CHAPTER 4 : THE RICARDIAN APPROACH AND EMPIRICAL MODEL OF CLIMATE CHANGE IMPACTS ON FIELD CROPS IN SOUTH AFRICA

4.1 Introduction

For the assessment of the economic impact of climate change on South Africa's major field crops, the present study adopts the Ricardian approach. The rest of the chapter is organised as follows. Section two will introduce the analytical framework of the Ricardian model. Section three presents the empirical model specification for South Africa. Sources of the used data and collection procedures are discussed in section four.

4.2 The Ricardian approach

4.2.1 Theoretical background

The Ricardian method is an empirical cross-sectional model to studying agricultural production. The method was named after Ricardo[7] because of his original observation that land rents would reflect the net productivity of farmland at a site under perfect competition (Ricardo, 1817 and 1822). Farm value consequently reflects the present value of future net productivity. This method has been developed by Mendelshon *et al*. (1994) to measure the economic impact of climate on land prices in the USA. By regressing farm values on climate, soil and other control variables, the method enables measuring the marginal contribution of each variable to land value. The model accounts for the direct impacts of climate on yields of different crops as well as the indirect substitution of different inputs, introduction of different activities and other potential adaptations to different climates. However, in the Ricardian analysis, adaptation cost is not considered and since the analysis makes forecasts based on current farming practices, it does not capture future changes affecting agriculture such as technical change and carbon dioxide fertilization.

[7] David Ricardo was a British economist, who articulated and rigorously formulated the "classical system" of political economy.

The Ricardian approach is based on the following hypotheses (Mendelshon *et al.*, 1994):

1) Climate shifts the production function for crops
2) Farmers at particular sites take environmental variables like climate as given and adjust their inputs and outputs accordingly
3) Farmers operate under perfect competition in both product and input markets
4) The economy has completely adapted to a given climate so that the current land rents have attained the long-run equilibrium that is associated with each site's climate
5) The way that farmers respond to alternative climates over space is the same way that farmers will respond in the long run to those same climates over time

4.2.2 The analytical model

The analytical Ricardian framework assumes a set of well-behaved production functions of the form (Dinar *et al.*, 1998):

$$Q_i = (K_i, E), \tag{4.1}$$

Where, Q_i is the quantity produced of good i, $K_i = \lfloor K_{i1},...K_{ij},...K_{iJ} \rfloor$ is a vector of all purchased inputs in the production of good i; K_{ij} is input j $(j = 1,...J)$ used in the production of good i, and $E = [E_1,...E_m,...E_M]$ is a vector of exogenous environmental inputs such as temperature, precipitation, and soils which are common to a production site.

Given a set of factor prices w_j for K_j, E, and Q, cost minimization leads to the cost function:

$$C_i = C_i(Q_i, w, E) \tag{4.2}$$

Where C_i is the cost function for the production of good i and $w = \lfloor w_1,...w_j,...w_J \rfloor$ is the vector of factor prices.

Given market prices P_i for good i, producer' profit maximization equation on a given site can be specified as:

$$Max\pi = \sum_i [P_i Q_i - C_i(Q_i, w, E) - P_L L_i] \tag{4.3}$$

Where P_L is the annual cost or rent of land at that site and L_i is the land under the production of good i. Note that C_i is the above cost function for all purchased inputs other than land; therefore the full cost function of production of good i is defined as $C_i + P_L L_i$.

Perfect competition in the land market will drive profits to zero:

$$P_i Q_i^* - C_i^*(Q_i^*, w, E) - P_i L_i = 0 \tag{4.4}$$

If the production of good i is the best use of the land given E, the observed market on the land will be equal to the annual net profits from the production of good i. Solving for P_L from the above equation (4.4) gives land rent per hectare to be equal to the net revenue per hectare:

$$P_L = [P_i Q_i^* - C_i^*(Q_i^*, w, E)] / L_i \tag{4.5}$$

The present value of the stream of current and future revenues gives land value V_L :

$$V_L = \int_0^\infty P_{Lt} e^{-rt} dt = \int_0^\infty [(P_{it} Q_{it} - C_{it}(Q_{it}, w, E)) / L_{it}] e^{-rt} \; dt \tag{4.6}$$

