Chapter 5: Conclusion

Rainfall is responsible for the spatial and temporal variability of water resources and any changes in precipitation impact on hydrology and water resources (Novtny & Stefan, 2007). The study of long-term rainfall trends and the potential impact on southern African rivers has the potential to serve as an important foundation for water resource planning and management strategies. The variability and trends of rainfall and river flow in time and space are important to water resource managers and planners (Fanta *et al.*, 2001) since data can be extrapolated to display future trends.

The key aim of this study was to determine the impact of rainfall changes on river flow indifferent regions of southern Africa. Annual, seasonal and 5-year moving average rainfall and river flow data from the eastern, western, eastern-central and western-central regions of South Africa were analysed. Climate change is expected to intensify the global hydrological cycle resulting in major impacts on regional water resources (Mukheibir, 2005). This has important implications for the rivers studied as these fluvial systems serve as important sources of water for the different sub-regions of southern Africa. A change in the total amount, frequency and the intensity of precipitation will directly affect the amount and timing of runoff thereby affecting the amount of water available for abstraction for human consumption (Mukheibir, 2005).

The analysis of mean annual rainfall indicated that of the 15 rainfall stations examined across southern Africa, 10 stations displayed a decreasing trend in mean annual rainfall, although only one was a significant decreasing trend at the Villiers station within the Vaal River catchment. Of the 5 remaining rainfall stations, only one displayed a significant increasing trend (i.e. the Tugela Ferry station in the eastern region of South Africa). The rainfall stations in the Breede River catchment displayed insignificant increasing trends for the annual rainfall totals. The Mistley, Moorside and Swartwater stations located in the eastern region of southern Africa indicate decreasing annual rainfall trends, while the New Hanover and Tugela Ferry rainfall stations record increases in annual rainfall, however the Tugela Ferry rainfall station has potential data errors. The Tugela Ferry station recorded high rainfall in 1992, which was not reflected in the

other two rainfall stations in the Tugela River catchment. An inaccuracy in measurement 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. Indications are that the catchments in the east of South Africa are becoming drier whilst the western interior region is becoming wetter.

Eighty percent of the rivers in this study exhibited significant decreasing trends in annual river flow over the period 1923 to 2008. Despite the increase in rainfall over the Breede River catchment, the Bree River flow at Ceres station in the Western Cape of South Africa exhibited a significant decreasing trend in annual flow over the period 1925 to 2008, suggesting a possible pronounced increase in water abstraction from the Breede fluvial system. The Mgeni and the Tugela Rivers in the eastern region of South Africa record 39% and 38% flow declines respectively. The Vaal River also recorded a significant decline (64%) in annual flow over the period 1940 to 2008. However, the Orange River displayed an insignificant increasing (34%) long-term annual flow.

Kendall's tau is used to measure the strength of monotonic relationships between rainfall and river flow and has been reported to be lower than the traditional correlation coefficients (Helsel & Hirsch, 2002). The Kendall tau correlation coefficients were weak and insignificant for most of the rainfall and river flow relationships in this study indicating that the correlation of rainfall variability with river flow cannot be conducted in isolation. River flow is also impacted by several natural factors such as rainfall, catchment storage, evaporation and catchment management (Kundzewicz *et al.*, 2006) as well as abstraction. The Orange River flow presented the greatest correlation with the rainfall stations in the Orange River catchment in this study. The Malabar rainfall station data also exhibited a strong correlation with the annual Breede River flow. The Tugela Ferry mean annual rainfall data indicate the weakest correlation with the Tugela River flow, which is anticipated given the inaccuracies observed in the rainfall data and the possibility of the abstraction of water impacting the river flow to a greater extent.

A study of the seasonal rainfall trends indicates that the rainfall at the Villiers station in the Vaal River catchment significantly decreased for all three seasons, and the rainfall at the Mistley station in the Mgeni River catchment significantly decreased during the late rainfall season. The

late rainfall season trends decreased the most, with a 25% and 37% decline at the Klerksdorp and Villiers stations respectively, over the interior of the Vaal River catchment. However, only the Villiers station data indicate a significant decreasing trend. This study also found that the stations located to the west of South Africa displayed increasing trends for the seasonal rainfall but the trends were not significant. The seasonal trends at the majority of the rainfall stations used in this study were insignificant.

