# Chapter Four: Results and Discussion

## 4.1 Introduction

Rainfall in South Africa is highly variable in spatial distribution, with the southeastern coastal region receiving high annual rainfall, whilst the western and interior regions of the country are arid to semi arid (Mukheibir, 2005). In addition, South Africa experiences seasonal and inter-annual variations in rainfall (Mukheibir, 2005), resulting in low river flow for much of the year with periodic high flows, thereby limiting the availability of water resources through the dry season (Mukheibir & Sparks, 2003). Inter and intra-annual climate variability has a great impact on the agricultural sector (Fauchereau *et al.*, 2003). For instance, the timing of rainfall in early February is crucial for the growth of maize in southern Africa (Jury *et al.*, 2002). The most severe 20$^{th}$ century drought is said to be that of 1983, and was followed by the 1991 to 1992 drought in southern Africa. Drought is associated with abnormally low rainfall and thus associated with reduced flow thereby demonstrating the severe impact drought can have on the water resources and food security of the country (Mason & Joubert, 1997). In contrast, the floods of September 1997 and February to March 1998 had equally devastating regional impacts.

Although claims that southern Africa is becoming drier date back to the 1800's, more recent instrumental records do not support the contention for decreasing rainfall in southern Africa (Mason, 1996). A natural variation in annual rainfall is expected, with wet and dry periods usually lasting for a number of years (Van Wageningen & du Plessis, 2008). Dry spells were found to be more persistent than wet spells, and South African rainfall data are sufficient and reliable to indicate a quasi 20 year oscillation, with the fluctuations having undergone a shift only once when the world climate underwent changes (Tyson, 1980). Studies have shown that oscillations are regionally specific where the quasi 20 year oscillation corresponded with the summer rainfall region, while the 10 to 12 year oscillation coincided with all season rainfall regions of the southern Cape and a quasi oscillation occurring every two years in the arid interior region of southern Africa (Tyson, 1980).

The study of daily, monthly and seasonal observed rainfall changes is important for comparison with the changes simulated by models, because model outputs have to be downscaled to represent correct regional climate change impacts (Fauchereau *et al.*, 2003). This study examines long-term annual precipitation data, seasonal data and 5-year moving average annual total trends in strategically chosen catchments across southern Africa to cover the southern, eastern interior and western interior regions of the country. This chapter presents the results and discusses rainfall trends and their potential impact on river flow.

## 4.2 Trends in inter-annual rainfall

Annual rainfall over southern Africa ranges from over 1000mm along the eastern mountain regions to less than 200mm in some western parts of the sub-continent (Tennant, 1998). The following section examines the long-term annual rainfall trends for three stations in each region of southern Africa using the Mann Kendall statistic, and correlates the rainfall to long-term river flow data using Kendall tau.

### *4.2.1 Vaal River*

The Vaal River was chosen to represent the western-central interior region of southern Africa. The Klerksdorp Hartbeesfontein (hereafter referred to as Klerksdorp), Bloemhof and Villiers rainfall stations were selected because the stations represent upstream points to the Vaal River at Schoolplaats river flow station and therefore the rainfall received at these stations impact on the flow of the river. The monthly mean values exhibit the distribution of climate and climate variation over an average year (Nicholson, 2000). Southern African rainfall exhibits distinct seasonality within each year (Tyson, 1978), with the greater amount of rainfall received between October and March (Appendix, Tables 1 to 3) (Mason, 1996), apart for the Western Cape.

An analysis of the annual precipitation data over the period 1909 to 2008 reveals a decreasing trend at the three rainfall stations: Klerksdorp, Bloemhof and Villiers located upstream of the Vaal River station (Fig. 7). The annual precipitation at the Villiers station displayed the steepest declining slope estimator according to Sen's method (Q = -2.6) of the three stations and was the only significant rainfall trend in the Vaal River catchment (Fig. 7). The annual rainfall decreased by 41% at the Villiers station, by 24% at the Klerksdorp station and 19% at the Bloemhof station over the period 1940 to 2008. This period was chosen since it is the data set with the shortest record length in the Vaal River catchment and therefore the common period of record between stations.

In correspondence with the significant decreasing average rainfall trend in the Vaal River catchment, the river flow at the Schoolplaats gauge (Fig. 8) also significantly decreased over the period 1940 to 2008, with a Kendall tau correlation coefficient of 0.3 and a traditional linear correlation coefficient r of 0.5. Kendall tau utilizes a different scale of correlation compared to the traditional linear correlation coefficient r, therefore Kendall tau is generally lower in values compared to r, for example a strong linear correlation coefficient of 0.9 corresponds to a Kendall tau value of 0.7 (Helsel & Hirsch, 2002). The Vaal River flow declined by 64% while the average annual rainfall declined by 19% over the period 1940 to 2008, indicating that the abstraction of water and evaporation from the river increased with time. However a complete abstraction record was not available to confirm this. In addition, the Vaal Dam was completed in 1938 and the wall height was increased, during the 1950s and in 1985, consequently increasing the capacity of the dam and thereby decreasing the downstream flow (DWAF, 2009). The period after 1970 showed a consistent decline of runoff for most rivers in southern Africa (Fanta *et al*., 2001).

The Kendall tau correlation values between the individual rainfall stations in the Vaal River catchment and the Vaal river flow ranged from of 0.2 to 0.3 (Table 5). Distinct peak river flow

