

Vulnerability and adaptation of farming to climate change in South Africa

by

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*To the Almighty,
one and only GOD,
the glory!*

DECLARATION

I, Glwadys Aymone GBETIBOUO, declare that the thesis, which I hereby submit for the degree of PhD in Environmental Economics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Parts of the thesis have been published and submitted for publication in journals.

Any errors in thinking and omissions are entirely my own responsibility.

Signed:

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January 2011

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Gbetibouo G. A. (2011)

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Vulnerability and adaptation of farming to climate change in South Africa

by

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ABSTRACT

This study made an attempt to improve the understanding of the interrelations between climate change and agriculture in South Africa with special focus on the role of human agency in determining vulnerability to climate change.

An indicator approach is adopted to assess the relative distribution of vulnerability across the nine provinces within South Africa. Nineteen indicators drawn from an extensive review of the literature were selected to comprehensively operationalise the concept of vulnerability defined as exposure, sensitivity and adaptive capacity. Using data from various secondary sources of national statistics, the principal components analysis was then used to assign weights to the selected indicators and to construct the overall vulnerability index. This analysis revealed that climate change is spatially differentiated across the farming areas in the country. Thus, although a national climate change adaptation policy is necessary, policymakers should develop region-specific policies and address climate change at provincial level as well as at a lower scale to really tailor to local conditions. The study also demonstrated the multifaceted nature of vulnerability which demands consideration of both climate risk exposure and pre-existing

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environmental and socio-economic conditions. Indeed, provinces most exposed to the risks of climate change and variability are not necessarily those that are the most vulnerable when socio-economic factors are taken into account. Vulnerability to climate change is intrinsically linked with the level of socio-economic development. The results showed that the most vulnerable provinces within South Africa are Limpopo, Kwazulu-Natal and the Eastern Cape, which are all characterised by: i) a high number of small scale farmers relying on rain-fed agriculture; ii) a high level of soil and land degradation; iii) a high rural population density; high unemployment; iv) low literacy levels; and v) a low infrastructure index. Climate change adaptation should therefore be placed within the broader development context and be addressed in concomitance with all pre-existing development problems.

Analyses of farmers' perceptions and adaptation responses to climate change was based on data collected from a survey of 794 farmers sampled in the Limpopo River Basin in South Africa. The study was conducted in two stages. Firstly, the accuracy of farmers' perceptions of climate change was assessed by comparing their perceptions of long-term changes in temperature and rainfall with climate trends recorded at nearby meteorological stations. A seemingly unrelated biprobit model was then employed to investigate factors influencing farmers' perceptions. The analyses revealed that perceptions are not entirely based on actual climate conditions but are also influenced by others factors such as farmers' experience, availability of extension services and access to irrigation and fertile soil. Accordingly, improved farmer education and awareness about climate change and improved access to climate information could enhance adaptive capacity. Secondly, both a Heckman probit model and a Multinomial logit model were applied to investigate the determinants of farmers' adaptation strategies to climate change. The results indicated that tenure security; farmers' asset base, farming experience, and access to water, credit, extension services, off-farm income and employment opportunities; are keys to enhancing farmers' adaptive capacity. Appropriate government interventions to improve farmers' access to and the status of these factors are therefore needed for reducing farmers' vulnerability to climate adversities.

Key words: *climate change and variability; agriculture; vulnerability; perception, adaptation, indicator approach, choice models*

Gbetibouo G. A. (2011)

TABLE OF CONTENTS

DECLARATION	I
ACKNOWLEDGEMENTS	II
ABSTRACT	IV
LIST OF TABLES	X
LIST OF FIGURES	XI
ACRONYMS AND ABBREVIATIONS	XII
DEFINITIONS OF KEY TERMS	XIV
CHAPTER 1: INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement and Motivation	2
1.3 Research objectives	6
1.4 Hypotheses of the study	7
1.5 Approach and methods of the study	7
1.6 Organisation of the thesis	8
CHAPTER 2:	9
VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE: A THEORETICAL AND CONCEPTUAL BACKGROUND	9
2.1 Introduction	9
2.2 Conceptual framework of vulnerability to climate change	9
2.2.1 Defining vulnerability	9
2.2.2 Conceptual roots of vulnerability	13
2.2.2.1 The risk hazard approach	14
2.2.2.2 The political economy approach	16
2.2.3 Epistemological approaches to vulnerability in the climate change research	18
2.2.4 Basic components of vulnerability	21
2.3 Conceptual framework of adaptation to climate change	24

Gbetibouo G. A. (2011)

2.3.1	Defining adaptation	24
2.3.2	Adaptation as a climate change policy response	26
2.3.3	The roots, determinants and types of adaptation	28
2.3.3.1	The roots of adaptation concept	28
2.3.3.2	Determinants of adaptation	29
2.3.3.3	Types of adaptation	30
2.3.4	Agricultural adaptation	32
2.3.4.1	The process and types of agricultural adaptation	32
2.3.4.2	Understanding autonomous farmers' adaptation process	35
2.4	The framework vulnerability – adaptation to climate change	38
2.4.1	Interrelations vulnerability and adaptation to climate change	38
2.4.2	The causal chain of the framework vulnerability-adaptation	39
2.5	Concluding remarks	44
CHAPTER 3:		45
CLIMATE CHANGE AND AGRICULTURE IN SOUTH AFRICA		45
3.1	Introduction	45
3.2	Profile of South African agriculture	45
3.2.1	Landscape	45
3.2.2	Farming areas, crops and livestock production	47
3.2.2.1	Farming areas	47
3.2.2.2	Crops and livestock production	49
3.2.3	Major farming systems in South Africa	52
3.2.4	Economic performance of agriculture in South Africa	55
3.2.4.1	Output and GDP contribution	55
3.2.4.2	Competitiveness and contribution to external trade balance	56
3.2.4.3	Contribution to employment, rural poverty and food security	58
3.2.5	South African agricultural policy	59
3.3	Current climate regime and impact on agriculture in South Africa	60
3.3.1	South Africa current climate	60
3.3.2	Climate variability and its impact on agriculture	62
3.4	Climate change projections and predicted impacts on agriculture in South Africa	65
3.4.1	Future climate change projections	65
3.4.2	Predicted impacts of climate change on agriculture in South Africa	69
3.4.3	Gaps in existing knowledge on climate change impacts in South Africa	74
3.5	Concluding remarks	77
CHAPTER 4:		79
REVIEW OF METHODS AND EMPIRICAL STUDIES FOR MEASURING VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE		79

Gbetibouo G. A. (2011)

4.1	Introduction	79
4.2	Assessment of vulnerability to climate change	79
4.2.1	Approaches for measuring vulnerability	79
4.2.1.1	The vulnerability variable assessment	80
4.2.1.2	The indicator approach	82
4.2.1.3	The choice of vulnerability approach for the present study	83
4.2.2	Empirical studies for vulnerability indices	85
4.2.2.1	General composites indices	85
4.2.2.2	Climate change and climate variability vulnerability indices	88
4.3	Assessment of adaptation to climate change in agriculture	91
4.3.1	Methods to the study of adaptation	91
4.3.1.1	Top-down approach	91
4.3.1.2	Bottom-up approach	92
4.3.2	Empirical adaptation studies	94
4.3.3	The choice of adaptation approach for the present study	97
4.4	Concluding remarks	98
CHAPTER 5		99
SOUTH AFRICAN FARMING SECTOR VULNERABILITY TO CLIMATE CHANGE: A SUB-NATIONAL LEVEL ASSESSMENT		99
5.1	Introduction	99
5.2	The causal model of vulnerability: choice of indicators	100
5.2.1	Exposure	101
5.2.2	Sensitivity	102
5.2.3	Adaptive capacity	104
5.3	Calculating the vulnerability indices	109
5.4	Results and discussion	112
5.4.1	Descriptive statistics	112
5.4.2	The three dimensions of vulnerability	113
5.5	Summary and policy implications	122
CHAPTER 6:		124
SOUTH AFRICAN FARMERS' PERCEPTIONS AND ADAPTATIONS TO CLIMATE CHANGE AND VARIABILITY		124
6.1	Introduction	124
6.2	The study area and sources of data collection	125
6.3	Assessing farmers' perceptions to climate change	128

Gbetibouo G. A. (2011)

6.3.1	Comparison between perceptions of changes and meteorological stations' recorded data	128
6.3.1.1	Temperature perceptions	129
6.3.1.2	Rainfall perceptions	132
6.3.2	Spatial clustering of climate change perceptions	137
6.3.3	Factors influencing farmers' perceptions	138
6.4	Determinants of farmers' adaptation options to climate change and variability	142
6.4.1	The adaptation choices in the study area	142
6.4.2	The analytical framework	144
6.4.3	Empirical specification of the variables	148
6.4.4	Results and discussions	153
6.4.4.1	The Heckman Probit model results	153
6.4.4.2	The Multinomial Logit model results	156
6.5	Summary and policy implications	161
CHAPTER 7:		164
SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS		164
7.1	Introduction	164
7.2	Mapping South African farming sector vulnerability to climate change	164
7.3	Understanding farmers' perceptions and adaptation to climate change	166
7.4	Conclusions and implication for research and policy	168
APPENDIX		200

Gbetibouo G. A. (2011)

LIST OF TABLES

TABLE 2.1: SELECTED DEFINITIONS OF VULNERABILITY IN THE CLIMATE CHANGE RESEARCH FIELD	11
TABLE 2.2: SELECTED DEFINITIONS OF ADAPTATION	24
TABLE 3.1: LAND COVER IN SOUTH AFRICA	46
TABLE 3.2: PLANTED AREAS AND PRODUCTION OF SELECTED CROPS: 2009	50
TABLE 3.3: SOUTH AFRICAN HOUSEHOLDS' ACCESS TO AGRICULTURAL LAND: 2006	53
TABLE 3.4: FARMER TYPOLOGIES IN SOUTH AFRICA	54
TABLE 3.5: SOUTH AFRICA'S TRADE IN AGRICULTURAL GOODS: 1965-2005	57
TABLE 4.1: LIST OF IDENTIFIED ADAPTATIONS OPTIONS ACROSS AFRICA	96
TABLE 5.1: VULNERABILITY INDICATORS, VARIABLES AND DATA SOURCES	108
TABLE 5.2: THE MATRIX OF VULNERABILITY TO CLIMATE CHANGE AND VARIABILITY FOR PROVINCES IN SOUTH AFRICA	117
TABLE 5.3: FACTORS SCORES FROM PCA1 AND ASSOCIATED STATISTICS	120
TABLE 6.1: LIMPOPO BASIN AREAS	126
TABLE 6.2: FARMERS' PERCEPTION OF CHANGES IN TEMPERATURE AT PROVINCIAL LEVEL (%)	130
TABLE 6.3: ANALYSIS OF TEMPERATURE DATA: 1960-2003	131
TABLE 6.4: FARMERS' PERCEPTIONS OF CHANGES IN RAINFALL AT PROVINCIAL LEVEL (%)	134
TABLE 6.5: ANALYSIS OF THE RAINFALL DATA: 1960-2003	135
TABLE 6.6: MORAN'S I TEST FOR SPATIAL CORRELATION OF CLIMATE CHANGE PERCEPTION	138
TABLE 6.7: RESULTS OF THE SEEMINGLY UNRELATED BIPROBIT OF FARMERS' PERCEPTION OF CHANGE IN THE CLIMATE, LIMPOPO RIVER BASIN	141
TABLE 6.8: FARMERS' ADAPTATION STRATEGIES IN THE LIMPOPO RIVER BASIN (%)	143
TABLE 6.9: BARRIERS TO ADAPTATION IN THE LIMPOPO RIVER BASIN (%)	144
TABLE 6.10: VARIABLES HYPOTHESISED TO AFFECT ADAPTATION DECISIONS OF FARMERS IN THE LIMPOPO RIVER BASIN	152
TABLE 6.11: RESULTS OF THE HECKMAN PROBIT MODEL OF ADAPTATION BEHAVIOUR, LIMPOPO RIVER BASIN	155
TABLE 6.12: COEFFICIENT ESTIMATES OF THE MULTINOMIAL LOGIT ADAPTATION MODEL, LIMPOPO RIVER BASIN	159
TABLE 6.13: ESTIMATE OF THE MARGINAL EFFECTS OF THE MNL ADAPTATION MODEL, LIMPOPO RIVER BASIN	160
TABLE A2.1: SELECTED DEFINITIONS OF VULNERABILITY IN OTHER RESEARCH FIELDS	200
TABLE A2.2: TWO APPROACHES TO THE STUDY OF VULNERABILITY IN CLIMATE CHANGE RESEARCH	202
TABLE A4.1: A REVIEW OF METHODS AND INDICATORS USED TO CONSTRUCT VULNERABILITY	203
TABLE A5.1: COMPONENTS OF THE CROP DIVERSIFICATION INDEX	222
TABLE A5.2: COMPONENTS OF THE INFRASTRUCTURE INDEX	224
TABLE A5.3: EXPOSURE INDICATORS	225
TABLE A5.4: SENSITIVITY INDICATORS	226
TABLE A5.5: ADAPTIVE CAPACITY INDICATORS	227
TABLE A5.6: NORMALISED VALUE OF THE INDICATORS FOR THE VULNERABILITY INDEX	228
TABLE A6.1: PERCEPTIONS OF CHANGES IN TEMPERATURE BY FARMER EXPERIENCE (%)	232
TABLE A6.2: PERCEPTIONS OF CHANGES IN RAINFALL BY FARMER EXPERIENCE (%)	232
TABLE A6.3: PERCEPTIONS OF CHANGES IN TEMPERATURE BY FARMER EDUCATION LEVEL (%)	233
TABLE A6.4: PERCEPTIONS OF CHANGES IN RAINFALL BY FARMER EDUCATION LEVEL (%)	234
TABLE A6.5: CORRELATION MATRIX OF THE INDEPENDENT VARIABLES FOR THE ADAPTATION MODELS	235
TABLE A6.6: SUMMARY STATISTICS OF THE VARIABLES FOR THE ADAPTATION MODELS	236

Gbetibouo G. A. (2011)

LIST OF FIGURES

FIGURE 2.1: FOUNDATIONAL RISK HAZARD MODEL	15
FIGURE 2.2: THE PRESSURE AND RELEASE (PAR) MODEL OF VULNERABILITY	17
FIGURE 2.3: FRAMEWORK DEPICTING TWO INTERPRETATIONS OF VULNERABILITY TO CLIMATE CHANGE	21
FIGURE 2.4: ADAPTATION CYCLE WITH ITS MAIN DETERMINANTS	30
FIGURE 2.5: THE CAUSAL CHAIN VULNERABILITY - ADAPTATION TO CLIMATE CHANGE	42
FIGURE 2.6: FRAMEWORK OF FARMERS' AUTONOMOUS ADAPTATION TO CLIMATE CHANGE	43
FIGURE 3.1: DISTRIBUTION OF POTENTIAL ARABLE LAND IN SOUTH AFRICA	47
FIGURE 3.2: DISTRIBUTION OF CROPS AND LIVESTOCK ACROSS SOUTH AFRICA	49
FIGURE 3.3: INDICES OF VOLUME OF AGRICULTURAL PRODUCTION OVER THE YEARS: 2005-2010	51
FIGURE 3.4: SOUTH AFRICAN PROVINCES SHARE CONTRIBUTION TO AGRICULTURAL GDP	56
FIGURE 3.5: CLIMATE ZONES IN SOUTH AFRICA	61
FIGURE 3.6: MEAN ANNUAL RAINFALL IN SOUTH AFRICA	62
FIGURE 3.7: SOUTH AFRICAN ANNUAL RAINFALL COEFFICIENT OF VARIATION	63
FIGURE 3.8: MAIZE YIELD AND ANNUAL RAINFALL: 1970-2006	64
FIGURE 3.9: HADCM3 CLIMATE MODEL PREDICTIONS BY 2050 RELATIVE TO MEAN CONDITIONS OVER THE 1961 TO 1990 PERIOD FOR SOUTHERN AFRICA	69
FIGURE 5.1: CONTRIBUTION OF DIFFERENT INDICATORS TO VULNERABILITY	107
FIGURE 5.2: EXPOSURE INDEX ACROSS THE PROVINCES IN SOUTH AFRICA	113
FIGURE 5.3: SENSITIVITY INDEX ACROSS THE PROVINCES IN SOUTH AFRICA	115
FIGURE 5.4: MAP OF EXPOSURE-SENSITIVITY INDEX ACROSS THE FARMING PROVINCES IN SOUTH AFRICA	115
FIGURE 5.5: MAP OF ADAPTIVE CAPACITY INDEX ACROSS THE PROVINCES IN SOUTH AFRICA	116
FIGURE 5.6: VULNERABILITY INDEX ACROSS THE FARMING REGIONS IN SOUTH AFRICA	121
FIGURE 5.7: MAP OF VULNERABILITY INDEX ACROSS SOUTH AFRICA'S PROVINCES	121
FIGURE 6.1: PROVINCES AND WATER MANAGEMENT AREAS IN THE LIMPOPO RIVER BASIN	127
FIGURE 6.2: FARMERS' PERCEPTIONS OF CHANGES IN TEMPERATURE IN THE LIMPOPO RIVER BASIN SOUTH AFRICA	130
FIGURE 6.3: TREND TEMPERATURE DATA FOR THE LIMPOPO RIVER BASIN: 1960-2003	131
FIGURE 6.4: FARMERS' PERCEPTIONS OF CHANGES IN RAINFALL IN THE LIMPOPO RIVER BASIN	133
FIGURE 6.5: TREND RAINFALL DATA FOR THE LIMPOPO RIVER BASIN: 1960-2003	135

ACRONYMS AND ABBREVIATIONS

ACRU	Agricultural Catchments Research Unit
AEZ	Agro Ecological Zone
AgriSA	Agri South Africa
AR4	Fourth Assessment Report
ARC	Agricultural Research Council
BFAP	Bureau for Food and Agricultural Policy
BMZ	German Federal Ministry for Economic Cooperation and Development
CEEPA	Centre for Environmental Economics and Policy in Africa
CERES	Crop Estimation through Resources and Environmental Synthesis
CIESIN	Centre for International Earth Science Information Network
CO ₂	Carbon Dioxide
CSAG	Climate Systems Analysis Group
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSM	Climate Systems Model
DEAT	Department of Environmental Affairs and Tourism
DAFF	Department of Agriculture, Forestry and Fisheries
DSSAT	Decision Support Systems for Agrotechnology Transfer
DWAF	Department of Water Affairs and Forestry
ECHAM	German Climate Research Centre
EM-DAT	Emergency Events Database
ESI	Environmental Sustainability Index
EVI	Environmental Vulnerability Index
FAO	Food and Agriculture Organization of the United Nations
FAR	First Assessment Report
FARM	Future Agricultural Resources Model
GCCC	Government Committee on Climate Change
GCIS	Government Communication Information System
GCM	Global Circulation Model
GDP	Gross Domestic Product
GHG	Greenhouse Gases
HadCM	Hadley Centre for Climate Change Prediction and Research
HDI	Human Development Index
HIV/AIDS	Immunodeficiency Virus/ Acquired Immune Deficiency Syndrome
IFPRI	International Food Policy Research Institute
IFRC	International Federation of Red Cross
IIA	Irrelevant Alternatives
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
JRC	Joint Research Centre
LTMS	Long Term Mitigation Scenario
MELE	Maximum Entropy Leuven Estimator

Gbetibouo G. A. (2011)

MNL	Multinomial Logit
NAFU	National African Farmers' Union
NCCC	National Committee on Climate Change
NCCRS	National Climate Change Response Strategy
NDA	National Department of Agriculture
OECD	Organisation for Economic Co-operation and Development
PAR	Pressure and Release
PCA	Principal Component Analysis
PCU	Positive Chill Units
SA	South Africa
SAR	Second Assessment Report
SAWS	South African Weather Service
SEI	Stockholm Environment Institute
SOPAC	South Pacific Applied Geosciences Commission
SPI	Standardized Precipitation Index
SRES	Special Report on Emissions Scenarios
SSA	Statistics South Africa
TAR	Third Assessment Report
UKCIP	United Kingdom Climate Impacts Programme
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNDRO	United Nations Disaster Relief Organization
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USDA	United States Department of Agriculture
VAD	Value Added
VEP	Expected Poverty
VER	Uninsured Exposure to Risk
VEU	Low Expected Utility
WMAs	Water Management Areas
°C	Degree Celsius
%	Percent
Km ²	Square kilometres
Mm	Millimetres

DEFINITIONS OF KEY TERMS

Climate change and climate variability: There is a fundamental difference between climate change and climate variability. Climate change constitutes a shift in meteorological conditions that last for a long period of time, usually centuries. Climate variability represents short term fluctuations happening from year to year. In this work both definitions are used: climate change as the conceptual global change that is taking place and climate variability as the process taking place in South Africa within the time-frame considered in this study. The underlying conception is that global climate changes cause local scale impacts and that it is not possible to treat variability separate from climate change (Hageback et al. 2005; Mearns et al. 1997; Smit et al. 1999 & 2000)

Vulnerability: or “*vulnerare*” refers to the capacity to be wounded, i.e. the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed as well as the system’s sensitivity and adaptive capacity (IPCC 2007).

Adaptive capacity/Adaptation: Adaptive capacity of a system or society reflects its ability to modify its characteristics or behaviour so as to cope better with existing or anticipated external stresses and changes in external conditions (Brooks 2003). Adaptation is adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts (IPCC 2007). Adaptation does not occur instantaneously; a system requires time to realise its adaptive capacity as adaptation. Adaptive capacity represents potential rather than actual adaptation.

CHAPTER 1: INTRODUCTION

1.1 Background

During the late 20th century to the early 21st century, global environmental change research increasingly focused on the link between human dimensions and global change by shifting from impact assessments based on climate model scenarios to analyses of vulnerability. The consequences of environmental change are now well understood as a function of the ability of people and social systems to adapt to global environmental change. Thus, capacity to cope and adapt, like mitigation, became an important issue in addressing vulnerability to global environmental change. For this reason, the concepts and methods contributing to increased knowledge on and understanding of vulnerability and adaptation have become major foci of human dimensions research on global environmental change (Downing et al. 2000; Kasperson and Kasperson 2001; Polsky et al. 2003).

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) highlighted that for Africa a great deal more needs to be done in order to understand the interactions between vulnerability and adaptation to climate change and variability, and between the short and long term consequences of those changes. Indeed, previous assessments of climate change impacts (Hulme 1996; IPCC 1996; IPCC 2001; IPCC 2007) have concluded that Africa's major economic sectors are vulnerable to climate change and variability, with huge economic impacts. This vulnerability is exacerbated by existing developmental challenges such as endemic poverty; complex governance and institutional dimensions; limited access to capital, including markets, infrastructure and technology; ecosystem degradation; and complex disasters and conflicts. These in turn have contributed to Africa's weak adaptive capacity, increasing the continent's vulnerability to projected climate change. It is also recognised that the vulnerability of human populations and natural systems to climate change will not be uniform across continents, within continents and even within countries. Africa is a region of much diversity in terms of climate, landforms, biota, cultures and economic circumstances. Therefore, it will be

Gbetibouo G. A. (2011)

necessary to develop and apply more localised assessment models that reflect key factors for each sub-region, country or sub-country or even at a much lower scale.