A study of the seasonal flow trends indicates that the Orange River displayed insignificant increasing long-term trends in seasonal flow. River flow significantly decreased along the Vaal, Tugela and Breede Rivers for the early, mid and late rainfall seasons but only decreased during the mid season for the Mgeni River. A study of the seasonal Kendall tau correlation coefficients also indicates the greatest correlation coefficients for the Orange River catchments across all seasons, followed by the Breede, Tugela, Mgeni River catchments and lastly the Vaal River catchment. The mid rainfall season trends correlated best with the Orange River flow for all 3 stations, however, this trend was not applicable across all other catchments. Although the Vaal River flow and the Villiers rainfall station in the Vaal River catchment display a significant decreasing trend during all seasons, the correlation coefficient was weak. The significant decline of river flow for majority of the rivers may be a result of abstraction since the correlation coefficients are weak.

The 5-year moving averages provide important information about the long-term wet and dry trends across various southern African catchments, which is important for predicting possible future patterns of rainfall and flow, particularly in the context of appropraite water resource planning. The 5-year moving average examined the frequency, duration and amplitudes of each rainfall and river flow station in order to determine long-term trends. The overall frequency of wet and dry periods within the data sets was similar across the majority of stations.

The average annual rainfall over the Vaal catchment is characterized by a long wet period at the beginning of the record and an extended dry period at the end of the record, indicating a decrease in moisture of the Vaal catchment. The increase in negative departures from the long-term mean over time was significant, whilst the amplitudes in the wet periods decrease over time, also indicating drier condition over the Vaal catchment. The 5-year moving average rainfall over the

Orange River catchment indicates an insignificant increasing trend, whilst the Orange River flow significantly increased over the period 1910 to 2008. However, the amplitudes of the wet periods decreased over time, whilst the negative departures from the long-term mean increased with time. The significant decline in rainfall over both the Mgeni and Tugela River catchments, together with significant declines in the Mgeni and Tugela River flows, indicate drier conditions with time over the eastern region of southern Africa. The average rainfall over the Breede catchment displayed a significant increase in rainfall with time, indicating wetter conditions in the western region of southern Africa. However, the Breede River flow significantly decreased over time, possibly indicating a greater water demand through storage and abstraction, than supply.

The strong correlation coefficients between some rainfall and river flow data and the correspondence of low or high flow periods with dry or wet periods indicate that rainfall changes cause river flow changes, at least to some extent. However, river flow is impacted by several natural factors such as rainfall, catchment storage, evaporation and catchment management, thus making it is difficult to determine the extent to which firstly climate variability and climate change affects river flow (Kundzewicz *et al.*, 2006), particularly given that the data for these factors are simply not available. Given that 80% of the rivers in this study showed a decline in annual flow over the period of record and did not correlate with the annual rainfall trend indicates that the aforementioned natural factors play a role in the observed declining trend. In a study on the streamflow in Winconsin, it was concluded that both land use changes and climate change were impacting on river hydrology (Juckem *et al.*, 2008). River flow patterns are affected by a combination of anthropogenic disturbances such as abstraction and impoundments (Hannaford & Marsh, 2006). The prediction of the impact of rainfall changes on hydrology is important to the water scarce southern African region, especially with the consensus of models indicating a 20% rise in evaporative loss over the 21st century (Jury, 2002). In addition, it is thought that the impact of climate change on rainfall distribution, quantity and intensity within particular regions of countries may become more variable (Weritty, 2002).

A comprehensive analysis on regional rainfall change requires a good coverage of stations within the region (Tyson *et al.*, 1975). However, the lack of high quality long-term rainfall data and

river flow station data presents some major limitations to ascertaining conclusive trends over time. Easterling *et al.* (2000) identified a lack of high quality long-term data as a setback when determining historical climate trends. It is therefore recommended that an analysis of a greater quantity of stations across southern Africa be undertaken so as to obtain more conclusive trends and cycles in historical data, and ultimately to improve water resource planning. Notwithstanding these concerns, this study provided some interesting trends with the majority of data indicating that water resources in southern Africa are indeed under threat due to the finding that annual and seasonal river flow significantly declined over several areas of southern Africa, thereby decreasing water resources. This implies that future water resource planning is critical to ensure an adequate supply of water over much of southern Africa. The 5-year moving average data provide valuable insight into the trends of the past, and may present a foundation for predicting future trends.