The issue of interest to this analysis is measuring the impact of exogenous changes in environmental variables (E) on net economic welfare (ΔW). Consider an environmental change from the environmental state A to B, which induces environmental inputs to change from E_A to E_B. The change in annual welfare from this environmental change is given by:

$$\Delta W = W(E_A) - W(E_B) = \int_0^{Q_B} [(P_{it} Q_{it} - C_{it}(Q_{it}, w, E_B)) / L_{it}] e^{-rt} \; dQ - \int_0^{Q_A} [(P_{it} Q_{it} - C_{it}(Q_{it}, w, E_A)) / L_{it}] e^{-rt} \; dQ \tag{4.7}$$

If market prices are unchanged as a result of the change in E, then the above equation reduces to:

$$\Delta W = W(E_B) - W(E_A) = \left[PQ_B - \sum_{i=1}^{n} C_i(Q_i, w, E_B) \right] - \left[PQ_A - \sum_{i=1}^{n} C_i(Q_i, w, E_A) \right] \quad (4.8)$$

Substituting $P_L L_i = \left[P_i Q_i^* - C_i^*(Q_i^*, w, E) \right]$ from (4.5) into the above equation (4.8):

$$\Delta W = W(E_B) - W(E_A) = \sum_{i=1}^{n} (P_{LB} L_{Bi} - P_{LA} L_{Ai}) \quad (4.9)$$

Where P_{LA} and L_A are, respectively, price and land units at E_A, and P_{LB} and L_B are at E_B.

The present value of this welfare change is thus:

$$\int_0^{\infty} \Delta W_t e^{-rt} dt = \sum_i (V_{LB} L_B - V_{LA} L_A) \quad (4.10)$$

The Ricardian model takes the form of either (4.5) or (4.10) depending on whether the dependent variable is annual net revenues or capitalized net revenues (farm values). The value of change in the environmental variable is captured exactly by the changes in land values across differing environmental conditions. Cross sectional observations, showing spatial variation in normal climate and edaphic factors can hence be utilized to estimate climate impacts on production and land rents.

4.4 Specification of the empirical model

4.4.1 The field crops' climate response model

The standard Ricardian model relies in an implicit form of land value as a function of its determinants (Mendelshon *et al.*, 1994):

$$V = V(F, Z, G) \quad (4.11)$$

Where V is the land value; F is a vector of climate variables; Z set of soil variables and G is a vector of socio-economic variables.

Due to imperfect land markets and weak documentation of agricultural farm values in South Africa, this study could not use land value as the dependent variable. Following the approach of Sanghi *et al.* (1998) and Kumar and Parikh (1998) for India, net revenue per hectare (NRHA) rather than land value was used as the response variable in this study. Indeed land prices are presumably based on expected future net revenues, therefore the current net revenue is considered as a proxy for expected future net revenue.

4.4.2 Regressors of the model

Net revenue per hectare (NRHA) the dependent variable will be regressed on the following set of regressors: (1) Climate variables: temperature and precipitation; (2) Soil types and (3) Socio-economic variables, e.g. Population, labour, irrigated land and geographical coordinates.

Climate variables will be included in the model in both linear and quadratic terms for monthly temperature (T) and precipitation (R). In the regression the year is subdivided into two main periods, summer and winter. Summer in South Africa corresponds to the period between October to March. Winter extends over April to September. Interaction terms between precipitation and temperature are introduced for each season.

Soil types vary significantly over the various districts of South Africa and hence need to be controlled for in order to isolate climate from other effects. Four soil dummies have been defined and were included in the model.

Population density is also included to control for urban influences on agricultural rent. The number of persons employed on a given farm may influence the productivity of that farm as one element of adaptation. Therefore labour per hectare is included in the equation.

The study also extends the Ricardian model to thoroughly capture the impact of water availability on farm value. It is true that water comes to farms in the form of precipitation and that is already reflected in the Ricardian model. However, farmers have two other sources of water: surface water and groundwater. Because the sources of this additional water can be remote from the farm, the climate at the farm may give little indication of the amount of surface and groundwater accessible to the farm (Mendelsohn and Dinar, 2003). Thus the percentage of cropland that is irrigated is included in the model to compare the climate sensitivity of irrigated land to rain-fed land (Mendelsohn and Dinar, 2003). Geographical coordinates such as District latitude and mean altitude are included in the model as proxies for solar flux and day length respectively. Table 4.1 defines the variables included in the empirical model for the South African field crops.