1.2 Problem Statement and Motivation

In Southern Africa, the manifestations of climate change are predicted to be greatest in the northern regions. Temperature increases in the range of 1 °C to 3 °C are expected by the mid-21st century, with the highest increases expected for the most arid parts of Southern Africa. There is no general agreement whether rainfall over the region is likely to decrease or increase. However, rainfall patterns are likely to change with greater seasonal and interannual variability and large spatial variations across the country (Hewitson 1999; Hewitson and Crane 2006; Scholes and Biggs 2004). Of greater consequence for South Africa, as a semi-arid country, is the prediction of an increasing incidence of both droughts and floods, with prolonged dry spells followed by intense storms (Hewitson et al. 2005).

These predictions raise concerns that climate change could have a significant adverse impact on crop and livestock production in the country, which would have important implications for the wellbeing of South African farmers, particularly for poorer, emerging farmers in the country. Agriculture plays a prominent role in the stability of rural communities. As in many countries, the poor in South Africa are disproportionately found in rural areas, and most rural households depend on agriculture for food and income. Numerous initiatives have sought to analyse the impact of global climate change on agriculture in South Africa. Indeed, previous climate change studies conducted in South Africa focus on the implications of future climate change on crop yields and production, emphasising the physical impacts of climate change (Du Toit et al. 2000; Midgley et al. 2007; Schulze et al. 1993; Walker and Schulze 2008) and the economic impacts derived from yields losses (Erasmus et al. 2000; Blignaut et al. 2009). Other studies developed a more comprehensive analysis of the economic impacts by including adaptation options (Benhin 2008; Deressa et al. 2005; Gbetibouo and Hassan 2005). Based on predictions regarding the physiological responses of affected plants, these studies predict that climate change is more likely to negatively impact the agriculture sector, induce (or require) major shifts in farming practices and patterns in different regions of the country. Crops yields were found to be sensitive

Gbetibouo G. A. (2011)

to the different climate change scenarios applied. In general, there is a higher likelihood for crops yields to suffer significant reductions. Furthermore, general aridification of rangelands, increase in frequency and spatial extent of livestock disease outbreaks and bush fires intensities predicted by most climate models, are more likely to impact negatively the overall livestock production of the country (DEAT 2000).

However, it is increasingly accepted that the vulnerability of agricultural populations to climatic conditions cannot be solely understood through the quantification of biophysical impacts (Wehbe et al. 2005). Such a narrow biophysical focus, invariably neglects the social, economic and political factors that influence differential vulnerability between individuals and social groups (Hewitt 1995). According to Wehbe et al. (2005), the degree to which climatic events affect an agricultural system depends on a wide variety of factors, including among others things, the types of crops or livestock produced, the scale of the operation, farm's orientation towards commercial or subsistence purposes, the quality of the natural resource base, and specific human variables of farm managers (e.g.: education, risk tolerance, age, etc.). Vulnerability is also mediated by institutional factors, including the rules, norms and policies that govern land tenure, the availability of markets, financial capital, insurance and support programs, and the degree of technology development and distribution.

In South Africa, a number of studies have made efforts to improve the knowledge of the social aspects of vulnerability to climate change with in-depth examination of the underlying socio-economic and institutional factors (O'Brien and Vogel 2003; Vogel and Drummond 1993; Reid and Vogel 2006; O'Brien et al. 2009). However, these studies are mainly done in the natural hazard and geography research areas. Climate change studies in agriculture that adopted a social driven process of vulnerability are therefore needed.

The agriculture sector of South Africa displays a diverse range of social, economic, political and environmental conditions. Indeed agriculture in South Africa is characterised by a developed commercial farming sector functioning alongside a large subsistence farming sector. Rural infrastructure development and farming systems also vary across the South African landscape as a result of variations in economic development and climate patterns. This diversity suggests that vulnerability to climate change might also vary considerably across South Africa's provinces. It

Gbetibouo G. A. (2011)

is therefore important to identify the agricultural areas, production systems, and populations that are most vulnerable to climate change.

The primary objective of this study is to analyse the vulnerability of South African agriculture to climate change and variability by developing a vulnerability index and comparing vulnerability indicators across provinces of the country. Environmental and socio-economic, institutional indicators are identified and combined to derive vulnerability indices mapped as vulnerability profiles. This will result in better knowledge of which and where are the vulnerable farming areas in South Africa and will therefore assist decision-makers in designing policies aimed at reducing vulnerability to climate change as accurately as possible. Hence directing resources to where they are most needed.

The extent to which climate change impacts are felt depends in large part on the capacity of affected communities to adapt. Studies show that without adaptation, climate change would be detrimental, but with adaptation, vulnerability can be significantly reduced (Easterling et al. 1993; Mendelsohn 1998; Reilly and Schimmelpfennig 1999; Rosenzweig and Parry 1994; Smit and Skinner 2002; Smith 1996). Therefore identifying the vulnerable agricultural regions should be an inclusive process with the understanding of the adaptation process of the vulnerable farmers in those vulnerable places. Vulnerability and adaptation are inseparable themes in the climate change research.

The need for research that will improve farm-level adaptation to climate change is well recognised (Brklacich et al. 1997; Kandlikar and Risbey 2000; Leary 1999; Smit et al. 2000; Smith et al. 1998). However, in South Africa, past climate change studies have largely ignored or did not properly address adaptation in their analyses. Using prescriptive models (crop growth models, production functions and Ricardian studies), they investigate possible or potential adaptation measures, rather than ones actually adopted. These studies often assume certain adaptations and little explicit examination of how, when, why and under what conditions adaptation actually occurs in economic and social systems (Akpalu et al. 2008; Deressa et al. 2005; Du Toit et al. 2000; Durand 2006; Gbetibouo and Hassan 2005; Schulze et al. 1993; Walker and Schulze 2008). To assist farmers in adapting to climate change it is necessary to understand farmers' perceptions of climate variability and climate change, how they are affected

Gbetibouo G. A. (2011)

by climatic conditions, the adaptive strategies that are available to them, and the constraints and opportunities for enhancing their adaptive capacity (Belliveau et al. 2006; Smit and Pilifosova 2002; Yole and Tol 2002).

Two recent studies investigate farmers' adaptations behaviour to climate change and variability in South Africa. Ziergovel et al. (2006) assessed agricultural decision-making in a communal irrigation scheme in Vhembe district, in the Limpopo province and concluded that adaptation strategies within a community are socially differentiated and present differing objectives and priorities. However, they used experimental computer based interview and therefore their analyses were based on perceived adaptations instead of past adaptations actions. Thomas et al. (2007), looking at farmers across three provinces in the country also concluded that a range of specific coping and adaptation strategies are employed by farmers to respond to climate shifts, some are generic across regions and some are facilitated by specific local factors. However, they fail to identify which factors determine adoption of adaptation strategies among individuals within community. Several authors warn about undermining intra-community differential vulnerability. Communities or even individuals within the same household are not necessarily homogenous. Being exposed to the same climate risks does not imply that each member of the community is affected in the same way (Bankoff 2001; Yamin et al 2005).

Several recent studies addressing the determinants of household level actual adaptation adaptations using multivariate techniques have emerged in the literature. Using datasets covering farmers across different countries in Africa including South Africa (Belliveau et al. 2006; Brklacich et al. 1997; Hassan and Nhemachena 2008; Maddison 2006; Smit et al. 1996), studies investigate factors affecting the choice of adaptations strategies to climate change at the individual farm level. However, because of the aggregation level, their results did not provide country specific factors which determine adaptations choices. Deressa et al.(2009) investigate the determinants of adaptation in the Nile Basin in Ethiopia. However, extrapolate their results to make the case for adaptation in South Africa is limited due to the heterogeneity of farmers and farmers' responses across and within geographical areas. Even, heterogeneity exists within country, therefore more localised micro-level studies of the impact of climatic variability and change on people's livelihoods at the farm level and their consequent responses assume critical importance in South Africa.

Gbetibouo G. A. (2011)

To pursue this objective, the study surveyed farming households in the arid Limpopo River Basin in South Africa to assess farmers' perceptions regarding long-term changes in local climate and their primary adaptations responses and factors constraining their capacity to adapt. The research therefore generates important policy information on how to enhance adaptive capacities of rural households in stressed environments like the Limpopo Basin.

1.3 Research objectives

The primary objective of this study is to examine the vulnerability of South Africa's farming sector. A national vulnerability profile of the farming sector to climate change at provincial level is developed to identify the most vulnerable areas and social groups in the country. In addition to the vulnerability assessment, this research investigates the adaptation process of farmers in the arid Limpopo River Basin of South Africa in face of climate change and variability by identifying the factors that enhance or constrain adaptive capacity of farmers.

Specifically the research has:

1. Developed indicators for spatially explicit vulnerability to climate change at provincial level.
2. Produced national maps of vulnerability which rank provinces depending on their vulnerability score.
3. Captured the extent of farmers' awareness and perceptions of climate change and variability.
4. Identified the types of adjustments they have made in their farming practices in response to these changes.
5. Applied quantitative approaches for analysing adaptation behaviour of farmers.
6. Developed general directions for agricultural adaptations options (responses options) to climate change for South Africa.

Gbetibouo G. A. (2011)

1.4 Hypotheses of the study

Based on the problem statement and objectives of the research set out above, the following hypotheses are advanced to be tested:

1. The most exposed provinces to the physical manifestations of climatic change (change in average conditions and/or occurrence of extreme climate events) are not necessary the most vulnerable agricultural provinces to climate change in South Africa when socio-economic factors are taken into account.
2. Farmers' perceptions of climatic change correspond with climate data recorded at meteorological stations.
3. Improved access to resources such as (credit, extension, information, water, etc) enhances farm-level use of adaptation measure.

1.5 Approach and methods of the study

This study employs two main analytical techniques to attain above stated objectives. It firstly adopts the indicator approach to analyse the vulnerability of South African farmers to climate change and variability by developing a vulnerability index and comparing vulnerability indicators across provinces of the country. In this approach environmental and socio-economic, institutional indicators are identified and combined into vulnerability indices and mapped as vulnerability profiles. Secondly, the study examines how farmers' perceptions correspond with climate data recorded at meteorological stations and analyses farmers' adaptation responses to climate change and variability. A seemingly unrelated Biprobit model is employed to investigate factors' perceptions of climate change. Further, both a Heckman probit model and a multinomial logit (MNL) model are used to examine the determinants of adaptation to climate change and variability.

The empirical estimations are based on a mix of secondary data collected from various secondary sources and primary data from existing survey data obtained from a project entitled Food and

Gbetibouo G. A. (2011)

Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa. The project was funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) and aimed to analyse the potential impact of climate variability and climate change on household vulnerability and farm production in the Limpopo River Basin of South Africa. The survey was carried out by the Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, in collaboration with the International Food Policy Research Institute (IFPRI).

1.6 Organisation of the thesis

This study is organised into seven chapters. Chapter 1 gives a general background to the research problem, objectives and methods of the study. The theoretical and conceptual aspects of vulnerability and adaptation to climate change are discussed in chapter 2. Chapter 3 gives an overview of South Africa current climate, socio-economic conditions in which the agriculture sector operates and the projected climate change and its subsequent impacts. Chapter 4 presents a review of approaches and empirical studies for measuring vulnerability and adaptation to climate change. Chapter 5 evaluates the relative distribution of South African farming sector vulnerability to climate change and variability across the nine provinces. Chapter 6 addresses the second objective of contributing to enhanced adaptive capacity in the face of changing climate. Finally, chapter 7 gives the main conclusions and recommendations of the study.

CHAPTER 2:

VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE: A THEORETICAL AND CONCEPTUAL BACKGROUND

2.1 Introduction

The vulnerability of developing countries to the potential impacts of climate change and the options for adaptation are rapidly emerging as central issues in the debate around policy responses to climate change. In order to prioritise, design and implement interventions to adapt to climate change, it is essential to adopt a coherent and consistent set of definitions and frameworks for examining vulnerability and adaptation. In practice, a variety of definitions of vulnerability and adaptation are found in the literature. The purpose of this chapter is to identify theoretical approaches that provide a framework for the study of vulnerability and adaptation to climate change. The focus is on the vulnerability and adaptation of human individuals and communities to climate stress, in particular the vulnerability and adaptation of farmers or farming regions to climate change and variability. This chapter has three main sections. In section 2.2 the concept of vulnerability is discussed from its conceptual roots to its current interpretation in climate change research. Section 2.3 reviews the concept of adaptation in general and adaptation in the agriculture sector in particular. The relations between these two concepts are discussed and the conceptual framework adopted for this study is presented in section 2.4.

2.2 Conceptual framework of vulnerability to climate change

2.2.1 Defining vulnerability

Grammatically in the Oxford dictionary, the word vulnerability, or “*vulnerare*” from its Latin root refers to: “exposed to the possibility of being attacked or harmed, either physically or emotionally”. However, in research, vulnerability is a term with more than 30 definitions (Table

Gbetibouo G. A. (2011)

2.1 and Appendix 2.1). Originally from the geography and natural hazards field, the term has been expanded over the years by social scientists and it is now a central concept in a variety of other research contexts such as ecology, public health, poverty and development, famine and livelihoods, sustainability science, land change and climate impacts and adaptation (Fussel 2007). Vulnerability has been used interchangeably or in conjunction with other terms such as resilience, resistance, risk, marginality, adaptability, susceptibility, fragility, exposure, sensitivity, coping capacity, criticality, robustness, etc. (Bogardi 2006; Fussel 2007; Liverman 1990). The sources of these terminological discrepancies could be founded in the different epistemological foundations, diverse methodological applications, the different policy context and the variations in describing hazards and exposure units (Cutter 1996; Fussel 2007; Weichselgartner 2001). Recently, attempts have been made to develop general applicable conceptual framework of vulnerability (Fussel 2007) and formal models of vulnerability, both statically (Luers et al. 2003; Luers 2005; Metzger et al. 2005) and dynamically (Ionescu et al. 2009). But the research is still in its infancy and no general consensus on the definition of vulnerability has yet been found.

Considering the complexities and uncertainties associated with the term, elaborating and analysing all the various schools, historical development and academic definitions of vulnerability is beyond the scope of this chapter¹. Rather we will attempt to explore the concept of vulnerability and its evolution within the context of global environmental change, particularly climate change, to address issues related to reducing long-term climate change impacts and catalysing sustainable development.

¹ Intensive and general review of vulnerability can be found in (Cardonna 2004; Cutter 1996; Hewitt 1997; Kasperson et al. 2005; Liverman 1990; Timmermann 1981) .

Gbetibouo G. A. (2011)

Table 2.1: Selected definitions of vulnerability in the climate change research field

Author(s)	Definitions
Kates (1985)	Vulnerability is the 'capacity to suffer harm and react adversely'.
Chambers (1989)	Vulnerability refers to exposure to contingencies and stress, and difficulty in coping with them. Vulnerability has two sides: an external side of risks, shocks and stress to which an individual or household is subject; and an internal side which is defencelessness, meaning a lack of means to cope without damaging loss.
Liverman (1990)	Distinguishes between vulnerability as a biophysical condition and vulnerability as defined by political, social and economic conditions of society. She argues for vulnerability in geographic space (where vulnerable people and places are located) and vulnerability in social space (who in that place is vulnerable).
Downing (1991)	Vulnerability has three connotations: it refers to a consequence (e.g. famine) rather than a cause (e.g. drought); it implies an adverse consequence (e.g. maize yields are sensitive to drought; households are vulnerable to hunger); and it is a relative term that differentiates among socio-economic groups or regions, rather than an absolute measure of deprivation.
Dow (1992)	Vulnerability is the differential capacity of groups and individuals to deal with hazards, based on their positions within physical and social worlds.
Bohle et al. (1994)	Vulnerability is best defined as an aggregate measure of human welfare that integrates environmental, social, economic and political exposure to a range of potential harmful perturbations. Vulnerability is a multi-layered and multidimensional social space defined by the determinate political, economic and institutional capabilities of people in specific places at specific times.
Dow and Downing (1995)	Vulnerability is the differential susceptibility of circumstances

Gbetibouo G. A. (2011)

Author(s)	Definitions
	contributing to vulnerability. Biophysical, demographic, economic, social and technological factors such as population ages, economic dependency, racism and age of infrastructure are some factors which have been examined in association with natural hazards.
Vogel (1998)	Vulnerability is perhaps best defined in terms of resilience and susceptibility, including such dimensions as physical, social, cultural and psychological. Vulnerability and capacities that are usually viewed against the backdrop of gender, time, space and scale.
Adger and Kelly (1999)	Individual and collective vulnerability and public policy determine the social vulnerability to hazards and environmental risks, defined here as the presence or lack of ability to withstand shocks and stresses to livelihood.
IPCC (2001)	The degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. Under this framework, a highly vulnerable system would be one that is highly sensitive to modest changes.
Moss et al. (2001)	Vulnerability has three dimensions: the physical-environmental dimension accounts for the harm caused by climate; the socio-economic dimension refers to a region's capacity to recover from extreme events and adapt to change over the longer term. The third dimension, external assistance is defined as degree to which a region may be assisted in its attempts to adapt to change through its allies and trading partners.
UNEP (2002)	Vulnerability is a function of sensitivity to present climatic variability, the risk of adverse future climate change and capacity to adapt...the extent to which climate change may damage or harm a system; vulnerability is a function of not only the system's

Gbetibouo G. A. (2011)

Author(s)	Definitions
	sensitivity, but also its ability to adapt to new climatic conditions.
Eriksen and Kelly (2007)	Vulnerability is a function of the system's exposure and capacity to respond.
Ionescu et al. (2009)	Vulnerability is a relative term; it is the vulnerability of an entity to a specific stimulus with to a certain preference criteria that refer to future evolutions of the entity. Notion of sensitivity is not necessary to define vulnerability.

Source: Updated from Kaspersen et al. (2005)

2.2.2 Conceptual roots of vulnerability

The conceptualisation of vulnerability varies across research domains. A review of vulnerability definitions reveals a distinction in the literature between two main roots of conceptual approaches: the risk hazard approach and the political economy approach. The risk hazard school of thoughts emerged from the pioneering research of Gilbert White of the University of Chicago beginning in the 1940s on the theorisation of human exposure to natural disasters and the drivers of the nation's increasing vulnerability to losses from natural hazards (Cutter et al. 2009; Eakin and Wasler 2008). This natural event exposure-based approach prevailed for three decades until researchers began to question the validity of such natural event focus. In contrast, the political economy school of thought has arisen out of interpretive social science paradigms where the role of human agency is made explicit by attributing the drivers of vulnerability to the social, political and economic pressures imposed on individuals, which constrained their responses and ability to cope with disasters (Cutter et al. 2008; Liverman 1990). According to Eakin and Luers (2006), the weakness of the political economy approach resides in the absence of a clearly defined vulnerability outcome, which has produced generic descriptions of inequities in resource distribution and opportunity without demonstrating ties to differential susceptibility to harm. The approach has also been criticised for over emphasising the role of human agency and ignoring/diminishing the role of physical processes. Building on the limitations of these two

Gbetibouo G. A. (2011)

conceptual roots of vulnerability, other conceptual approaches have been developed². It is also important to note that interdisciplinary models of vulnerability that analysed vulnerability from the perspectives of human ecology of food production, various forms of exchange entitlements and the political economy of food systems have also been developed by Watts and Bohle (1993) and Bohle et al. (1994). In the following sections, we describe broadly the two conceptual roots of vulnerability research.

2.2.2.1 The risk hazard approach

Risk hazard approach refers sometimes to the biophysical perspective of vulnerability (Brooks 2003; Cutter 1996; Fussel 2007; Liverman 1990; McLaughlin and Dietz 2008). It uses the biophysical threat as the point of departure and describes on a very broad scale: i) “what are we vulnerable to?”; ii) “what consequences might be expected?”; and iii) “where and when those impacts may occur?” (Eakin and Luers 2006). Vulnerability in this framework is the threat to which people are exposed where the risk context is contingent on the specification of hazards or shocks (Gabor and Griffith 1980).

According to Turner et al. (2003) foundational risk hazard models (Figure 2.1) sought to explain the impact of a hazard as a function of exposure to the hazard event and the dose–response (sensitivity) of the entity exposed. The risk hazard framework distinguishes two factors that determine the risk to a particular system (Fussel 2007): the ‘hazard’, which is “a potentially damaging physical event, phenomenon or human activity [that] is characterised by its location, intensity, frequency and probability”, and the ‘vulnerability’, implicit in the framework, which denotes the “relationship between the severity of hazard and the degree of damage caused”. The vulnerability relationship is variably denoted as ‘hazard-loss relationship’ in natural hazards research, ‘dose-response relationship’ or ‘exposure-effect relationship’ in epidemiology, and

² Human ecological approach emphasis on environmental variation as a causal force influencing social change and vulnerability: see Moran (1990). Constructivist perspective emphasises the role that culture plays in shaping definitions of exposure to risk: see Tansey and O’Riordan (1999). Political ecology approach argue for a more balanced consideration of both biophysical and social dynamics, with explicit attention to the representation of those dynamics in policy and decision making: see Stonick (1993; 2000). Resilience approach: focus of the couple human-environment systems, vulnerability is seen as a dynamic property of a system in which humans are constantly interacting with the biophysical environment: see Adger and Kelly (1999).

Gbetibouo G. A. (2011)

‘damage function’ in macro-economics. This formulation is therefore based on the assumption of exogenous causal factors of risks and requires a clear separation between selected causal events and outcomes.

Thus, studies using the risk hazard approach are characterised by a focus on the distribution of some hazardous condition, the human occupancy of this hazardous zone (e.g. floodplains, coastal areas, seismic zones), and the degree of loss (life and property) associated with the occurrence of a particular event (flood, hurricane, earthquake) (Cutter 1996). Generally, the exposure units are populations, places, building and civil engineering works, sectors, activities, landscapes, regions. The decision scale is regional or global. Furthermore, by identifying the specific causal risk factors and the relative degree of risk, this approach can inform the types of interventions, the locations, timing, target population and level of effort that are needed to avoid the undesired outcome (Dilley and Boudreau 2001).

