Chapter One: Introduction

1.1 Background to the study

Water is a basic human need and is essential for all life forms. The demand on water resources is expected to increase globally due to population growth (Kundzewicz *et al.*, 2007). It is estimated that by 2025, a third of the world's population will be living in water stressed countries (Arnell, 1999). In addition, droughts and poor rainfall add increasing pressure on water resources (Ragab, 2002). In some places in the world climate change might place additional pressure on the already limited water resources, therefore it is important to determine the effect of climate change on water resources under an increasing population and economic development (Arnell, 1999).

The climate change scientific community has agreed that the earth's temperature increased by approximately 0.7°C over the 20th century, with the warming in the latter half of the century being a consequence of anthropogenic greenhouse gas emissions (Burns *et al.,* 2007). The increase in temperature results in an increase in evaporation which is expected to result in an increase in precipitation. Models predict a global mean precipitation increase of 3 to 5% for an increase in temperature of 1.5 to 3.5°C (Ragab, 2002), but the majority of precipitation occurs over oceans and rainfall trends decline over the greater part of the land (Arnell, 1999). In addition, regional and inter-annual rainfall varies significantly (Ragab, 2002). The impact of climate change on stream flow and groundwater recharge also varies regionally (Kundzewicz *et al.*, 2007).

The relationship between climate change and hydrologic change has been extensively studied worldwide, such as in Lesotho (Sene *et al.*, 1998), Wisconsin, United States of America (USA) (Juckem *et al.*, 2008), in Minnesota, USA (Novtny & Stefan, 2007), Canada (Westmacott & Burn, 1997), New York, USA (Burns *et al.*, 2007), on Mt Kenya (Notter *et al*., 2007), in the United Kingdom (UK) (Hannaford & Marsh, 2006), Scotland (Werritty, 2002), Poyang, China (Guo, 2008), Malawi (Ngongondo, 2006), Ireland (Dunne *et* al., 2008), Denmark (Thodsen, 2007), and the list goes on. These studies were conducted using historical trend analysis as well as using general circulation models (GCMs). Although models are useful tools, the predicted changes do not take into account natural climatic variability, often resulting in the generation of different values under different climate scenarios. In addition, GCMs have produced inaccurate and unreliable outputs at regional scales (Werritty, 2002). Historical climate trend studies provide information on how the climate has changed and can also be used to verify climate models in order to improve model prediction. In addition, South Africa is one of the few countries in the Southern Hemisphere with a large quantity of climate records; therefore the historical studies provide invaluable insight of the climate in the region (Kruger, 2006).

South Africa is a water stressed country, with a natural climate of low rainfall and high evaporation and rainfall variability, which contribute to the low water availability (DWAF, 2004). In a global model analysis of the impact of climate change on water resources, Arnell (1999) found that the greatest negative impact would be in the Middle East and southern Africa. The impact of climate change on water resources in South Africa has been studied using GCMs (Schulze & Perks, 2000; New, 2002). Although historical rainfall trends over southern Africa (e.g. Tyson *et al*., 1975; Dyer & Tyson, 1977; Kruger, 2006) and regional rainfall trends in areas such as Potchefstroom (Lynch *et al*., 2008), the Upper Orange River Catchment (Carter, 1967), the Eastern Cape (Dollar & Rowntree, 1985), KwaZulu-Natal (Nel & Sumner, 2006; Nel, 2008) and in the Western Cape (Van Wageningen & du Plessis, 2008) have been examined, the correlation of rainfall trends with river flow data has been limited (DEAT, 1999). Relatively few studies have focused on long-term trends of river flow on a national scale (Fanta *et al.,* 2001, Alemaw & Chaoka, 2002a, 2002b, 2006). In addition, there have been even fewer studies that examine the relationship between river flow and rainfall on a national scale. This study therefore investigates historical rainfall trends in different sub-regions of southern Africa, specifically South Africa and Lesotho, using the Mann Kendall statistic and Sen's method, and also examines the correlation between rainfall and river flow using the Kendall tau method.

