to the line of equality refers to Nuweberg raingauge. Statistically the spread of quartiles values amongst the gauges revealed in all the graphical output that most of gauges are close to the line of equality except Nuweberg that lies significantly away from the line (Table 5.3).

Table 5.3: Calculated inter-quartile range values for the 8 analysed gauges.

Quartile ranges	**b1**	**b2**	**b11**	**b13**	**b14**	**b17**	**b18**	**Nuweberg**
IqR_Median	240.9	283.6	243.4	307.8	328.4	709.3	619.7	525.5
IqR_upper 75 – Mid	127.4	132.4	88.5	126.6	219.7	388.3	334.6	**377.8**
IqR_lower 25 – Mid	113.5	151.2	154.9	181.2	108.7	321.0	285.1	147.7

The final output from the linear regression between MAP and the standard deviation of the long-term annual rainfall data is shown in Figure 5.4. Nuweberg (nb) again showed that it is clearly dispersed away from the rest of the gauges and not closed to the regression line. There is a strong statistical relationship between the rests of the gauges in the catchment due to their positive spread on the regression line.

The mean annual rainfall values for raingauges b14 and Nuweberg are close but big differences occur with relation to the standard deviation as it statistically located away from the regression line which has resulted in Figure 5.4.

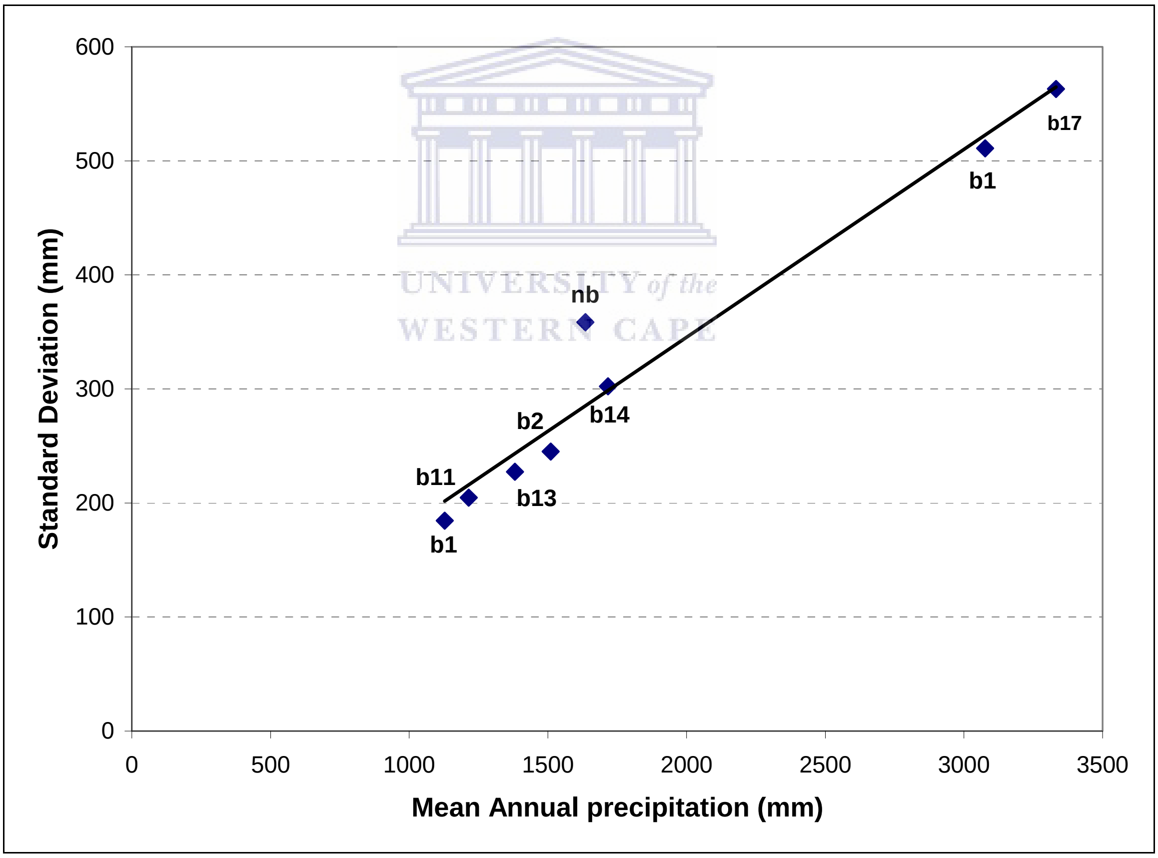


Figure 5.4: Linearly parametric statistics for the 8 gauges.

5.3 Sequential Analysis

The use of the sequential analysis on the annual long-term data was to ascertain relationships between gauges and to investigate variability among raingauges in the catchments. This has lead to a more in depth look into the rainfall phenomena in order to establish trend behavioural patterns arising from year to year and between gauges found in the catchment. The spatial graphical output from the linked scatterplots for each gauge reflect annual differentiation between gauges in the catchment but show strong correlation among gauges found inside the Jonkershoek catchments.

The comparison of individual gauges such as Nuweberg with the rest of the gauges for different time cycles indicates different correlations and discrepancies. Annual rainfall values are sequentially linked (Figures 5.5-5.13) if they follow a statistical symmetrical trend. Statistically it was found that the annual data between the dependant gauges and the independent Nuweberg gauge, forms a direction of association for certain time periods. These rainfall time periods are sequentially linked with the gauges in the catchment area, but also show contrasting behavior in the annual 61-year of rainfall. Sequentially linkages also referred to as snake trails are annually rainfall linked and plotted on the line of equality.

Figure 5.5 shows the graphical sequential evaluation for the three 20-yearcycles between b1 and the Nuweberg raingauge. The annual rainfall for all three-time cycles pointed out that all the cycles were predominantly sequentially linked except for specific anomalous years. An anomaly refers to the crossed linked line connections between gauges going in the opposite direction compared to the rest of the point data in the scattered plot. An anomalous year occurs when two gauges reveals an opposite trend in their rainfall. One gauge showed an increase compared to the second with a decrease in rainfall for the same year. The rainfall for both gauges does not fall in the symmetrical pattern and lies vertically on the line of association as depicted in Figure 5.5. The graphical output also showed that each 20-year cycle is characterised by rainfall anomalies found in the annual rainfall totals for each gauge.

The graphical output from Figure 5.5 showed that b1 experienced eight anomalous years specifically in 1954-1955, 1967-1968, 1976-1977, 1979-1980, 1983-1984, 1986-1987, 1992-1993 and 2001-2002 with an associated negative response in rainfall varying between -26 mm – 99 mm over the 61-year period. Nuweberg (nb) showed a positive response with its annual values varying between 54 mm and 581 mm for the same period. The results also revealed an opposite rainfall behavior between gauges for the years 1972-1973, 1998-1999 and 2002-2003. Raingauge b1 experienced wetter spells prior to raingauge Nuweberg's decreasing rainfall trend. Most of the rainfall anomalies between the two gauges occurred in the last forty years of the 61-year period. The last 20-year graphical presentation of the annual rainfall pattern produced a concave shape indicating that b1 and Nuweberg experienced relatively wetter spells than the previous 20-year periods. Overall it was found that anomalies represented 8% of the entire 61-year period for both analysed gauges.

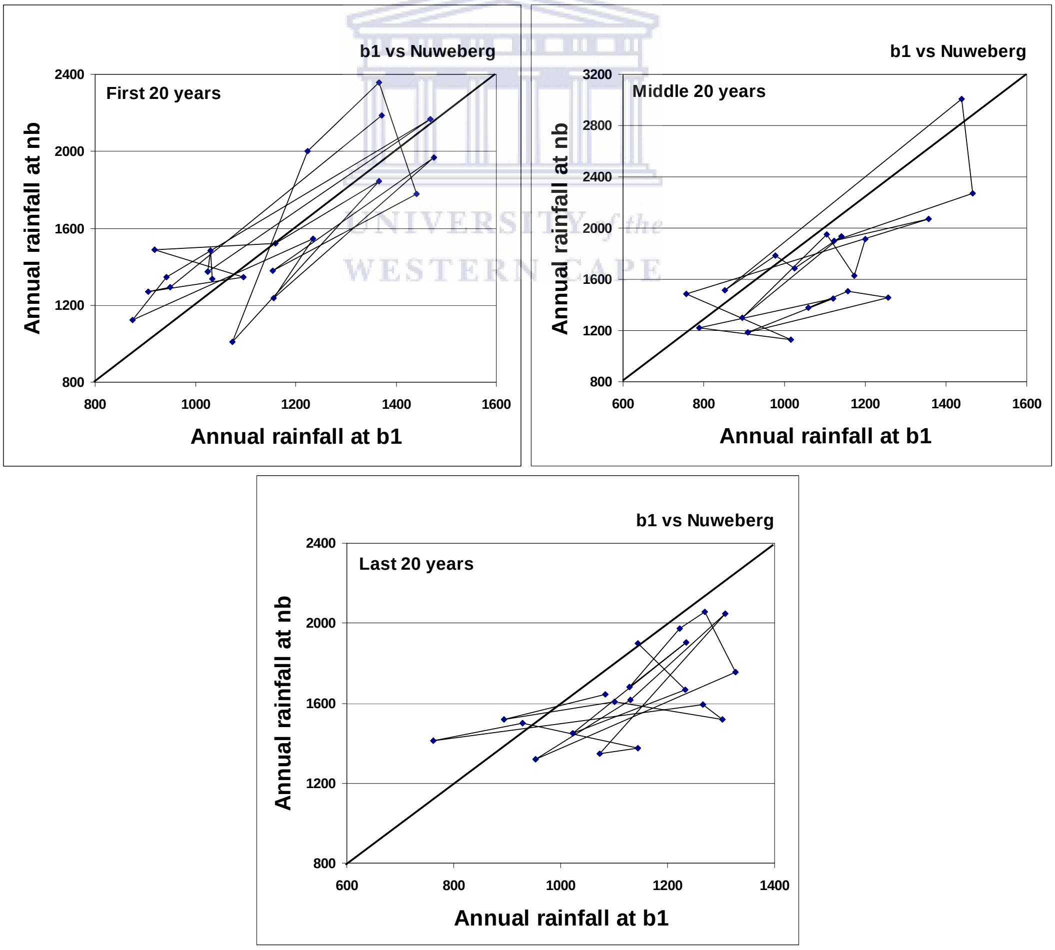


Figure 5.5: Sequential evaluation of b1 against Nuweberg.

The second graphical sequential evaluation demonstrated in Figure 5.6, between gauge b2 and Nuweberg has accordingly showed that in each 20-yearcycle of rainfall data the annual rainfall is statistically sequentially linked despite some anomalies in the annual data. These anomalous years amongst b2 and nb represent 21% of the 61-years of data. Most of the anomalies occurred in the last forty years of the data. The period from 1986 to 2005, seems to be wetter than the previous two cycles.

The annual rainfall trend between 1945 and 2005 seems positively dispersed and linearly spaced on the line of equality. The rainfall anomaly found in the second 20-yearcycle in year 1976-1977 showed greater discrepancy in the data due to a significant decrease of 739 mm of rainfall for Nuweberg in contrast to gauge b2 which had an increase of 69 mm. Raingauge b2 experienced its wettest year in 1976. Rainfall anomalies over the three 20-yearperiods occurred in 1948-1949, 1972-1973 and 1990-1991. The decreases and increases in rainfall over the three years were more related to moderate losses and gains among the gauges. The last 20 years showed a wetter period similarly to that of gauge b1, with two prominent rainfall anomalies.

The comparative correlation results from Figure 5.6 revealed six anomalous years, 1948-1949, 1972-1973, 1976-1977, 1990-1991, 1998-1999, and 2002-2003. Gauge b2 experienced wetter annual years in contrast to Nuweberg decreases in rainfall. The increased totals of rainfall for the wet spells for b2 varied between 66.8 mm and 343.3 mm over the six anomalous periods. The drier climatic behavior experienced by raingauge b2 over seven individual years were 1954-1955, 1967-1968, 1971-1972, 1979-1980, 1986-1987, 1992-1993 and 2001-2002. The anomalous lower rainfall over the seven periods varied between 25.9 mm and 262.3 mm.