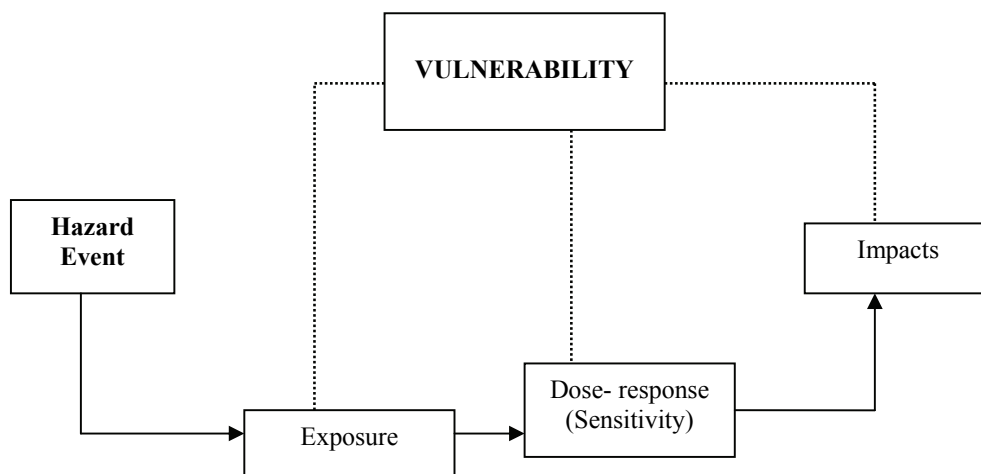


Figure 2.1: Foundational risk hazard model

Chain sequence beginning with hazard and the concept of vulnerability commonly implicit as noted by dotted lines.

Source: Turner et al. (2003).

Gbetibouo G. A. (2011)

2.2.2.2. The political economy approach

Originating from roots in structuralist and neo-Marxist thought, the political economy approach defines vulnerability by the political, social and economic conditions of a society. This approach to vulnerability is more human centric and examines the following questions (Cutter et al. 2009; Fussel 2007): i) “Why are particular populations vulnerable?” ; ii) “How are they vulnerable?”; and iii) importantly “who precisely is vulnerable?”. The political economic paradigm of vulnerability drew on the theoretical foundations of social marginalisation of classes (Susman et al. 1983) and the food entitlements theory of Sen (1981). The approach has been particularly influential in the environment, poverty and development literature, especially in theorising food insecurity and the incidence of famine due to droughts and climate hazards.

According to Susman et al. (1983) the basic cause of vulnerability is marginalisation, which comes from the continual process of impoverishment of poor classes by richer ones based on a world economy perpetuating technological dependency and unequal exchange. Overpopulation, unemployment, poverty, environmental degradation, flows of resources out of a region, land expropriations, exploitative labour conditions, political oppression and other processes associated with colonialism and capitalism are the structural causes of continuous human vulnerability to disasters. Vulnerability is therefore defined as the degree to which different classes in society are differentially at risk, both in terms of the probability of an extreme physical event and the degree to which the community absorbs the effects of extreme physical events and helps different classes to recover. According to this, vulnerability is not an outcome but rather a state or condition of being and a very dynamic one that is moderated by: i) existing inequalities in resource distribution and access; ii) the control individuals can exert over choices and opportunities; and iii) historical patterns of social domination and marginalisation (Eakin and Luers 2006). These perspectives on risk and vulnerability have been synthesised in the Pressure and Release model of Blaikie et al. (1994) known as the PAR model. In this model (Figure 2.2) progression of a community’s vulnerability to disaster is traced from the root causes at the macro level (social, political and economic structures) through the dynamic pressures at intermediate level (population growth, environmental degradation, etc.) to the unsafe conditions at the local level (social fragility, potential harm, poverty, etc.).

Gbetibouo G. A. (2011)

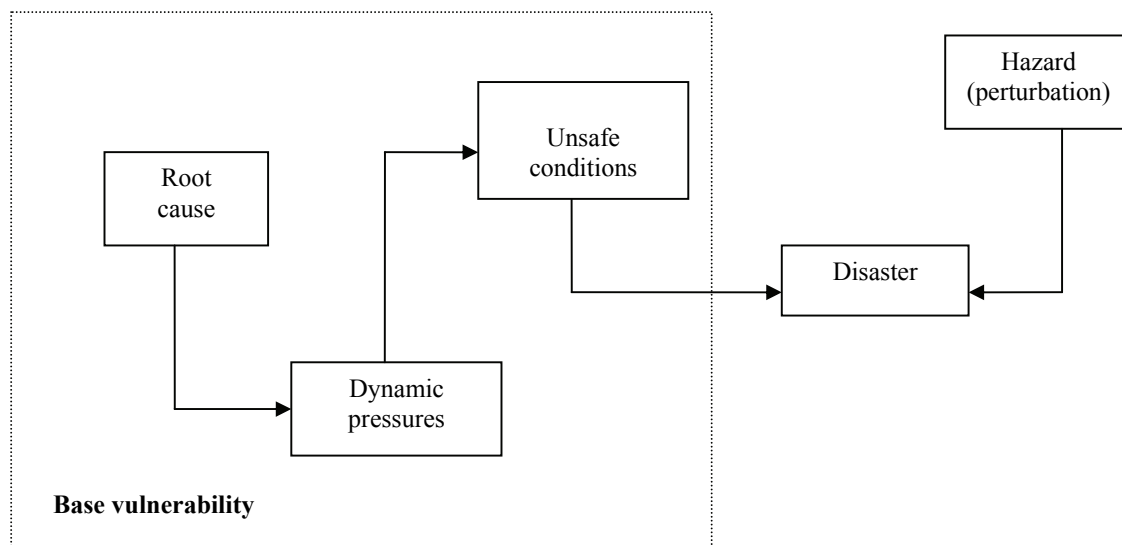


Figure 2.2: The Pressure and Release (PAR) model of vulnerability

PAR framework placed emphasis on the “social” conditions of exposure and the concept of vulnerability usually explicit.

Source: Turner et al. (2003).

Another influential theory is found on Sen’s seminal essay on poverty and famines, where he developed the entitlement approach and demonstrated that famine occurs not only from a lack of food, but from inequalities built into mechanisms for distributing food (Sen 1981). Entitlement theory embraces two related approaches to hunger: food security and coping strategy models on the one hand and social welfare on the other. Vulnerability is thus a socio-economic space which is delineated by the following three domains: i) market perturbations (economic exchange); ii) coping thresholds; and iii) social security limitations. Vulnerability delimits those groups of society: i) who are most exposed to market failures; ii) whose coping capacity with respect to unfavourable terms of exchange is low; and iii) who are insufficiently integrated into social security arrangements (Watts and Bohle 1993).

Gbetibouo G. A. (2011)

There are two basic concepts in Sen's entitlement approach: i) endowments; and ii) entitlements. An endowment set is defined as the combination of all the resources legally owned by a person. Resources included: i) tangible assets such as land, equipment, labour power, and membership of a particular community; ii) intangibles such as skills and knowledge; and iii) legal resources established by social norms and practices and official legislation. The entitlement of a person refers to the set of different alternative commodity bundles that a person can acquire through the legal means available in the society, including the use of production possibilities, trade opportunities or social networks. The process of transforming endowments to entitlements, thereby enhancing capabilities, is termed "entitlement mapping" (Sen 1981).

Entitlement approaches have primarily addressed the conditions under which food insecurity collapses into mass starvation, and in this sense it endeavours to provide a theory of famine causation (Watts and Bohle 1993). According to Sen (1981), there are four categories of legal sources of food: i) "production-based entitlement" (growing food); ii) "trade-based entitlement" (buying food); iii) "own-labour entitlement" (working for food); and iv) "inheritance and transfer entitlement" (being given food by others). A person will starve if his entitlement set does not include a commodity bundle with enough food. Also a person is reduced to starvation if some change occurs either in his endowment (for example, alienation of land, loss of labour power, ill health) or in his exchange entitlement (for example, fall in wages, rise in food prices, loss of employment, drop in the price of foods he produces) makes it no longer possible to acquire a commodity bundle with sufficient food (Sen 1990). Vulnerability in this framework is the risk that the household's entitlements will fail to buffer against famine, dislocation, or climate uncertainty. It is therefore the risk associated with the threat of large-scale entitlement deprivation.

2.2.3 Epistemological approaches to vulnerability in the climate change research

Research on vulnerability applied to the issue of climate change impacts and risk demonstrates full range of research traditions (natural hazards, political economy, human/political ecology, poverty) while contributing in a significant way to the development of newly emerging systems vulnerability analysis (Adger 2006). Vulnerability in the climate change research is now widely

Gbetibouo G. A. (2011)

seen as an integrative concept that can link the social and biophysical dimensions of global environmental change (Adger 2006; O'Brien et al. 2007). Nevertheless, the climate change literature provides two main distinct epistemological approaches to conceptualising vulnerability which could be related to the main two conceptual roots of vulnerability described above. The two opposing research foci and traditions of vulnerability in the climate change research have been classified by several authors as: i) “end point” vulnerability vs. “starting point” vulnerability by Kelly and Adger (2000); ii) “biophysical” vulnerability vs. “social” vulnerability by Brooks (2003); and iii) “outcome” vulnerability vs. “contextual” vulnerability by O'Brien et al. (2007).

Vulnerability according to the “end point” approach is defined in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (Jones and Boer 2003). The end point approach considers vulnerability as the end point of a sequence of analyses beginning with projections of future emissions trends, moving on to the development of climate scenarios, and hence progresses through biophysical impact studies to the identification of adaptive options (Kelly and Adger 2000). This view has arisen from the traditional risk hazard vulnerability approach, in which the role of human systems in mediating the outcomes of hazard events is downplayed or neglected. The end point approach is found in earlier studies of integrated assessment modelling of climate change impacts. In this approach, vulnerability is understood as a residual of climate change impacts minus adaptation; it is therefore the net impact of climate change. Climate change impacts studies have typically examined factors such as increase in the number of people at risk of flooding based on projections of sea-level rise (Nicholls et al. 1999). In the agriculture sector, studies trace the impact of a specific change in physical input variables such as temperature on yields or biomass (Du Toit et al. 2000; Easterling et al. 1993; Makadho 1996; Rosenzweig et al. 1995). This approach is referred as biophysical vulnerability because it suggests both a physical component associated with the nature of the hazard and its first-order physical impacts, and a biological or social component associated with the properties of the affected system that act to amplify or reduce the damage resulting from these first-order impacts (Brooks 2003). The approach is also named outcome vulnerability because the result of the analysis (monetary cost, human mortality, production costs, agricultural yield, etc.) is an outcome that can be attributed to climate change (O'Brien et al. 2007). While positive outcomes are possible, it is the negative outcomes that are associated with vulnerability.

Gbetibouo G. A. (2011)

Thus, the end point represents a strong scientific understanding of climate change and other environmental problems. An assumed knowledge of future climate is deeply embedded in end-point analyses.

In contrast, the second approach considers vulnerability as the “starting point,” i.e. as a state that exists within a system before it encounters a hazard event (Brooks 2003; Kelly and Adger 2000). This approach to assessment of vulnerability to climate change has its origins in the political economy conception of vulnerability. According to Kelly and Adger (2000), the vulnerability of any individual or social group to some particular form of natural hazard is determined primarily by their current state, which defines their capacity to respond to that hazard, rather than by what may or may not happen in the future. Vulnerability is accordingly determined by the internal properties of a system, and is a variable condition generated by multiple environmental and social processes, including climate change. It is a contextual vulnerability because climate change and variability are considered to occur in the context of political, institutional, economic and social structures and changes, which interact dynamically with contextual conditions associated with a particular exposure unit (O'Brien et al. 2007). As viewed through the starting point approach, the inability to cope with or adapt to climate change and variability may be termed “social vulnerability,” since we are concerned about social systems. Social vulnerability is determined by factors such as poverty and inequality, marginalisation, food entitlements, access to insurance, and housing quality, etc. (Adger 1999; Blaikie et al. 1994; Cross 2001).

Figure 2.3 below gives a schematic construction of vulnerability in the two approaches and more detailed distinctive features could be found in appendix 2.2.

Gbetibouo G. A. (2011)

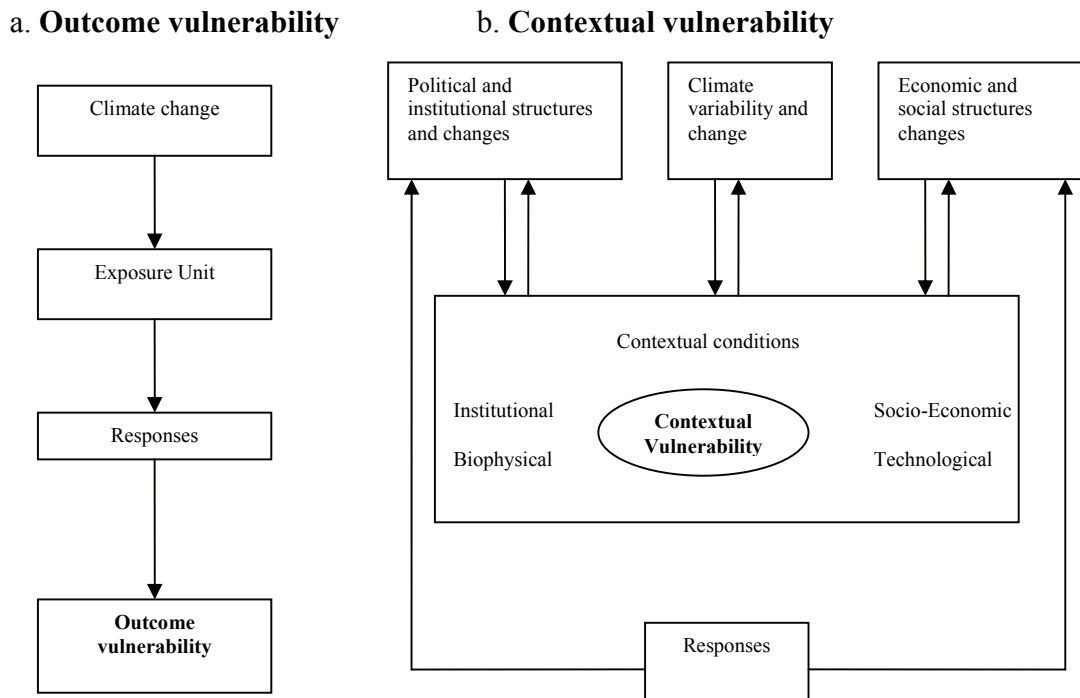


Figure 2.3: Framework depicting two interpretations of vulnerability to climate change

Source: O'Brien et al. (2007)

2.2.4 Basic components of vulnerability

Previous sections have tried to emphasise the complexity of the term vulnerability and how interpretations of the word vulnerability are diverse depending on the disciplinary context. Nevertheless, in the multidisciplinary domain of literature on global environmental change, particularly, in the climate change arena, an evolution towards common grounds of understanding of vulnerability can be found.

The most fully elaborated definition of vulnerability is provided by Chambers (1989) who puts forward the two sides of vulnerability. According to him, vulnerability is the exposure to

Gbetibouo G. A. (2011)

contingencies and stress, and the difficulty of coping with these exposures. Adger (1996) also identifies two components of vulnerability: the effects that an event may have on humans (referred to as capacity or social vulnerability), and the risk that such an event may occur (referred to as exposure). Thus, vulnerability refers to both internal and external dimensions. The internal dimension relates to defencelessness and insecurity, as well as the capacity to anticipate, cope with, resist, and recover from the impacts of a hazard. The external dimension involves exposure to risks and shocks. Furthermore, Bohle (2001) developed a conceptual framework of vulnerability named the “double structure of vulnerability”, which comprises exposure and coping. Here, the external perspective refers mainly to the structural dimensions of vulnerability and risk, while the internal dimension of vulnerability focuses on coping and actions taken to overcome or at least mitigate the negative effects of economic and ecological change.

The IPCC Second Assessment Report (SAR) and Moser (1998) changed the focus of vulnerability from emphasising internal/coping and external/exposure, to examining two similar but different factors: sensitivity and adaptive capacity (or resilience). The SAR defines vulnerability as the extent to which climate change may damage or harm a system. Vulnerability therefore depends not only on the system’s sensitivity, but also on its ability to adapt to new climatic conditions (IPCC 1996). According to Moser (1998), any definition of vulnerability requires identification of two components, namely: sensitivity and resilience. Sensitivity refers to the responsiveness of a system to climatic influences and the degree to which this responsiveness might be affected by climate changes. Resilience is the ease and capacity of a system’s recovery from stress.

The IPCC Third Assessment Report (TAR) reconciled both sides by adding a third component to vulnerability, defining it as: *“The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity”* (IPCC 2001). According to this definition, vulnerability includes an external dimension that is represented by the exposure of a system to climate variations, as well as a more complex internal dimension comprising its sensitivity and adaptive capacity to these stressors (Fussel and Klein 2006). The IPCC Fourth Assessment Report (AR4), which reports recent advances in our understanding of climate change, contains a

Gbetibouo G. A. (2011)

vulnerability definition consistent with that of the TAR (IPCC 2007). Under this framework, a highly vulnerable system would be one that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to adapt is severely constrained.

Adger (2006) examines the evolution of approaches to vulnerability originated in social and natural sciences. He concludes that vulnerability is most often conceptualised as being constituted by three components that include exposure to perturbations or external stresses, sensitivity to perturbation, and the capacity to adapt. Many authors (for example Brown et al. 2010; Downing et al. 2001; Ford et al. 2008; Gallopin 2006; Ionescu et al. 2009; Luers et al. 2003) have characterised vulnerability in terms of these three components. In what they call the “space of vulnerability,” Watts and Bohle (1993) describe the external side of vulnerability as the risk of exposure to hazards, while the internal side comprises capacity (the risk of having inadequate capacity to mobilise resources to deal with hazards) and potentiality (the risk of severe consequences). Downing et al. (2001) distinguish three domains of vulnerability: present criticality, adaptive capacity, and climate change hazard. Luers et al. (2003) propose a method for quantifying vulnerability (given the system, outcome variable, and stressor of concern) based on its three components: exposure, sensitivity, and adaptive capacity. Turner et al. (2003) recognise that vulnerability is determined not by exposure to hazards (perturbations and stresses) alone, but also depends on the sensitivity and resilience of the system that is experiencing such hazards. These authors develop an integrated conceptual framework of vulnerability built on these three major dimensions of vulnerability, namely exposure, sensitivity and adaptation/resilience.

Thus, vulnerability to climate change is understood as a function of the following three components which are influenced by a range of biophysical and socio-economic factors:

- (1) **Exposure** describes the nature of and degree to which a system is exposed to significant climatic variations;
- (2) **Sensitivity**, the degree to which a system is affected either adversely or beneficially, by climate related stimuli. It reflects the responsiveness of a system to climatic influences; and

Gbetibouo G. A. (2011)

- (3) **Adaptive capacity** which describes the potential or ability of a system, region, and community to adjust to the effects or impacts of climate change (including climate variability and extremes).

2.3 Conceptual framework of adaptation to climate change

2.3.1 Defining adaptation

According to Collins dictionary, adaptation or “action of adapting” from the Latin word “*adaptare*” means modification of an entity/being to suit new conditions or needs. Adaptation refers to both a process of adapting and a condition of being adapted. As a process, adaptation is synonymous with words such as conversion, change, shift, variation, adjustment, transformation, modification, alteration. Words such as acclimatisation, naturalisation, habituation, familiarisation and accustomedness are used as synonyms for adaptation as a condition. According to Smithers and Smit (1997) the term adaptation has more specific interpretations and definitions depending on the science discipline. In the climate change literature, numerous definitions of adaptation are found (Table 2.2). Although the various definitions are similar there are important nuances that might not answer completely certain questions, namely: i) “adapting to what?”; ii) “who and what adapts?”; and iii) “how does adaptation occur?” (Smit et al. 2000).

Furthermore, Levina and Tirpak (2006) review these various definitions and highlight that adaptation means slightly different things to different organisations involved in climate change research and policy. Adaptation is referred to as adjustment, practical steps, process and outcome. Process is an open-ended term lacking time or subject references. Adaptation as an outcome is likely to have more tangible results than adaptation as a process. Therefore, these seemingly small differences create different levels of expectation from different stakeholders and have implications for monitoring and evaluating outcomes and developing adaptation indicators.

Table 2.2: Selected definitions of adaptation

Gbetibouo G. A. (2011)

Author(s)	Definitions
Burton et al. (1993)	Adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides.
Smit (1993)	Adaptation involves adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer term climate change.
Stakhiv (1993)	The term adaptation means adjustment, whether passive, reactive or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change.
Smith and Lenhart (1996)	Adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system.
IPCC (1996)	Adaptability refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in conditions.
Pielke (1998)	Adjustments in individual groups and institutional behaviour in order to reduce society's vulnerability to climate.
Smit et al. (2000)	Adjustments in ecological socio-economic systems in response to actual or expected climatic stimuli, their effects or impacts.
Brooks (2003)	Adjustments in a system's behaviour and characteristics that enhance its ability to cope with external stress.
UKCIP (2004)	The process or outcome of a process that leads to a reduction in harm or risk of harm or realisation of benefits associated with climate variability and climate change.

Gbetibouo G. A. (2011)

Author(s)	Definitions
UNDP (2005)	A process by which strategies, to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed and implemented.
UNFCCC (2006)	Practical steps to protect countries and communities from the likely disruption and damage that will result from effects of climate change. For example, flood walls should be built and in numerous cases it is probably advisable to move human settlements out of flood plains and other low-lying areas.
IPCC (2001 & 2007)	Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation.

Source: Updated and compiled from Smit *et al.* (2000) and Levina and Tirpak (2006)

2.3.2 Adaptation as a climate change policy response

Adaptation to climate change is an integral part of the United Nations Framework Convention on Climate Change (UNFCCC³) in two related but distinct ways associated with different policy domains (Burton et al. 2002). The first is the prevention of dangerous interference with the climate system by the stabilisation of greenhouse gas (GHG) concentrations in the atmosphere, commonly referred to as mitigation. The second is the reduction of vulnerability to climate change by the process of adaptation. Thus, there are two directions and purposes in adaptation research: i) adaptation research for mitigation policy; and ii) adaptation research for adaptation policy (Burton et al. 2002).

³ United Nations Framework Convention on Climate Change (UNFCCC) was one of three international conventions adopted at the 1992 Rio de Janeiro Earth Summit that sets general goals and rules for confronting climate change. The main goal of the treaty is to prevent "dangerous" human interference with the climate system. At present, 192 countries around the world have joined.

Gbetibouo G. A. (2011)

Much of the literature on adaptation has been conducted in response to the mitigation issue. Both the First and Second Assessment Reports of IPCC (1990 & 1996, respectively) under the assumption that climate change will happen in the future emphasised the importance of reducing emissions to prevent future climate change. Thus, the global community took initial steps in 1992 (UNFCCC) and then again in 1997 (the Kyoto Protocol⁴) to curb global greenhouse gas emissions by at least 5% below 1990 levels within the commitment period (i.e. until 2012). However, these efforts have produced only modest gains in a handful of countries. The resulting emission reductions are nowhere near what they should be in order to halt or slow the pace of climate change. On the contrary, emissions have been increasing in parallel with the growth of the world economy (Biro and El-Ashry 2008).

In 2001, the IPCC's TAR recognised that climate change is unavoidable because of lags in physical systems. Mitigation policies for the reduction of GHG and even the stabilisation of their concentrations in the atmosphere at a low level will not altogether prevent climate change or sea-level rise; or prevent their impacts. Therefore, adaptation becomes a necessary strategy at all scales to complement climate change mitigation efforts.