1.2 Aims

The aim of this project is to investigate the potential association of recent climate change (precipitation) with river flow over southern Africa, using long-term data. This study aims to quantify precipitation changes in different catchments of southern Africa over the past 55-100 years and compare the trends with those of river flow in specific catchments, which could provide insight into changing water resources in the chosen study areas.

The aims are to discuss:

1. The long-term rainfall trends at the selected locations in southern Africa over the last 55 to 100 years.

2. The river flow trends for selected catchments in southern Africa over the last 55 to 100 years.

3. The impact of rainfall changes (if any) on river flow in the eastern, western and interior regions of South Africa.

Objectives:

1. To evaluate any changes in river flow for the following stations within different catchments in southern Africa:

- The Tugela River catchment was chosen to represent the eastern high rainfall area of southern Africa.
- The Mgeni River was chosen to represent the region with the highest runoff (11.4%) in southern Africa, also located in the eastern region.
- The Breede River in the Western Cape was chosen to represent the western winter rainfall region of southern Africa.
- The Vaal River was chosen to represent the western-central interior region of southern

Africa.

- The Orange River was chosen to represent the eastern-central interior region of southern Africa.

Specific stations were chosen according to the availability of long-term precipitation and flow data within the various regions.

2. To quantitatively describe rainfall changes at weather stations within the catchments for which river flow data were analysed.

- The Moorside, Swartwater and Tugela Ferry rainfall stations were selected because the stations represent upstream catchment points to the Tugela at Tugela Ferry river flow station. The rainfall stations upstream to the river flow stations were selected because the former impacts downstream flow.
- The New Hanover and Mistley Estate rainfall stations were selected because the stations represent upstream points to the Mgeni at Table Mountain river flow station.
- The Malabar and Touwsrivier rainfall stations were selected because the stations represent upstream points to the Bree at Ceres river flow station.
- The Klerksdorp Hartbeesfontein, Bloemhof and Villiers rainfall stations were selected because the stations represent upstream points to the Vaal at Schoolplaats river flow station.
- The Lille, Middelplaats and Zastron rainfall stations were selected because the stations represent upstream points to the Orange River at Aliwal river flow site and have the longest data record. In addition, rainfall data from Lesotho were used to compare with the South African data.

3. To correlate rainfall with river flow data.

1.3 Study area

South Africa is surrounded by oceans with different characteristics on all sides except the north. Consequently, air masses with different properties predominate over the west, south and east coasts of South Africa (Klopper *et al.,* 1998). The Southern ocean substantially influences some of the weather systems that affect southern Africa. The South Atlantic Ocean contains the wind driven, Benguela upwelling system, resulting from the Atlantic High pressure system, which creates cold water along the west coast of South Africa (Lutjeharms *et al.*, 2001). The Agulhas Current is responsible for moving the warm water along the east coast of South Africa, thereby creating the east to west coast gradient of rainfall (Tennant, 1998). Rainfall variability over Africa is influenced by the El Niño Southern Oscillation (ENSO), sea surface temperatures and land atmosphere feedback (Nicholson, 2000).

Southern Africa receives an average rainfall of 500 mm per annum (Tyson, 1986). The southeastern coastal region is the only region in South Africa that receives high rainfall, whilst the western and interior regions of the country are arid to semi arid (Mukheibir, 2005). Groundwater is an important water resource, especially in rural areas, however given that South Africa's geology is dominated by hard rock, major groundwater aquifers are limited (Mukheibir, 2005). South Africa has complex geological formations, rich in mineral deposits including the well known Witwatersrand quartzites (gold), the Bushveld Igneous Complex (platinum) and coal deposits in Karoo sediments, of which the latter covers the majority of the country (Geology, 2009).