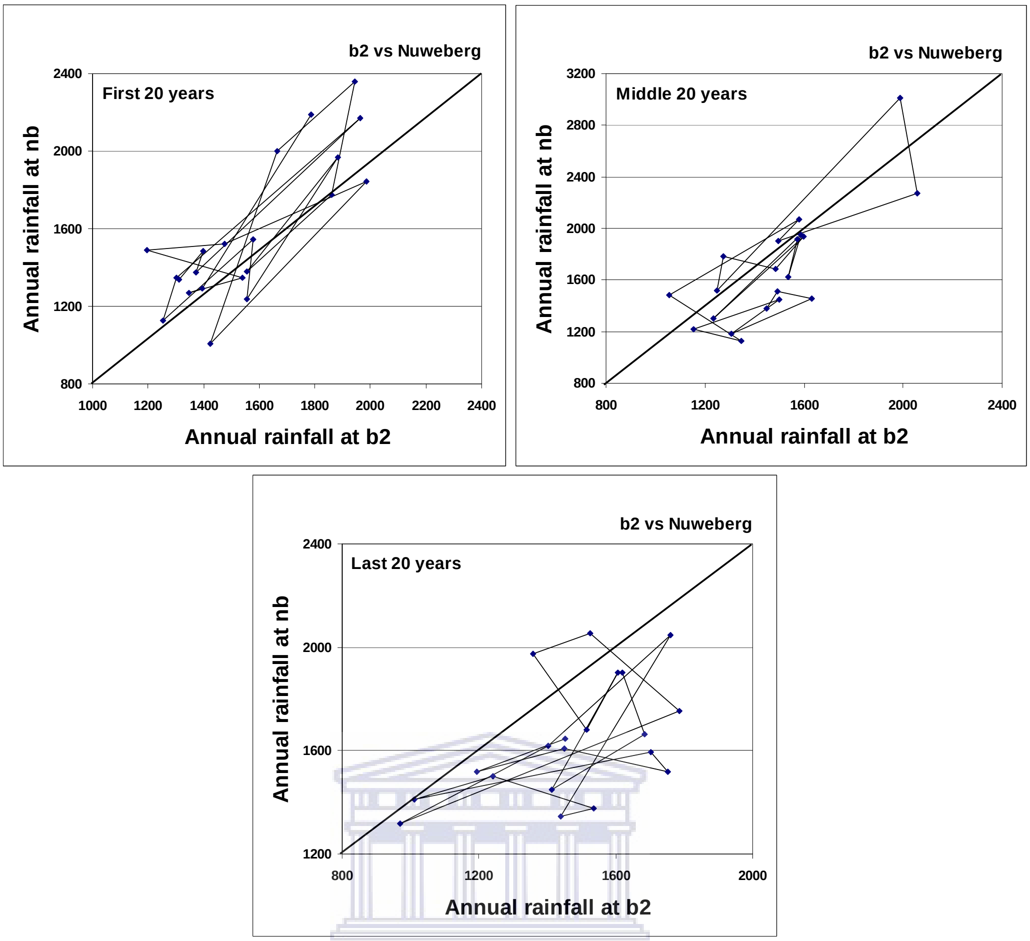


Figure 5.6: **Sequential evaluation of b2 against Nuweberg.**

The third comparative graphical display found in Figure 5.7 for gauges b11 against Nuweberg, showed that more than 25% of the annual rainfall data at b11 is associated with rainfall anomalies. The first 20 years demonstrate a bigger spread out trend in the annual rainfall on both sides of the line of equality with the highest anomaly between Nuweberg and b11 during 1976 and 1977. The middle 20 years is perfectly sequentially linked showing a positive linear trend due to the distribution of the annual data close and above the line of equality. This is also an indication that the middle 20-year period was subjected to a drier cycle compared to the first and last 20-year cycles for b11. The three 20-yearcycles display trends indicating that the annual rainfall data between the two gauges are still statistical sequentially linked.

The anomalous eight years for b11 resulted in a drier and decreasing rainfall, compared to Nuweberg and varying between 54.9 mm to 581 mm per annum. These years included 1954-1955, 1964-1965, 1967-1968, 1971-1972, 1979-1980, 1983-1984, 1986-1987 and

1992-1993. The contrasting six wetter years, 1948-1949, 1963-1964, 1972-1973, 1976-1977, 1998-1999 and 2002-2003 showed that the additional rainfall for gauge b11 varied between 29.5 mm to 219.1 mm for the same period.

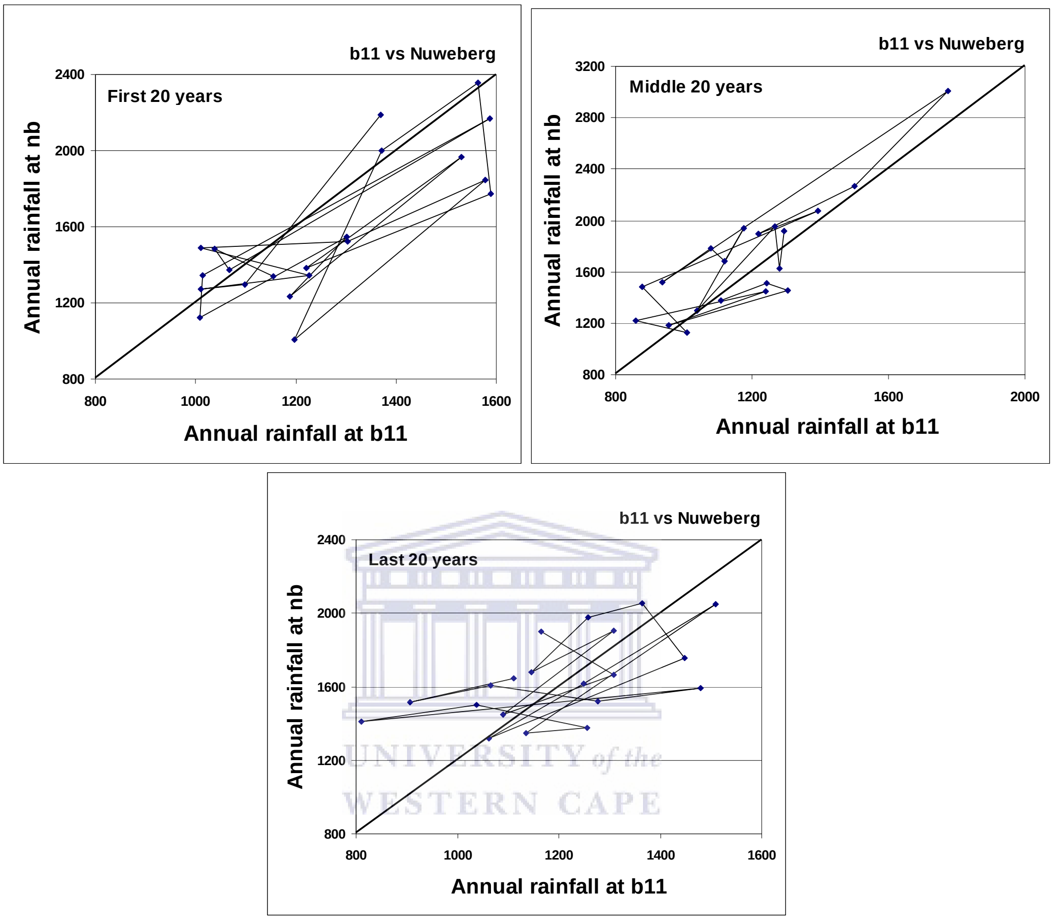


Figure 5.7: Sequential evaluation of b11 against Nuweberg.

The sequential evaluation displayed in Figure 5.8 for gauge b13 compared to Nuweberg showed a decrease in rainfall discrepancies between the two gauges. Overall the period from 1945 to 2005 showed that the annual rainfall of the two gauges was sequentially linked and was strongly visible in the first forty years of the annual data. Each 20-yearcycle had there own anomalies in the total amount of annual rainfall, spread over the 61-year period. The period from 1966 to 1985 held the extreme wet year of 1977, along with a considerable wetter spell for the period. Alternatively, the graphical figure showed that in the last twenty years both gauges experienced wetter spells.

The annual rainfall discrepancies between the analysed gauges showed that b13 rainfall increased and the calculated additional rainfall varied between 68.7 to 306.3 mm for the years, 1948-1949, 1972-1973, 1984-1985, 1998-1999 and 2002-2003 in comparison to Nuweberg, which showed decreases of 143.3 to 352.9 mm for the same period.

Alternatively, the five years, 1954-1955, 1964-1965, 1967-1968, 1979-1980 and 1986-1987 showed decreases in the annual rainfall for b13, ranging from 45.2 to 128 mm compared to the Nuweberg wetter spells of 54.9 to 581 mm for the same period.

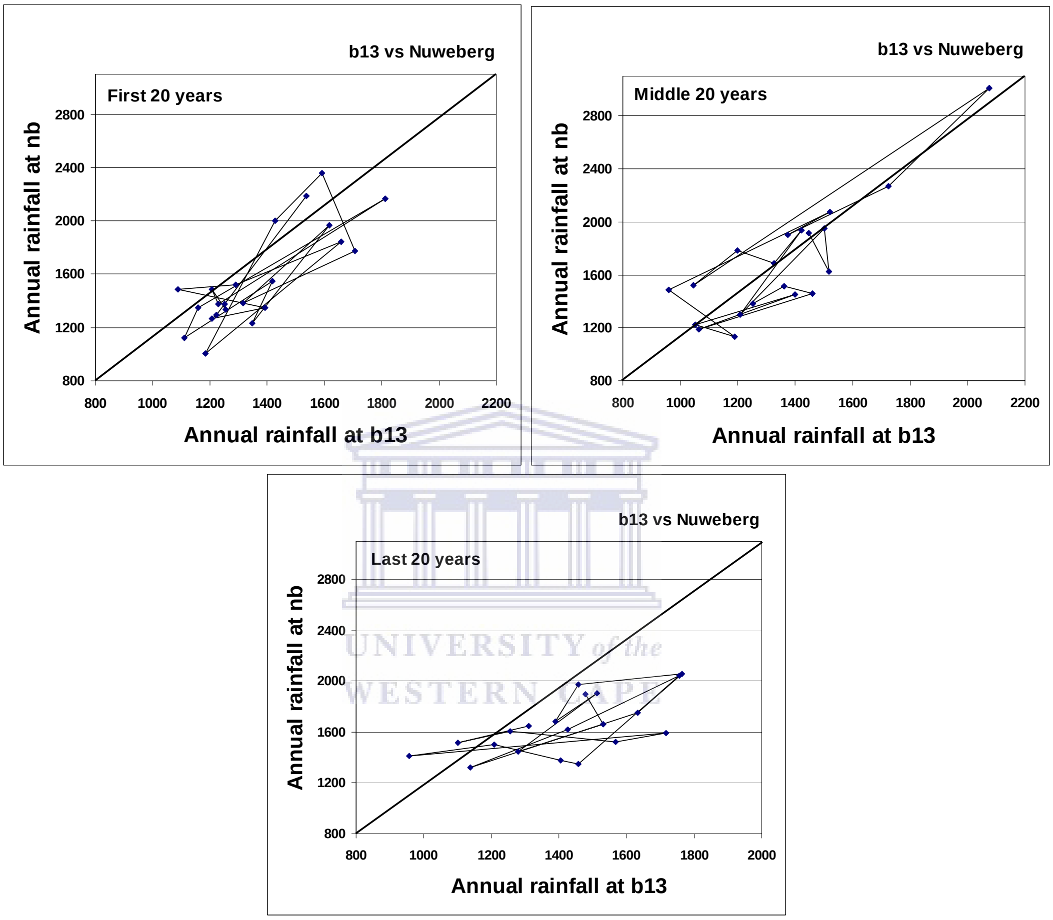


Figure 5.8: **Sequential evaluation of b13 against Nuweberg.**

The results from b14 against Nuweberg (Figure 5.9) showed the highest sequentially linked behavior between two gauges. The anomalous rainfall data between the two gauges represented 10% of the 61-years of the data. The first few years illustrated a wetter period, but eventually the rainfall started to increase gradually over time. The first twenty year cycle identified two distinctive clusters of data points at the lower and at the upper end of the connected scatterplot (snake trail). The last twenty years again exposed a concave form of the scatterplot for the two correlated gauges. Despite the dry spells in the last 20 years, the trend continued positively and linearly on the line of equality.

Only five years, 1948-1949, 1972-1973, 1984-1985, 1998-1999 and 2002-2003 showed positive annual responses. The positive increases for gauge b14 varied between 174.6 and 399 mm over the same five year period. The following two years, 1971-1972 and 1979-1980, b14 had drier spells and experienced decreases of 82.3 and 100 mm annually compared to Nuweberg rainfall increases of 92 and 100mm for the same period.