In 2007, the IPCC's AR4 presented the first evidence that climate change is now occurring (with 0.6°C increase in world temperature) and that impacts are being observed (more frequent occurrence of climate events such as hurricanes and drought). Consequently, interest in adaptation as a legitimate policy response has increased, led by developing country negotiators. There is now a growing recognition that adaptation is critical inevitable and that even if fully implemented on time the Kyoto Protocol would only be a first small step towards achieving the stabilisation of GHGs in the atmosphere.

According to Burton et al. (2002) the need to change the character of adaptation research from one that largely addresses the needs of the mitigation policy agenda, to one that also responds

⁴ The Kyoto Protocol of the UNFCCC was adopted at the Third Session of the Conference of the Parties to the UNFCCC in 1997 in Kyoto, Japan. It contains legally binding commitments in addition to those included in the UNFCCC. Recognising that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities." Countries included in Annex b of the protocol (most OECD countries and countries with economies in transition) agreed to reduce their anthropogenic GHG emissions by at least 5% below 1990 levels within the commitment period 2008 to 2012. As at present, there are 84 signatories and 192 Parties have ratified or acceded to the Kyoto Protocol. Talks on commitments for the post-2012 period are on-going.

Gbetibouo G. A. (2011)

explicitly to the needs of adaptation policy has gained a prominent place. Now adaptation research has a critical role to help us collectively understand and develop adaptation options to enhance the benefits and reduce the social and economic vulnerabilities induced by climate change and variability (Wheaton and Maciver 1999).

2.3.3 The roots, determinants and types of adaptation

2.3.3.1 The roots of adaptation concept

The concept of adaptation originates from biology where it has at least two meanings (Bennett 2006), namely:

- (1) genetic evolution which concerns feedbacks and interactions between the environment and the gene pool of organisms, leading to selective survival of particular traits that result in the organism so that it may better cope with specific environmental features; and
- (2) biology which concerns behaviour of the organism during its life span that will permit the organism to cope with environmental factors. The feedback processes in this case functioning on the level of perpetual and cognitive processes, not genetic ones.

Application of the term adaptation to human systems derived from the second biological meaning. It can be traced to the anthropologist and cultural ecologist Julian Steward, who used “cultural adaptation” to describe the adjustment of “culture cores” to the natural environment through subsistence activities. Cultural adaptation refers to the non-biological responses of the individual or population to modify or ameliorate an environmental stress (Frisancho 1995). Cultural adaptation, both during contemporary times and in evolutionary perspective, represents humanity’s most important tool. It is through cultural adaptation that humans have been able to survive and colonise far into the zones of extreme environmental conditions.

Smit and Wandel (2006), reviewing the evolution of adaptation science, put in contrast: i) earlier treatment of adaptations in social science as a consequence of selection acting on variation through cultural practices (adaptation) which have historically allowed a culture to survive, with;

Gbetibouo G. A. (2011)

ii) more recent social science work, which treats adaptation as cultural practices that allow societies to survive and beyond that flourish based on behaviour and technological innovation.

2.3.3.2 Determinants of adaptation

Adaptation is widely used in many scholarly fields of research today including human and cultural ecology, political ecology/economy, natural hazards research, ecological anthropology, cultural geography, ecological economics, entitlements and food security and more recently climate change. However, the process of adaptation, and therefore necessarily adaptation research, is driven by a broad range of multi-dimensional determinants characterised by four core questions (Preston and Stafford-Smith 2008), namely: i) “Who or what adapts?”; ii) “What do they adapt to?”; iii) “How do they adapt?”; and iv) “What do they want to achieve?”. The multidimensional determinants are related and part of a model of an adaptation cycle that change through time and space. The adaptation cycle is iterative, dynamic, interconnected, non-linear, and likely chaotic and any specific adaptation research can start at any point in the adaptation cycle (Wheaton and Maciver 1999).

There are likely to be both limits and barriers to adaptation as a response to climate change. Generally barriers are the conditions or factors that inhibit adaptation or render adaptation ineffective and limits are view as a set of immutable thresholds in biological, physical, economic, financial and technological parameters. Adaptation barriers and limits disrupt the relationship between determinants and the adaptation process. Figure 2.4 below mapped the adaptation cycle with its main four dimensions.

Gbetibouo G. A. (2011)

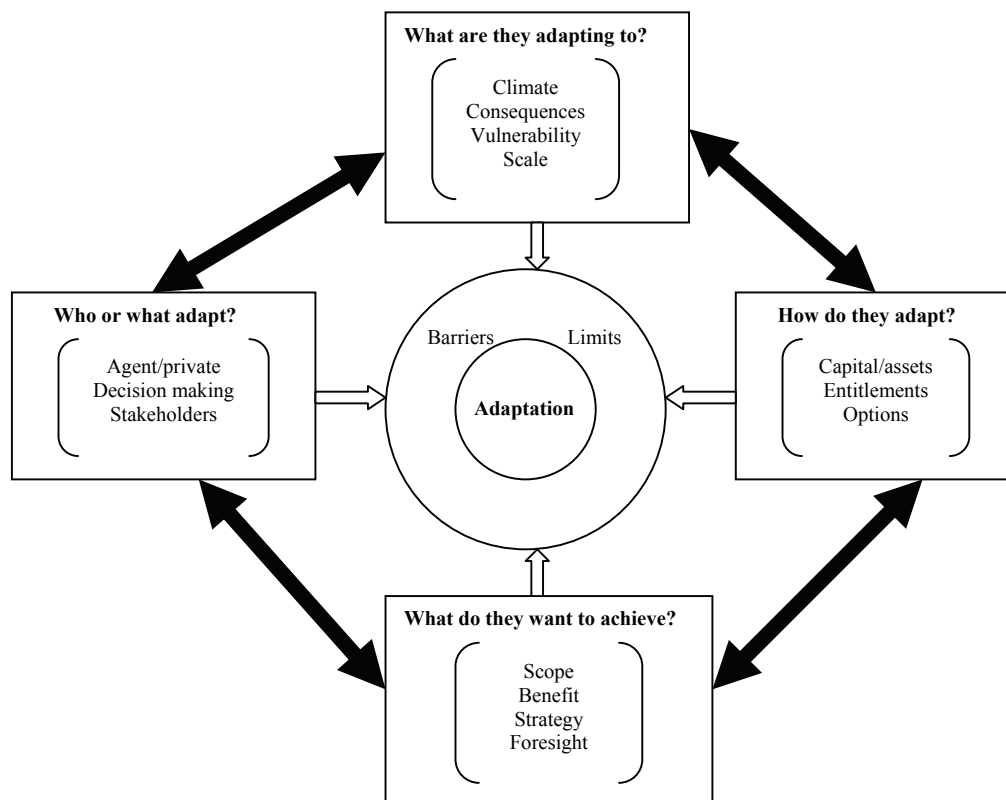


Figure 2.4: Adaptation cycle with its main determinants

Source: Preston and Stafford-Smith (2008)

2.3.3.3 Types of adaptation

The literature on adaptation to climate change suggests different typologies of adaptation options from different perspectives (Smith and Lenhart 1996; Burton 1997; Smithers and Smit 1997; Risbey et al. 1999; Reilly and Schimmelpfennig 1999; Bryant et al. 2000; Smit et al. 2000; Mendelsohn 2001; Kurukulasuriya and Rosenthal 2003). Adaptation to climate change can be distinguished in six different ways based on: i) the intent; ii) the timing of the action; iii) the temporal scale; iv) the spatial scope; v) the intended outcome; and vi) the form.

Gbetibouo G. A. (2011)

Based on the intent, adaptation can be either planned or autonomous. A planned adaptation is a change in anticipation of a variation in climate. It is an inherently strategic and conscious effort to increase the capacity of a system to cope with (or avoid) the consequences of climate change (Smithers and Smit 1997). Advance planning can help increase the coping capacity of the system. Systems also have a capacity to improve their ability to cope over time as a reaction to climate pressures. This is commonly known as autonomous or spontaneous adaptation. Adaptation initiated by public agencies is usually conscious strategies, but adaptation undertaken by private individuals or communities may be autonomous or planned, or some combination of the two, especially when the adaptation in question is undertaken at different spatial and temporal scales (Smithers and Smit 1997).

Based on timing of the action relative to the climate stimulus, adaptation may be reactive (or responsive or *ex post*), concurrent (during), or anticipatory (proactive or *ex ante*). Based on the temporal scope, adaptation can be short-term or longer-term. This distinction is often considered to be synonymous with tactical versus strategic adjustments (Smit et al. 1996). In the natural hazards field it is adjustment versus adaptation (Burton et al. 1993) and is associated with instantaneous versus cumulative and autonomous versus policy (Easterling 1996). Based on their spatial scope or institutional extent, adaptation can be localised or widespread.

Based on their intended outcome, adaptation actions are divided between strategies or actions aimed to: i) buffer a system against environmental perturbation meaning enhance stability or modify effects; and ii) facilitate a shift or evolution to a new state to enhance resilience or flexibility or reduce vulnerability (Jepma et al. 1996). Based on the form they take, adaptation can be distinguished according to whether they are primarily technological, behavioural, financial, institutional or informational.

Gbetibouo G. A. (2011)

2.3.4 Agricultural adaptation

2.3.4.1 The process and types of agricultural adaptation

Agriculture is inherently sensitive to climate conditions and is among the most vulnerable sectors to the impacts of global climate change (Rosenzweig and Parry 1994; Smit et al. 1996). As a result, agricultural adaptation, the process of maintaining various farming objectives (e.g. yield, production, profitability, sustainability) in the face of changes in external conditions, becomes a necessary option to cope with the expected impacts of climate change (Risbey et al. 1999). Although modern agriculture has progressed by weakening the downside risks of climate and environmental factors through irrigation, the use of pesticides and fertilisers, the substitution of human labour with energy devices, and the manipulation of genetic resources; large changes in climate will make it difficult for world agriculture to sustain production levels and even increase production to meet the food requirements of the growing population (Kandlikar and Risbey 2000). More particularly, in less industrialised countries, where agriculture is the occupation of close to 60% of the population and contributes to over 30% of the Gross Domestic Product (GDP), climate change is expected to seriously impact agriculture, deepen rural poverty and by consequence affect their whole economy.

Agricultural adaptation to climate change is a complex, multidimensional and multi-scale process that takes on a number of forms and actors (Bryant et al. 2000). One important question to the understanding of agricultural adaptation is “What are they adapting to?”, meaning the characteristics of the stress or stimulus to which actors and systems respond. There are two major issues in responding to this question, namely: i) short-term climate variability versus long-term climate change; and ii) climate risks versus others markets and socio-economic related risks.

Climate change includes not only long-term changes in mean conditions, but also a change in the year to year variation in growing season conditions, and the frequency and magnitude of extreme weather events. For some authors (Smit et al. 1996; Bryant et al. 2000; Smit and Skinner 2002; Thomas et al. 2007), agricultural adaptation to climate change should emphasis adaptation to short-term climate variability. Indeed according to them, agriculture activities are generally well adapted to mean or average conditions, but are more susceptible to irregular or extreme conditions such as more frequent droughts and deviations from ‘normal’ growing conditions.

Gbetibouo G. A. (2011)

They further argue that adaptation to short-term climate variability may facilitate adaptation to long-term climate changes (Burton 1997). However, other authors (Smithers and Smit 1997; Mendelsohn et al. 2000; Adger et al. 2005; Ziervogel et al. 2008) argue that adaptation undertaken in response to short-term climate variability, which could be classified as coping responses, may not be well suited for or could increase vulnerability to long-term climate change. This is termed ‘maladaptation’. Such maladaptation may serve short term goals, but comes with future costs to society.

There is a need to anticipate long-term changes and make appropriate adjustments in addition to coping with current climate conditions. This strategic adaptation should involve government intervention to promote and guide adaptation of the agricultural system (Smithers and Smit 1997). According to Kurukulasuriya and Rosenthal (2003), without precluding the fact that there are some adaptation actions that will be successful regardless of the temporal dimension of climate impacts; it is important that policy is appropriately targeted to address the exact nature of climate concerns.

Agriculture is operated in a highly volatile environment continually faced by an array of changing contexts (agricultural policies such as subsidies, incentives, tariffs, insurance, environmental regulations, changes in technology and inputs to farming, climate variability etc.) and it is not really clear what agriculture is adapting to and therefore this could lessen climate adaptation efforts (Smit 1994; Brklacich et al. 2000; Bradshaw et al. 2001). Adaptation will need to take place in response to a variety of drivers, with climate change and variability being only one of them. For some authors (Bryant et al. 2000; Brklacich et al. 2000; Smit and Skinner 2002) it makes little sense to isolate climate-specific adaptation from other steps that will need to be taken.

Analyses of agricultural impacts should place climate within the context of the other forces by recognising different adaptation criteria and by identifying the trade-offs that governments and farmers need to make. Indeed, according to Kandlikar and Risbey (2000) the kinds of tactical responses available to farmers and the efficacy of these responses are constrained by a considerable degree by the larger environmental and economic conditions in which they operate.

Gbetibouo G. A. (2011)

Another important question to the understanding of agricultural adaptation is “Who or what need to adapt?”. Depending on different spatial scales (local, regional, global) or temporal dimension (*ex ante* or *ex post*) foci on agricultural adaptation, there is a number of decision agents such as farmers, state governments and agencies, national governments, world market traders, insurance industry, agribusiness etc. For example, farmers operate mostly on a farm scale whereas national governments tend to view agricultural output on a regional and national scale as it relates to domestic and international policy. Furthermore, Kandlikar and Risbey (2000) stress that in addressing agricultural adaptation to climate change, it is even critical to differentiate between farmer types. Generally subsistence farmers, largely found in less industrialised countries have very different objectives for adaptation from those commercially oriented farmers largely found in industrialised countries. The prime objectives of the majority of farmers in developing countries are food and livelihood security, thus their time horizons for decision making are much shorter and are typically a function of the local agricultural cycle, household poverty, and availability of formal institutions including markets for smoothing consumption.

Kurukulasuriya and Rosenthal (2003) categorise adaptation options in agriculture into four types:

- (1) Micro level options that include farm production adjustments such as diversification and intensification of crop livestock production; changing land use and irrigation, and altering the timing of operations;
- (2) Market responses that include the development of crop and flood insurance schemes, innovative investment opportunities in crop shares and futures, credit schemes, and income diversification opportunities;
- (3) Institutional changes mainly government responses that include pricing policy adjustments such as: i) the removal of perverse subsidies; ii) the development of income stabilisation options; iii) the introduction of agricultural policy including agriculture support and insurance programs; and iv) the improvement in agricultural markets, and broader goals such as the promotion of inter-regional trade; and

Gbetibouo G. A. (2011)

- (4) Technological developments consisting of the development and promotion of new crop varieties and advances in water management techniques (e.g. irrigation, conservation tillage).

Reilly and Schimmelpfennig (1999) define six “major classes of agricultural adaptations to climate change” as follows: i) seasonal changes and sowing dates; ii) different variety or species; iii) water supply and irrigation system; iv) other inputs (fertiliser, tillage methods, grain drying, other field operations); v) new crop varieties; and vi) forest fire management, promotion of agroforestry, adaptive management with suitable species and silvicultural practices.

It is undisputed that adapting to climate change in the agriculture sector will require large scale changes and will require the involvement of many agents and institutions and actions at local, regional and national levels. The following two main agents are of critical importance in the process of agricultural adaptation: i) government; and ii) private agents mainly the farmers. Government can play a coordinating role by providing an enabling environment for adaptation which is effective, efficient and equitable. However, the uptake of adaptation actions remains in the hand of the farmers themselves. Thus, understanding the autonomous adaptation process of farmers is a prerequisite for a better planning of adaptation policy.

2.3.4.2 Understanding autonomous farmers’ adaptation process

Though adaptation is a continuous process, Risbey et al. (1999) suggests four stages in the adaptation process:

- 1) The signal detection, where it is decided what is adapted to and what is ignored;
- 2) The evaluation, where the signal is interpreted and foreseeable consequences are evaluated;
- 3) The decision and response, which results in a observable change in behaviour and performance of the system; and

Gbetibouo G. A. (2011)

- 4) The feedback, which involves monitoring of decision outcomes to assess whether they are as expected.

Similarly, based on empirical studies of coastal management, Klein et al. (1999) adopted the following four steps in adaptation decision-making: i) information collecting and awareness building; ii) planning and design; iii) implementation; and iv) monitoring and evaluation. Thus, models always begin with an appraisal of the risk and continue with an appraisal of possible adaptation options.

According to Risbey et al. (1999) the manner and form of adaptation for any decision-maker will depend on how the signal is defined. That is, what is adapted to (signal)? Decision-makers with an operational focus on different temporal and spatial scales will tend to define signal in terms of processes they can observe at their characteristic scales of attention. Adaptation is conditional on detecting a recognisable signal: no detected signal, no response. Farmers' perception of climate change risks is a necessary condition for them to undertake autonomous adaptation. According to Maddison (2006), adaptation to climate change requires that farmers first notice that the climate has changed, and then identify useful adaptations and implement them.

Weber (1997) identifies perception and expectation of climate change as important preconditions for economic and technological adaptation of USA farmers. Thus perceptions influence people's decisions both in deciding whether to act or not. According to Grothmann and Patt (2005), the main determinant of the motivation to adapt is the relative risk perception, indicated by motives like goals, values or norms. The relative risk perception expresses the perceived probability of being exposed to climate change impacts and to the appraisal of how harmful these impacts would be. Perception refers to a range of judgments, beliefs and attitudes (Taylor et al. 1988), from which it can be inferred that perception is neither universal nor static, but rather a value laden, dynamic concept. Social, economic, political and cultural settings influence the way people perceive their environment and the way they react to it (Danielsen et al. 2005).

In the specific case of climate change, Kolstad et al. (1999) cited by Maddison (2006), argue that farmers will learn and detect gradually climate change and that their expectations of (and therefore response to) climate change lag behind actual climate change. A farmer may perceive several hot summers but rationally attribute them to random variation in climate. However, there

Gbetibouo G. A. (2011)

is ample evidence in the literature suggesting that farmers' perceptions and behavioural responses may be more related to recent climate events or trends as opposed to long-term changes in average conditions (Smit et al. 1997; Thomas et al. 2007). Furthermore, perceptions can be influenced and acted upon. Indeed, farmers' perceptions can be influenced by their peers' perceptions and by values present in their communities as well as their professional associations.

It is argued for the potential of the provision of accurate and accessible rural climate information to support adaptation and manage climate risk (Archer et al. 2007; Vogel and O'Brien 2006 and Ziervogel et al. 2005). Hansen et al. (2004) suggest that information about climate derived from personal experience and information from external source such as extension officers yield different choice results under conditions of climate risk and uncertainty. Decisions based on personal experience are likely to give greater weight to recent events.

The second stage in autonomous adaptation undertaken by farmers is the question related to how perceptions of climate change are translated into agricultural decisions. If farmers learn gradually about the change in climate, Maddison (2006) argues that they will also learn gradually about the best techniques and adaptation options available. According to Maddison (2006), farmers learn about the best adaptation options through three ways, namely: i) learning by doing; ii) learning by copying; and iii) learning from instruction. Furthermore, there is recognition that farmers' responses vary when faced with the same stimuli. Such varied responses, even within the same geographic area, are partly related to the variety of agricultural systems involved and the different market systems in which farmers operate (Bryant et al. 2000).

A more important factor of varied farmers' responses is the differences between farmers in terms of personal managerial and entrepreneurial capacities and family circumstances. According to Adger (2003), the capacity to adapt to climate change for individuals is a function of their ability to access resources. Thus, institutional formal or informal structures and entitlements are important determinants of adaptive capacity and adaptation. However, Grothmann and Patt (2005) suggest that a more important factor of adaptation is the farmer's perception of his/her own ability to successfully adapt to a threat. If an individual feels empowered to reduce his/her own vulnerability he/she will usually do so, however, if he/she feels powerless to affect change

Gbetibouo G. A. (2011)

he/she is likely to enter a stage of denial and adopt a maladaptive response such as non-action (Anthony 2004).

Adaptation choices are made within the framework of perceived alternatives and available information. Alternatives and information are profoundly affected by people's attitudes and values and the roles they play in relation to the decision to be made (Maddison 2006).

2.4 The framework vulnerability – adaptation to climate change

2.4.1 Interrelations vulnerability and adaptation to climate change

Vulnerability and adaptation are interrelated, central issues in the debate surrounding policy responses to climate change. As discussed above (section 2.1.4) there is general consensus that the vulnerability of any system is a function of the exposure and sensitivity of that system to hazardous conditions and the ability or capacity of the system to cope with and adapt to the effects of those conditions. However, this conceptualisation does not suggest specific relation and also specifies *a priori* particular factors, processes or functional relationships between exposure, sensitivity and adaptive capacity. There are broad social, economic, political and ecological conditions that affect exposure, sensitivity and adaptive capacity (Smit and Wandel 2006). Vulnerability and adaptation are linked via the adaptive capacity component. Indeed adaptations are manifestations of adaptive capacity. Adaptation actions or changes in the system to better deal with problematic exposures and sensitivities reflect adaptive capacity (Smit and Wandel 2006). Vulnerability and adaptation are therefore inseparable themes in the climate change research.

The linkages between vulnerability, adaptive capacity, and adaptation are often circular rather than linear in nature. The ability of people to control the variables that determine vulnerability might be translated into their capacity to adapt (Kelly and Adger 2000; Luers 2005; Smit and Wandel 2006). The true vulnerability of people can only be assessed after adaptation has taken place (Kelly and Adger 2000). A useful simplified formulation is that vulnerability is a function of impacts and adaptation. Impacts depend upon the exposure of a system to climate and its

Gbetibouo G. A. (2011)

sensitivity. Adaptation depends upon the capacity of systems to adapt and also on the will or intent to deploy adaptive capacity to reduce vulnerability (Burton et al. 2002).

The way in which vulnerability to climate change is considered in a given analysis influences the way in which the relationship between vulnerability and adaptive capacity is viewed. O'Brien et al. (2007) argue that by viewing vulnerability as an end point, adaptation and adaptive capacity refer to future adaptations, and therefore determine vulnerability. In this case, adaptive capacity means the ability to carry out specific technological adaptations to climate change. The end point interpretation focuses on technology and its transfer as adaptation options, while viewing vulnerability as starting point implies that vulnerability determines adaptive capacity. In the latter case, adaptive capacity is the ability to adjust to changing environmental and socio-economic conditions, and therefore pertains to present day vulnerability. The starting point approach addresses the fundamental causes of vulnerability, including the geopolitical and economic contexts, and the adaptation options in this case are related to development.

2.4.2 The causal chain of the framework vulnerability-adaptation

Vulnerability to climate change presents two main distinct discourse and framing of the climate change problem. We cannot suggest that any particular approach to the concept of vulnerability is more or less appropriate in the context of climate impact studies. In reality, they can be seen as complementary (O'Brien et al. 2007). Each focuses on a particular aspect of the vulnerability puzzle. Any assessment of the consequences of climate change will rest on a combination of the two approaches: end point and starting point.