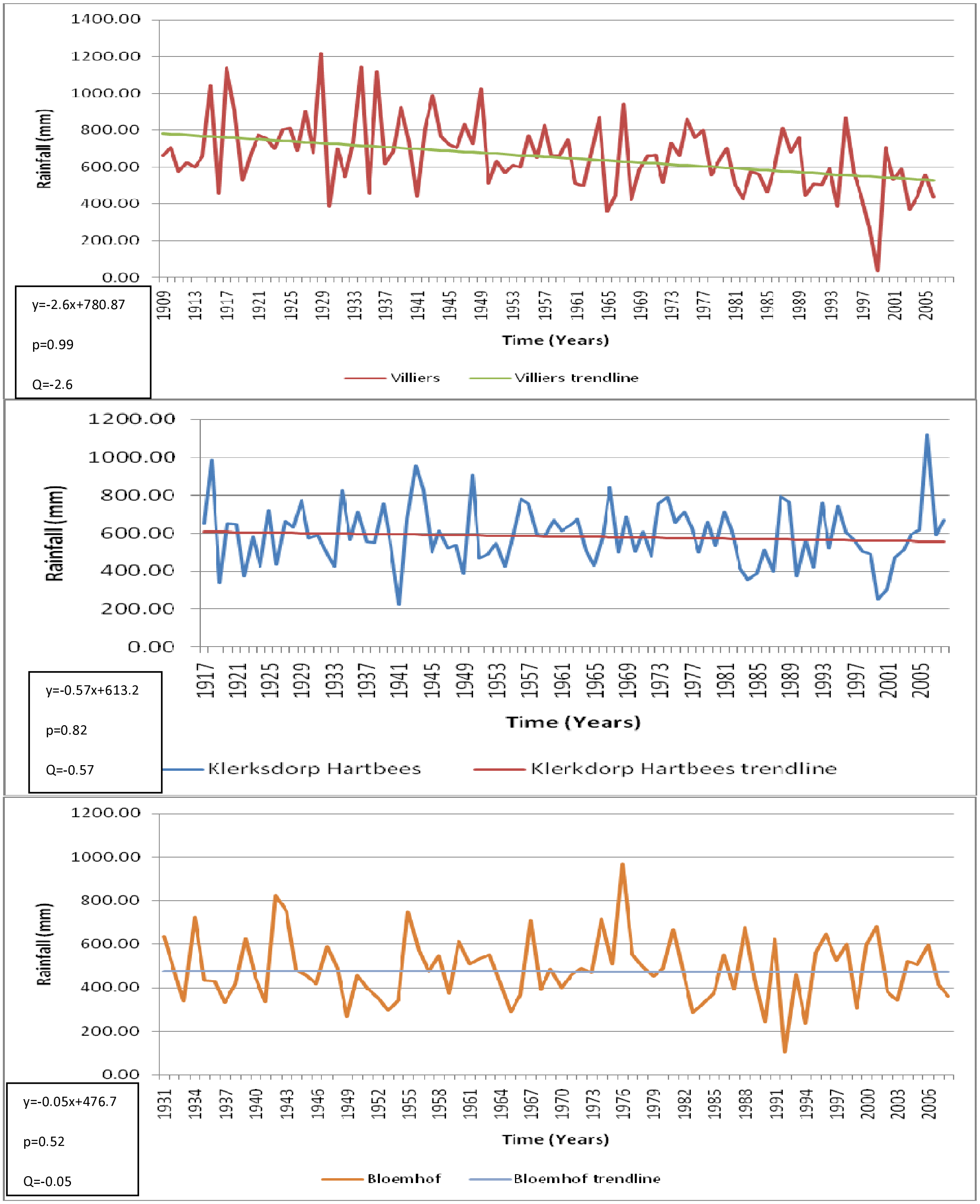



Figure 7: Time series showing the annual rainfall for the different stations in the Vaal River catchment.

is observed at the Schoolplaats station during 1943, 1944, 1957, 1975, 1976, 1996 and 2000 and the average rainfall for the region also displayed peak rainfall during 1943 and 1976 (Fig. 8). The Vaal River experienced reduced flow over the periods 1969 to 1973, 1979 to 1987, 1990 to 1995 and 2003 to 2005 (Fig. 8). The Vaal River also experienced reduced flow over the period 1958 to 1966, but not to the extent that has been measured during more recent years. According to Tyson (1980), 1963 to 1972 was a prolonged dry period over the entire sub-continent, while 1954 to 1962 was a wet spell over the majority of the region. However, the Vaal River only experienced high levels of flow in 1955 and 1957, despite the extended wet spell (Fig. 8).

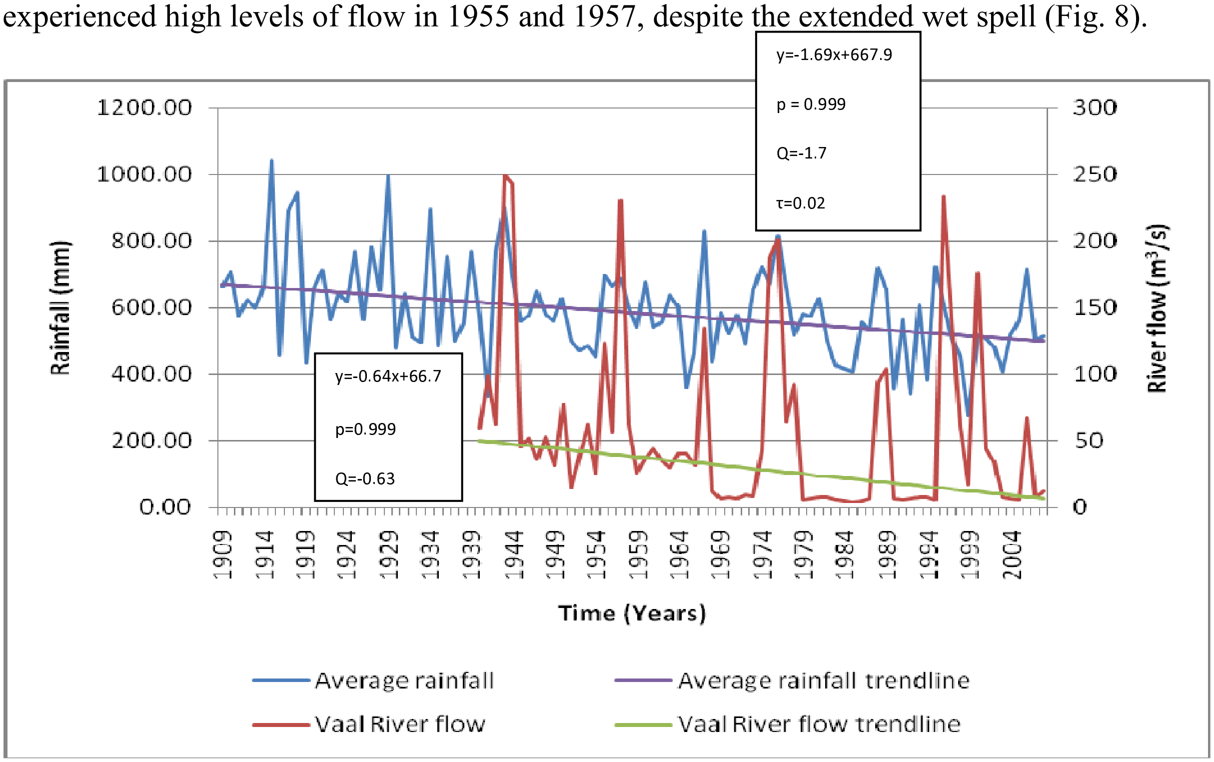



Figure 8: Time series showing the average rainfall in the Vaal River catchment and annual river flow at the Schoolplaats station.

## *4.2.2 Orange River*

The annual rainfall at the Lille station within the Orange River catchment increased by 4% while the annual rainfall at the Middelplaats and Zastron stations decreased by 5% and 7% respectively over the period 1932 to 2008 (Fig. 9). The percentage increases and decreases in annual rainfall