Table 4-1: Definition of the variables included in the empirical analysis

Variables	Definition
NRHA	Net revenue for district i measured in R/ha
tempSummer	Average temperature in Summer over 30 years (1960- 2000) in degree Celsius
$tempSummer^2$	Square of average Summer temperature in degree Celsius
tempWinter	Average temperature in Winter over 30 years (1960- 2000) in degree Celsius
$tempWinter^2$	Square of average winter temperature in degree Celsius
rainSummer	Average rainfall in Summer over 30 years (1960- 2000) in millimetres
$rainSummer^2$	Square of average Summer rainfall in millimetres
rainWinter	Average rainfall in Winter over 30 years (1960- 2000) in millimetres
$rainWinter^2$	Square of average winter rainfall in millimetres
Temp*Rain Summer	The interaction term between temperature and rainfall for summer
Temp*Rain Winter	The interaction terms between temperature and rainfall for winter
Popd	Population density measured in inhabitants per km^2
$Popd^2$	Square population density
Soildum1	Soil type 1, takes the value of one if the soil is the red-yellow latosols well drained soils and zero other wise.
Soildum2	Soil type 2, takes the value of one if the soil is plinthic catena and zero other wise
Soildum3	Soil type 3, takes the value of one if the soil is with a strong texture contrast or with high clay content and zero otherwise.
Irrigation	Intensity of irrigation in district i, represents the share of total cultivated land, which is irrigated in a given district.
labour	Number of farm workers employed in a given district
latitude	Measured in degree centigrade
altitude	Measured in meters

4.4.3 Sources of the data

The study used district level data on crops' revenues and other variables of the model. Data on seven crops from 300 districts for the year 1993 were obtained from various sources. The seven crops included are: maize, wheat, sorghum, sugarcane, soybean, groundnut and sunflower. Data on area planted, production yields, input costs and output price for each of the seven field crops were provided by the Census of Agriculture 1993 from the National Department of Agriculture (SSA, 1998). However, for sugarcane, data were from the Sugar Cane Growers' Association of South Africa. The data used in this study were secondary data and focus mainly on the commercial agricultural sector.[8]

For each district, net revenue was calculated as the value of production of the seven crops minus total farm expenditure on inputs and labour used:

$$NRHA^{d} = \sum_{i=1}^{7}\left[\left(P_iQ_i\right) - C_i\right] / TA^{d} \qquad (4.13)$$

Where d refers to districts (1, …, 300) and i refers to crops (1, ..., 7), $NRHA^d$ is the net revenue per hectare for district d. P_i and Q_i are output prices and output quantities for crop i. C_i^d is the total expenditure on inputs and labour for crop i in district d. C_i^d was estimated by using the commercial enterprise budgets for each crop per district, published annually by the provincial departments of agriculture (COMBUD, 1993).

District total area under the seven crops (TA^d) was calculated as:

$TA^{d} = \sum_{i=1}^{7} A_i$ Where A_i is the area planted to crop i.

The data on climate variables were compiled from the National Weather Bureau of South Africa (NWBSA). The appropriate climate variables for this study were the normal[9] climate variables based on 30 years averages of temperatures and

[8] Although, it is well known that the subsistence-farming sub-sector is the most vulnerable to climate change since it does not have much in terms of crop substitutability and also limited ability to adapt, this study could not include this sub-sector due to lack of data. The subsistence-farming sector however, contributes about 10% of the total value added in South African agriculture (NDA, 2000).

[9] The normal climate is defined in climatology as 30-year average climate.

precipitation observed over the period 1970-2000. Indeed, normal climate variables are used instead of yearly climate variables because the analysis focus on the long-run impacts of precipitation and temperature on agriculture, not year to year variations of weather (Mendelshon *et al.*, 1994).

The information on climate variables provided by NWBSA was gathered at 74 weather stations across South Africa. Since the units of analysis in the study are districts, Geographical Information Systems (GIS) methods have been used to identify weather stations that can describe the climate for each district. The climate variables of weather stations within a given district have been averaged over to describe the district temperature and rainfall.