The contrast drawn in the previous sections has been deliberately exaggerated to illustrate the difference in focus of the two approaches (Adger and Kelly 1999). The purpose of the analysis must guide the selection of the most effective definition or conceptualisation. Recently, in an effort to find a compromise between these two approaches, hybrid approaches are increasingly being produced. Some scholars have proposed the use of nested flow charts that show how social and environmental factors interact to create situations vulnerable to sudden changes. The most often cited integrated conceptual models for vulnerability assessment are Turner et al.'s (2003)

Gbetibouo G. A. (2011)

vulnerability/sustainability framework and Cutter's hazards-of-place model of vulnerability (Cutter 1996; Cutter et al. 2000). This framework endeavours to integrate elements from risk/hazard approaches, entitlement analyses, and ecological theory into a single multi-scalar model of vulnerability. However, in practice this goal is challenged by the complexity of the framework (Turner et al. 2003). Large interdisciplinary teams and significant financial resources may also be required in order to capture the full dynamics, as described in the framework, of any particular system selected for study, making the application of the framework difficult in resource-scarce regions (Eakin and Luers 2006). Thus far, most of these frameworks remain relatively untested.

According to Turner et al. (2003), a full vulnerability assessment following these frameworks may lie well beyond the capacities of most research efforts. The authors therefore suggest that for practical and theoretical reasons, such frameworks should be modified or simplified to suit the specifics of a given application. Cutter et al. (2000), Hebb and Mortsch (2007), O'Brien et al. (2004) and Thornton et al. (2008) are examples of case studies that attempt to use reduced integrated frameworks of vulnerability.

The concept of vulnerability as an end point has played a useful role in increasing the scientific understanding of climate-sensitive systems under changing climate conditions, and informing the specification of targets for the mitigation of climate change. However, climate change vulnerability assessment tends to view vulnerability as a starting point for the enhancement of adaptive capacity. The main purpose of using the starting point approach to vulnerability assessment is to prioritise political and research efforts toward particularly vulnerable sectors and regions, and develop adaptation strategies that reduce climate-sensitive risks independent of their attribution (Fussler and Klein 2006; O'Brien et al. 2007).

In the present study, we have adopted a starting point approach of vulnerability, in which vulnerability is structured by three components exposure, sensitivity and adaptive capacity. We are concerned with the identification of vulnerable places and people and the key adaptation dimension of "how do they adapt?". The study investigates particularly vulnerable agricultural regions and autonomous adaptation process of farmers.

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Figure 2.5 below shows the causal chain of vulnerability adopted for this study. A system's vulnerability will be primarily determined by: i) its current socio-economic and biophysical conditions which predispose it to be responsive to exposure to climate events; and ii) the determinants of its adaptive capacity (assets, entitlements, economic structures, human capital, coping strategies, social networks; economic and institutional support; policy, etc.). When the system is exposed to climate events as a result of climate change and variability (such as floods, drought, higher temperatures), the characteristics of the climate events will play a significant role in conjunction with the existing environmental and socio-economic conditions to trigger the potential impacts. However, it does not suggest that impacts cause vulnerability. In face of the threats of the impacts, the system will react back through adaptation actions, which are the manifestations of its adaptive capacity.

Figure 2.6 is the adaptation framework adopted in this study which summarises the adaptation process and highlights the relevant factors that enhance or constrain farmers' autonomous adaptations. The adaptation process can be divided into the following two distinct steps influenced by a number of endogenous and exogenous factors: i) the signal detection phase: the perception phase; and ii) the response phase: the adaptation phase.

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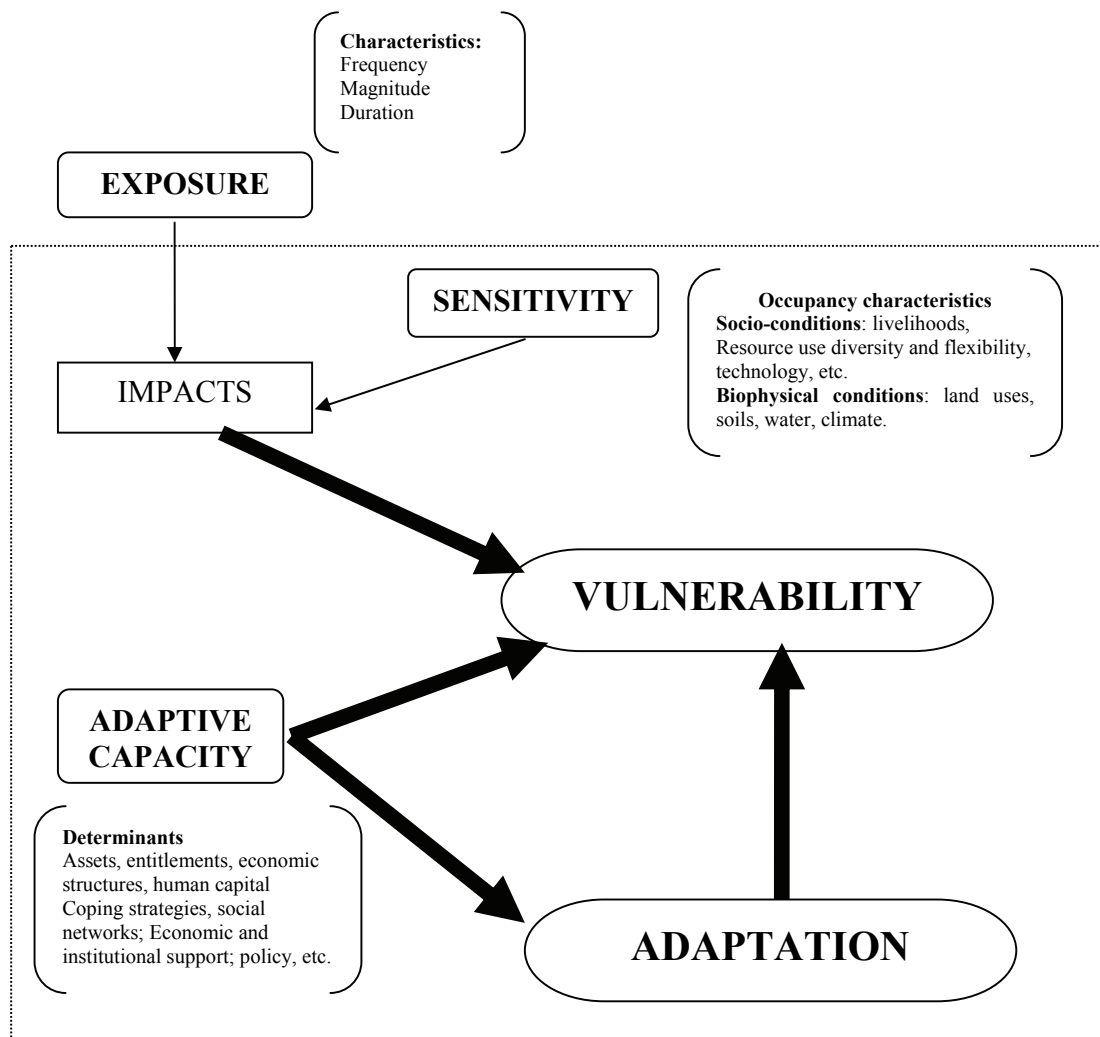


Figure 2.5: The causal chain vulnerability - adaptation to climate change

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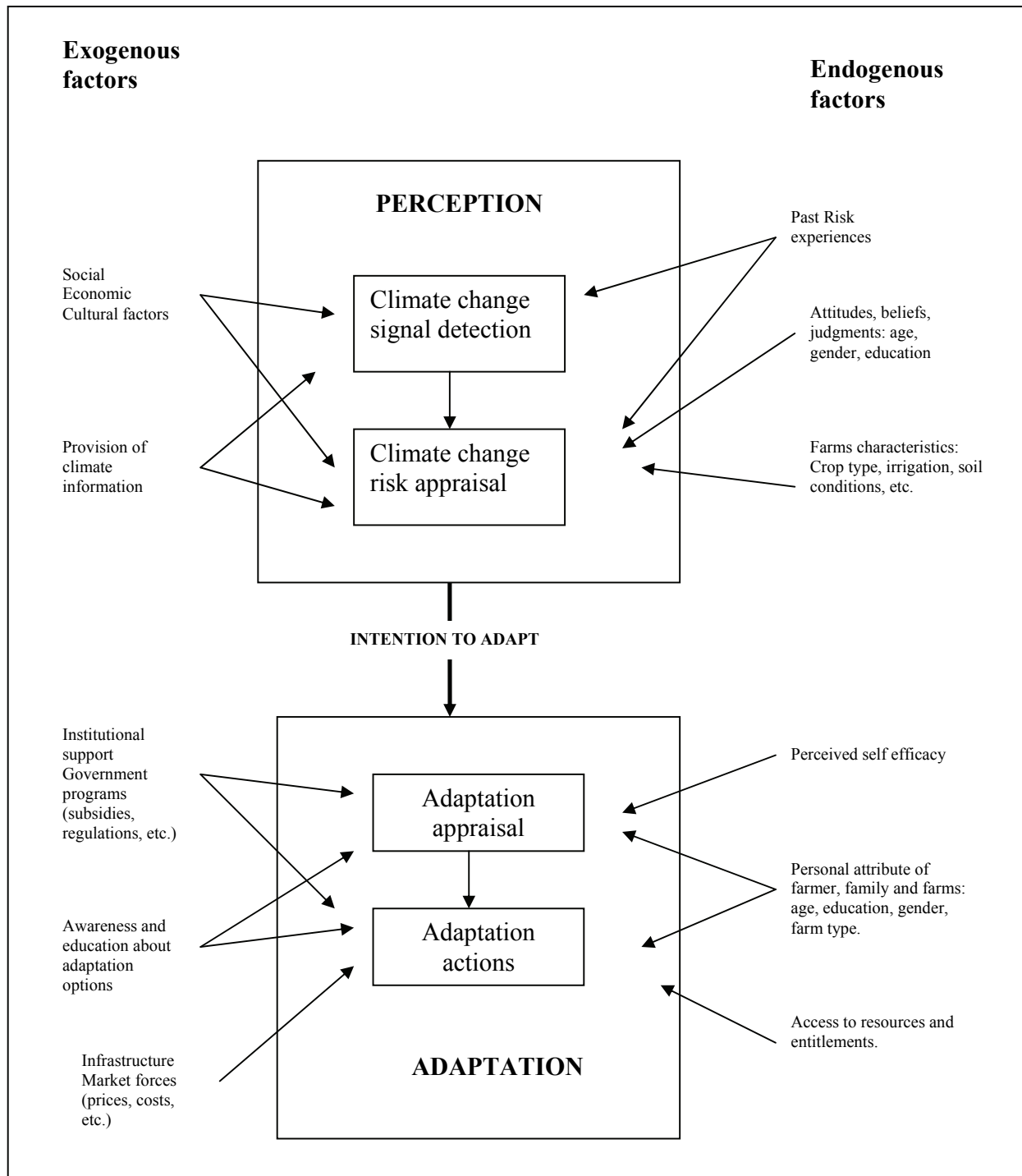


Figure 2.6: Framework of farmers' autonomous adaptation to climate change

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2.5 Concluding remarks

We have demonstrated in this chapter that vulnerability and adaptation are complex terms, defined in many different ways by various scholarly communities. Several conceptual frameworks have been developed to categorise vulnerability factors and to describe different vulnerability concepts. The two main interpretations of vulnerability in the climate change context are starting point (contextual) vulnerability and end point (outcome) vulnerability. These interpretations of vulnerability are based on different conceptual frameworks, they produce different rankings, and they suggest different strategies for adaptation.

Based on three attributes of vulnerability (namely exposure, sensitivity and adaptive capacity) commonly accepted in the climate change literature, a vulnerability – adaptation causal chain for our research taking on a starting point approach is presented.

To operationalise the framework presented here, several authors have emphasised that the term ‘vulnerability’ can only be used meaningfully with reference to a particular vulnerable situation (Brooks 2003; Downing and Patwardhan 2004; Fussel 2007; Luers et al. 2003; Metzger et al. 2005). Thus, one needs primarily to specify the vulnerable system in question and clearly define the hazards it is exposed to and the attributes at risk from this exposure. The next chapter will introduce background information on our system of analysis, South African agriculture under climate change and variability.

CHAPTER 3:

CLIMATE CHANGE AND AGRICULTURE IN SOUTH AFRICA

3.1 Introduction

During the recent decade, with the growing recognition of the possibility of climate change and clear evidence of observed changes in climate during the 20th century, an increasing emphasis was placed on food security and its regional impacts in the scientific community. In South Africa, substantial work has been done in the last decade aimed at understanding the nature and magnitude of changes in crops yields due to projected climate change. This chapter presents an overview of the state of knowledge of the possible effects of climate change and variability on agricultural production in South Africa. Has South Africa's climate changed? What do climate projections suggest about future shifts in the country's climate and what impacts might these have on agriculture? These are the fundamental questions that this chapter will address. It begins with an overview of South Africa's current climate and socio-economic conditions in which the agriculture sector operates (section 3.2). It proceeds to highlight the effects of past and present climate variability on agriculture (section 3.3). The chapter then presents predicted climate change and the impacts of climate change on the agriculture sector based on the scientific literature. Additionally, the chapter includes discussions regarding the uncertainties and limitations of these studies and identifies research gaps (section 3.4). Section 3.5 provides the main conclusions of the chapter.

3.2 Profile of South African agriculture

3.2.1 Landscape

South Africa covers an area of about 122 million hectares (ha) divided into nine administrative provinces (Figure 3.1). It is estimated that close to 18% of South Africa's natural land cover is

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transformed (Table 3.1), mainly by cultivation (10.46%), degradation of the natural cover (4.47%), urban land use (1.51%), and forestry (1.41%).

Table 3.1: Land cover in South Africa

Land-cover category	Area (millions hectares)	Percentage (%)
Cultivated areas	12.76	10.46
Bare and degraded areas	5.45	4.47
Urban areas	1.85	1.51
Mines	0.20	0.17
Waterbodies	0.68	0.55
Forest plantations	1.72	1.41
Grasslands	24.30	19.92
Indigenous forests	0.52	0.43
Wetlands	0.87	0.72
Woodlands and bushlands	31.34	25.70
Shrublands	42.27	34.66
Total	121.96	100.00

Source: CSIR and ARC (2003)

Although there are approximately 100 million ha (80%) of agricultural land in South Africa, only 14 million ha (11%) receive sufficient rainfall to be classified as potential arable land (DEAT 2008). Areas of moderate to high arable potential occur mainly in the eastern part of the country (i.e. in Mpumalanga and Gauteng). Scattered patches also occur in Kwazulu-Natal, the Eastern Cape, and Limpopo. Low to marginal potential areas occur in the eastern half of the country and in parts of the Western Cape (Figure 3.1). There are large areas in the drier parts of South Africa that are being cultivated (for example, in the southwestern Free State, the western parts of the Eastern Cape, and the North West Province), but which are not classified as having any potential for arable agriculture (DEAT 2008). Of the 12.76 million ha of cultivated areas in South Africa,

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more than 10.8 million ha (85%) are rain-fed and irrigated agriculture occupies slightly more than 1.2 million ha that produce 25% to 30% of the country's agricultural output (DAFF 2010).

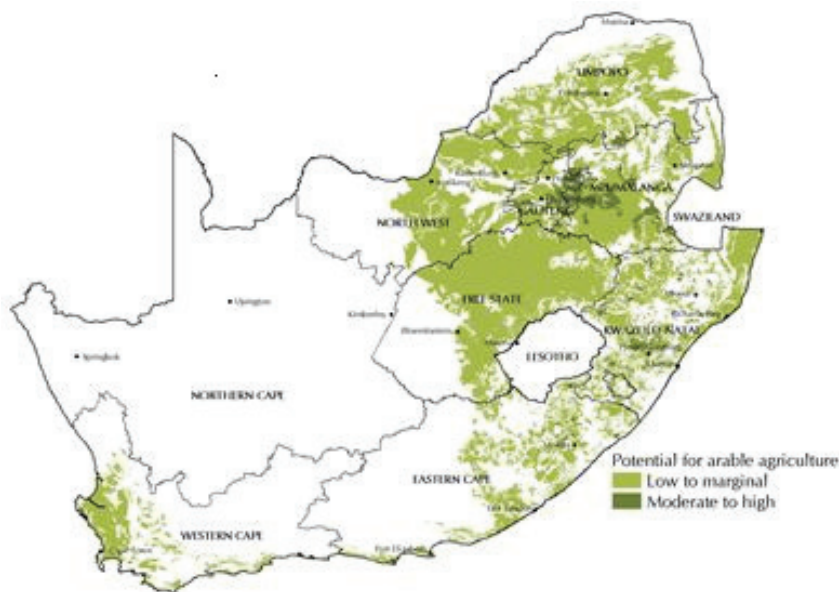


Figure 3.1: Distribution of potential arable land in South Africa

Source: DEAT (2008) <http://soer.deat.gov.za/themes.aspx?m=45>

3.2.2 Farming areas, crops and livestock production

3.2.2.1 Farming areas

Jooste and Van Zyl (1999) identified six agro-ecological zones in South Africa namely: i) the Cape Fold region; ii) the Nama Karoo Region; iii) the Interior region; iv) the Kalahari/Limpopo Plain region; v) the Eastern Plateau Slope or Lowveld region; and vi) the Highveld region. The different zones are based on differences in rainfall, vegetation, erodibility, biological productivity, water availability, resource quality and output and input price ratio. Agricultural activities in these regions range from intensive crop production and mixed farming in winter-rainfall and high summer-rainfall areas, to cattle ranching in the bushveld and sheep farming in the more arid regions.

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Crop production in South Africa is concentrated in the summer Highveld plateau of Gauteng, the Free State and Kwazulu-Natal's Highveld and midlands as well as the winter rainfall region of Western Cape, which has a Mediterranean climate (Gbetibouo 2004). According to Du Toit et al. (2000), the western provinces that consist of the western Free State and North-West provinces are usually dry and marginal for grain production. The eastern provinces (eastern Free State, Gauteng, Mpumalanga and Kwazulu-Natal provinces) are usually wet and more suitable for grain production. Agricultural production in the summer regions consists of mixed farming that comprises a mixture of crop production (maize, sorghum, groundnuts and potatoes) and dairy and pig farming. The winter rainfall region of the Western Cape consists of the production of winter cereals, deciduous fruits and wine (Gbetibouo 2004).

The dry marginal semi-arid Karoo region, which covers the greater part of the Northern and Western Cape, consists of extensive Merino sheep production. The Northern Limpopo region and the North West provinces consist of extensive cattle farming. The subtropical Lowveld of Mpumalanga and the Limpopo province provide viable conditions for citrus production as well as subtropical fruits and vegetables. Production of sugar, citrus, bananas, pineapples and timber is concentrated in the frost-free coastal belt of Kwazulu-Natal and the Eastern Cape (Gbetibouo 2004). Figure 3.2 shows the distribution of crops and livestock across South Africa.

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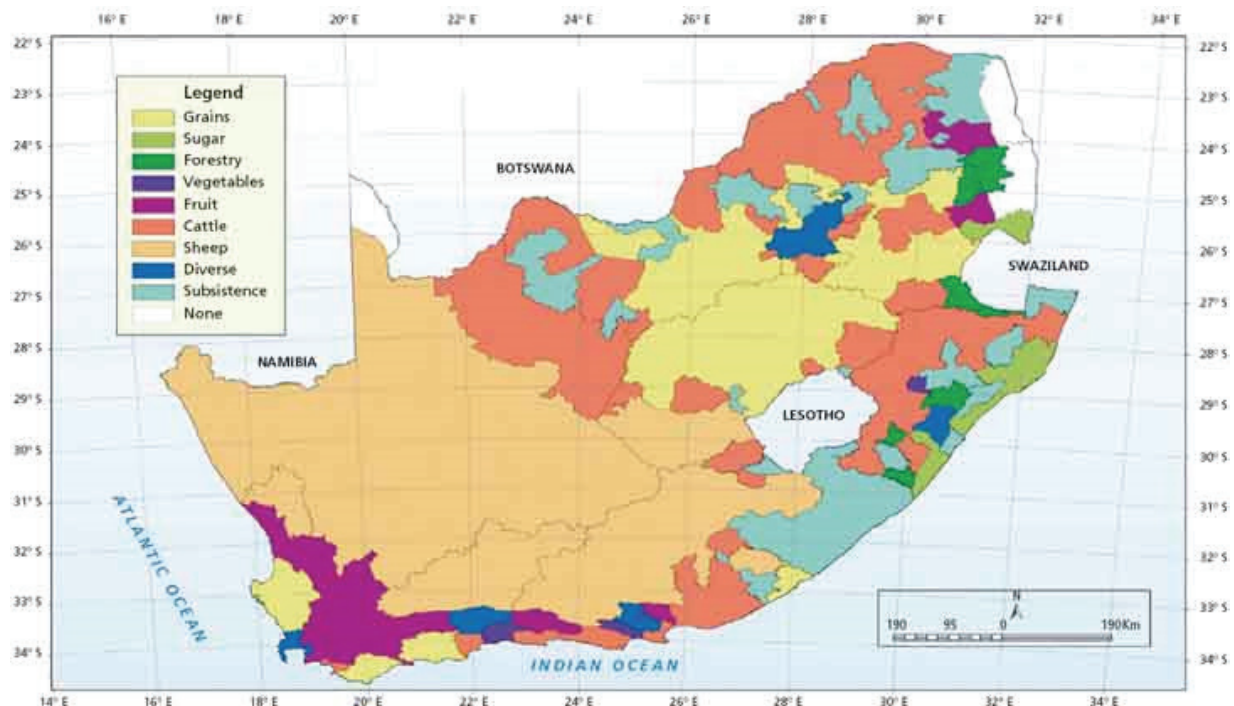


Figure 3.2: Distribution of crops and livestock across South Africa

Source: FAO (2005) <http://www.fao.org/docrep/008/y5998e/y5998e06.htm#TopOfPage>

3.2.2.2 Crops and livestock production

South African agriculture is characterised by a large diversity of crops and livestock that can be classified in three main groups: i) field crops; ii) horticultural; and iii) livestock. The main field crops are maize, wheat, sugarcane and sorghum. The minor crops include groundnuts, sunflower seeds, dry beans, tobaccos, and oats. The horticultural products are mainly deciduous fruits such as apples, table grapes, peaches, citrus fruits and other subtropical crops such as avocados, mangos, bananas, litchis, guavas, papayas, granadillas, and macadamia and pecan nuts. A large variety of vegetables is also produced (potatoes, tomatoes, pumpkins, carrots, etc.). The main livestock products are cattle, sheep, goat, pigs and poultry.