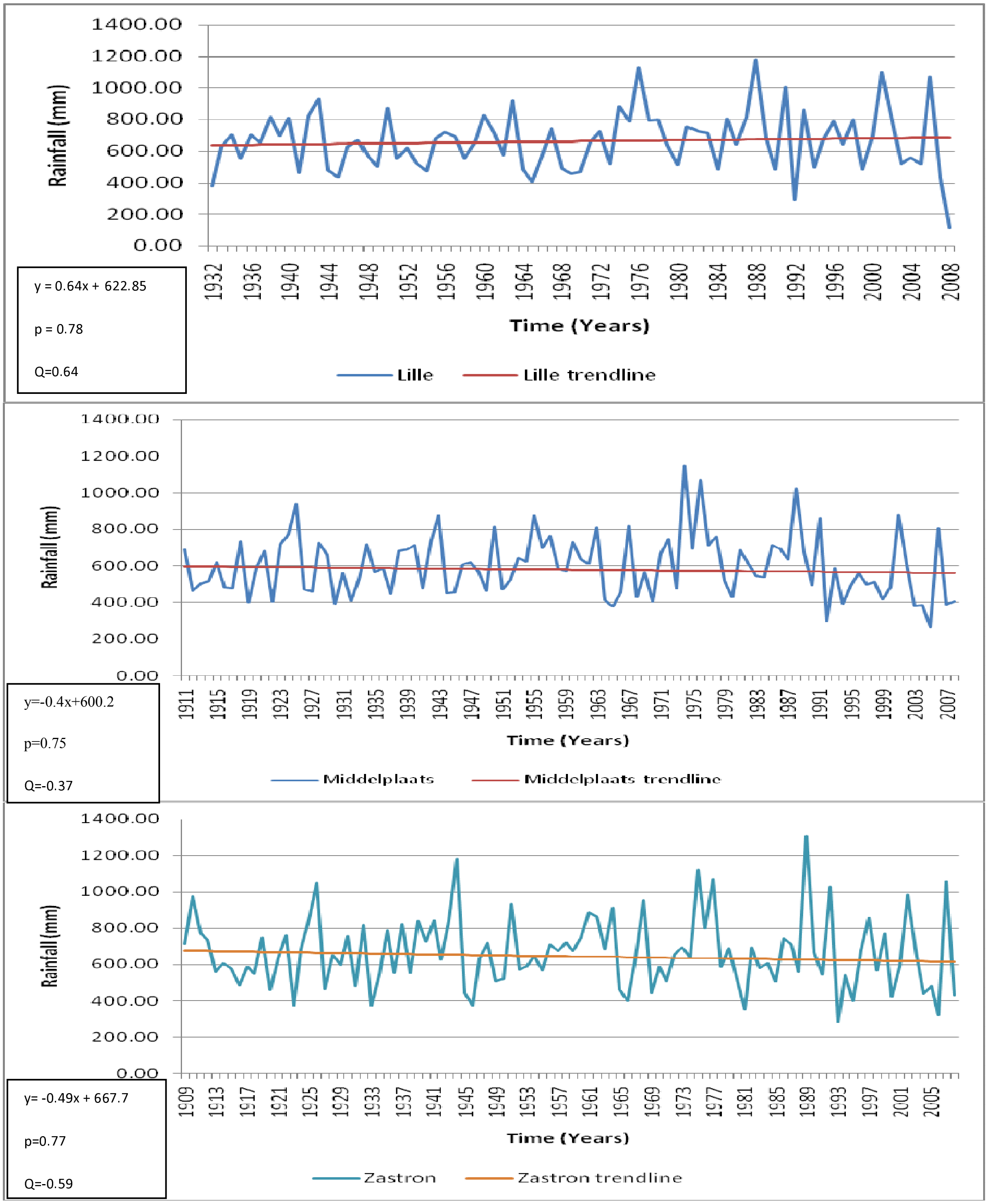



Figure 9: Time series showing the rainfall at different stations in the Orange River catchment.

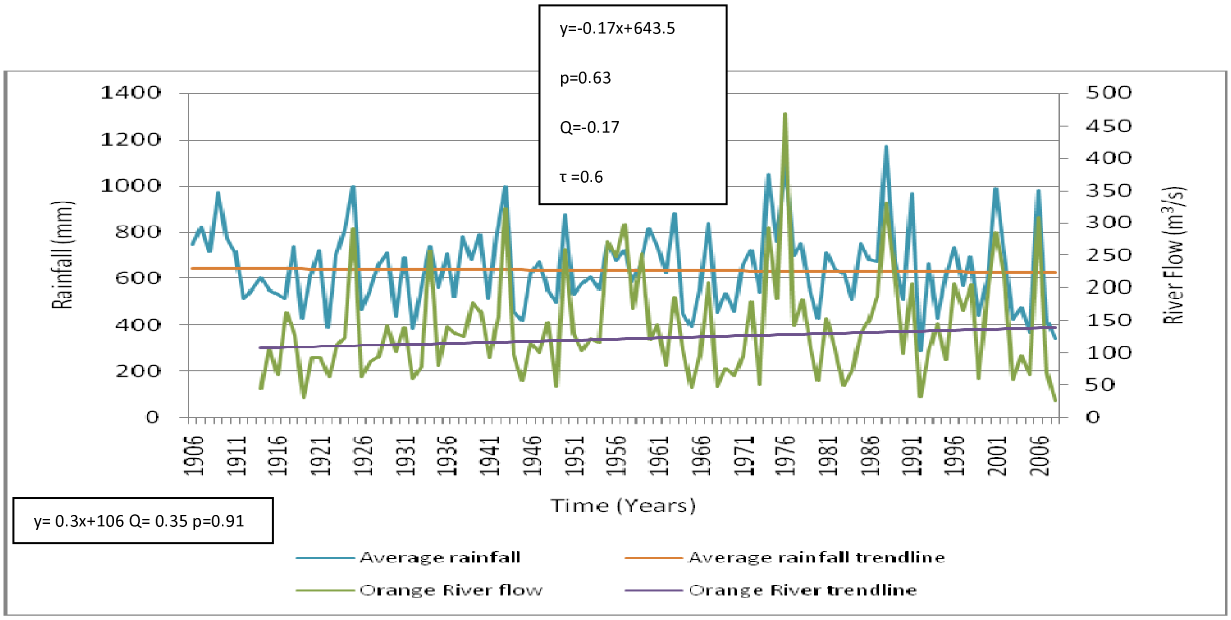



Figure 10: Time series showing the average rainfall in the Orange River catchment and annual river flow at the Orange at Aliwal North station.

are small, and it is possible that the accuracy of the measurements at the different stations may have contributed to the inconsistency in the data. The average annual rainfall for the Orange River catchment indicates an overall 2.5% decreasing trend, which does not correlate with the 34% increasing river flow trends at the Aliwal North station over the period 1932 to 2008 (Fig. 10). The Orange River is the only southern African river in this study that showed an increasing flow trend. However a decrease in annual flow over the period 1935 to 1997 was recorded at a downstream point along the Orange River (DEAT, 1999), DWAF operates three river gauges on the Orange River, close to the Lesotho border, which measure the runoff from Lesotho (Carter, 1967). New rainfall and river flow gauges were set up in the Upper Orange River Catchment during the study by Carter (1967), which was noted by the author at the time as extremely important for sourcing water from Lesotho. Schulze & Perks (2000), using GCMs, found that the mean annual runoff for the majority of quaternary catchments in the Orange River Catchment is expected to decrease with climate change, with the greatest reduction expected in the eastern part of the catchment in northern Lesotho. It is important to note that in order to provide an accurate assessment of the long-term river flow trends in association with catchment rainfall changes, it would be necessary to include full extraction, evaporation and catchment infiltration data, which are simply not available. Notwithstanding this, the study of the relationship between annual rainfall and river flow was important in the planning of the Lesotho Highlands Water Project, whereby water is sourced from Lesotho by South Africa. Whilst inter-annual variability in river flow is important for determining the reliability of water yields for transfer, understanding long-term precipitation trends is important for projections of future flow (Sene *et al.*, 1998).

Rainfall at the stations in the Orange River catchment was relatively high in comparison to other regions of South Africa. The Lille station received 1132mm of rainfall in 1976, 1181mm in 1988, 1008mm in 1991, 1105mm in 2001 and 1069mm in 2006. The Middelplaats station received 1114mm in 1974, 1070mm in 1976, 1025mm in 1988, 881mm in 2001, 807mm in 2006, while the Zastron station received 1118mm in 1974, 1069mm in 1976, 1307mm in 1988, 993 mm in 2001 and 1058 mm in 2006. In concurrence with the common years in which the stations received high rainfall, the Orange River at Aliwal North station also displayed high flow in 1976 (470 $m^3s^{-1}$), 1988 (331 $m^3s^{-1}$), 2001 (284 $m^3s^{-1}$) and 2006 (308 $m^3s^{-1}$).