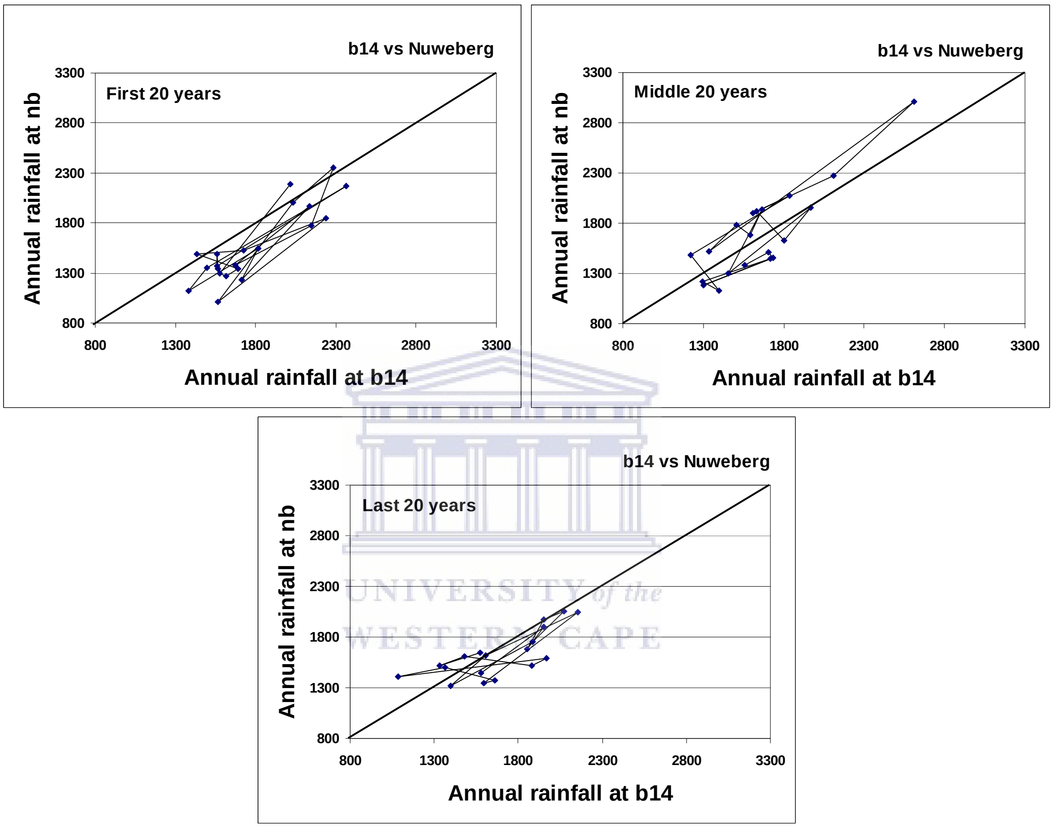


Figure 5.9: Sequential evaluation of b14 against Nuweberg.

Greater variability exists in the graphical output (Figure 5.10) from Nuweberg and b17 due to increasing anomalies found in the long-term annual data. The anomalous data for b17 represented 12% of the total amount of rainfall over the 61-year period. The overall trend in the first 40 years of data amongst the two gauges is clearly visible. Despite a wetter period experienced by b17 in the first 20-yearcycle, the rainfall between Nuweberg and b17 is sequentially linked for the entire period.

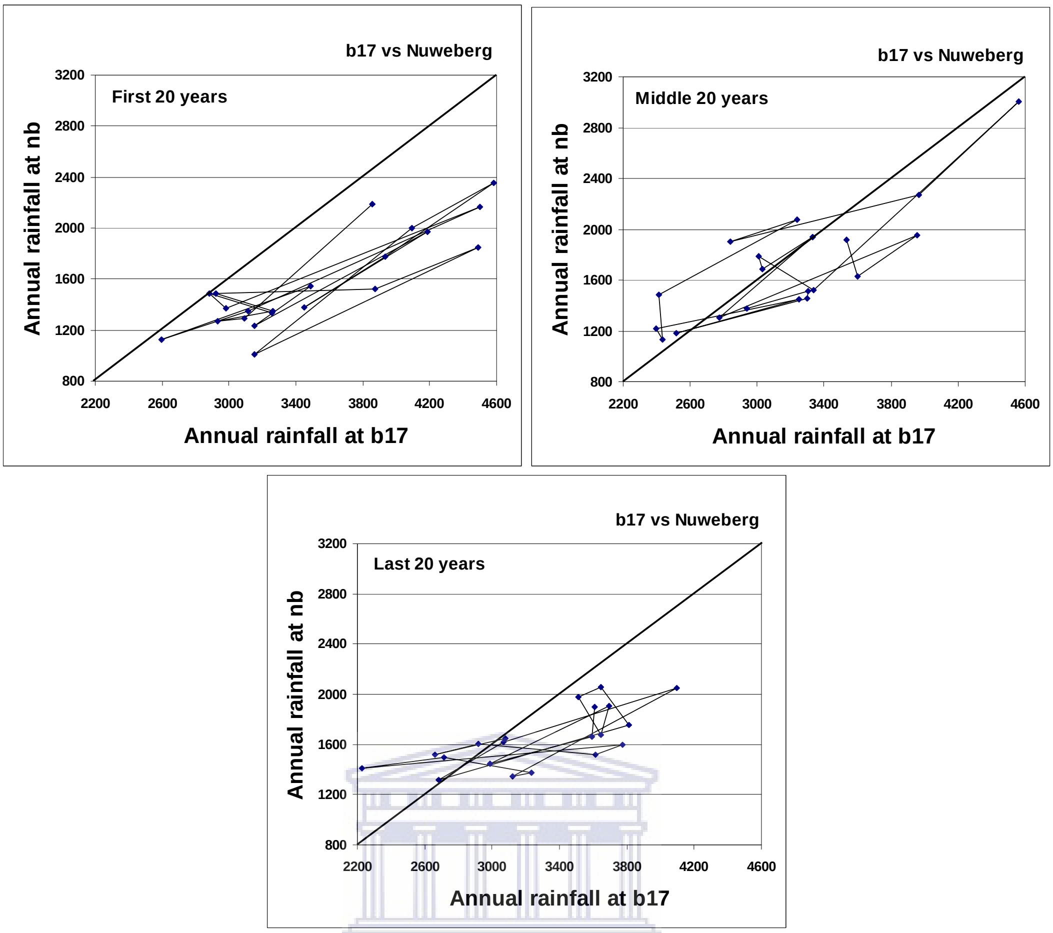


Figure 5.10: Sequential evaluation of b17 against Nuweberg.

The first 20-year cycle reflected higher rainfall for b17 raingauge according to its distribution of annual rainfall data. The middle 20-year spell is characterised by scattering from the annual rainfall data between the two gauges. The middle 20 years annual rainfall between the two gauges is statistical linearly related and an indication of a moderate wetter cycle for b17. This cycle also experienced its highest rainfall amounts for the two gauges, indicating that the average rainfall is slightly above normal. The last 20-yearscatterplot is flatter and deviates strongly from the line of equality. The moderate wet years found in the last 20 years seems to be continuing until the middle part where it starts increasing again. The last 20-year cycle has clearly demonstrated that b17 is a higher receiving rainfall gauge from the two analysed gauges.

For the following years, 1948-1949, 1963-1964, 1972-1973, 1978-1979, 1990-1991, 1998-1999 and 2002-2003, raingauge b17 experienced wetter years compared to Nuweberg, with opposite drier spells. During the wetter spells for b17, rainfall varied between 19.4-700 mm to Nuweberg's drier spells of 88.8 to 253.9mm for the same period. Nuweberg experienced wetter periods for the years, 1964-1965, 1971-1972, 1978-1979 and 1992-1993. The wetter spells from the Nuweberg raingauge was moderate compared to b17 and varied between 54.9-124.6 mm for the entire period. The drier spells for b17 were between 17.8-342.8 mm for the 4 year period. These anomalies were spread over the entire spectrum of rainfall for the 61-year period and showed a flatter rainfall pattern towards to the end of the data period.

The sequential evaluation of b18 against Nuweberg is illustrated in Figure 5.11. The overall output showed a sequential trend in the annual rainfall but with more clearly identified anomalies in the annual data points. Compared to b17, gauge b18 annual rainfall is spaced closer to the line of equality for the first 20-year cycle. The middle 20-yearcycle annual rainfall points were more scattered around the line of equality and show great variability between the two gauges. Anomalous years were clearly manipulating the spread of the annual data in the second 20-year spell. The extreme wet years in the middle 20-year cycle were visible in the scatter plot. The last 20 years showed a concave pattern in the linked annual data. The last 20 years also reflected drier years compared to the rest of the 40-year cycle due to the flatter trend in the data.

Figure 5.11/…

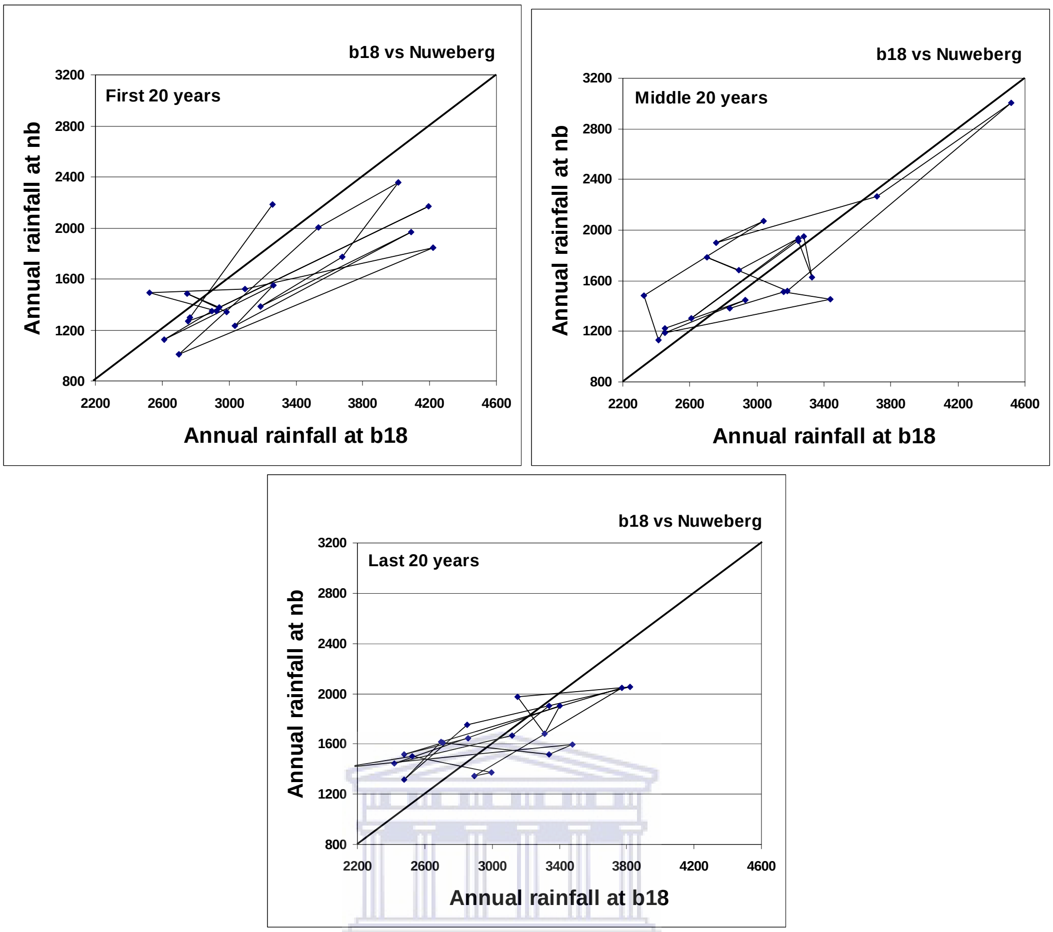


Figure 5.11: Sequential evaluation of b18 against Nuweberg.

During the years, 1948-1949, 1963-1964, 1967-1968, 1972-1973, 1978-1979, 1990-1991, 1998-1999 and 2002-2003, raingauge b18 experienced predominantly wetter period compared to Nuweberg's drier years. The wetter spells for b18 varied between 84.1-629.7 mm while Nuweberg's rainfall variation was between 88.8 and 253.9 mm for the same period. Nuweberg experienced wetter periods for years, 1964-1965, 1967-1968, 1971-1972, 1979-1980 and 1983-1984. During this time rainfall at the Nuweberg raingauge varied between 54.9 and 324.6 mm for the entire period. For the same time span for b18 was between 51.1 and 275.6 mm for the 5-year period.

The first 20-year cycle for both gauges was statistically lower than the middle 20-year cycle. The second 20-year period was characterised by rainfall anomalies especially for the higher located gauges. The middle 20-year cycle showed wetter periods for both gauges and was statistically sequentially better linked to each other. The last 20-year cycle seem to be drier than the first 40 years with characteristic and significant anomalies in the annual rainfall.

Most of the annual rainfall data for each of the eight gauges in the catchment against Nuweberg, over the 61-year period was sequentially linked. All the gauges demonstrated a linearly positive trend.