South Africa has 22 major rivers, 165 large dams, approximately 4000 small to medium dams, and hundreds of small rivers from which the country obtains water (DEAT, 1999). The total natural estimated mean annual runoff for South Africa is 49 200 million m^3 per annum, including the 9.7 % and 1.4% contributed by Lesotho and Swaziland's natural drainage into South Africa (Mukheibir, 2005). It is important to acknowledge that river flow is reduced by the abstraction and damming of water (Mukheibir, 2005), and must be taken into account when comparing long-term rainfall with long-term river flow trends. This study examines the long-term river flow of five of the major rivers located in the east, west, central interior and western interior of South

Africa (i.e. the Tugela, Mgeni, Orange, Vaal and Breede Rivers), together with the associated rainfall recorded at various stations, of which the spatial distribution is reflected in Figure 1 and Table 1. A closer view of the location of the river flow and rainfall stations is provided in Figures 2 to 6.

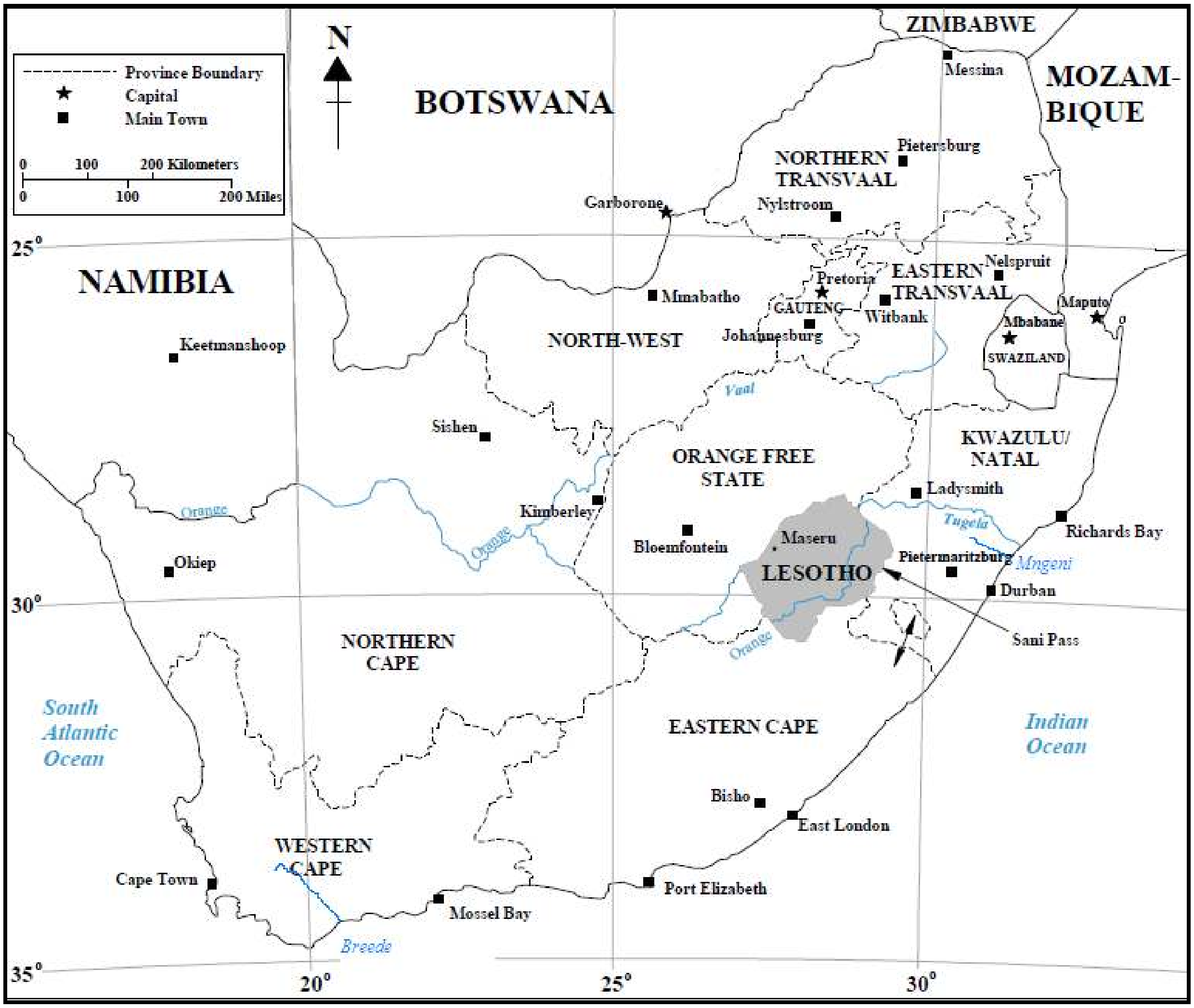

Figure 1: Map of South Africa showing rivers pertinent to this study (after Mills, 2006, original source United States of America central intelligence agency).

Table 1: The spatial distribution of rainfall and river flow stations in southern Africa.

Stations	**Location (Coordinates)**[1]	**Historical record**[2]	**Height (m)**[2]
Tugela Ferry River flow	28°45'1.40"S 30°26'33.10"E	1927 to 2008	
Swartwater rainfall station	28°21'36.00"S, 30°21'36.00"E	1932 to 2008	1372
Moorside rainfall station	28°23′60″S, 29°36′36″E	1914 to 2008	1219
Tugela Ferry rainfall station	28°45'1.40"S 30°26'33.10"E	1926 to 2008	549