The Lille rainfall station data display the strongest correlation with the Orange River flow, with a Kendall tau value of 0.57, while data from the Middelplaats and Zastron stations also display strong correlation coefficients of 0.55 and 0.53. In addition, the Thaba Tseka rainfall data in Lesotho also showed a strong correlation (0.53) with the Aliwal North station river flow data (Appendix, Table 8). The Thaba Tseka station, however, is missing annual rainfall data over the period 1971 to 1975. The lack of a complete record affects the type of trend observed at the Thaba Tseka station. The annual rainfall at the Thaba Tseka station indicates a long-term increase of 18%, whilst annual rainfall decreased by 0.6% at the Semonkong station over the period 1967 to 2006 (Appendix Table 8 and Figure 6). The Semonkong station, located in western Lesotho, received an annual rainfall of between 258mm and 863mm per annum over the period 1967 to 2006 while the Thaba Tseka station, located west of Semonkong, and received annual rainfall totals of between 400mm and 1200mm during the same period (Fig. 11). This could be due to the variability in rainfall across Lesotho, since the mean annual rainfall of 780mm per annum varies from 500mm in the southwest of the country to 1600mm in the northeast (Sene *et al.*, 1998). Although Hyden & Sekoli (2000) indicate that the highest annual rainfall in western Lesotho was 1097mm and the lowest 427mm over the period 1886 to 1993, the minimum recorded at Semonkong, was 254.5mm in 1992, whilst the maximum was 1183.2mm in 1976 (Appendix, Table 9). The highest annual rainfall at the Thaba Tseka station was 863.3mm in 2006 and the minimum was 258.3mm in 1968 over the period 1965 to 2006. However, the percentage change in annual rainfall at the South African rainfall stations in the Orange River catchment notably differ compared to the Lesotho stations. The annual rainfall decreased by 2% and 4% at the Middelplaats and Zastron stations respectively, and increased by 2% at the Lille station over the period 1967 to 2008.

The Kendall tau coefficient (section 4.2, Table 5) for the correlation between the average annual rainfall over the Lille, Middelplaats and Zastron stations and the river flow at the Aliwal North gauge was 0.6, the highest in this study (Fig. 10). The linear correlation coefficient for the average annual rainfall and the Orange River flow was 0.8 compared to the Kendall tau value of 0.6, indicating that the correlation is strong. The majority of the flow oscillations correspond well to average rainfall (Fig. 10), with the peak flows corresponding well with mean annual rainfall during 1943, 1950, 1988, 2001 and 2006. For instance, when the annual average rainfall, over the three rainfall stations in this study, dropped to 289mm in 1992, the annual river flow also decreased to $30m^3s^{-1}$. The 1983 river flow also decreased to $49m^3s^{-1}$ when the average annual rainfall, over the three rainfall stations in this study, was 622mm. Such disparity may be due to the fact that dry years are characterized by 50 to 80% reductions in 'normal' rainfall, whilst runoff is reduced by only 20 to 50% during such dry years (Jury, 2002). The mean 1994 rainfall and flow data do not correspond (Figure 10). An examination of the monthly flow (Appendix, Table 7) indicates a high flow during the first six months of the year and a low flow for the remainder of the year. This could be due to high rainfall in the later part of the previous year 1993, resulting in high flow in the earlier part of 1994.

### *4.2.3 Mgeni River*

The Mgeni River catchment is located in the eastern rainfall region of southern Africa, which has the highest runoff per annum (11.4%) in South Africa (DEAT, 1999). GCMs indicate that the Mgeni River catchment will display a 0 to 12% decrease in the mean annual runoff over the