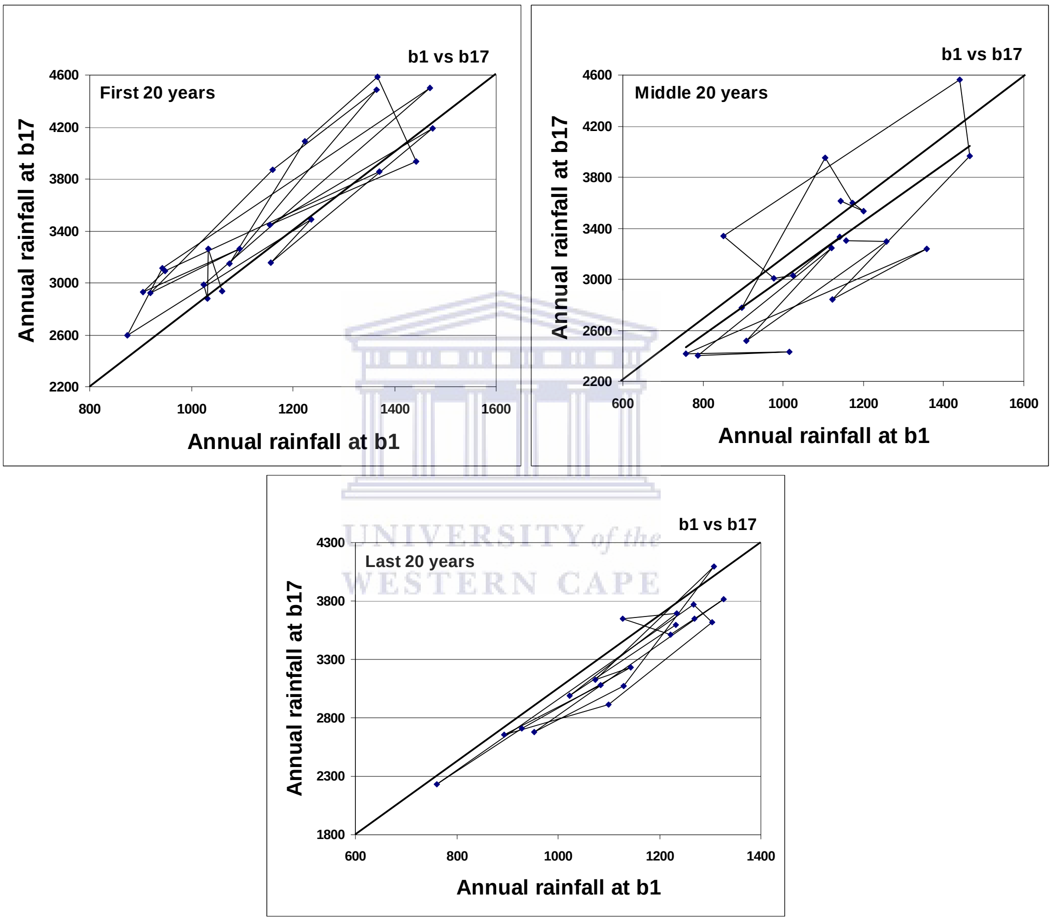


Figure 5.12: Sequential evaluation of b1 against b17 (Appendix 1).

The objective to compare the lowest (b1) and the highest (b17) located gauge was to demonstrate the sequence between the analysed gauges despite the anomalies found in the annual data.

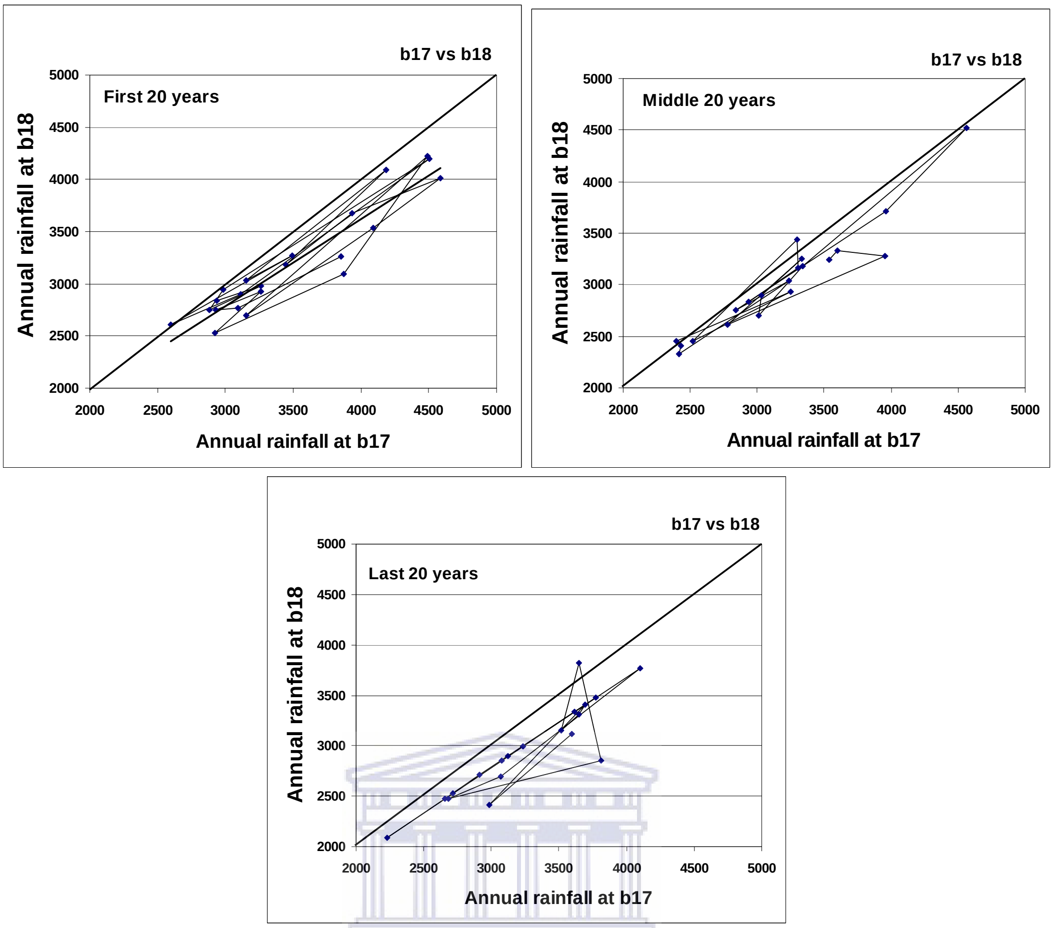


Figure 5.13: Sequential evaluation of b17 against b18 (Appendix 2).

The statistical relationship between the two highest located gauges (b17 & b18) has clearly demonstrated that the two gauges were sequentially linked. Both gauges formed a strong correlation due to their spread on the line of equality.

The last twenty years have clearly showed that b17 is a higher receiving gauge than b18 despite their locality.

5.4 Sequential Differences Analysed Results.

Further statistical transformation of the annual rainfall data was performed analysing the sequential differences between gauges to establish trends and cyclical rainfall behavior.

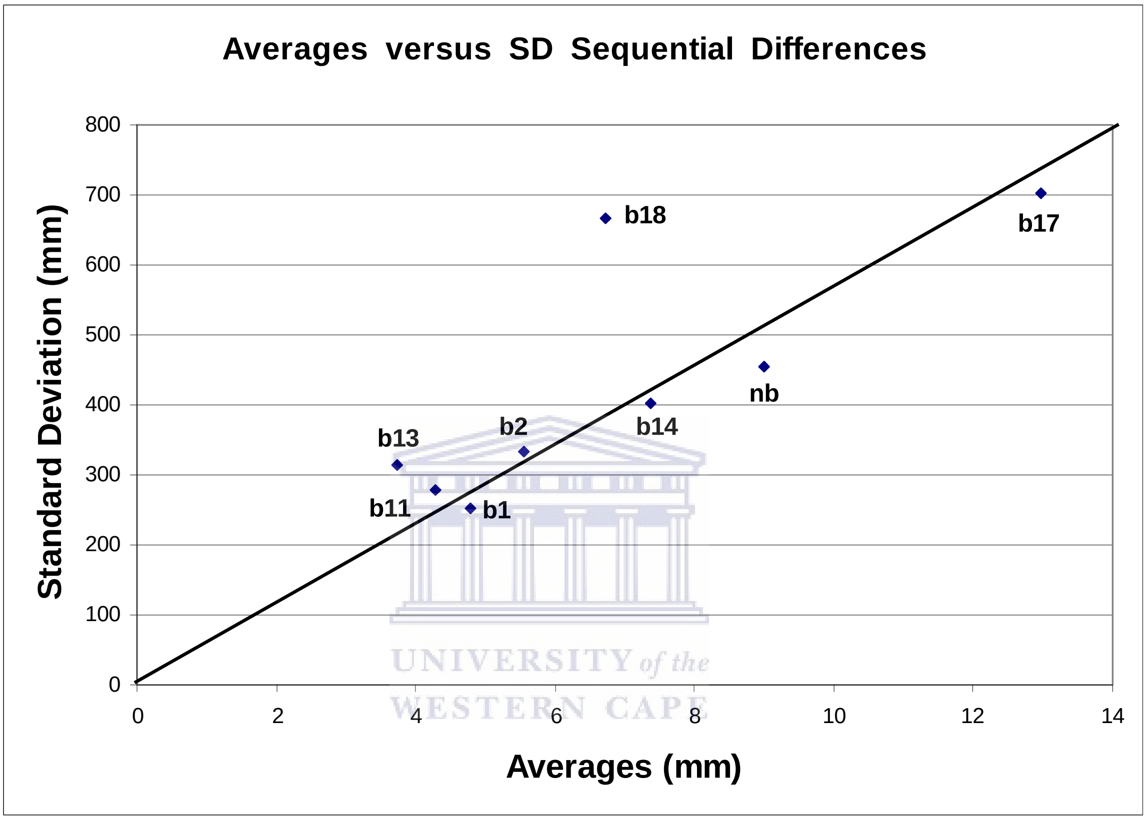


Figure 5.14: Statistical sequential differences between gauges.

The plotted sequential differences using the Standard Deviation (SD) and long-term averages (Figure 5.14) involving the gauges revealed that variability exists amongst the gauges located in the catchment. Raingauge b18 showed the biggest discrepancy on the equality line, in relation to the rest of the existing seven gauges. The standard deviation for b18 showed great dispersion compared to the rest of the seven gauges.

The results from the comparative descriptive statistics using the sequential differences (Figure 5.15) have shown that the maximum value for Nuweberg was out of sequence in relation to the rest of the raingauges in the catchment. B17 seem to be showing the highest rainfall losses during the 61-year period from the calculated minimum values. The values for the median were starting slightly below the zero line but increases at gauges b17, b18 before slanting back below the zero line. Alternatively the median is closely located to the zero line. The first and third quartiles were clearly showing the orographic effect of a mountain catchment rainfall with regard to location of gauges and increasing elevations. Annual rainfall of gauge b2 was also higher than the gauges in the same environment located at higher altitudes.

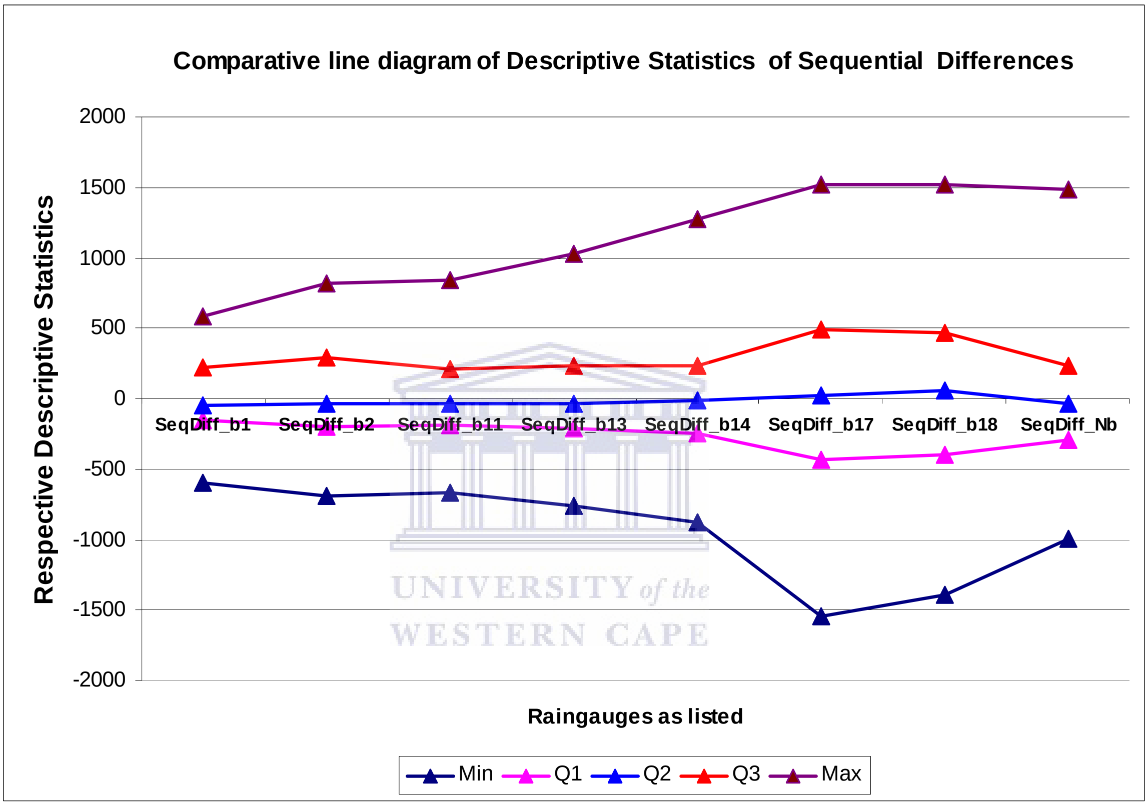


Figure 5.15: Descriptive statistics of sequential differences between gauges.

The quantitative results (Table 5.4) from the calculated sequential differences revealed different annual rainfall wet spells amongst the analysed gauges in the catchment.

Table 5.4: The wet spells of consecutive wet years for the 8 analysed gauges.

Gauges	b1	b2	b11	b13	b14	b17	b18	Nb
Wet spells (yrs)	24	26	27	28	28	32	32	28

While using all the positive values from the calculated sequential differences, Table 5.4 indicated that gauges responded particularly differently to the amount of good rainfall cycles in the annual rainfall data. Raingauge b1 had the lowest number of wetter rainfall spells as it is situated on the least elevated part of the catchment. Gauge b1 revealed a spread of 24 wet spells where it rained more than the previous years. In comparison b17 and b18 experienced a total of 32 occasions where it rained more than the previous years. These wetter years were spread over the entire period of the 61-years of annual data in the catchment.