Field crops occupy 92% of the total cultivated area (Table 3.2). Maize is the most important crop in South Africa, being both the major feed grain and staple food for the majority of the South

Gbetibouo G. A. (2011)

African population. Maize accounts for approximately 51% of the cultivated area. The area planted to maize declined from 5 million hectares in the mid-eighties, to approximately 2.8 million hectares in 2008/2009 (DAFF 2010). In general, major field crops have seen their land area decrease except for sunflower and soybean. Indeed, due to the recognition of their nutritional quality, area planted under sunflower and soybean changed from 331,000 and 22,000 hectares in 1980, respectively, to over 636,000 and 238,000 hectares in 2009, respectively.

Table 3.2: Planted areas and production of selected crops: 2009

Crops	Land area (‘000 hectares)	Average yield (tonnes/ha)	Production (‘000 tonnes)	Value of production (R 1000)
<i>Field crops</i>				
Maize	2,896	4.34	12,567	16,345,830
Wheat	648	3.01	1,955	3,057,155
Sunflower	636	1.3	833	2,377,319
Soybeans	238	2.16	516	2,377,319
Sugar cane	391	52.20	20,411	5,029,382
<i>Horticulture/fruit</i>				
Citrus	64	-	-	2,640,000
Subtropical fruits/nuts	50	-	-	930,000
Vines	180	-	-	3,600,000
Deciduous fruit	50	-	-	2,900,000
Vegetables	50	-	4,295	

Source: DAFF (2010)

Gbetibouo G. A. (2011)

93.6% of the volume of agricultural production is food products with 25% from field crops, 26% from horticultural and 48.3% from livestock (DAFF 2010). The volume of total production, although erratic, has been increasing over the last 30 years. The production of field crops is very erratic towards showing a downward trend whereas the productions of horticulture and livestock are increasing (Figure 3.3). The country is, however, still self-sufficient as far as most primary foods are concerned, with the exception of wheat, oilseeds, rice, tea, and coffee.

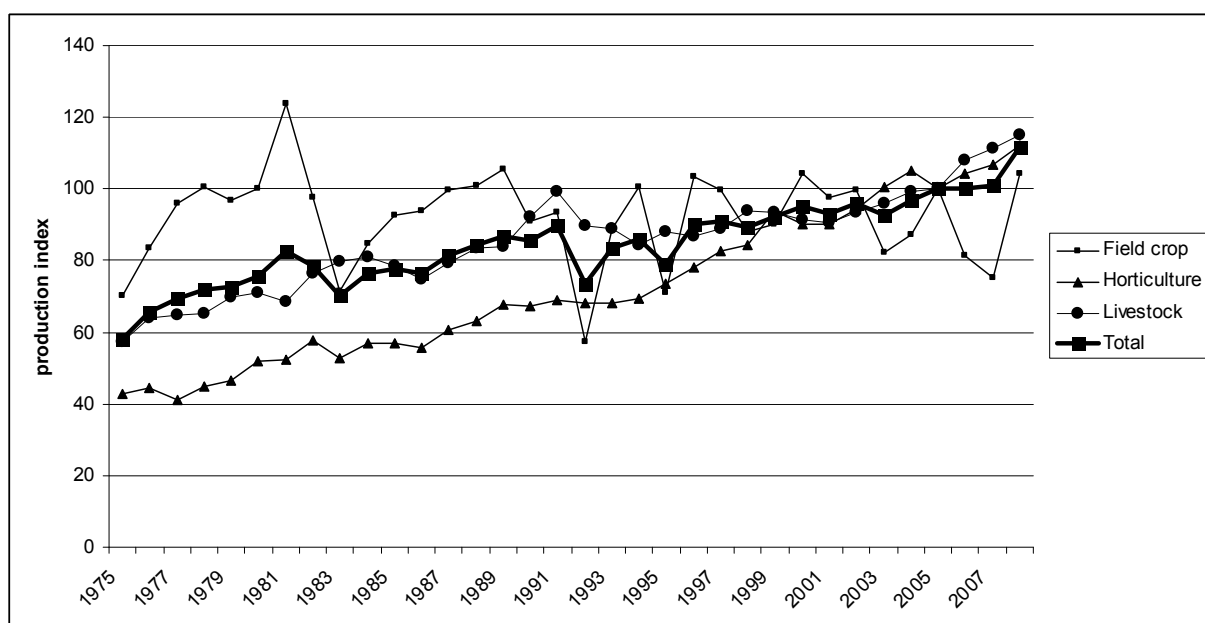


Figure 3.3: Indices of volume of agricultural production over the years: 2005-2010

Source: DAFF (2010)

South Africa normally produces 85% of its meat requirements and the remainder is imported from Namibia, Botswana, and Swaziland. The 2009 estimates of heads of cattle and sheep are 13.8 million and 21.9 million, respectively. The goat population is estimated to be 2.07 million. In 2009, approximately 2.8 million heads of cattle were slaughtered. South Africa accounts for 80% of world sales of ostrich products, including leather, meat, and feathers.

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3.2.3 Major farming systems in South Africa

Due to the history of apartheid policies, agriculture in South Africa is dualistic with a commercial sector located in the “former South Africa” and run predominately by white farmers, while a subsistence sector (traditional/small scale) is located in the former homeland areas and cultivated by black farmers. The institutional infrastructure of agriculture differs in quality, availability and accessibility between these two commercial and subsistence systems (Coetzee and van Zyl 1992).

The commercial sector is the dominant form of agricultural production in South Africa. It is large-scale, commercially oriented, capital-intensive, export-led, and it accounts for 90% of total value added (VAD) in agriculture and covers 87% of the agricultural land. The average size of commercial farms in South Africa is estimated to be about 1,200 hectares under private ownership and there are about 46,000 commercial farm units in the country. In contrast, the subsistence sector is an impoverished sector, dominated by low-input, labour-intensive production.

The estimated 3.4 - 4.8 million smallholders are predominantly settled in the former homelands and farm on the remaining 13% of the agricultural land (17 million hectares) for semi-subsistence purposes (Feynes and Meyer 2003). Land holdings in the former homelands are generally very small (Groenewald and Nieuwoudt 2003) and are under a communal land tenure system. The general household survey in 2006 identified that only 17% of the households living in the non-metro areas of South Africa (1.3 million households) have access to land for farming purposes and that these households engage in some farming, mostly on relatively small plots of land (Table 3.3).

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Table 3.3: South African households' access to agricultural land: 2006

Land size	Number (weighted)	%
< 0.5 ha	831,871	64.5
0.5 – 1 ha	235,454	18.3
1 – 5 ha	138,196	10.7
5 – 10 ha	38,146	3.0
10 – 20 ha	11,940	0.9
> 20 ha	34,546	2.7
Unknown	17,556	-
Total	1,307,710	100.00

Source: Vink and van Rooyen (2009)

With the advent of democracy in 2004, new agricultural policies were put in place with the expectation that transformation of South African agriculture would result in a wider range of farm sizes, a less stark distinction between commercial and “traditional” agriculture, and a less prominent border between the commercial and communal farming areas (Vink and van Rooyen 2009). Although the South African sector is still characterised by high inequalities mostly between commercial (mostly white) farmers and farmers in the communal areas, Vink and van Rooyen (2009) identified a broader spectrum of six farmer typologies in South Africa. The principal characteristics of this typology are shown in Table 3.4.

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Table 3.4: Farmer typologies in South Africa

Farmer type	Turnover	Ownership and management	Farming operations		Binding constraint	Support required
			Number	%		
Large commercial	> R 2 million	Private property Family owned but incorporated multiple farms and Rent in land Professional management	+/- 5,400	0.41	Market size Equity capital	Export market access Financial market innovation
Medium commercial	R 300,000 to R 2 million	Private property Family owned could be incorporated some renting in of land Family management	17,000	1.28	Land capital management	Mortgage capital for land access Management training
Small scale commercial	< R 300,000	Private property Family owned, generally part time. Some lifestyle farming (game ranches, weekend farms)	24,000	1.81	Management Time	
Communal Commercial	> R 300,000	Communal areas Communal ownership Development projects Private ownership	-	-	Capital Management Infrastructure	Grants for land access Property rights Comprehensive farmer support
Emerging commercial	< R 300,000	Communal areas >20 hectares Communal ownership Small scale farmers in development project Private ownership	35,000	2.64	Land (property rights) Capital labour Management Employment opportunities	Credit Physical infrastructure
Subsistence farmer		Communal areas < 20 hectares Communal ownership Private ownership Little formal market participation	1,256,000	93.86	Employment opportunities	Social welfare transfers

Source: Vink and van Rooyen (2009)

Gbetibouo G. A. (2011)

3.2.4 Economic performance of agriculture in South Africa

3.2.4.1 Output and GDP contribution

Agriculture has experienced relatively high rates of growth over the past century with an annual rate of growth of 10% for the last two decades. Real gross farm income increased from around R 25 billion in 1970 to almost R 50 billion in 2006. The share of the sector to the country's Gross Domestic Product (GDP) has declined from 20% in 1911 to 10% in 1965 and to less than 5% in the late decade (DAFF 2010) as a result of the transformation of the South African economy from a primary production to a more diversified economy. However, with the strong forward and backward linkages of agriculture within the economy, the agro-industrial sector as a whole contributes on average 15% of the GDP (Hassan 1998; McDonald et al. 1997; Townsend 1997; van Zyl et al. 1988). Poonyth et al. (2001) showed that a 1% growth in the agriculture sector induces more than a 1% growth in non-agriculture sectors. The share of contribution to agricultural GDP varies considerably among provinces (Figure 3.4). Over the years, Western Cape has been the most contributing province, with a shift over the last decade to Kwazulu-Natal province. Between 2000 and 2010, Kwazulu-Natal province made the largest contribution to agricultural GDP of 26.3% followed by the Western Cape 22.3%.

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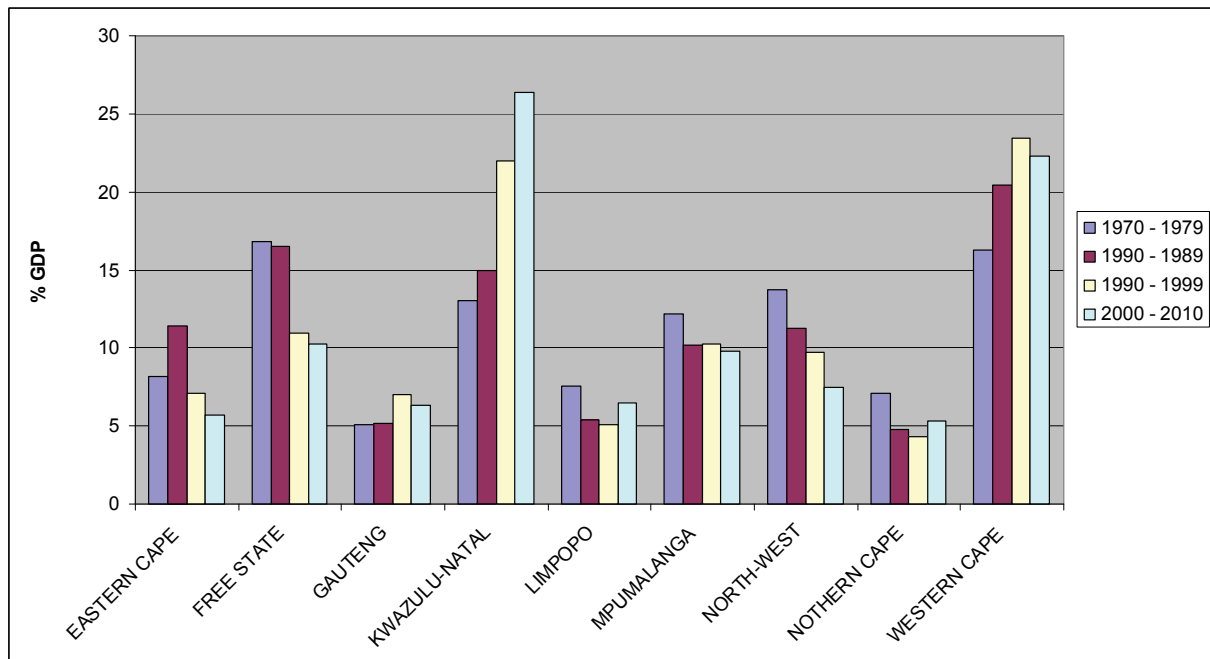


Figure 3.4: South African provinces share contribution to agricultural GDP

Source: DAFF (2010)

3.2.4.2 Competitiveness and contribution to external trade balance

Using the Revealed Trade Advantage Index to measure the extent of competitiveness of agribusiness supply chains in South Africa, Esterhuizen (2006) concludes that South African agriculture as a whole is no more than marginally competitive in the global market. South Africa can be classified as a ‘rising moderate performer’ along with a number of EU member states such as Belgium, Germany, and Italy. Esterhuizen (2006) further highlights that South African agriculture was at its most competitive in the mid – 1970s and at its least competitive in 1985, but the degree of competitiveness has been increasing since 1993. Agricultural subsectors such as maize, apples, pineapples, grapefruit and mohair have seen an increase in competitiveness during the period 1993 – 2002.

The trade performance of South Africa’s agriculture over the past four decades is given in Table 3.5. South Africa exports around 32% of its total agricultural output estimated at R 20 billion in

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2004 making up 8% of total exports (GCIS 2005). Especially from 1990, with the increase in openness of the country, agricultural exports have grown rapidly from only R5 billion to its current level of R 22 billion. However, agricultural imports have grown even faster. Therefore, the balance in agricultural trade has decreased from 5.38 in 1970 to 1.6 in 2000.

Table 3.5: South Africa's trade in agricultural goods: 1965-2005

	1965 - 1969	1970 – 1974	1975 - 1979	1980 - 1984	1985 - 1989	1990- 1994	1995 – 1999	2000 - 2005
EXPORTS								
Total exports (Rm)	1,222.00	2,092.00	7,305.00	20,746.00	45,164.00	72,534.00	133,623.00	272,382.00
Total agricultural exports (Rm)	430.00	689.00	1,412.00	1,946.00	3,613.00	5,520.00	12,132.00	22,293.00
Agricultural exports as a percentage of total exports	35.21	32.92	19.33	9.38	8.00	7.61	9.08	8.18
Agricultural exports as a percentage of total agricultural output	34.79	32.92	33.35	23.01	22.46	21.58	28.65	32.65
IMPORTS								
Total imports (Rm)	1,862.00	3,243.00	6,536.00	18,240.00	32,499.00	55,122.00	125,364.00	264,682.00
Total agricultural imports	56.00	174.00	290.00	870.00	1,689.00	3,476.00	8,317.00	13,687.00
Agricultural imports as a percentage of total imports	3.02	5.38	4.43	4.77	5.20	6.31	6.63	5.17
Agricultural imports as a percentage of total agricultural output	4.55	8.30	6.84	10.29	10.50	13.59	19.64	20.05
BALANCE	7.64	3.95	4.88	2.14	2.14	1.59	1.46	1.63
Openness	39.34	41.10	40.19	33.30	32.96	35.16	48.29	52.69

Source: Vink and van Rooyen (2009)

Gbetibouo G. A. (2011)

3.2.4.3 Contribution to employment, rural poverty and food security

Agriculture in South Africa has traditionally been the largest employer in the economy (Meyer 1998). However, agricultural employment is declining at an alarming rate reflecting the trends toward mechanisation in agriculture and increasing urbanisation. According to Simbi and Aliber (2000) during the 11 year period from 1988 to 1998, the commercial farm sector shed a staggering 140,000 regular jobs, causing a decline of roughly 20% of total employment in agriculture. Total formal employment in agriculture has declined markedly from more than 1 million jobs in 1970 to 800,000 jobs in 1998 and nearly only 700,000 jobs in 2009. Furthermore, there is a reduction in the employment of regular permanent workers and an increase in the use of seasonal casual workers (NDA 2000). The share of agriculture in total employment has declined from 30% in 1971 to 13% in 2000, to 10.2% in 2005 of the economically active population in South Africa (DAFF 2010).

Although the share of agriculture in total employment is decreasing, agriculture remains an important vehicle for poverty alleviation and food security in rural areas. Commercial farms provide livelihoods and housing to approximately six million family members of 1 million employees and provide for their educational needs. There are also 240,000 small farmers who provide a livelihood to more than one million of their family members and occasional employment to another 500,000 people. Furthermore, there are an estimated three million farmers, mostly in the communal areas of the former homelands, who produce food primarily to meet their own family needs (NDA 2000). A study involving 138 smallholder irrigation farmers in the Limpopo Province demonstrated that farming is the greatest contributor to household income, representing more than 40% of total rural household income (Machethe et al. 2004).

Except for rice, for which the country has no domestic resource base and thus imports, the country has met the needs for its main staple food by over 160%, 100%, 95%, and 80%, for sugar, maize, livestock needs and wheat, respectively. However, while South Africa may be food secure as a country, about 14 million people are said to be vulnerable to food insecurity and 43% of households suffer from food poverty (National Treasury 2003). The majority of poor households are concentrated mostly in the rural areas, especially in the former homelands. Indeed, 21% of the urban population and 63% of the rural population in South Africa live below

Gbetibouo G. A. (2011)

the minimum subsistence level (van Zyl and Kirsten 1992). Thus, promoting smallholder agricultural growth in South Africa can be an effective strategy to reduce rural poverty and achieve food security (Baiphethi and Jacobs 2009; Machethe et al. 2004).

3.2.5 South African agricultural policy

According to Vink and van Rooyen (2009) the performance of agriculture in South Africa has to be seen in the context of a long history of state intervention through most of the 20th century. The state supported farmers through legislation such as the Cooperative Societies Act (1925) and the Marketing Act (1968), which control prices, access to the use of natural resources, finance, capital, labour and local markets. Although these policies encouraged technological advances and increased production in commercial agriculture, they also had high social, economic and environmental costs. Foremost among these, were high capital-intensive production in the presence of widespread unemployment and expansion of farming into environmentally fragile areas (NDA 1998). On top of that a range of measures such as Land Act (1913) marginalised small scale black farmers as their access to resources such as land, credit and technical know-how was curtailed. Since the establishment of a democratic government in 1994, South Africa has undertaken a significant reduction of state involvement in agriculture by putting in place a series of new agricultural policy reforms in trade and marketing, land and resource management, labour, finance and extension. The two most important agricultural policy reforms are detailed below:

1. Marketing policy

The introduction of the Marketing of Agricultural Products Act, 1996 (Act 47 of 1996) put in place a deregulation process which entailed closing agricultural marketing boards, phasing out important export-control measures, eliminating subsidies, and introducing tariffs to protect the domestic agricultural industry value chains against unfair international competition. According to the OECD (2006) although the deregulation of markets created some uncertainty it opened opportunities for entrepreneurial farmers at the same time and led to a more efficient allocation of resources in agriculture. The net effect of these changes is that the South African agricultural

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industry has become less dependent on state support and internationally more competitive, although many sectors within the industry experienced a difficult period of adjustment.

2. Land Reform in South Africa

Land policy in South Africa consists of three main programs:

- 1) Land restitution: targeting people who lost their land in the past by racially discriminatory legislation;
- 2) Land redistribution: providing the poor and disadvantaged with land to improve their livelihoods, to resettle or to establish farming enterprises; and
- 3) Land tenure reform: ensuring security of tenure by strengthening the rights of residents on privately owned farms and state land and by enabling individuals to benefit from their property.

Almost after 15 years of implementation, the effects of land reform policy are limited due to a variety of financial, institutional, educational and technical constraints. Indeed, only 5% of white commercial farms' land has been transferred despite a 30% target (Vink and van Rooyen 2009).

3.3 Current climate regime and impact on agriculture in South Africa

3.3.1 South Africa current climate

South Africa is a predominantly semi-arid (80% of the country) according to the United Nations Convention on Combating Desertification (UNCCD) index of dryland. The climate varies from desert and semi-desert in the west to sub-humid along the eastern coastal area (Figure 3.5).

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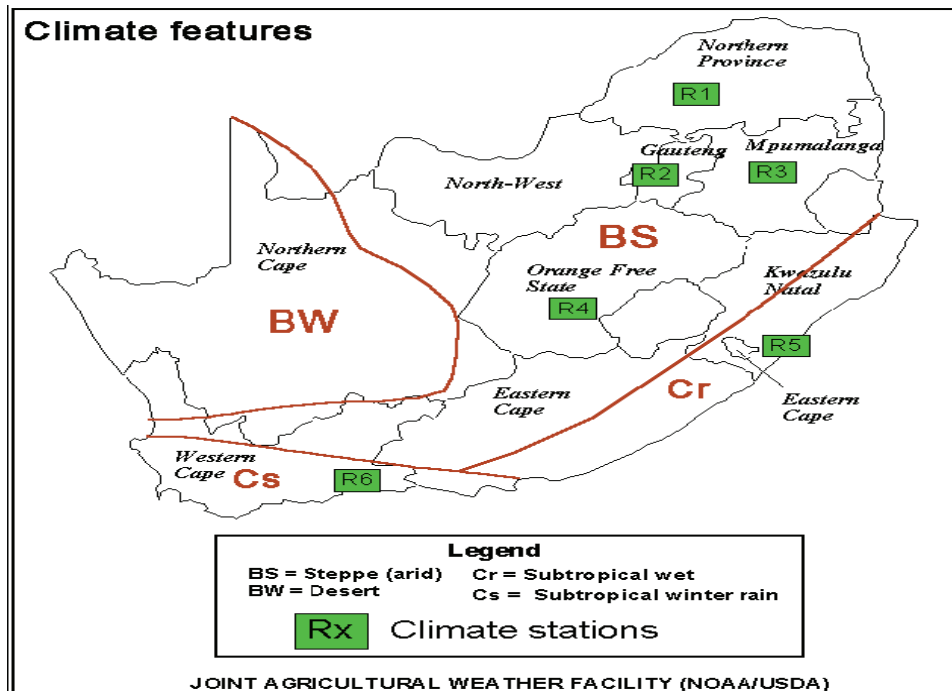


Figure 3.5: Climate zones in South Africa

Source: USDA Joint Agricultural Weather Facility (2000)

Most of the country has warm, sunny days and cool nights. Summer temperatures on average vary between mid-thirties to twenty degree Celsius across the country. Maximum temperatures often exceed 32°C in the summer and reach 38°C in some areas of the far north. Winters are not extremely cold and average temperatures vary between 20°C and 10°C. However, frost occurs in high altitudes during the winter months and the night-time minimum temperatures can drop to freezing point for at least 30 days a year over the entire high-lying interior (about 50% of the country).

Rainfall generally occurs during summer (November through March), although in the southwest, around Cape Town, rainfall occurs in winter (from June through August). South Africa receives an average annual rainfall of about 450 mm, well below the world's average of 860 mm. Furthermore annual potential evapotranspiration may exceed annual rainfall by ratios of up to 20:1 (Schulze 1997). However, there is wide regional variation in the country with an increase in rainfall from the western to the eastern parts (Figure 3.6).