Mistley Estate rainfall station	29 ° 12′2″S, 30° 40′12″ E	1940 to 2008	975
New Hanover rainfall station	29 ° 21′51″S, 30° 31′12″ E	1940 to 2008	791
Mgeni River at Table Mountain	29° 34′ 34.0″S, 30° 36′ 09.0″E	1951 to 2008	
Orange at Aliwal River flow	30 ° 40′42″S, 26°42′59″ E	1914 to 2008	
Lille rainfall station	30 ° 10′ 12″S, 27 ° 22′ 12″E	1932 to 2008	1463
Middelplaats rainfall station	30°27'2.00"S, 26°52'12.00"E	1911 to 2008	1585
Zastron rainfall station	30°18'2"S, 27°4'48"E	1906 to 2008	1661
Thaba Tseka rainfall station	29°31'0"S, 28°34'6"E	1965 to 2006	
Semonkong rainfall station	29°55'0"S, 28°1'6"E	1967 to 2006	
Vaal River at Schoolplaats	28° 06′ 52.5″S, 24° 54′ 53.5″E	1940 to 2008	
Villiers rainfall station	27°1′48″S, 28°36′5″ E	1905 to 2006	1493
Bloemhof rainfall station	27°38′6″S, 25°36′5″ E	1931 to 2008	1228
Klerksdorp Hartbeesfontein	26°56'24.00"S, 25°37'48.00"E	1917 to 2008	1325
Touwsrivier rainfall station	33°19'48.00"S, 20° 1'48.00"E	1918 to 2008	762
Malabar rainfall station	33° 8'60.00"S,19°22'48.00"E	1944 to 2008	1030
Breede River	33 ° 22′50″S, 19°18′06″ E	1923 to 2008	

1. http://earth.google.com

2. SAWS (2008).

Figure 2: Google Earth[3] image showing locations of the Tugela river flow and rainfall stations.

Figure 3: Google Earth image showing locations of the Mgeni River at table mountain flow and rainfall stations.

3. http://earth.google.com

Figure 4: Google Earth image showing locations of the Breede River flow and rainfall stations.

Figure 5: Google Earth image showing locations of the Vaal river flow and rainfall stations.

Figure 6: Google Earth image showing locations the Orange river flow and rainfall stations.