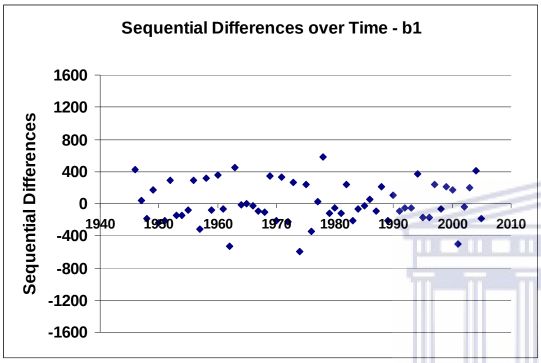
The gauges b13, b14 and Nuweberg experienced the same number of wetter spells over the 61-years of annual data but still below the norm. These wetter years do not reflect that the wetter spells happened simultaneously or sequentially, but were spread over the entire span of the 61-year period of annual data. The years for the wet spells were also not cyclical and the results from the sequential differences revealed no time periods where rainfall continued for periods longer than three years before the rainfall pattern changed again.

Further results from the sequential differences have revealed that for the year 1952, all the gauges exceeded their annual rainfall totals with Nuweberg having the lowest amount of rainfall. The sequential differences also showed that gauges b14 (66%), b13 (15%) and b2 (34%) received higher annual rainfall over the 61-year of data. Only raingauges b17 and b18 showed that Nuweberg's rainfall never exceeded the annual rainfall totals of these two gauges.

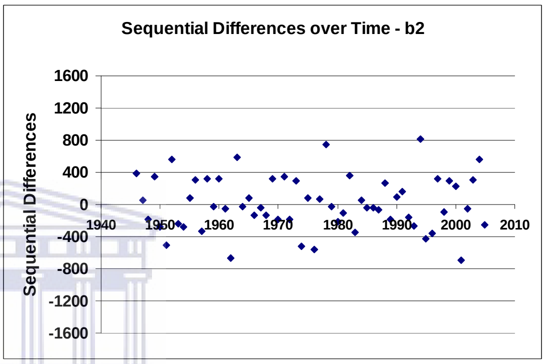
However, to test the number of wet spells found for each gauge was further examined by plotting the sequential differences over time. This analysis will produce possible trends of continued dry or wet spells in the long-term data set with the introduction of the time variable.

The statistical distribution characteristics are expressed in the following graphical plots (Figures 5.16(a-h) using the calculated sequential differences between gauges over the 61-year period. The results from the graphical displays have implicated great variability to their spreading amongst the gauges in and outside the catchment. The first outstanding features between gauges b1 and b17 have shown that variability about the dispersion of the annual rainfall has escalated for gauges located on higher altitudes. The estimated sequential differences revealed no relationship between the annual rainfall and the year due the random spread of the annual data. Incorporating of the time variable for each gauge was to highlight any trend behavior for each gauge.

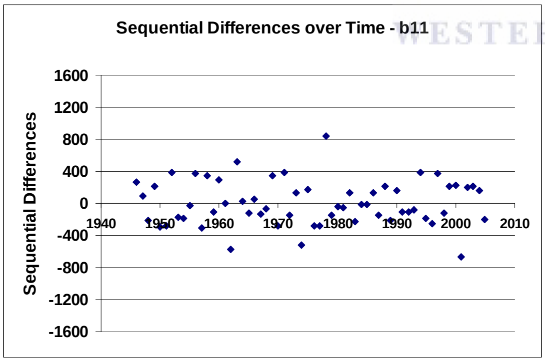
Gauges b17 and b18 showed excessive variability from year to year with poor linear relationship between gauges over time. The results from the sequential differences have implied that rainfall is randomly spread over time as seen in the graphical displays of Figures 5.16(a-h) of the sequential differences.



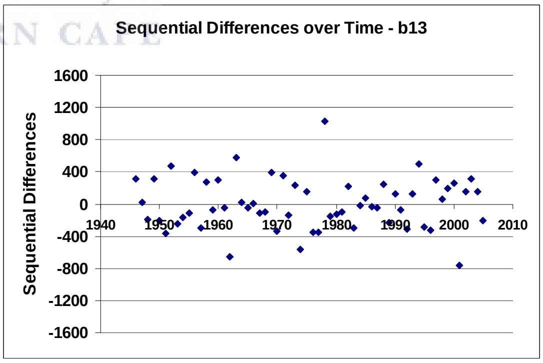
(a)



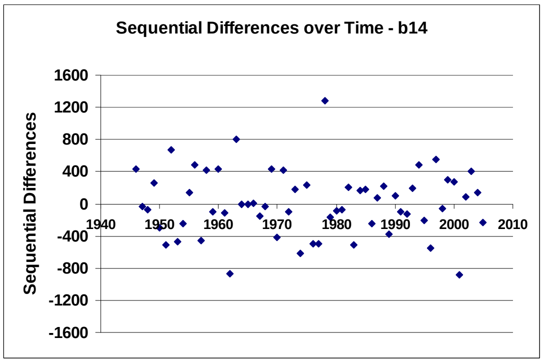
(b)



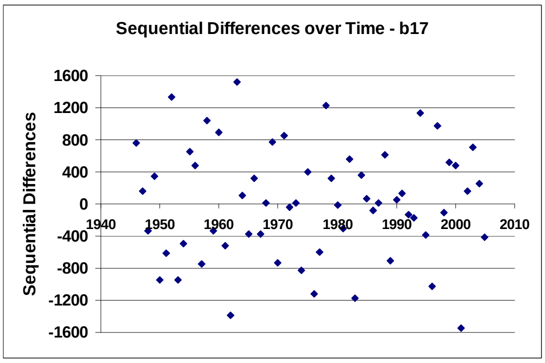
(c)



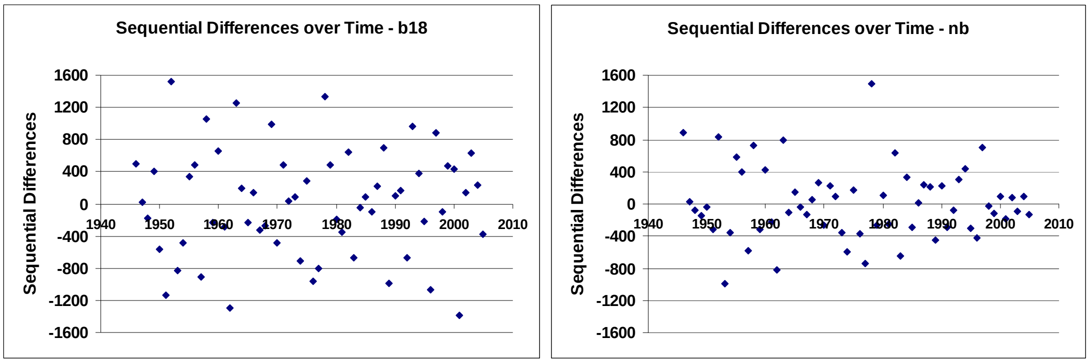
(d)



(e)



(f)



(g) (h)

Figure 5.16 (a-h): Calculated sequential differences between gauges over a 61-year period.

Raingauge b2 rainfall dispersion differs from similar gauges in the catchment due to its higher proportion of rainfall despite its spatial location in the catchment.

Rainfall extremes exposing the wet periods are clearly visible in gauges b11, b13 and b14. The positive values were more dispersed than the negative values in gauges b2 b11, b13 and b14. There seems to be strong relationship between the two variables, estimated sequential differences and time in the lower part of the catchment (Figures 5.16 (a-e).

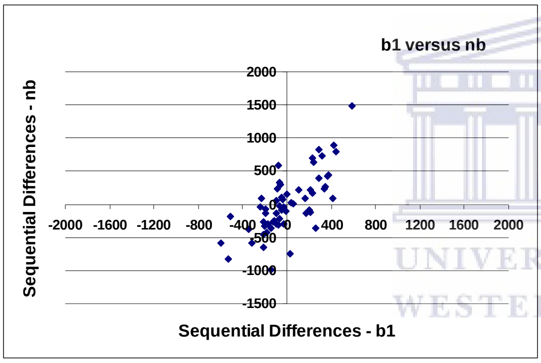
Rainfall dispersion in b17 and b18 is scattered all over the diagram for the 61-year period of rainfall data, indicating a weak linear rainfall relationship among the two gauges. The range of the data for the two gauges was also higher comparing to the rest of the gauges found in the catchment.

The Nuweberg's raingauge dispersion differs from the rest of the gauges found in the Jonkershoek catchment. The scattering pattern of annual rainfall for Nuweberg is funnel shaped and the data points seem to be closer spaced over the last 10 years. A simple statistical regression analysis for each gauge showed that all the gauges had negative slope values except b18 which revealed a positive one.

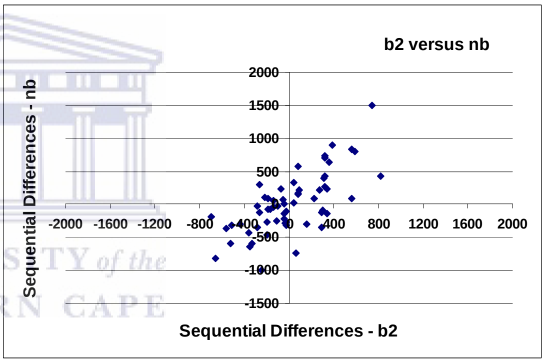
The statistical comparison of gauges (Figure 5.17 (a-g)) about their distribution characteristics using sequential differences has implicated different scattering of the annual rainfall for each gauge compared to Nuweberg. For the first four gauges located inside the catchment, spreading are more positive and most of the data points lie in the first quadrant of the plot. The upward trend is also steeper with the extreme wet year in 1977 for the first 4 gauges.

Gauges b13 and b14 showed the best statistical correlation with Nuweberg and recorded the highest correlation coefficient of 0.7. The dispersion of b17 and b18 become more positive in the first quadrant of both diagrams. The trends found in b17 and b18 tends to flattened around the zero mark with the associated dispersion in the first quadrant.

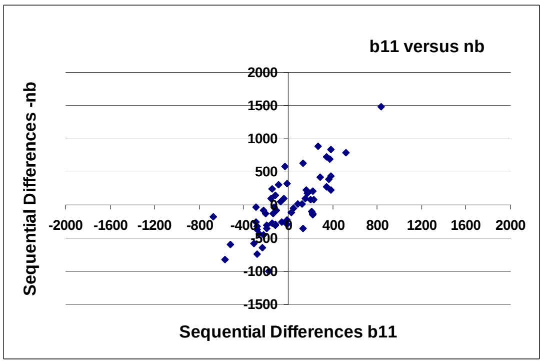
The most important derivative in all the diagrams is that whenever rainfall of Nuweberg increases or decreases linearly, the same trend is followed by the rest of the gauges. There is a strong linear relationship between the attributes of the two calculated variables in relation to the previous linked correlation analysis.



(a)



(b)



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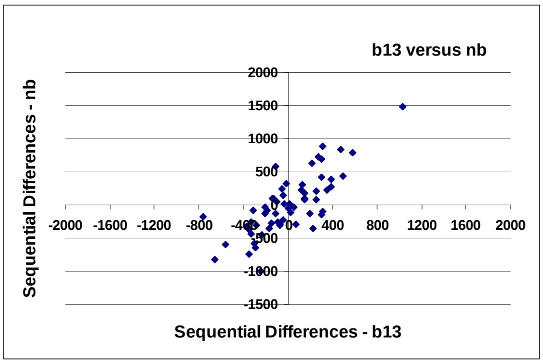