Gbetibouo G. A. (2011)

In approximately 22% of the northwest of the country, predominantly the Northern Cape province, annual rainfall often remains below 200 mm. Much of the eastern Highveld, in contrast, receives 500 mm to 900 mm of rainfall per year and occasionally, rainfall there exceeds 2,000 mm. A large area of the centre of the country, covering about 35% of the total land, receives approximately 400 mm of rain, on average, and there are wide variations closer to the coast. The 400 mm "rainfall line" actually divides the country into two sections with the land east of the rainfall line generally suitable for growing crops, and land west of the rainfall line, only suitable for livestock grazing or crop cultivation on irrigated land.

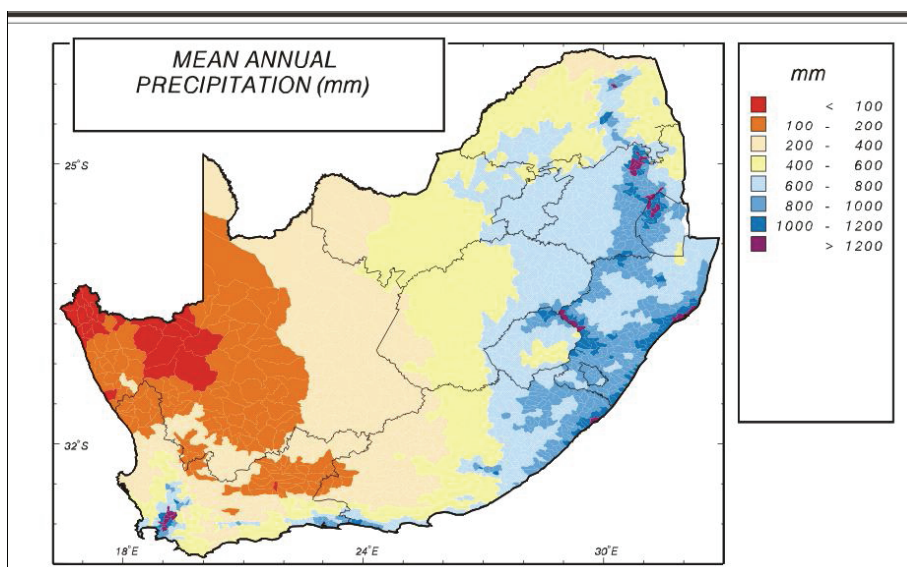


Figure 3.6: Mean annual rainfall in South Africa

Source: Schulze (2003)

3.3.2 Climate variability and its impact on agriculture

Records have shown that South Africa is characterised by strong interannual rainfall variability with prolonged dry periods and droughts, which are often terminated by severe floods (DWAF 1986; O'Keeffe et al. 1992; Richard et al. 2001). These droughts are usually associated with prolonged periods of anticyclonic activity over the inland plateau and are consequently most common in the summer rainfall region, particularly towards the west. The uncertainty of rainfall

Gbetibouo G. A. (2011)

is best expressed by the coefficient of variation in annual rainfall (Figure 3.7). Low rainfall regions have the highest coefficient of variation. Only a small part of the country, in the summer rainfall region has a coefficient of variation of less than 20%. The rest of the country has a rainfall coefficient of variation greater than 20%, indicating increasing susceptibility to drought. The rainfall coefficient progressively increases to over 40% towards the dry arid areas in the west. In drier arid areas receiving less than 600 mm rainfall, during the period 1956 to 1986, drought have been generally declared over 50% and up to over 70% of the time in some districts of the western arid areas (Hazelton et al. 1994).

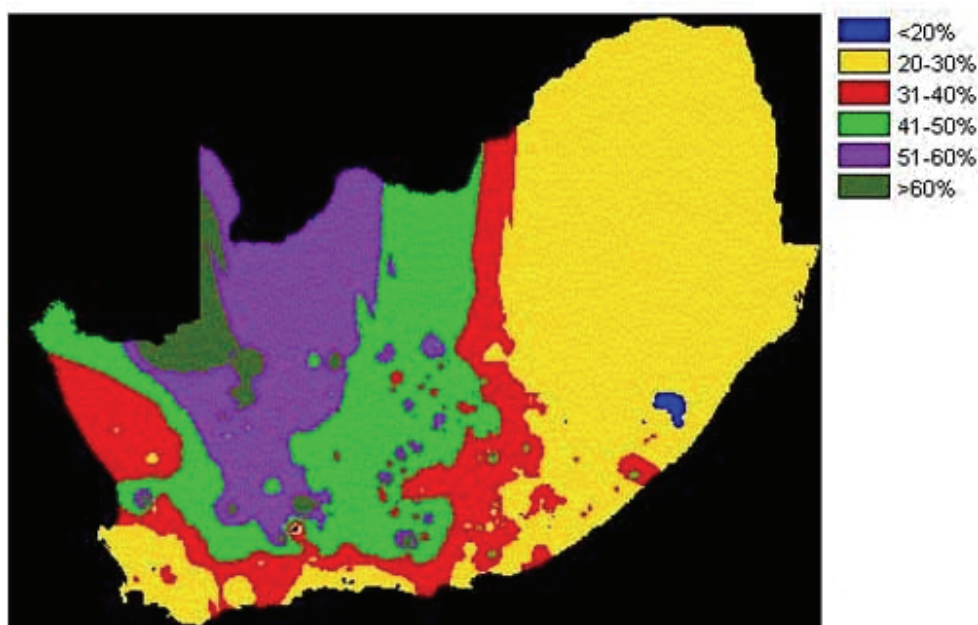


Figure 3.7: South African annual rainfall coefficient of variation

Source: FAO (2005)

In South Africa a clear oscillatory pattern is apparent in rainfall series, indicating a considerable decadal variability with the tendency to produce nine year spells of generally wet and generally dry periods in a quasi-cycle of about eighteen years (Tyson 1987; Bruwer 1990). According to the Standardised Precipitation Index (SPI), the eight most severe droughts at the 6-month time

Gbetibouo G. A. (2011)

scale for the summer rainfall region of South Africa occurred in 1926, 1933, 1945, 1949, 1952, 1970, 1983 and 1992 (Rouault and Richard 2003).

The impacts of extreme climate events are particularly evident in the agriculture sector and for vulnerable communities in the country (Wilhite and Vanyarkho 2000). Past droughts have resulted in a number of disruptive impacts, including decreased agricultural production, increased hunger and poverty and possible dislocation of communities (Vogel and Drummond 1993). In the past 30 years, although maize yield have seen an upward trend, the lowest yields in maize occurred during the devastating droughts years of 1983, 1992 and 1995 (Figure 3.8). During the 1992 drought, an estimated 243,000 head of cattle and 101,000 head of small stock were lost in three communal districts of North West province (Rwelamira 1997). Furthermore, between 1975 and 2001, nine droughts and famines affected over half a million people and 16 floods led to the loss of more than 1,000 lives, directly affected another 76,300 people and left 22,835 people homeless (Napier and Rubin 2002). Extreme climate events, particularly droughts in South Africa have an impact on the natural resource base, on people as well as on the viability of farming and regional economies. During the dry cycle between 1982 and 1995, annual economic growth has been reduced by between 0.5 and 1.2 % in the four years of 1982, 1983, 1992 and 1995 (Financial week 2002).

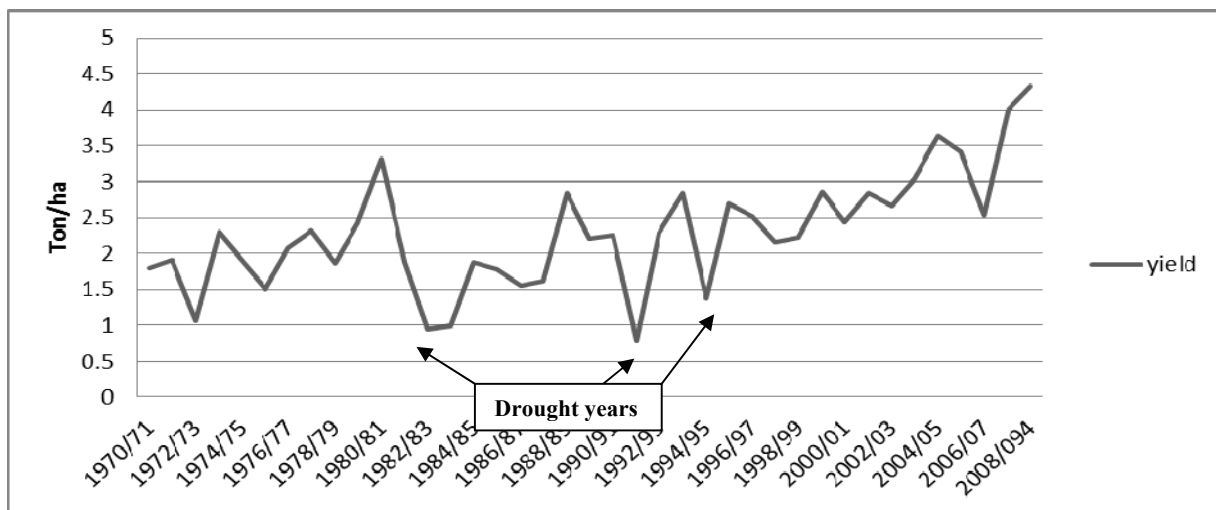


Figure 3.8: Maize yield and annual rainfall: 1970-2006

Source: DAFF (2010)

Gbetibouo G. A. (2011)

Using maize and wheat as proxies for all seasonal field crops to demonstrate the link between rainfall and crop output, Blignaut et al. (2009) show that there is a remarkable correlation between rainfall and crop production, whether summer (e.g. maize) or winter crop (e.g. wheat). For all the provinces contributing approximately 20% or more to national production for maize or wheat, highly statistically-significant relationships were found between crop production and rainfall. Maize production is found to be generally more sensitive to changes in rainfall than wheat production with elasticity of 1.16 and 0.5, respectively, for maize and wheat for the whole country. Thus, a 1% change in rainfall should lead to more than a 1% change in maize production. Blignaut et al. (2009) conclude that should it become still warmer in the future and should rainfall continue to decrease the three major maize and wheat production areas of the country will be susceptible to marked reductions in crop production.

3.4 Climate change projections and predicted impacts on agriculture in South Africa

3.4.1 Future climate change projections

It is now widely agreed that over the last 100 years human activities, such as changes in land use (e.g. deforestation) and the increased use of coal, oil, and natural gas (e.g. in automobiles, industry, and electricity generation), have contributed largely to the increased carbon emissions and other GHGs in the atmosphere (IPCC 2007). The accumulation of GHGs in the atmosphere is expected to alter the atmospheric balance and enhance the natural greenhouse effect, leading to a change in climate variables such as temperature, rainfall and solar radiation. There is already evidence that temperatures have warmed by approximately 0.5°C over the past century (IPCC 2007). If there is no mitigation of GHG emissions over the next century, global temperatures are expected to rise between 2°C and 4°C depending on the emission scenarios (IPCC 2007). However, there is a great deal of uncertainty about future climate change scenarios.

The anticipated temperature increases are likely to be greater near the poles and lower near the equator. The temperature changes will not be uniform across the planet. Furthermore, the changes in temperature are likely to increase the energy in the hydrological cycle, leading to

Gbetibouo G. A. (2011)

more clouds, more rain and more evapotranspiration. The ways in which these changes will be distributed across the planet are poorly understood and there is little agreement about the distribution. Meteorological processes are likely to change, leading to weather patterns shifting from place to place. In addition to the gradual increase in annual temperature or rainfall, warming may change seasonal distributions, reduce diurnal range by reducing heat loss at night, or lead to an increase in interannual variance. Furthermore, it is predicted that GHG emissions will lead to sea-level rise and also increase the severity or frequency of extreme climate events such as hurricanes and other storms.

In the case of South Africa, results from detection studies of climate parameters show that trends corresponding to a warming over South Africa in the second half of the 20th century are already evident (Schulze (2007) with spatial variation across the country. The following key observations were made for the period 1950 to 2003:

- 1) Annual mean maximum temperatures showed a significant increase for the period 1960 to 2003 with trends higher for central stations than those closer to the coast (Kruger and Shongwe 2004).
- 2) Annual minimum temperatures showed positive trends over the period 1960 to 2003; however some central interior stations did not show significantly positive trends (Kruger and Shongwe 2004).
- 3) Trends of mean seasonal temperature showed that temperature trends are not consistent throughout the year, with the average trend for autumn showing a maximum and spring a minimum (Kruger and Shongwe 2004).
- 4) Trends in diurnal temperature range are almost equally divided between positive and negative, with positive trends in the central interior (Kruger and Shongwe 2004).
- 5) Daily maximum temperatures indicate an increasing trend of the maxima across the region. Significant evidence is found for stations in the southeast of the Western Cape, as well large portions of the Eastern Cape, Northern Cape and Free State. Number of days and nights with relatively high temperatures have increased (Schulze and Maharaj 2004).

Gbetibouo G. A. (2011)

- 6) Increasing trends for daily minimum temperatures is also found. In general, days and nights with relatively low temperatures have decreased (Kruger and Shongwe 2004; Warburton et al. (2005).

According to Schulze (2007) this increasing trend of temperatures at the extremes of distribution is really important and poses a significant threat to agriculture in South Africa. Indeed, heat waves desiccate the soil and result in lower yields and/or higher irrigation water demands and frost occurrence can curtail the duration of a crop's growing season, cause internal damage to plant and also break life cycles of pests and diseases. The 20th century historical record shows strong trends in southern Africa's regional climate, most notably with respect to secondary attributes of rainfall such as intensity and frequency (Hewitson et al. 2005; New et al. 2006). On the hemispheric scale there are also suggestions that the El Niño - Southern Oscillation teleconnection to southern Africa may become less robust (Landman and Mason 1999; Sewell and Landman 2001), with associated implications for climate predictability in the region.

Observed trends in daily rainfall indices in South Africa for the period 1910 to 2004, show that in the largest part of South Africa, there has been no real evidence of changes in rainfall but in some identifiable areas, significant changes in certain characteristics of rainfall have occurred (Kruger, 2006). Using rainfall data collected from over 3,000 station records across South Africa, Hewitson et al. (2005) also show no general trend but the following large spatial differences across the country: i) an increase in the late summer dry spell duration for much of the summer rainfall region; ii) arid zones, in general, receiving more rain days; and iii) contrasting changes in the winter rainfall region, with mountainous regions receiving more rain days per month and increased totals, while the neighbouring coastal plain regions display the reverse.

Climate change predictions for South Africa were derived from scenarios generated by Bruce Hewitson's group (University of Cape Town, South Africa) using up to three General Circulation Models (GCMs: Genesis, HadCM2 and CSM). Under an assumption of a doubling of CO₂ concentration in the atmosphere, the climate models predict an increase in temperature across the country of between 1°C and 3°C over the next 50 years (Hewitson 1999). They suggest that

Gbetibouo G. A. (2011)

warmer conditions will be the greatest in the northern regions and slightly warmer conditions for the coastal regions (Figure 3.9).

There is no general agreement in the direction and spatial distribution of the changes in rainfall across the global climate models for South Africa. For example, Scholes and Biggs (2004) using the HadCM3 climate model projected overall drying of the Southern African region by 2050 relative to mean conditions over the 1961 to 1990 period (Figure 3.9). In contrast, Hewitson et al. (2005) predicted a general increase in summer rainfall in the interior and the eastern part of the country, and a decrease in winter rainfall in the Western Cape region. However, Hewitson and Crane (2006) noted the following contrasting results from the three downscaled models applied to South Africa (HadAM3, ECHAM4.5 and CSIRO): i) mild winter increase in rainfall over the southwest corner of South Africa is predicted by HadAM3, in contrast to the drying predicted by CSIRO and ECHAM4.5; and ii) ECHAM4.5 predicts mild increase over the northern border in summer, whereas the other two models (HadAM3 and CSIRO) indicate drying. According to Lumsden et al. (2009), the arid interior and moister north-eastern regions of South Africa are likely to be subjected to elevated evapotranspiration rates, increased stress, and more frequent flood events, whereas the south-western regions of the country are likely to experience increased early winter frontal and orographic rainfall.

Although, accurate prediction of rainfall patterns are not available yet, it is worthwhile noting that rainfall patterns are likely to change with greater seasonal and interannual variability and large spatial variations across the country (Hewitson and Crane, 2006; Lumsden et al. 2009).

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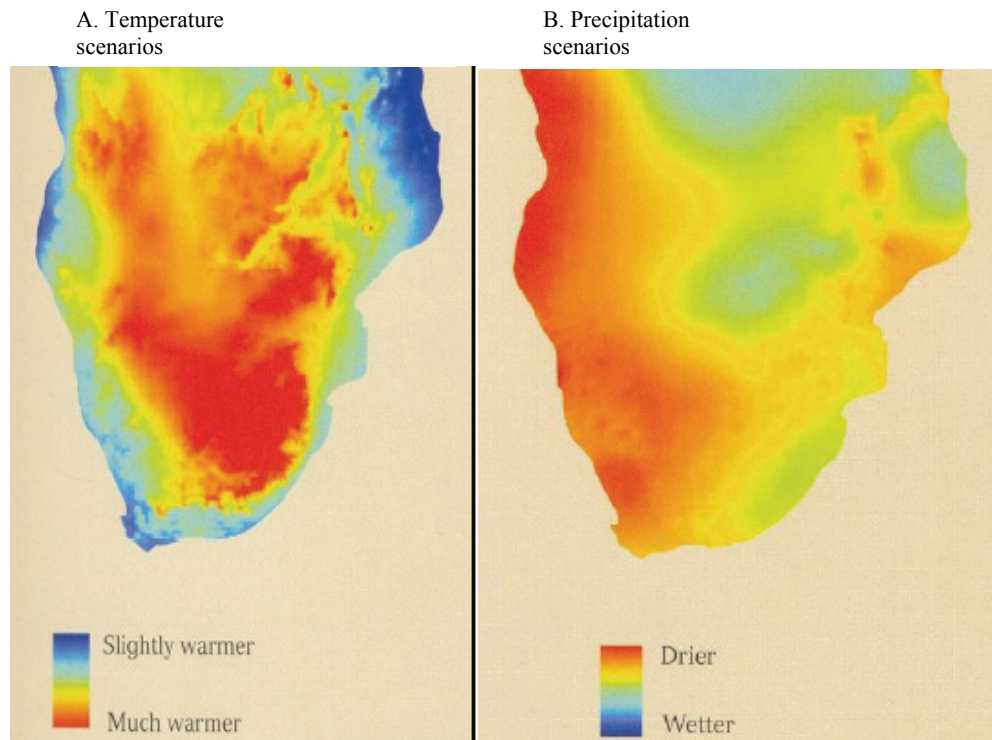


Figure 3.9: HadCM3 climate model predictions by 2050 relative to mean conditions over the 1961 to 1990 period for Southern Africa

Source: Scholes and Biggs (2004)

3.4.2 Predicted impacts of climate change on agriculture in South Africa

The predictions of changes in climate illustrated above raise concerns that climate change could have significant impacts on crop and livestock production in the country, which would have important implications for the wellbeing of South African farmers, particularly for poorer, emerging farmers in the country. Numerous initiatives have therefore sought to analyse the impact of global climate change on agriculture in South Africa.

A set of studies were undertaken to evaluate the impacts of global warming on climate derivatives such as climate zones, the spatial and temporal changes in heat units, chill units, or potential evaporation which play an important role on the physiology and growth of plants and animals. Schulze (2005) ascertains how, in broad terms, agricultural belts may shift geographically with global warming over South Africa with some zones enlarged (mainly in

Gbetibouo G. A. (2011)

already hot areas) while others decrease in area, both in absolute (km²) and relative (%) terms when compared with present climatic conditions. The climatic zones most likely to be reduced markedly are in the already environmentally sensitive winter and all-year rainfall regions. Such shifts in climate zones towards a general aridification of rangelands will affect fodder production and impact on the marginal costs of ranching.

The First National Communication on Climate Change (2000) report suggested that over the savanna regions in the northeast of the country, forage production may decrease by about one fifth, which would impact on the cattle ranching industry by reducing the national cattle herd by approximately 10%. Furthermore, these climate zones shifts will impact future agricultural production, not only with regard to changes in yield and climatically optimum growth areas, but also with respect to pest and disease incidences, foreign exchange earnings from agriculture and rural employment patterns (Schulze 2005).

Using climate modelling techniques Schulze and Maharaj (2006a) found that annual heat unit will increase by 10% to 35%, with the most dramatic relative increases over the higher lying southern and eastern escarpment/mountain areas. These projected increases in heat units are likely to induce marked changes in planting dates, timing/length of phenological periods and pest/disease incidences. Using also the Positive Chill Units (PCU) model, Schulze and Maharaj (2006b) investigated possible effects of global warming on chill unit relevant to certain biennial plants which require a period of accumulated minimum temperatures below a threshold in order to stimulate growth, develop leaves, flower or set fruit. They show that chill units will decrease in the nine provinces of South Africa with sensitivity varying by 25% for a 1°C increase, 45% for a 2°C and 60% for a 3°C increase in temperature. They concluded that production of deciduous fruit in the Western Cape Province will be compromised and that deciduous fruit farmers may therefore have to consider relocating to higher altitudes. Indeed, for a highly plausible 2°C temperature increase in a future climate, the chill units in the Western Cape would resemble those of Mpumalanga, where sub-tropical fruit is produced under present climatic conditions.

Under a simulated climate change scenario of a 1°C increase in temperature, crop reference evapotranspiration is expected to increase annually by approximately 2.5% on average in the arid Northern Cape and by 3.8% in the Eastern Cape (Schulze and Chapman 2006). For a scenario of

Gbetibouo G. A. (2011)

3°C temperature change the increase in potential crop evaporation ranges from 7.9% to 11.9% with greater rise in the Western Cape region during the winter season. Net water requirements for crops in the summer rainfall region are projected to increase throughout South Africa with an increase of less than 10% in the south and north but of 30% along the Kwazulu-Natal coast and the central Free State areas. According to Schulze (2007), the increase in potential evapotranspiration also implies a reduction in runoff per unit of rainfall as well as higher reservoir evaporation levels, both of which can have severe implications on irrigated agriculture.

Another set of studies, using simple type or complex structure crop growth models, investigated projected changes in yield at a given location. Schulze et al. (1993) undertook the first assessment of the potential effects of climate change on maize yields in South Africa. Using a hybrid ACRU/CERES-maize model, and taking into account only the expected increases in temperature and allowing for carbon dioxide fertilisation effect, results pointed to an overall increase in potential maize production with varied intensity across geographic sites (Schulze et al. 1993). This simulated yield increase is seen primarily in regions with mean annual rainfall between 400 and 800 mm. Insignificant yield changes are observed in the higher-rainfall zones.

In contrast with these positive gains, using the same CERES-Maize crop simulation model, Du Toit et al. (2000) found that South African maize yield is vulnerable to fluctuations in seasonal rainfall. Four potential climate scenarios were tested for 19 individual sites representing most of the current maize production area. The results showed that maize yields will either remain at current levels or decrease by 10 to 20% according to the climate scenario used. Some of the marginal western areas may become unsuitable for maize production under current management strategies while some of the eastern production areas may remain unchanged or experience an increase in production levels. According to Turpie et al. (2002) the economic losses based on Du Toit et al.'s (2000) study could be estimated at ZAR 681 million without the CO₂ fertilisation effect, and a considerably smaller loss of ZAR 46 million with the fertilisation effect.