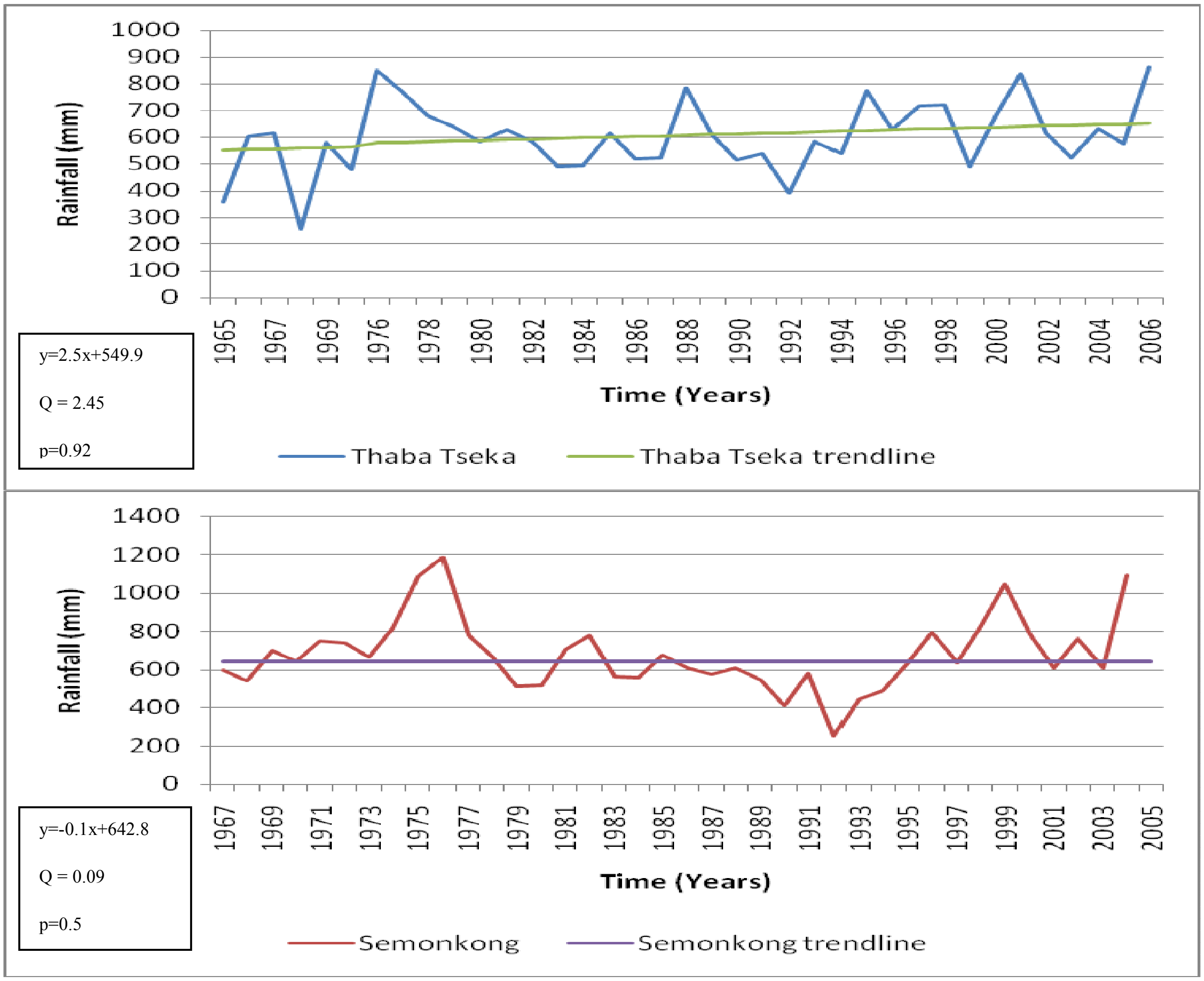


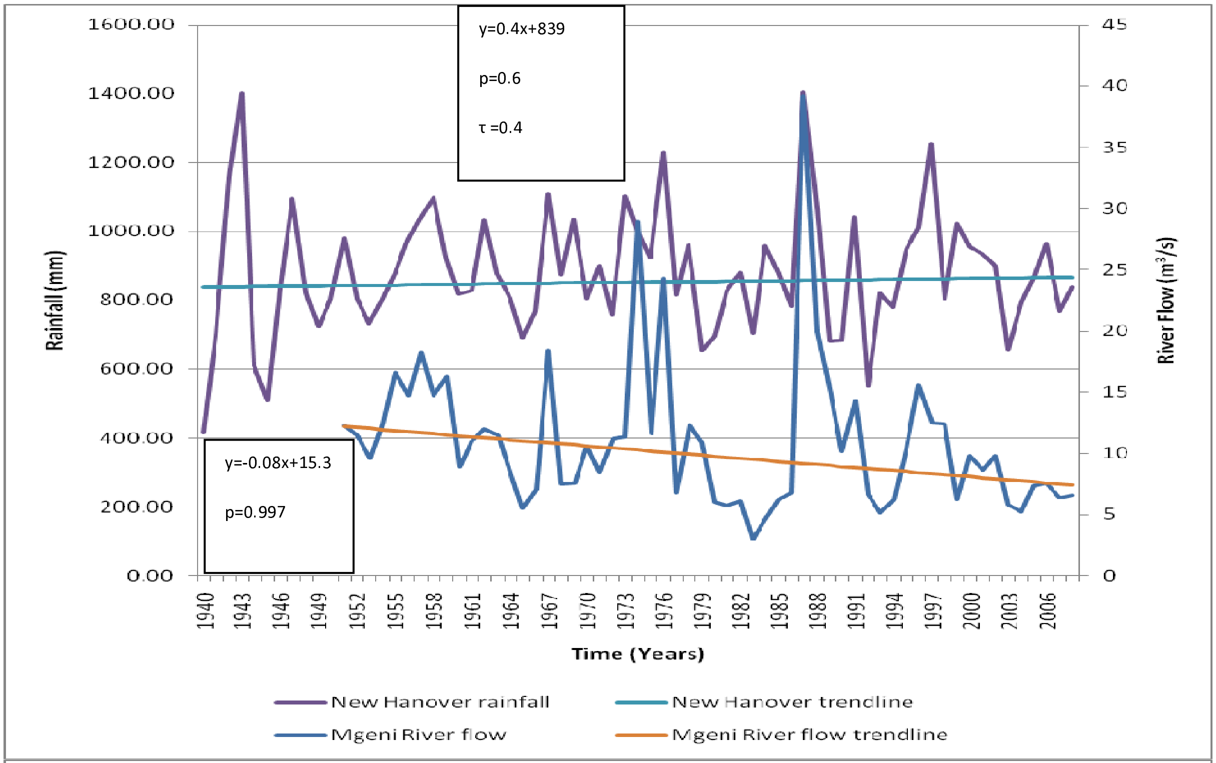

Figure 11: Time series showing the rainfall at the Lesotho stations in the Orange River catchment.

eastern half and a 12 to 25% reduction over the western half of the catchment under future climate conditions (Schulze & Perks, 2000). Once again, as observed over the Orange River catchment, in order to obtain a complete assessment of rainfall and river flow trends in a catchment, several stations need to analysed, but the primary limitation is the lack of all required data. The longest available river flow data for the Mgeni River catchment is only 57 years.

The annual precipitation at the Mistley rainfall station in the Mgeni River catchment indicates a 1.5% decreasing trend, however an 11% increasing trend is observed at the New Hanover station over the period 1940 to 2008, yet neither trend was significant at the 95% significance level. It is important to note that the Mistley station has a larger portion of missing data (5%) compared to the New Hanover station (1.5%) (Appendix, Tables 11 and 12), which may have influenced to the differing trends at the two stations within the catchment, since the substitute average data are not a true reflection of the actual rainfall. The Mistley station recorded unusually low annual totals for the eastern region of South Africa in 1999, 2003 and 2005, which contributed to the decreasing trend observed. It has been previously shown that KwaZulu-Natal has experienced significant decreases in annual precipitation (Kruger, 2006). In contrast, Groisman *et al.* (2005) argue that the annual rainfall totals over the eastern regions of South Africa have not changed over the period 1906 to 1997. In addition, a third study showed that the eastern half of South Africa is expected to become wetter (Christensen, 2006). As a result, the different studies have produced different trends in the eastern region of South Africa. The Mgeni River flow data indicate the most dramatic decreasing trend of all the rivers examined in this study, over the period 1951 to 2008, with a slope estimate of 0.83 (Fig. 12). The extraction of water from the Midmar Dam may be an important contributing factor for the drastic decline in river flow.

The Kendall tau correlation coefficient between the Mgeni river flow and the annual rainfall at the New Hanover station is 0.4, while the Kendall tau correlation coefficient for the Mistley station annual rainfall and Mgeni River flow is 0.2. The average peak flow recorded in 1987 at the Mgeni river flow station corresponded to the maximum rainfall at the New Hanover station (Fig. 12). The major monthly contributors to the peak average annual flow in 1987 were the September and October events (Appendix, Table 13). River flow dropped substantially in 1983, but the decrease cannot necessarily be linked to rainfall, given that a dramatic drop was not observed at both stations, thus indicating a possible increase in abstraction (Fig. 12).

Both the New Hanover and the Mistley stations experienced high rainfalls during 1942 and 1943 (Fig.12). Annual rainfall at the Mistley station was 1222mm and 1530mm for 1942 and 1943 respectively, whilst the New Hanover station received 1157mm and 1401mm of rainfall during the same years.



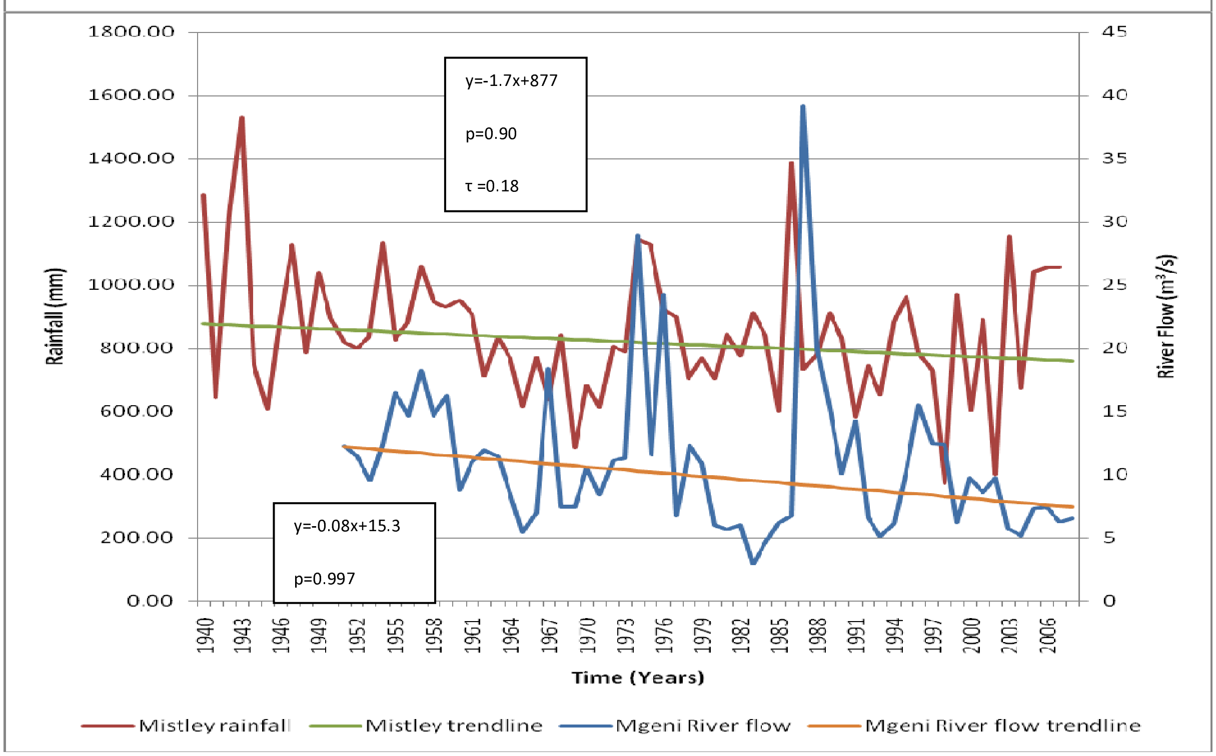



Figure 12: Time series showing the rainfall at the New Hanover and Mistley stations and river flow in the Mgeni River catchment.