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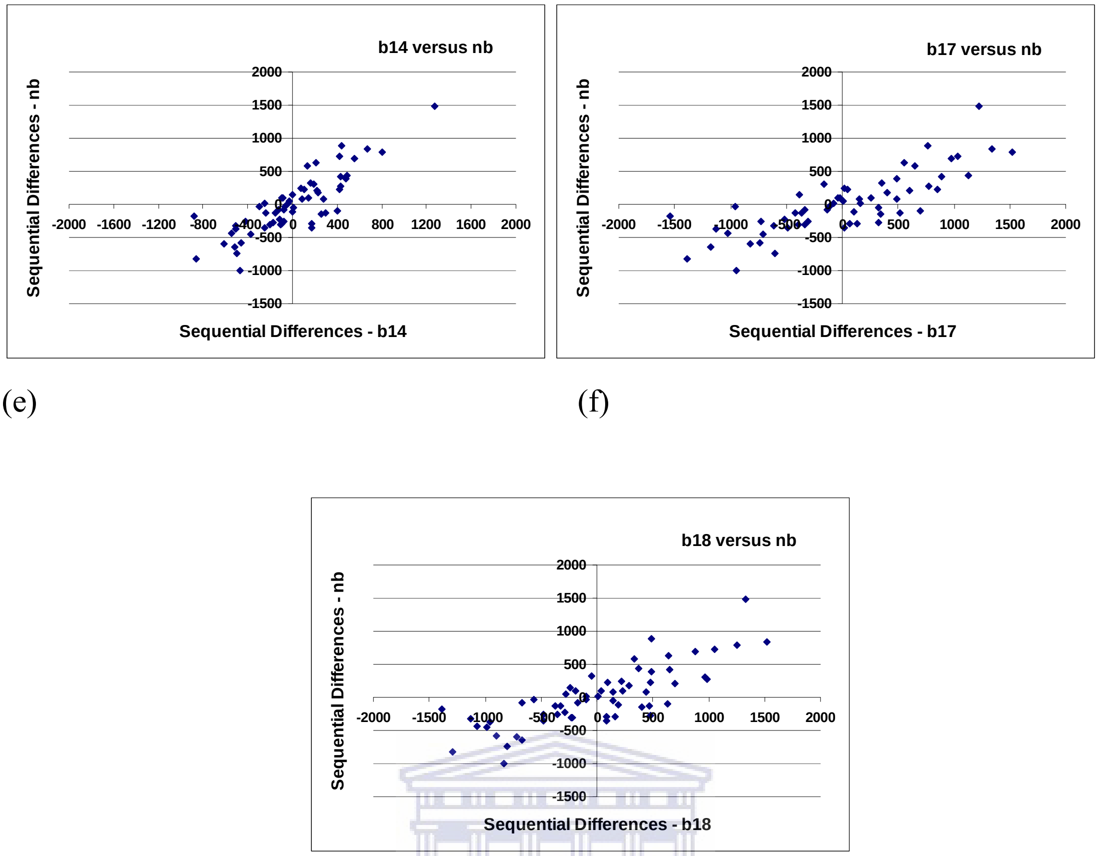


(e) (f)

(g)

Figure 5.17 (a-g): **Comparative quadrant correlation diagrams between gauges.**

5.5 Analysis of the centralised moving medians

The computed nine year moving medians (Figure 5.18) for the rainfall at each gauge revealed some cyclical behavior over the 61-year period. The first three years were relatively dry but from year 1949 to 1957 it was slightly wetter for all the gauges. This period was followed by a drier spell which leads to the extreme dry periods before 1973. A second wetter spell picked up after 1973, which showing a slight increase in rainfall until 1995 when rainfall started to decrease again and is still showing the decreasing trend.

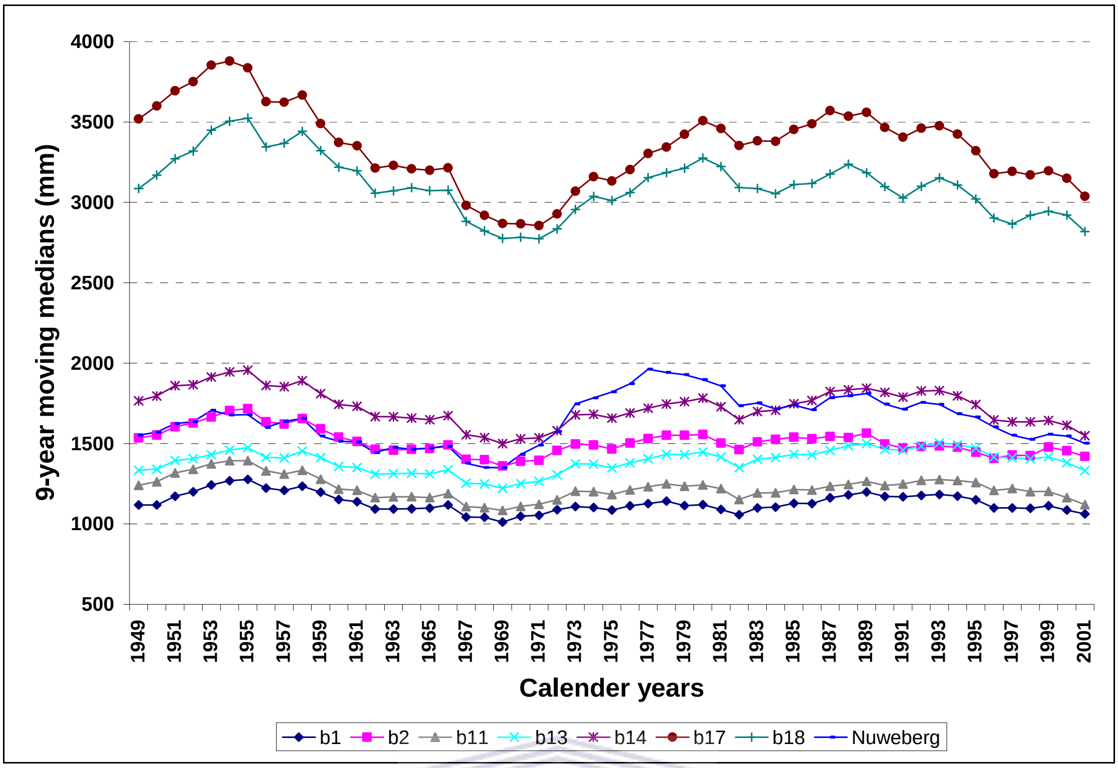


Figure 5.18: Nine year centralised moving medians for each gauge.

The higher-altitude gauges, b17 and b18 show greater variation than the rest of the gauges located inside the cathment. The wet and dry extremes are more clearly visible in the records of b17 and b18. Raingauge b2 annual rainfall is higher than its surrounding gauges locate at higher altitudes except for Nuweberg, b14, b17 and b18.

The outstanding factor is the big difference in rainfall between gauges located inside the catchment and the higher altitudinal gauges. There is also less fluctuation and variation in the annual rainfall data in the low lying gauges in comparing to the higher located gauges. Two prominent wet and dry cycles were observed from the nine-year centralised moving median graphical display. The first long-term cycle seems to cover the first 22 years and the second cycle lasted for the last 23 years over the 61-year period. The estimated nine-year SD revealed that year 1967 had the lowest amount of rainfall for all the raingauges and the maximum is approximately found in year 1973.

The results from almost all the eight raingauges have shown an increase in the dispersion in the moving standard deviation between years 1967 and 1973 (Figure 5.19). Structural heteroscedastisity or dispersion was observed in raingauge Nuweberg only, between the comparisons of the medians with the corresponding moving standard deviations.

Most of the raingauges displayed in Figures 5.18 and 5.19 reflects some cyclic behavioural pattern from both the estimated moving medians and standard deviations with regard to its calendar years. The estimated standard deviations annual rainfall trend is more prominent with at least three approximated twenty year cycles.

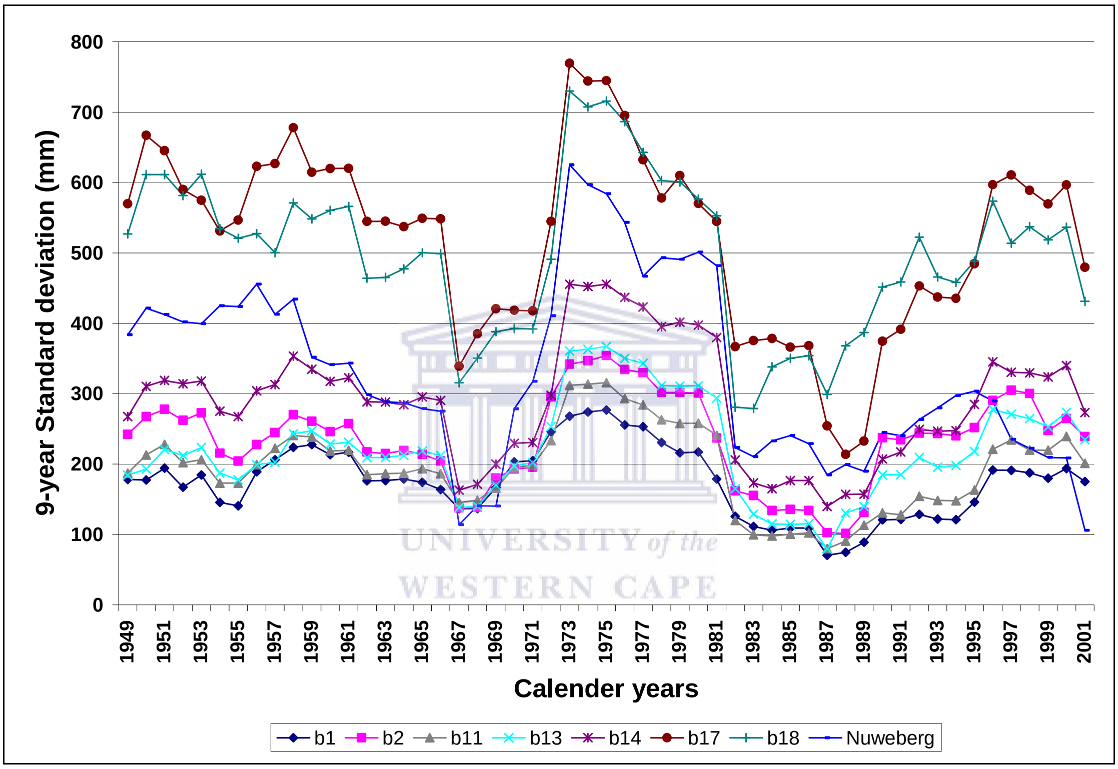
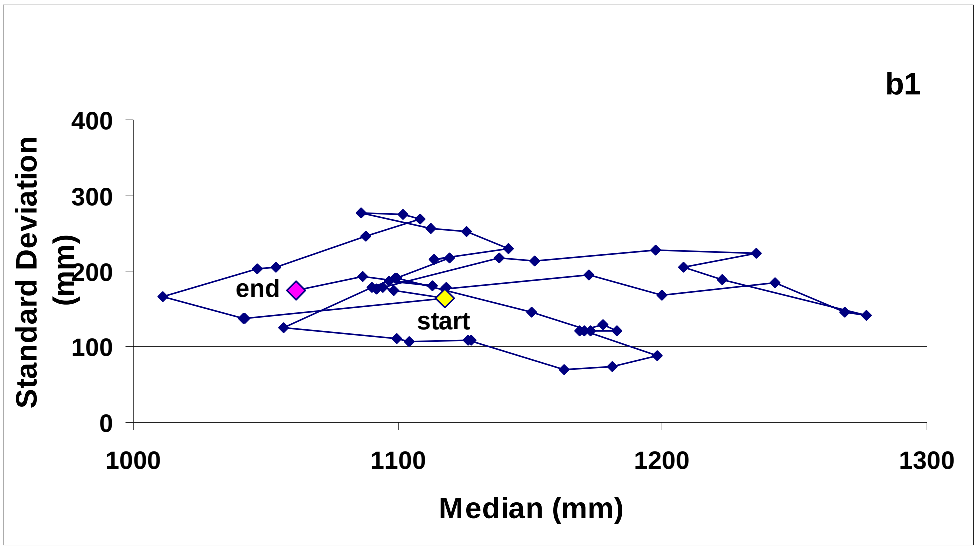
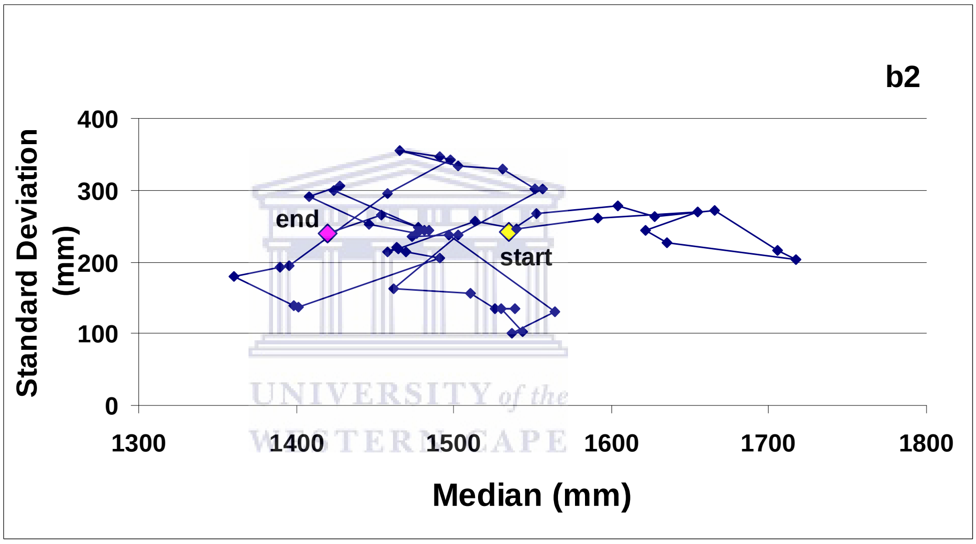


Figure 5.19: Nine year moving Standard deviations for the eight gauges.