Data on population for the year 1993 (year of the analysis) were deducted from the 1996 Population census of the Department of Statistics South Africa by discounting the 1996 population numbers by the South African population annual growth rate of 1.5% (SSA, 2002b). Data on number of farm workers per district and percentage of land under irrigation were extracted from the Census of Agriculture 1993 (SSA, 1998).

The four groups of soil types have been derived from the Map of Generalized Soils patterns of South Africa produced by the Institute for Soil, Climate & Water (ISCW) and The Agricultural Research Council (ARC).

Soil type 1: is the category of the red-yellow latosols, well drained soils lacking a strong texture contrast. These soils are deep with no clear horizon boundaries. The physical properties of these soils are good. They have rapid infiltration and low water holding capacities. They are very low in plant nutrients as very weatherable materials are found.

Soil type 2: is the category of soils within a plinthic catena with red yellow and greyish soils. This category is composed of low medium base status or high base status. The water holding capacity is low with rapid infiltration. These soils are poor in organic carbon and phosphor content.

Soil type 3: is the category of black to very dark grey brown with high clay content. These soils are very productive. Drainage is poor and soil reaction is neutral.

Soil type 4: is the category of greyish, sandy well-drained soils with high base status. The texture is fine sand to coarse sand. Infiltration is rapid. These soils enable the growth of deep-rooted crops. Soils are very low in soil organic matter and plant nutrients. Generally, crops can be grown with high management.

As noted earlier, the Ricardian model could be applied at country level if there is sufficient spatial variation in net revenue and climate variables across the country. In South Africa, the level of net revenue per hectare seems to be highly correlated with variations in climate patterns across the country. Figure 4-1 presents the distribution of the field crops' net revenue hectare across South Africa for the 300 districts. Kwazulu Natal and Mpumalanga appears to be the most valuable agricultural regions whereas Limpopo and the North West the least valuable regions. It is apparent from Figure 4-2 to Figure 4-5 that the most valuable regions are the hottest and wettest regions. Thus, high temperature and abundance of rainfall may be beneficial to field crops' net revenues.

Figure 4-1: Net revenue Hectare in South Africa by district (1993)