### *4.2.4 Tugela River*

The annual precipitation at the Tugela Ferry station indicates an 18% increasing trend (Fig. 13), whilst 5% and 11% decreasing rainfall trends are recorded at Moorside and Swartwater respectively over the period 1932 to 2008 in the Tugela River catchment (Fig. 13). An examination of the monthly and daily rainfall at the Tugela Ferry station indicates that the high rainfall recorded for 1992 is a result of 455mm of rainfall recorded on the 8th of December, 110mm on the 21st of December and 95mm on the 23rd of December. The high rainfall may be due to errors in the data records. Any inaccuracy in measurement also affects the type of trend observed for the Tugela Ferry station; that is an increasing trend was observed whereas the remaining stations in the Tugela River catchment exhibited decreasing trends. Although the annual rainfall totals over the period 1906 to 1997 did not change much over the eastern regions of southern Africa during the last 30 years, there has been a significant increase in heavy rainfall events during this time (Groisman, 2005). Overall, the average rainfall for the three rainfall stations in the Tugela River catchment indicate a significant decreasing trend, which corresponds with the Tugela River flow data at the Tugela Ferry station (Fig. 14), however the correlation coefficient is weak ($\tau$=0.25) (Table 5). The weakest correlation ($\tau$=0.07) is between the Tugela Ferry rainfall and the river flow data, which may be a result of the inaccuracy of measurements at the station. DEAT (1999) is aware that Tugela River is experiencing reductions in flow, and has projected that the river will be fully utilized by 2025 (DEAT, 1999).

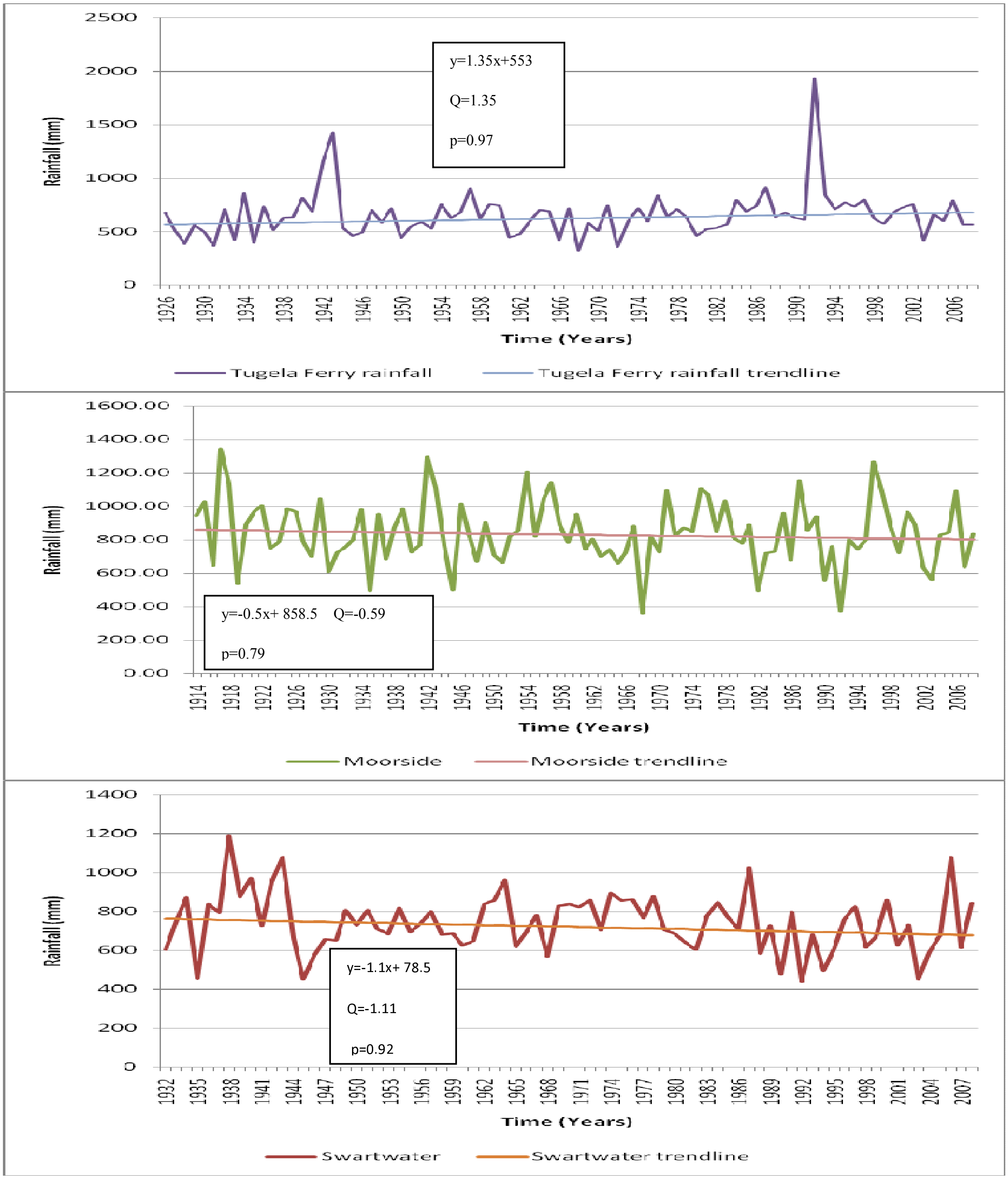



Figure 13: Time series showing the rainfall at different stations in the Tugela River catchment.