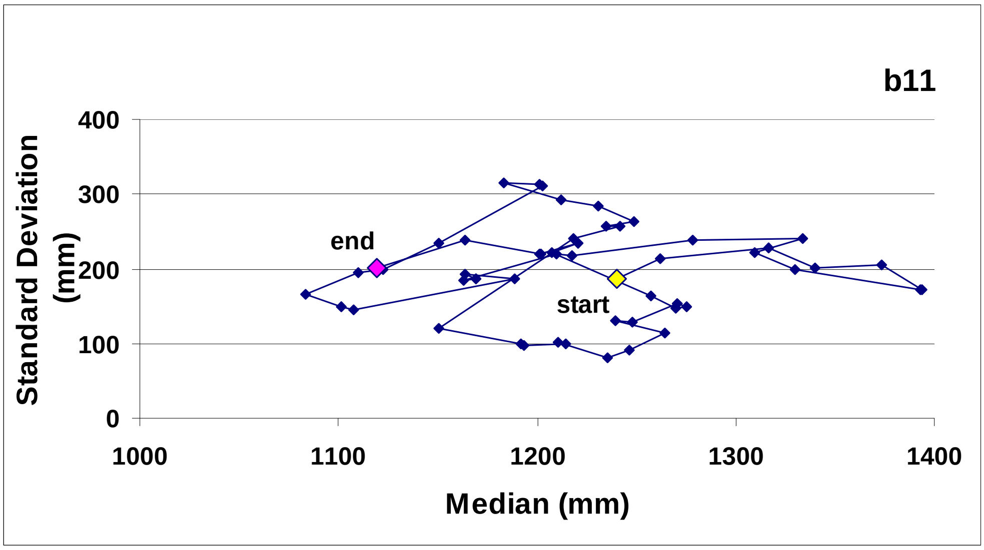
The final plotted rainfall snake trails between the moving medians and the moving standard deviations for Nuweberg is much more evident, when compared, with the other gauging stations found in the catchment (Figures 5.20 (a-h).


b1
Standard Deviation (mm)
400
300
200
100
0
1000
1100
1200
1300
Median (mm)
end
start

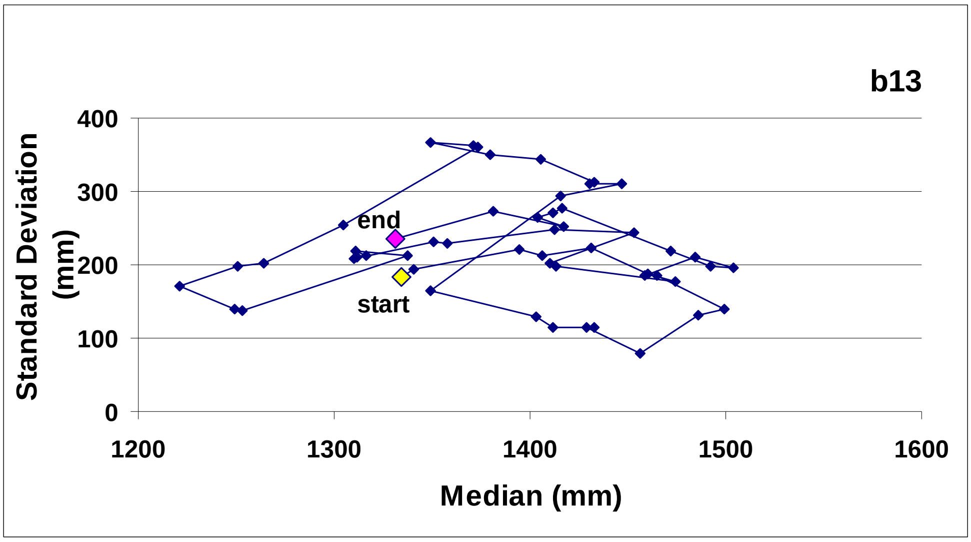
(a)


b2
Standard Deviation (mm)
400
300
200
100
0
1300
1400
1500
1600
1700
1800
Median (mm)
end
start

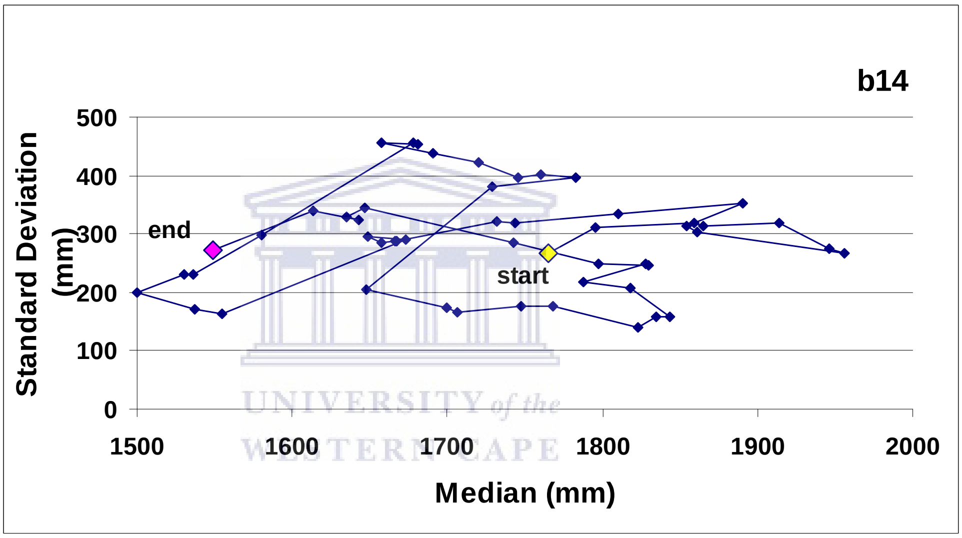
(b)


b11
Standard Deviation (mm)
400
300
200
100
0
1000
1100
1200
1300
1400
Median (mm)
end
start

(c)


b13
Standard Deviation (mm)
400
300
200
100
0
1200
1300
1400
1500
1600
Median (mm)
end
start

(d)


b14
Standard Deviation (mm)
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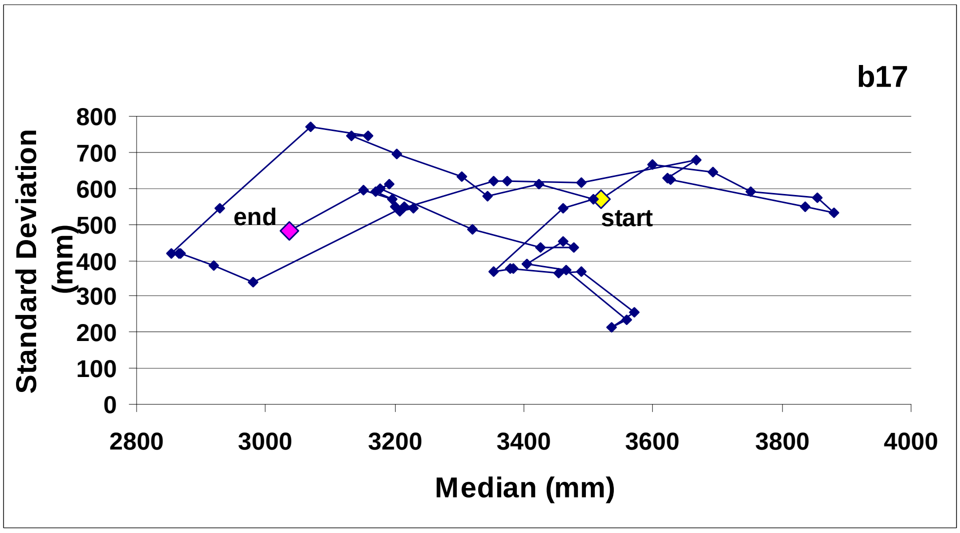
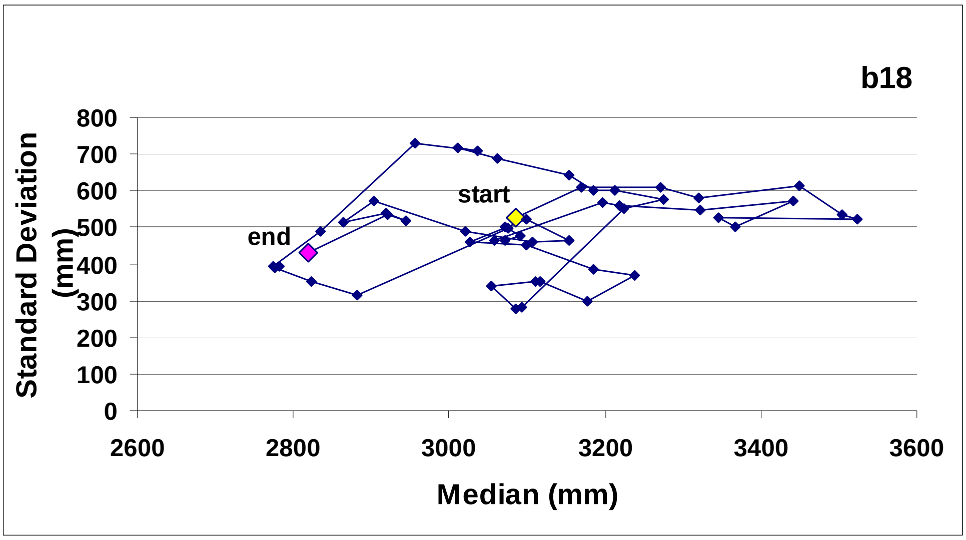
400
300
200
100
0
1500
1600
1700
1800
1900
2000
Median (mm)
end
start

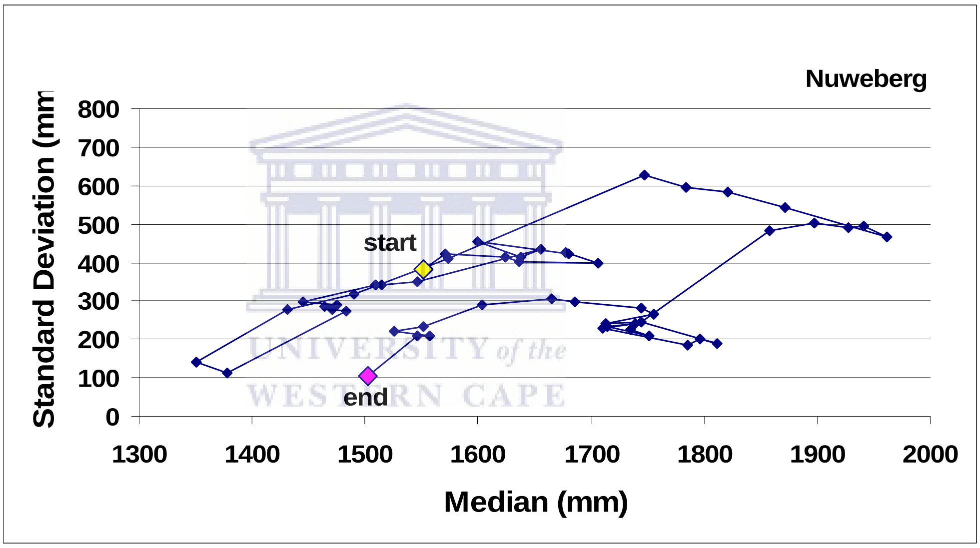
(e)


b17
Standard Deviation (mm)
800
700
600
500
400
300
200
100
0
2800
3000
3200
3400
3600
3800
4000
Median (mm)
end
start

(f)



(g)



(h)

Figure 5.20 (a-h): **Moving Standard deviations against Moving medians for the eight gauges.**

The snake trails for the first seven gauges except Nuweberg showed that by comparing moving medians against the standard deviations revealed a strong linearity in the beginning of the correlation but the linking patterns eventually started to decline in the direction of the moving median values.

The snake trail (Figure 5.20h) of the moving medians and moving standard deviations of Nuweberg cannot be discussed in a similar fashion to the correlation plots made between pairs of raingauges of different locations. The pattern described by the snake trail is relatively simple and linear in nature. Most of these linking lines increased as the values of both the moving median and moving standard deviation increased for gauge Nuweberg (Figure 5.20 (h). The increasing linear pattern occurs more sequentially than the decreasing pattern in the rest of the seven analysed gauges.

CHAPTER 6

DISCUSSION

6.1 Data quality procedure

The typical climate of the Western Cape is normally identified by two seasons namely a wet and a dry one. Rainfall mainly falls in the winter between May and August. Winter rain arrives with the cold fronts from the northwest and because of valley orientation, higher rainfalls occur at gauges b17 and b18. The location of these gauges has clearly indicated that the amount of rainfall is related to altitude. However, the statistical correlative scatter plots drawn between the gauges have confirmed a strong relationship between gauges irrespective of topographic characteristics.

The 61-year annual rainfall data revealed cyclical trends. These trends occurred to be longer than 20-year periods with associated extremities of wetness and dryness in the annual rainfall. This behavior could be a result of the atmospheric mechanism responsible for and caused by pressures in the system crossing from the southern parts of the Atlantic Ocean. Walker (1990) concluded that penetration of the warmer Agulhas current water into the South Atlantic Ocean depends on strong easterly wind forcing itself across the south-west Indian Ocean (which also has a cyclic behavior).

6.2 Analysis of the historical long-term data

The annual rainfall pattern typically shows that rainfall in the catchment is driven by topographical factors. All the gauges are located at different altitudes and each gauge faces a different aspect which produces a different rainfall total annually.