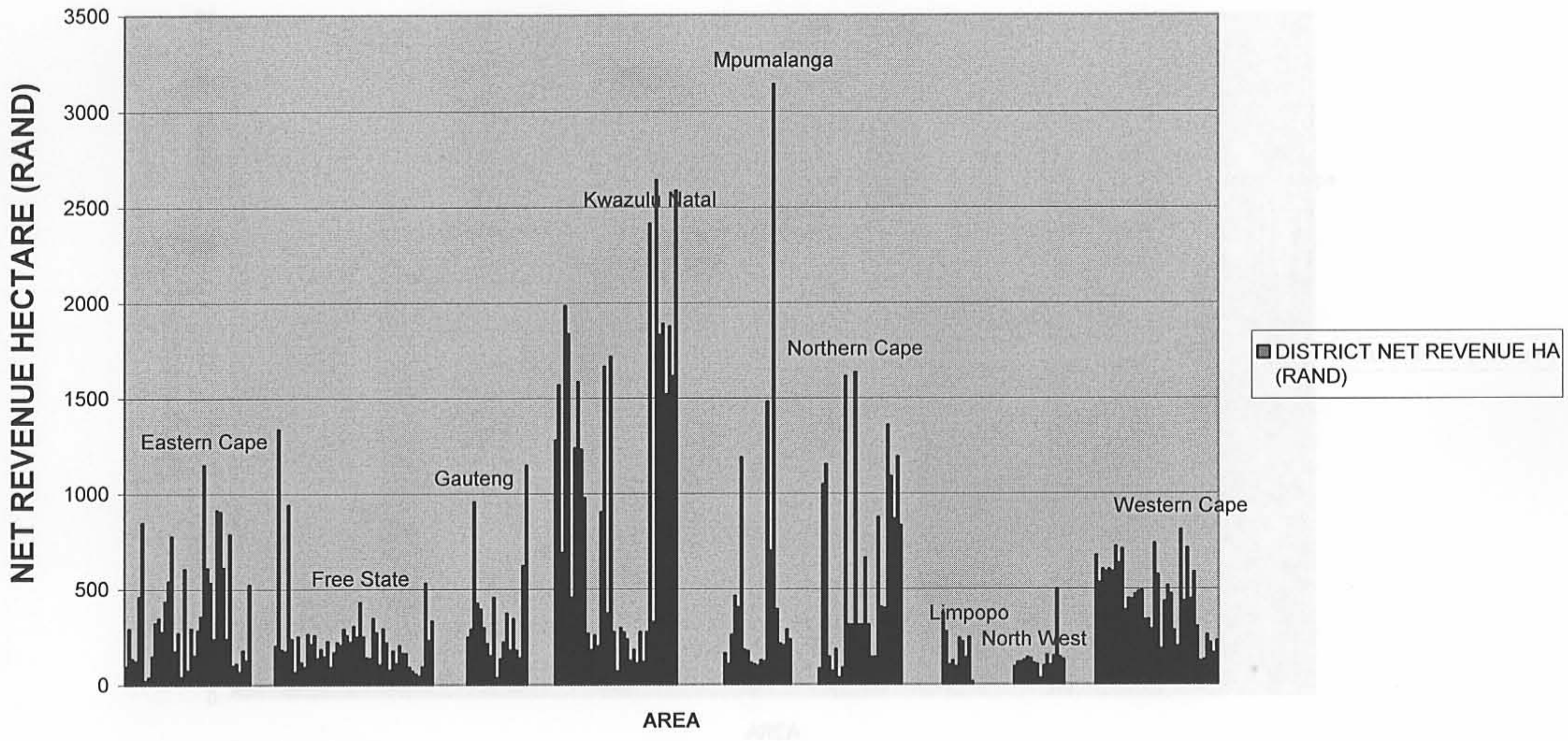

Figure 4-2: Average Summer Temperature in South Africa by district (1970- 2000)