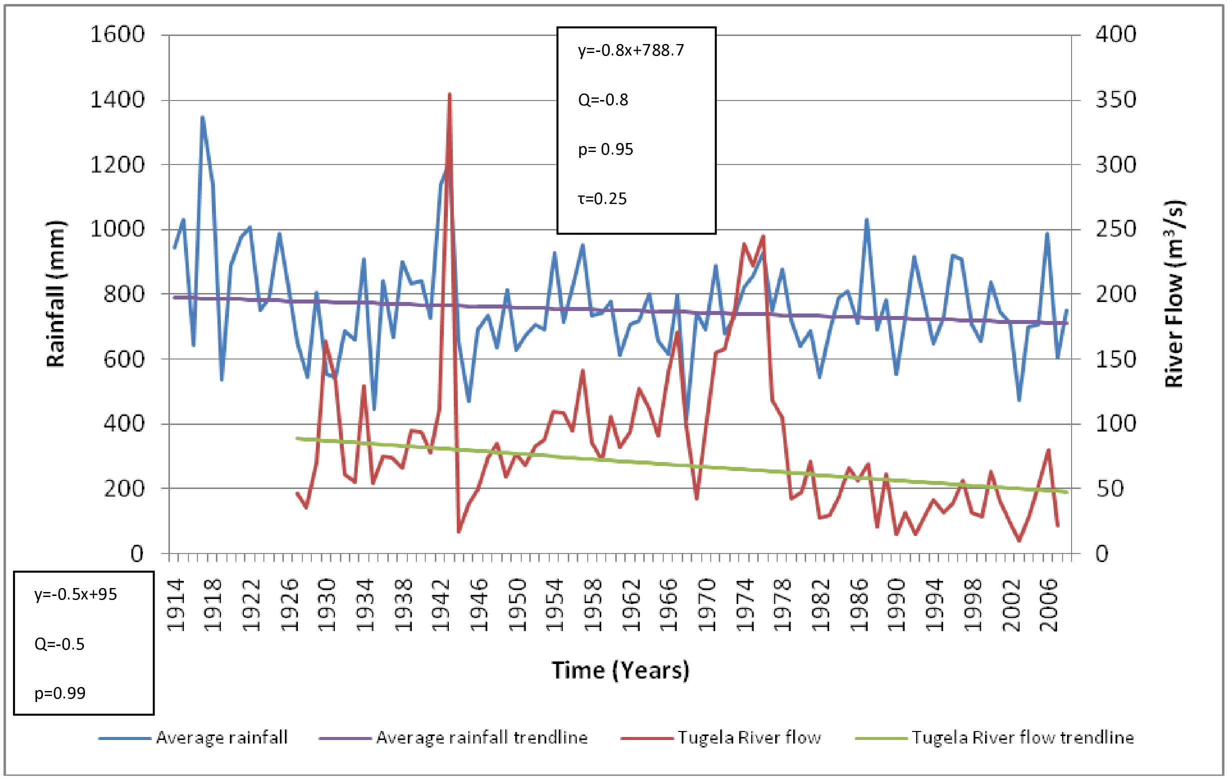



Figure 14: Time series showing the average rainfall and the Tugela River flow in the Tugela River catchment.

### *4.2.5 Breede River*

The Breede River catchment, located in the southwestern region of southern Africa, receives winter rainfall (DWAF, 2004), which averages between 200mm and 1500mm per annum (Tennant, 1998). A study of the monthly total rainfall for the Malabar station (Appendix, Table 19) clearly indicates that the region receives most of its rainfall between April and September. A study focusing on the southwestern Cape region has identified significant inter-annual rainfall variability (Reason *et al.*, 2006).

Although the annual precipitation at the Touwsrivier and Malabar stations in the Breede River catchment has increased over the period 1918 to 2008 and 1944 to 2008 respectively, the annual river flow significantly decreased at the Bree River at Ceres station over the period 1923 to 2008 (Fig. 15). The Breede water management area consists of several dams, whereby water is

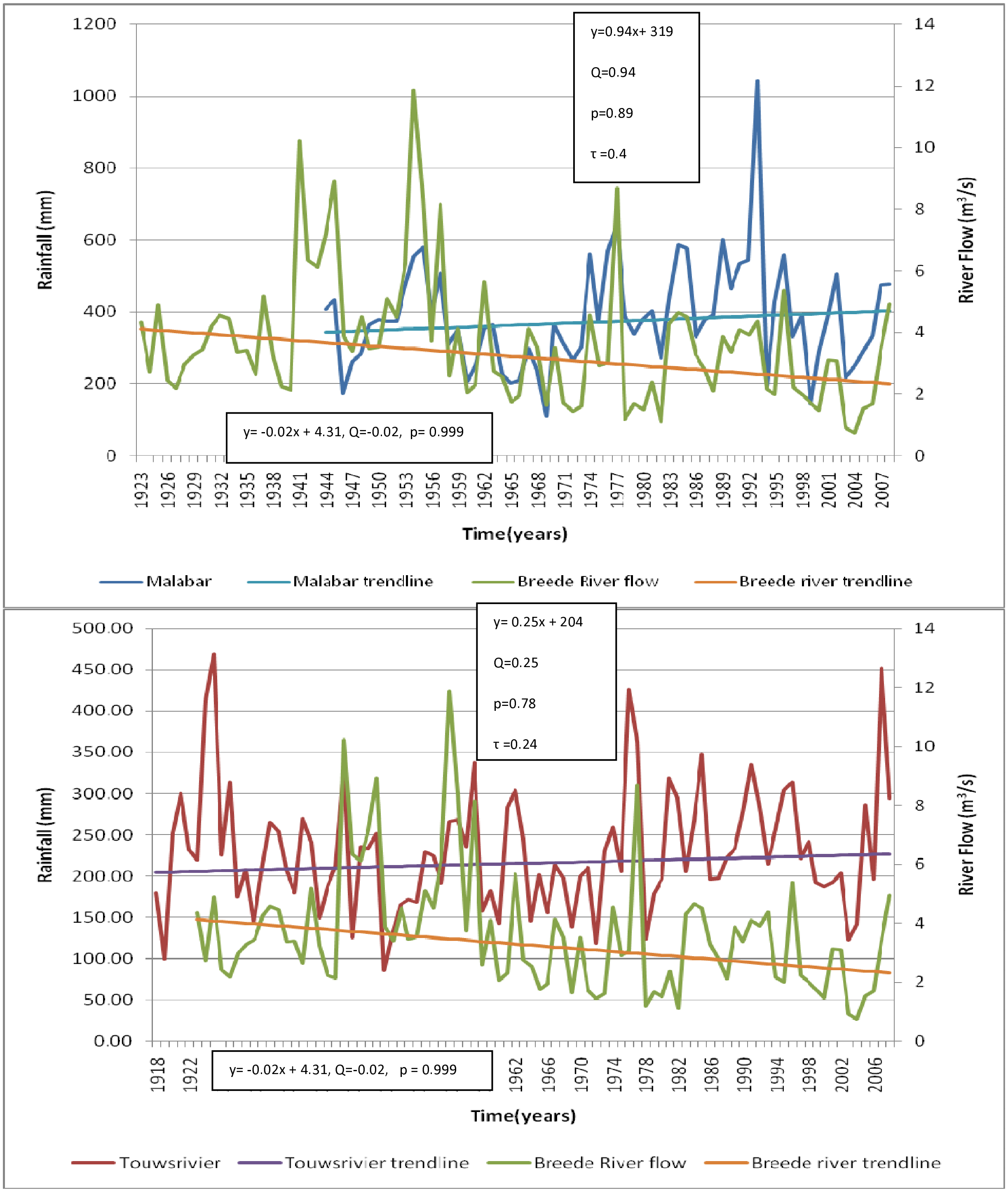



Figure 15: Time series showing the annual rainfall at different stations and river flow in the Breede River catchment.

transferred into the dams from the Berg water management, seasonally stored and transferred back to the Berg water management during the dry season with additional water from the Breede water management area (DWAF, 2001). The decreased annual river flow found in this study could be due to the increased extraction of water from the Breede River, but this is difficult to confirm as extraction data are not available. The Malabar annual rainfall displayed a greater correlation ($\tau$=0.4) to the annual river flow at the Bree River at Ceres than the Touwsrivier ($\tau$=0.24) annual rainfall over the period 1944 to 2008 (Table 5). Rainfall peaked at 1042mm at the Malabar station in 1993, with the remaining years recording between 200 and 600mm per annum over the period 1944 to 2008. The exceptionally high 1993 annual total for Malabar is due to the high rainfall total of 547mm in July (Appendix, Table 19), which is unusual for the Western Cape, yet was not observed at Touwsrivier (Fig. 15). The annual rainfall at the Touwsrivier station varied between 100 and 450mm over the period 1918 to 2008. The Breede River experienced devastating floods in November 2008, which damaged properties and agriculture along its banks (Cape Argus, 2008). However the Malabar, Touwsrivier and Bree at Ceres November 2008 records are missing, thus such recent data that would have affected long-term trends could not be included.

An examination of the annual precipitation trend line intercepts (Figures 7 to 15 and Table 5, column B) for all the regions under study indicates that the highest rainfall occurs in the eastern regions of southern Africa, with the Mgeni River catchment receiving the highest amount, followed by the Tugela River catchment. The southwestern regions of southern Africa (Breede River) receive the lowest annual rainfall totals. Only the southeastern coastal region receives high rainfall, whilst the western and interior regions of the country are arid to semi arid (Mukheibir, 2003).