The mountains also act as barriers and any rainfall arriving with prevailing winds will be influenced by these mountains. Big differences in the rainfall gradient between the lower and higher located gauges are obvious. The difference in rainfall between raingauges b1 and b17 is 2129 mm. This is typical of the orographic effect of winter rainfall in these mountain areas of the southern Cape (Figure 6.1). A dependence of rainfall on distance from a physiographic barrier has frequently been reported (e.g. Wicht *et al.* 1969 in the South-western Cape). This orographic rainfall effect is also clearly evident from the statistical descriptions of the median and mean annual rainfall values, indicating that the gauges located on the windward side received higher rainfall than the gauges located at the leeward side of the mountains. This is a typical behavior of winter rainfall where the weather systems lose momentum as rain passes the mountains, fronts decreases to the leeward side of the mountain. This explains the decreasing annual estimated rainfall totals for gauges b18 and Nuweberg (Figure 6.1).

Raingauge b2 which experiences a higher rainfall than the surrounding higher elevated gauges may be as a result of the exposure of the gauge to other external topographical and orientation factors. The gauges to the south are less influenced by mountains and are therefore more exposed to summer rainfall or frontal systems approaching further south.

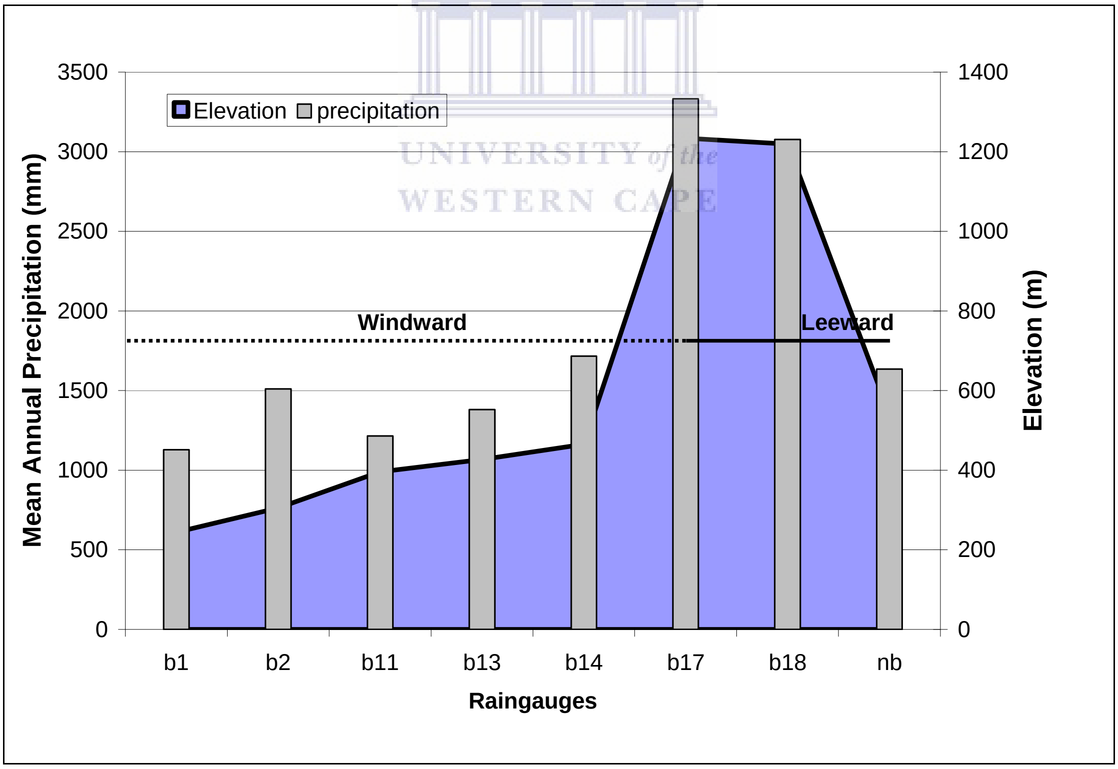


Figure 6.1: **Altitudinal rainfall relationship of the eight gauges**.

6.3 Statistical exploration of the annual rainfall for each gauge

The statistical exploratory analysis using the parametric and non-parametric techniques has graphically revealed that rainfall discrepancy occurred between the eight gauges. All seven gauges excluding Nuweberg, showed a positive linear relationship based on the rainfall amongst the gauges in the catchment. This linear relationship substantiates the same pattern in relation to elevation and raingauge location.

The Nuweberg (nb) raingauge expressed a completely different climatic behavior from the rest of the gauges and these differences occur within a radius of approximately 16km. We can therefore assume that Nuweberg falls into a different weather scale type of climate and experiences a different rainfall pattern. The raingauges found in the catchment showed symmetry among themselves regarding their rainfall patterns but great skewness with relation to the Nuweberg raingauge.

The quartile statistical analysis run on all the raingauges showed that the Nuweberg gauge experiences more dispersion in relation to the raingauges found in Jonkershoek.

The significant decreasing trend found in the linear parametric regression analysis has shown that the Nuweberg data could have been influenced by an external climatic factor. The assumption can be made from the exploratory statistical analysis that rainfall distribution is consistent among seven gauges, but that Nuweberg experienced an opposite annual rainfall response. The use of the parametric and non-parametric statistical techniques proved that variability does exist between raingauges in relation to their annual rainfall, but the response was differently among the gauges.

6.4 Sequential analysis and sequential differences results

The sequential analysis revealed that there is a strong rainfall relationship between gauges located inside and near the top of the mountain range.

The sequential analysis has provided evidence that gauges located inside and near the top of the mountain range showed spatial resemblance towards their topography and climatic characteristics. The results from the sequential analysis also indicated that a higher proportion of annual rainfall tends to be sequentially linked, due to influences on all the raingauges. Two distinct weather scenarios had been identified, residing from incoming frontal rainfall from the Atlantic Ocean. First frontal rainfall patterns enter the catchment from a north-westerly direction and secondly from a southerly aspect coming from the ocean. This was clearly established from the rainfall patterns between the gauges in and around the catchment and from anomalous rainfall patterns from Nuweberg raingauge.

Reason *et al.,* (2003) cited from their research article on inter-annual winter rainfall variability that the HadAM3 model years with wet and dry winters over the study area also tended to be those that were anomalously wet or dry. The HadAM3 climate model is an atmospheric general circulation model using average monthly global sea surface-temperatures (SST) to measure inter-annual variability in rainfall, over a 10-year period.

The statistically sequential analysis showed that one weather pattern is the dominant driving process of the annual rainfall values that formed the symmetrical or sequential pattern and falls in the line of association amongst them. The second behavior is the opposite weather pattern experienced by the raingauges in and around the catchment from the anomalous rainfall. These opposite annual rainfall events seem to be derived from different weather behavior in the catchment.

These rainfall events are clearly anisotropic and driven by mesoscale weather systems. This opposite weather behavior observed between the local gauges and Nuweberg, were established by the sequential analysis. These opposite climatic influences are further contributing to rainfall dispersion and variability among gauges and dry and wet annual differentiation rainfall spells between Nuweberg and rest of the other gauges. Reason *et al.,* (2003) argued that South Atlantic Sea-Surface Temperatures (SST) patterns induce atmospheric conditions favourable for rainfall in three ways. Firstly he referred to negative Sea-Surface Temperature anomalies that act like positive orographic forcing, in order to satisfy the conservation of potential vorticity which resulted in storm tracks approaching the southwestern Cape further north than usual.

Analysis of the sequential differences of annual rainfall years revealed that the number of dry spell occurrences are more prevalent among the gauges located in the catchment, but is declining when moving higher up in altitude along the mountain sides. These drier spells experienced by gauges inside the catchment were normally following similar trend behavior with few extreme rainfall occurrences. The lowest lying gauge b1 seem to be more susceptible to dry conditions over the 61-years of annual data. A possible leading driver of the drier conditions is likely driven by frontal systems coming from a more south westerly direction from the ocean.

The wetter rainfall spells seem to show some sort of consistency in some of the annual rainfall events to the number of wet years for most of the gauges. Again, the results from the sequential differences revealed that the higher you move up the valley the wetter it becomes. From the 61-years of annual rainfall, only three years responded to the same sort of rainfall behavior for all the eight gauges. The rainfall behavior illustrated for years 1972, 1978 and 2002 showed that irrespective of increases or decreases from all the gauges, the rainfall response was the same. It was found that only gauge b1 had the lowest amount of wet spells. The amount of additional rainfall caused by these wet spells is significantly higher and totals were found between 343 to 700 mm per annum.

The climatic weather drivers behind these wet spells are cold frontal systems moving from a north-westerly direction up the trough of the catchment. The gauges could also be classed in altitudinal rainfall bands as the gauges with the same heights expose the same number of wet spells. We can therefore expect that gauges overall responded similarly on the same altitudinal level or close to that specific elevation. The sequential differences revealed that Nuweberg raingauge is experiencing a different weather pattern due to opposite rainfall behaviour with the rest of the other gauges. The higher altitudinal gauges experienced higher wetter spells due to exposure to both north-westerly and southerly driven rainfall patterns and were less affected by mountain barriers.

The sequential differences illustrated that specified cyclical rainfall periods for all the gauges cannot be distinguished from the annual rainfall totals. Years with rainfall events differ after every three year cycle when the rainfall changes in totals and direction again. The sequential differences revealed that rainfall variability and dispersion increased as the altitudes increased. Climatic factors like wind and eddying effects could have contributed to the rainfall variability for higher located gauges. The distribution of the rainfall is exposed to more scattering at the higher altitudes and less positive spreading of rainfall.

6.5 Analysis of centralised moving medians

The smoothing of any annual rainfall data needs to be done carefully especially in a complex terrain like that of the Jonkershoek valley, because the mountains act as a blocking system or mountain barrier and create more orographical type of rainfall. This is especially so in winter because any rainbearing clouds approaching the valley will be subject to a trigger effect of the high peaks of the Jonkeshoek catchment. Tyson and Preston-Whyte (2000: page 135) described approaching fronts as ‘the equilibrium boundary of separation between neighbouring masses of cold and warm air is never vertical, but always slopes to a degree dependant on both the temperature and the velocity differences in air masses.

The incoming frontal systems are entirely dependant on the ruggedness of the Jonkershoek catchment terrain as a result of the orientation of the slopes in the valley. The fact that raingauge b2 receives a higher annual rainfall than the gauges located at a higher altitude is due to this slope orientation. This mesoscale rainfall behavior could be the result of rainfall shifts and according to Tyson and Preston-Whyte (2000) it can range between a kilometre and a few hundred kilometres driven by local wind systems. This could be the result of a different behavior of the climate that has lead to possible decline in westerly winds to the southern coast from the Atlantic Ocean. The climatic trend Atlas by Schonwiëse and Rapp (1997) observed the same negative behavior for data analysed between years 1891-1990.

Rainfall losses depicted from the gauges in the Jonkershoek valley demonstrate the elevation-dependent behavior of rainfall in the catchment. The highest loss over the 61-period was found on the crest of the mountain at gauge b17 and the lowest at b1 located at an elevation of 244 m.a.s.l. The results show that losses at higher altitudes are 10 times more than the losses at gauges located at lower levels.

The 61-year of annual rainfall is subjected to trends or cycles in the rainfall. These cycles are linked with either wet of dry periods which is subjected to time. The trends also revealed that rainfall is decreasing slightly over time. This behavior is confirmed by the linked scattering analysis with the exception of Nuweberg with its opposite rainfall behavior.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The objective of the analysis was to establish long-term trends in the annual rainfall values in the Jonkershoek valley and whether declines or increases had taken place in rainfall over time. The analysis gives sufficient evidence to reveal that there are two clear decisive rainfall patterns between the gauges found in the catchment. The relationship between gauges in the catchment, depending on their annual rainfall values, has no specific pattern and varies from year to year.

A tendency is that the Jonkershoek valley is becoming more exposed to south westerly frontal systems. These south-westerly frontal systems are associated with drier conditions in the catchment, but are linked with rainfall elsewhere in the Cape Province. This behavior could possibly be related to a shift in mesoscale weather systems around the southern part of the continental land mass. From the calculated moving medians, this shift could have started in the 1970's.

When carrying out statistical tests on the annual rainfall data, assumptions were made that rainfall data were normally distributed and that the annual observations were independent among each other. Having shown this, the normal distribution of the annual rainfall data allowed the use of the different statistical parametric tests.

The annual rainfall in the Jonkershoek valley is clearly related to the topographical characters and associated with orographic rainfall behavior over the catchment.

The final conclusion is that rainfall has revealed mesoscale variability about the gauges, with the apparent rainfall patterns changing to a more southerly aspect. This needs to be further explored. Decline in rainfall over time is also evident, but on a very small scale. The 61-year rainfall data set was found to be of limited value for revealing definite long-term changes. A longer period of data may prove to be of a more applicable option.

The application of the sequential methods for the analysis seems to be the best appropriate measure to investigate the long-term rainfall in the catchment. Annual rainfall events are complex weather behavior with each one consisting of its own characteristics. Using the sequential analysis methods expresses a chance to analyse rainfall data for an individual year before reaching a conclusion to move to the following year's rainfall. The sequential analysis distinguished between the normal and anomalous rainfall behavior and contributed to the reaching of certain conclusions about the declining rainfall and a possible change in mesoscale weather behavior.

A greater advantage would have been the display of the results from the sequential analysis in a spatial format.

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