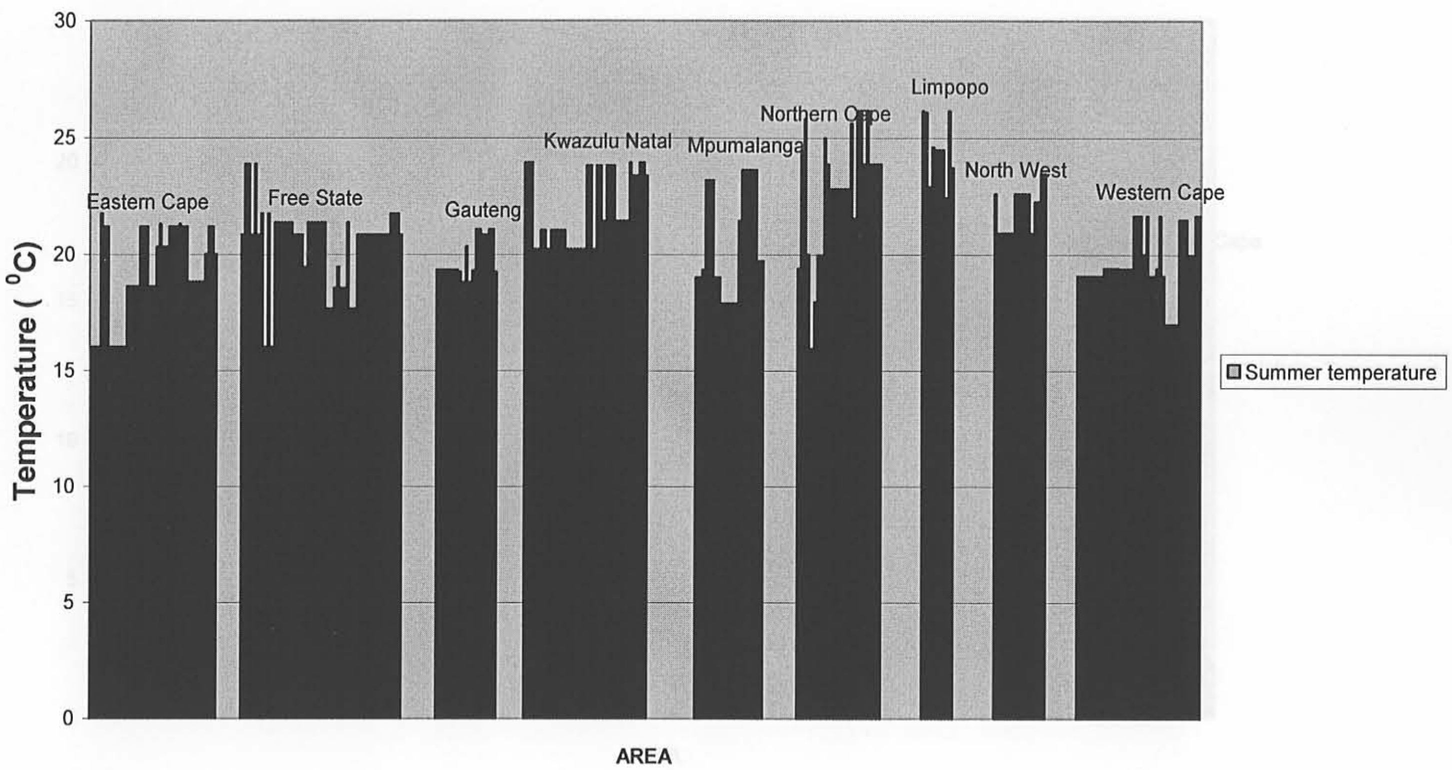

Figure 4-3: Average Winter Temperature in South Africa by district (1970 – 2000)

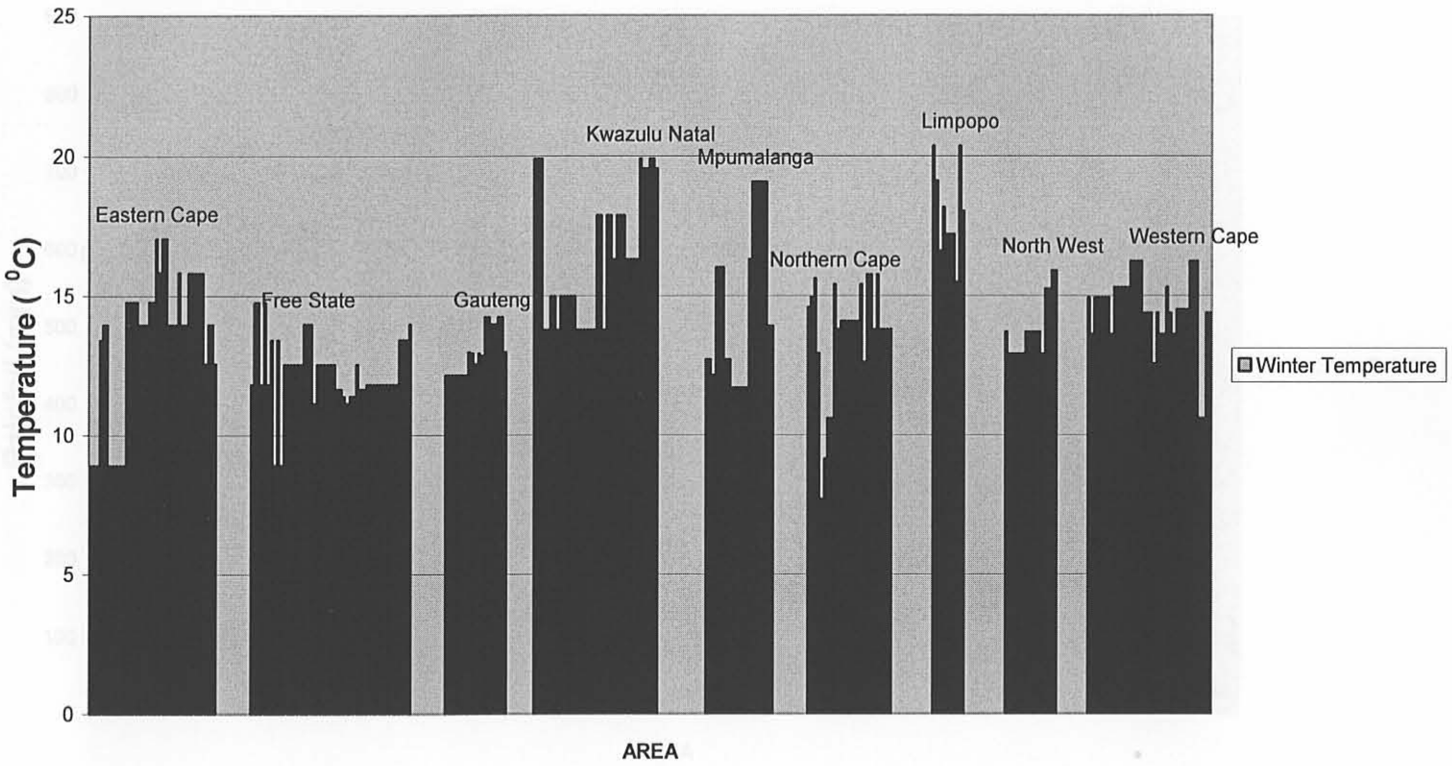

Figure 4-4: Summer Rainfall in South Africa by district (1970 –2000)