In summary, it may be seen from Table 3 that the annual rainfall trends differed across various sub-regions. Of the 15 rainfall stations examined across southern Africa, 10 stations display a decreasing trend in annual rainfall, however only one was a significant decreasing trend at the 95% significance level, namely that at Villiers. Of the 5 remaining rainfall stations, only one displayed a significant increasing trend, namely that at the Tugela Ferry station. However the Tugela Ferry station recorded high rainfall in a well known drought year, which may be an error and is likely to have affected the trend. An interesting note is that both the stations that displayed a significant trend have long record lengths. According to Tyson *et al.* (1975), the length of record has an inverse relationship with the occurrence of a trend because the number of stations with significant trends increased, as the intervals of different lengths within an observation period decreased. However, Kruger (2006) argues that a longer record length and a greater quantity of rainfall stations are required for the identification of regional trends. In addition, Westmacott and Burn (1997) also acknowledge that short data sets together with natural variability may be inadequate to identify trends.

All three rainfall stations upstream of the Vaal River flow station displayed decreasing rainfall trends and the overall average rainfall for the region exhibits a significant decreasing trend (by 19%) over the period 1940 to 2008. The average rainfall for the interior regions seems to have decreased in both the Vaal and Orange River catchments, but this does not agree with Joubert (1996) findings, which suggest that the interior region of South Africa is likely to become wetter. The annual average rainfall in the Tugela River catchment exhibits a considerable decrease of 7% over the period 1940 to 2008, whilst the Mgeni River catchment has had a 4% decline in rainfall over the same period, but the trend was not significant at the 95% significance level. The annual average rainfall in the Breede River catchment displayed a significant 36% increasing trend over the period 1940 to 2008. The CSIRO general circulation model found that changes in annual mean rainfall over southern Africa under doubled $CO_2$ was not statistically significant (Joubert, 1996). Dry years were found to increase over southwestern, western and eastern regions and decrease over the interior of southern Africa (Joubert, 1996).

Eighty percent of the rivers in this study exhibit significant decreasing trends (Table 4) of annual flow, which concurs with the study by Alemaw & Chaoka (2002). The Vaal River in the central interior region of southern Africa displayed an 85% decline in annual flow, followed by the Mgeni and Tugela Rivers in the eastern region of the country at 39% and 38% decline respectively over the period 1951 to 2008 (Table 4). Annual river flow for the Bree at Ceres in the Western Cape records a highly significant 34% decreasing trend over the period 1951 to 2008. The Orange River flow at the Aliwal North gauge records the greatest annual flow for any river south of the Zambezi, which is understandable given its catchment size, and was the only river indicating an insignificant increasing trend. Reductions in river flow of up to 10% are

Table 3: Mann Kendall trend statistic results for the annual rainfall across southern Africa.

| Region | Rainfall | Normalized | Probability | Trend (A 95% | Sens Q | Sens B (intercept) |
|---|---|---|---|---|---|---|
| Vaal | Klerksdorp | -0.91 | 0.82 | No trend | -0.57 | 613.2 |
| | Bloemhof | -0.23 | 0.59 | No trend | -0.05 | 476.7 |
| | Villiers | -4.06 | 1.00 | Decreasing | -2.6 | 780.87 |
| | Average | -3.64 | 0.99 | Decreasing | -1.7 | 667.9 |
| Orange | Lille | 0.79 | 0.79 | No trend | 0.635 | 622.85 |
| | Middelplaats | -0.62 | 0.73 | No trend | -0.37 | 597.7 |
| | Zastron | -0.86 | 0.81 | No trend | -0.59 | 675.07 |
| | Average | -0.32 | 0.63 | No trend | -0.17 | 643.51 |
| Lesotho | Thaba Tseka | 1.43 | 0.92 | No trend | 2.45 | 549.88 |
| | Semonkong | -0.03 | 0.51 | No trend | 0.09 | 642.79 |
| Mgeni | Mistley | -1.3 | 0.90 | No trend | -1.71 | 876.95 |
| | New Hanover | 0.34 | 0.63 | No trend | 0.39 | 838.68 |
| | Average | -0.49 | 0.7 | No trend | -0.45 | 867 |
| Tugela | Moorside | -0.82 | 0.79 | No trend | -0.59 | 858.48 |
| | Swartwater | -1.45 | 0.93 | No trend | -1.11 | 781.55 |
| | Tugela Ferry | 1.92 | 0.97 | Increasing | 1.35 | 553.02 |
| | Average | -1.68 | 0.95 | No trend | -0.823 | 778.79 |
| Breede | Touwsrivier | 0.8 | 0.79 | No trend | 0.25 | 204.48 |
| | Malabar | 1.25 | 0.89 | No trend | 0.94 | 319.67 |
| | Average | 3.5 | 0.99 | Increasing | 1.3 | 213.8 |

Table 4: Mann Kendall trend statistic results for the annual river flow across South Africa.

| River Name | Normalized Test Statistic(Z) | Probability | Trend (95% significance level) | Sens Q (slope) | Sens B (intercept) |
|---|---|---|---|---|---|
| Orange | 1.34 | 0.910511 | No trend | 0.35 | 106.59 |
| Breede | -3.16 | 0.999199 | Decreasing trend | -0.02 | 4.31 |
| Tugela | -2.91 | 0.998181 | Decreasing trend | -0.5 | 95.1 |
| Vaal | -3.35 | 0.999598 | Decreasing trend | -0.63 | 66.67 |
| Mgeni | -2.76 | 0.997142 | Decreasing trend | -0.083 | 15.3 |

Table 5: The Kendall tau correlation coefficients for annual rainfall at the various rainfall stations and river flow stations in southern Africa.

| Correlation between: | | Kendall tau Correlation coefficient | Significance (p value) |
|---|---|---|---|
| **Rainfall station** | **River flow** | | |
| Average rainfall for Tugela River catchment | Tugela River flow | 0.2580 | 0.0003 |
| Swartwater | Tugela River flow | 0.1371 | 0.0389 |
| Moorside | Tugela River flow | 0.2963 | 0.0000 |
| Tugela Ferry | Tugela River flow | 0.0975 | 0.0987 |
| Average rainfall for Mgeni River Catchment | Mgeni River flow | 0.2897 | 0.0007 |
| Mistley | Mgeni River flow | 0.18 | 0.02 |
| New Hanover | Mgeni River flow | 0.3865 | 0.0000 |
| Average rainfall for Orange River Catchment | Orange River flow | 0.5886 | 0.0000 |
| Lille | Orange River flow | 0.5714 | 0.0000 |
| Middelplaats | Orange River flow | 0.5519 | 0.0000 |
| Zastron | Orange River flow | 0.5335 | 0.0000 |
| Thaba Tseka | Orange River flow | 0.5345 | 0.0000 |
| Semonkong | Orange River flow | 0.3271 | 0.0015 |
| Average rainfall for Vaal River Catchment | Vaal River flow | 0.3 | 0.00005 |
| Villiers | Vaal River flow | 0.2336 | 0.0024 |
| Bloemhof | Vaal River flow | 0.27 | 0.0005 |
| Klerksdorp | Vaal River flow | 0.22 | 0.003 |
| Touwsrivier | Breede River flow | 0.2490 | 0.0003 |
| Malabar | Breede River flow | 0.4317 | 0.0000 |
| Average rainfall for Breede River Catchment | Breede River flow | 0.2793 | 0.0001 |

expected over the western parts of the country by 2015 (DWAF, 2004); and according to DWAF (2004), the decline in such runoff will gradually move from west to east.