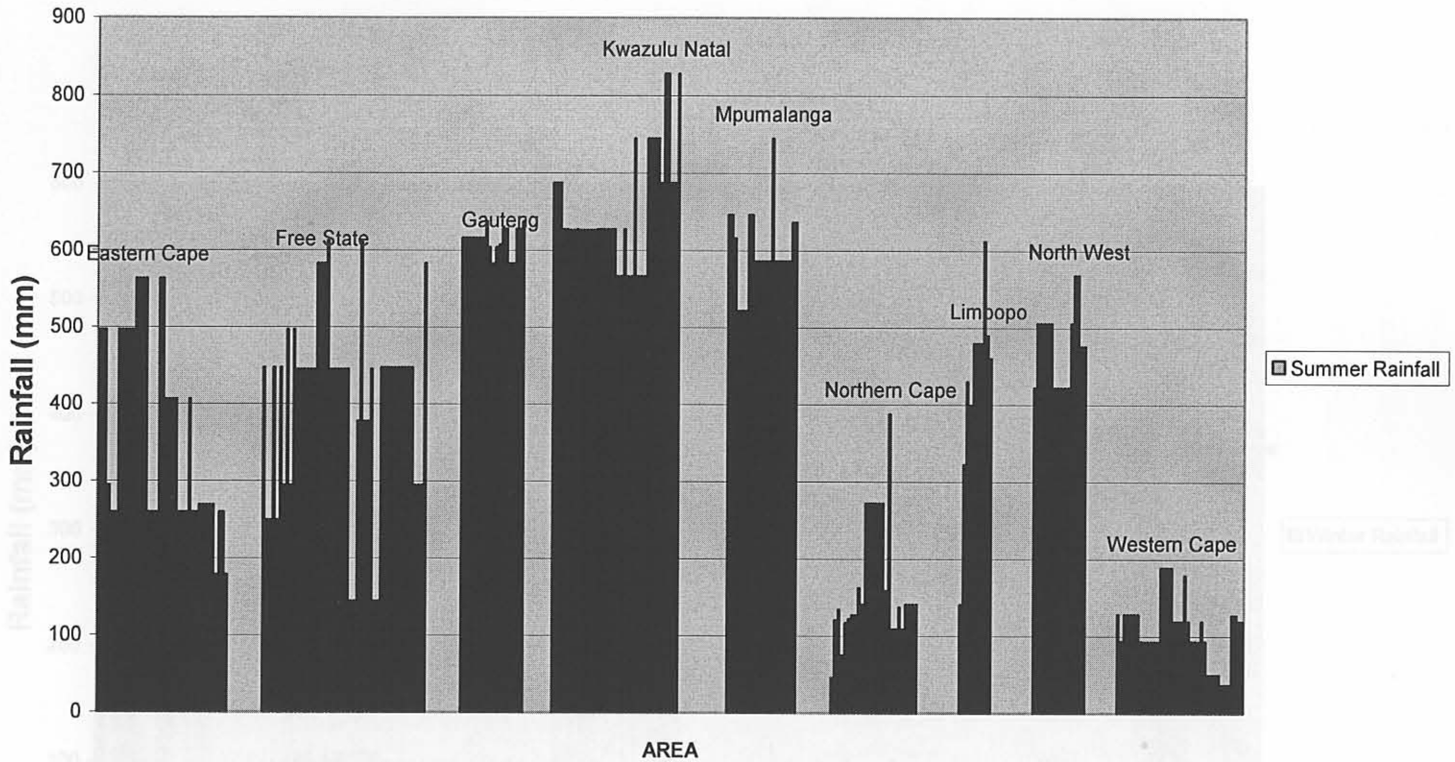

Figure 4-5: Winter Rainfall in South Africa by district (1970 – 2000)