Durand (2006) also conducted pilot analyses on the effect of climate change on maize with the CERES-maize under four climate change scenarios in three districts Lichtenburg, Wesselsbron and Middelburg. She found that all four climate change scenarios had a negative effect on maize yield with the most severe reduction in the Lichtenburg district, where future maize production

Gbetibouo G. A. (2011)

might become totally uneconomical. Furthermore, Walker and Schulze (2008) confirmed the results that climate change will result in maize yields reductions. Indeed, using CERES-Maize over a 44-year period with nine plausible future climate scenarios, they show that climatic changes could have major negative effects on the already drier western, and therefore more vulnerable, areas of the South African Highveld. An increase in temperature increases the variability of yields in the relatively moist Piet Retief area, while at the more sub-humid Bothaville, the inter-annual variability remains the same but mean yield over 44 seasons is reduced by 30%.

In addition to the natural science studies cited above, economic studies have also been undertaken to address the direct impact of climate change and variability on crop yields, specifically maize yield, in South Africa. Mqadi (2005) using data from 19 experimental sites estimated a production function for maize yield. She found that rainfall and net solar radiation diffused within the maize crop have a nonlinear and significant impact on average maize yield. Increasing rainfall levels will increase maize yields whereas an increase in solar radiation particularly during tassel initiation to grain filling would decrease maize yield considerably.

Another study by Akpalu et al. (2008) also estimated a production function for maize using a Maximum Entropy Leuven Estimator model (MELE) and found that increased rainfall, increased temperature, and irrigation have a positive impact on yield. The impact of rainfall on maize yield is stronger than that of temperature, meaning that the impact of climate variability on maize yield could be negative if the change increases temperature but reduces rainfall at the same rate and simultaneously. Moreover, the impact of irrigation on yield is positive but with a lower elasticity coefficient than that of rainfall, which supposes that irrigation may only partially mitigate the impact of reduced rainfall on yield.

Others have also tried to study the expected economic impacts of climate change on agriculture. Erasmus et al. (2000) used a sectoral mathematical programming model by incorporating predicted climate change, specifically rainfall, in the GCM to determine the effects on key variables of the regional farm economy of the Western Cape in South Africa. They found that climate change would lead to lower rainfall, which implies that less water will be available to agriculture in the Western Cape. This will have a negative overall effect on the Western Cape

Gbetibouo G. A. (2011)

farm economy. According to the study, climate change will lead to a relative shift away from intensive production sectors in agriculture towards more extensive systems. Both producer welfare and consumer welfare will decrease. Total employment in the farming sector will also decrease as producers switch to a more extensive production pattern. Total decline in welfare, therefore falls disproportionately on the poor in the province.

The Bureau for Food and Agricultural Policy (BFAP 2007) estimated the possible economic impacts of climate change on the maize sector for the country as a whole incorporating the estimated average yield change in maize production estimated by Du Toit et al. (2000) as exogenous shocks to the BFAP agriculture sector model, recursive and partial equilibrium model. Under the first scenario, where the fertilisation effect does not come into play, maize prices increase rapidly and South Africa becomes a net importer of white and yellow maize. In a second scenario, the fertilisation effect marginalises the impact of climate change and South Africa remains a net exporter of white maize, and trades at autarky in the case of yellow maize.

Some studies (Benhin 2008; Deressa et al. 2005; Gbetibouo and Hassan 2005; Poonyth et al. 2002) employed the Ricardian approach of Mendelsohn et al. (1994) to investigate the impact of some climate variables on net revenue from commercial and subsistence farming in South Africa by regressing farm net revenue on climate, soil and other socio-economic variables. Poonyth et al. (2002) explored the agriculture sector's performance with respect to climate change by including several crops and covered the whole country concluding that an increase of 2°C in average temperature decreases agricultural net revenue hectare by 25%. Deressa et al.'s (2005) study of the impact of climate change on South African sugarcane production indicated that climate change reduces sugarcane production's net revenue per hectare and that sugarcane production in South Africa is more sensitive to future increases in temperature than rainfall. The impact of a rise in temperature by 2°C and rise in rainfall by 7% will reduce net revenue per hectare for irrigated systems by 26% and by similar percentage in dry land conditions, on average.

Based on agricultural data for seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean), climate and edaphic data across 300 districts in South Africa, Gbetibouo and Hassan (2005) showed that production of field crops was sensitive to marginal

Gbetibouo G. A. (2011)

changes in temperature as compared to changes in rainfall. With minimal reduction in rainfall, benefits from rising temperature exceed the negative impacts from lowering rainfall. With further reduction in rainfall, the benefits effects from rising in temperatures are more than offset by the negative effects of rainfall reduction giving negative net effects. Furthermore, Benhin (2008) extends the previous Ricardian studies by incorporating relevant hydrological variables and data from farm household surveys, long-term climate data, major soils and runoffs and estimated a 1% increase in temperature will lead to about US\$ 80 increase in net crop revenue while a 1 mm/month fall in rainfall leads to US\$ 2 loss, but with significant seasonal differences in impacts. There are also significant spatial differences across the different farming systems. Using selected climate scenarios, the study predicts that crop net revenues are expected to fall by as much as 90% by 2100 with small-scale farmers been most affected.

In general, climate change studies on agriculture in South Africa predicted that climate change is more likely to negatively impact the agriculture sector, induce (or require) major shifts in farming practices and patterns in different regions of the country.

3.4.3 Gaps in existing knowledge on climate change impacts in South Africa

Most climate change studies conducted in South Africa focus on the implications of future climate change on crop yields and their resulting economic impacts. They rely on climate models (Schulze 2005; Schulze and Chapman 2006; Schulze and Maharaj 2006a; Schulze and Maharaj 2006b), crop growth models (Du Toit et al. 2000; Durand 2006; Schulze et al. 1993; Walker and Schulze 2008) or production function estimation (Akpalu et al. 2008; Mqadi 2005) to assess crop yields, more particularly maize yields, across South Africa under current conditions as well as under climate change. Economic impacts of changes in yield were evaluated by means of cross section analysis of economic variable such as net revenue per hectare or agricultural income (Benhin 2008; Blignaut et al. 2009; Deressa et al. 2005; Gbetibouo and Hassan 2005) or by constructing partial equilibrium model of a region economy (Erasmus et al. 2000) or an agriculture sector countrywide (BFAP 2007).

Gbetibouo G. A. (2011)

The vulnerability of agriculture in these studies is viewed in terms of the impact of specific change in temperature, rainfall, chill days, or heat days or evapotranspiration on crop yields and/or net farm revenue. The results of these studies are therefore given in terms of negative outcomes such as a 2°C increase in temperature and a 7% rise in rainfall will reduce average net revenue per hectare of sugarcane for irrigated systems by 26% (Deressa et al. 2005). Therefore, climate impact studies on agriculture sector in South Africa could be classified in what we call the “end-point” or “outcome” approach of vulnerability.

Thus, a neglected area in the South African assessments is social vulnerability, particularly the role of human agency in determining vulnerability to climate change. Indeed, according to Wehbe et al. (2005) the vulnerability of agricultural populations and systems to climatic conditions cannot be solely understood through the quantification of biophysical impacts. The relationship between climate and society is not pre-determined and formulaic, as done in previous studies that rely on direct translation of a climatic anomaly to yield losses and then to economic impacts.

According to Kandlikar and Risbey (2000) the significance and consequences of a climate event are not direct functions of its physical characteristics but rather vary with ways in which society has organised its relation to its resource base, its relation with other societies, and the relations among its members. A narrow biophysical focus undertaken in those studies, invariably neglects the social, economic and political factors that influence differential vulnerability between individuals and social groups (Hewitt 1995). Climate change is expected to occur and interact dynamically with contextual conditions in which the farming systems operate. Therefore, climate change assessments using a contextual approach of vulnerability become necessary. This is particularly important in the case of agriculture in South Africa which has long been regulated by a policy of marginalisation creating a dualistic sector.

Furthermore, the consequences of climate change are now well understood as a function of the ability of people and social systems to adapt to global environmental change. Thus, adaptation, like mitigation, became an important issue in addressing vulnerability to global environmental change. However, in South Africa, past climate change studies have largely ignored or did not properly address adaptation in their analyses. Indeed studies based on production function or

Gbetibouo G. A. (2011)

crop growth models (Akpalu et al. 2008; Du Toit et al. 2000; Durand 2006; Mqadi 2005; Schulze 2005; Schulze and Chapman 2006; Schulze and Maharaj 2006a; Schulze and Maharaj 2006b; Schulze et al. 1993; Walker and Schulze 2008) failed to take into account farmers' adaptation strategies in analysing impacts of climate change. These studies overestimate negative climate impacts and underestimate positive impacts because they fail to account for adaptation that farmers continuously undertake in order to cope with climate pressures (Adams et al. 1990 & 1998; Mendelsohn et al. 1994; Mendelsohn et al. 1996). The Ricardian studies (Benhin 2008; Deressa et al. 2005; Gbetibouo and Hassan 2005) with the use of cross – sectional data, accomplish more comprehensive analyses by accounting for autonomous adaptation undertaken by farmers. However, in contrast with crop growth models that assumed the “dumb farmer scenario” (no adaptation), Ricardian studies assumed a “clairvoyant farmer scenario” therefore perfect and full adaptation by farmers.

Under the Ricardian models, technologies to respond to climate change are presumed to be accessible to all farmers at any given time and these technologies will be adopted by farmers. However, if appropriate technologies are developed at the same pace with climate change, according to Polsky (2004) there is ample evidence from the literature on innovation adoption and diffusion to suggest that farmers will not necessarily adopt the technologies. Furthermore, past studies ignored the heterogeneity of farmer's tactical behaviour and decision-making that largely depends on a variety of environmental and socio-economic factors. Adaptation is therefore a socially driven process and research and analysis on climate adaptation should not be confined to prescriptive models but should broadly focus on understanding how societies can be made more resilient to climate change and variation through adaptation.

Ziergovel et al. (2006) focusing on agricultural decision-making in a communal irrigation scheme in the Vhembe District (within the Limpopo Province, South Africa) conclude that adaptation strategies within a community are socially differentiated and present differing objectives and priorities. However, they used experimental computer based interview and therefore their analyses were based on perceived adaptation actions instead of past adaptation actions. Thomas et al. (2007) looking at farmers across three provinces in the country also concluded that a range of specific coping and adaptation strategies are employed by farmers to respond to climate shifts, some are generic across regions and are some facilitated by specific

Gbetibouo G. A. (2011)

local factors. However, they fail to identify which factors determine adoption of adaptation strategies among individuals within community.

With only two studies (Thomas et al. 2007; Ziervogel et al. 2006) in South Africa that attempt to examine actual farmers' adaptations strategies, there is a need to address the social aspects of vulnerability to climate change with in-depth examination of the underlying socio-economic and institutional factors that determine how farmers respond to and cope with climate hazards.

Research results have an important influence on policy outcomes. As put forward by Madzwamuse (2010) the policy environment for climate change adaptation in South Africa is, to some extent, a reflection of the inadequate focus on adaptation by scientists studying the impacts of climate change. Thus, the National Climate Change Response Strategy (NCCRS), based on national vulnerability assessment studies cited above, is biased towards the biophysical aspects of climate change and neglects the socio-economic aspects that are critical for mainstreaming climate change adaptation into national economic development planning. The NCCRS does not adequately reflect the socio-economic implications of climate change and therefore does not provide for strategic interventions that would build the resilience of key sectors, regions, vulnerable groups and ensure adaptation preparedness. Research aimed at generating important policy information on how to enhance adaptive capacities of vulnerable populations, particularly rural households, is therefore needed in South Africa.

3.5 Concluding remarks

South African agriculture operates in an already stressed environment with 80% of the country classified as semi-arid and 10% of agricultural land as potentially arable. Water availability is a significant limiting factor with an average annual rainfall of only 450 mm, well below the world average of 800 mm. The country is further characterised by strong interannual rainfall variability with prolonged dry periods and droughts, which are often terminated by severe floods. However, South African agriculture has had a relatively good performance achieving self-sufficiency in virtually all major agricultural products and is a net exporter of many agricultural products such as wine, citrus, sugar, grapes, maize, fruit juice, wool and deciduous fruit (apples, pears, peaches

Gbetibouo G. A. (2011)

and apricots). The sector contributes approximately 3% of the GDP and nearly 8% of formal employment but there are strong backward and forward linkages to the economy, so that the agro-industrial sector contribution is estimated to be 15% of GDP.

Studies have shown that South African agriculture will likely face adverse impacts of climate change. Trends corresponding to a warming over South Africa in the second half of the 20th century are already evident and similarly, changes in rainfall attributes have occurred, in both cases with statistical significance. A warming of between 1°C to 3°C is likely to occur over the next 50 years. Although there is no agreement in the overall trend of future rainfall, large expected spatial and seasonal variations are expected.

The impacts facing agriculture include a reduction in the area of arable land suitable for both arable and pastoral agriculture, a shortening of the growing season and a decrease in crop yields and net revenue from agriculture. While previous research have shown that South African agriculture is sensitive to climate change, they mainly took an impact assessment approach and based their outputs only on the biophysical assessment of the agriculture sector's vulnerability to climate change.

A lack of understanding and knowledge of how the South African agriculture sector is vulnerable to climate change, with deep examination of the underlying socio-economic and institutional factors may itself be a barrier to implementing large-scale adaptation. Therefore, there is a need for systematic assessments of the vulnerability of the South African farming sector from a starting point approach of vulnerability analysis under a comprehensive framework that considers exposure, sensitivity and adaptive capacity. We emphasise that identifying the vulnerable people and places, and understanding their adaptation process and strategies must be an inclusive process.

CHAPTER 4:

REVIEW OF METHODS AND EMPIRICAL STUDIES FOR MEASURING VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE

4.1 Introduction

This chapter provides the basis to select appropriate methods for the assessment of the vulnerability of South African agriculture and the determinants of farmers' adaptation to climate change and variability. Section 4.2 starts by a review of methods for measuring vulnerability, follows by a discussion of the approach chosen to assess vulnerability in this study and ends with a review of past studies using the selected approach. Section 4.3 is concerned with the adaptation component and therefore discusses the various methods and empirical studies that have been used for assessing adaptation to climate change in agriculture as well as the selection of the approach of this study. Section 4.4 summarises the chapter.

4.2 Assessment of vulnerability to climate change

4.2.1 Approaches for measuring vulnerability

Approaches to vulnerability assessments attempt to explore the following types of questions: i) "who and what are vulnerable?" ; ii) "to what are they vulnerable?" ; iii) "to what degree are they vulnerable?" ; iv) "what are the causes of their vulnerability?"; and v) "what responses can lessen their vulnerability?". However, defining criteria for quantifying vulnerability has proven difficult in part because vulnerability is often not a directly observable phenomenon (Downing et al. 2001) and also due to definitional ambiguity and the dynamic nature and changing scale of analysis (Cutter et al. 2009). Vulnerability assessment methods have been developed over the past several decades in natural hazards, food security, poverty analysis, sustainable livelihoods

Gbetibouo G. A. (2011)

and related fields. These approaches, each with their own nuances provide a core set of best practices for use in studies of climate change vulnerability and adaptation (Downing and Patwardhan 2004). In the climate change literature, there are multiple and overlapping ways of measuring vulnerability and some methods are favoured depending on conceptualisation of vulnerability as outcome or contextual. However, most studies followed two main approaches: i) vulnerability variable assessment; and ii) the indicator approach.

4.2.1.1 The vulnerability variable assessment

The vulnerability variable assessment approach is an econometric approach that measures welfare loss for selected variables of concern (e.g. household consumption, agricultural yield) due to specific sets of stressors, such as climate change. The vulnerability variable assessment studies are based generally on household level socio-economic surveys' cross sectional or panel data.

A few generic vulnerability metrics have been proposed. For example, in the literature on the economics of poverty and food security, vulnerability is expressed as being determined by the expected mean and variance of a household's income or consumption using three main methods to quantify vulnerability⁵ (Hoddinot and Quisumbing 2003), namely: i) uninsured exposure to risk (VER); ii) expected poverty (VEP); and iii) low expected utility (VEU). The VER method is an *ex post* assessment of the extent to which households are successful at insulating their consumption from changes in their income opportunities and other shocks (Skoufias 2003). The VEP and VEU measures are *ex ante* assessment and make reference to a benchmark for the welfare indicator and enumerate a probability of falling below this benchmark. Specifically, the VEP computes the probability that the household's welfare (consumption or income) will be below the benchmark of consumption or poverty line (Chaudhuri et al. 2002; Christiansen and Subbarao 2001; Pritchett et al. 2000). Whereas VEU is the difference between the utility a household would derive from consuming some particular bundle with certainty and the household's expected utility of consumption. This measure can be naturally decomposed into

⁵ Overviews of these methods can be found in Hoddinot and Quisumbing (2003), Ligon and Schechter (2003), Dercon (2005) and Gunther and Harttgen (2009).

Gbetibouo G. A. (2011)

distinct measures of poverty, exposure to aggregate risk, exposure to idiosyncratic risk, and unexplained risk plus a measurement error (Ligon and Schechter 2003).

In agricultural studies, vulnerability is expressed in terms of losses in a response variable (crop yield, farm profitability, regional economy and hunger, etc.) as a result of changes in specific variables (temperature, rainfall, etc.). In the specific area of climate change, two distinct model classes⁶ are useful to estimate metrics in agriculture:

(1) Crop/agroecosystem models with or without coupling to economic trade models (Du Toit et al. 2000; Easterling et al. 1993; Makadho 1996; Rosenzweig et al. 1995). Crops models such as DSSAT (Tsuji et al. 1994), EPIC (Williams 1995), AEZ (Fischer et al. 2002), are biophysical representations of crop growth and production that include explicit representation of land and crop management techniques. These models compute seasonal dynamics of crop yields as well as its inter-annual variability at local, regional and global scales under current and future climate conditions (Tubiello and Rosenzweig 2008).

(2) Ricardian economic approaches (Benhin 2008; Gbetibouo and Hassan 2005; Kumar and Parikh 2001; Kurukulasuriya et al. 2006; Mendelsohn et al. 1994 & 1996). Ricardian approaches on the other hand primarily provide assessments of the monetary impacts on agricultural systems, such as land value at risk under climate change.

Despite the different methods, generally, the vulnerability variable assessment approach can be mathematically presented as V_{ht} , the vulnerability of a household measured by:

$$V_{ht} = \Pr(W_{h,t+1} \leq l) \quad (4.1)$$

Where

$W_{h,t+1}$ is the household's variable of concern at time $t+1$, which could be household consumption or agricultural yield, etc. and

l is a benchmark value of W .

⁶ These models are part of the first generations of climate impact studies that define vulnerability as an outcome.

Gbetibouo G. A. (2011)

The variable of concern of the household W , at any period is influenced by a range of cross-sectional or/and inter-temporal socio economic and environmental variables:

$$W_{ht} = W(X_h, \beta_t, \alpha_h, \varepsilon_{ht}) \quad (4.2)$$

Where:

X_h denotes a bundle of observable household characteristics,

β_t is a vector of parameters describing the state of the economy at time t ,

α_h represent an unobservable time-invariant household-level effect,

ε_{ht} idiosyncratic factors that contribute to differential welfare outcomes for households that are otherwise observationally equivalent.

Substituting equation 4.2 into equation 4.1, the expression for the vulnerability can be rewritten as:

$$V_{ht} = \Pr(W_{h,t+1} = W(X_h, \beta_{t+1}, \alpha_h, \varepsilon_{h,t+1}) \leq l | X_h, \beta_t, \alpha_h, \varepsilon_{ht}) \quad (4.3)$$

Equation 4.3 suggests that a household's level of vulnerability is derived from the stochastic properties of the inter-temporal stream of the variable of concern it faces, and this in turn depends on a number of household characteristics and the characteristics of the environment in which it operates (Chaudhuri et al. 2002). According to Luers et al. (2003), vulnerability variable assessment can assess relationships across a wide range of stressors. Covariant shocks such as drought, floods and earthquakes, which affect whole communities are represented in equation 4.3 as α_h while ε_{ht} are household-specific shocks such as job losses, death in the household, death of the breadwinner, indebtedness, illness, injury, and birth in the family, etc.

4.2.1.2 The indicator approach

The indicator approach is the traditional approach of quantifying vulnerability and is broadly used in economic, social and environmental analysis (Adger 1999; Birkmann 2007; Cutter et al.

Gbetibouo G. A. (2011)

2003). This approach can be applied at any scale (e.g. household, county/district, national, system). Indicators are quantitative measures intended to represent a characteristic or a parameter of a system of interest (Cutter et al. 2008) and therefore tend to bridge the gap between theoretical concepts of complex systems and decision-making (Gallopín 1997). In the context of vulnerability assessment, vulnerability cannot be captured by one single indicator instead multi-dimensional concepts, such as composite indicators, are needed to assess the vulnerability of a system. The indicator approach therefore uses a specific set or combination of indicators (proxy indicators) and measures vulnerability by computing indices, averages or weighted averages for those selected variables or indicators. Generally, the indicator approach uses equations such as:

$$V = \sum_{i=1}^n (B_i \times A_i) \quad \text{or} \quad V = \frac{1}{n} \sum_{i=1}^n (B_i \times A_i) \quad (4.4)$$

Where

V is the vulnerability index of a system,

B_i is the weighting factor for indicator i ,

A_i is the measured value of the selected indicator i and

n is total number of indicators under concern.

4.2.1.3 The choice of vulnerability approach for the present study

The vulnerability variable assessment approach presents useful analytical tool to measure welfare loss attributed to shocks. Because it is based on strong mathematical tools, the approach has the advantage to produce reliable results and therefore could be used to define current and future management needs and policy decisions. The main aim of using this approach is to identify factors that are contributing to the vulnerability most generally at the household level. However, the choice of the selection of the appropriate approach for the present study is guided by the objective of the study. Thus, we will not use this approach because we are concerned in identifying vulnerable agricultural regions not factors of vulnerability. Furthermore, a single

Gbetibouo G. A. (2011)

metric (income or yield) used in the vulnerable variable assessment approach to characterise vulnerability is insufficient to fully capture all the three dimensions of the vulnerability framework: exposure, sensitivity and adaptive capacity (Luers et al. 2003) described in section 2.2.4.

The indicator approach, on the other hand, is the most common method adopted for quantifying vulnerability in the global change community. However, the approach has received a number of criticisms. These criticisms are centred on: i) its inability to capture the complex temporal and social dynamics of the various systems being measured; ii) the considerable subjectivity in the selection of variables and their relative weights; iii) the unavailability of appropriate data for various scales; and iv) the difficulty of testing or validating the different metrics (Luers et al. 2003).

In spite of the criticisms, indicator approach has its own merits. Vulnerability in the climate change literature is defined as a hierarchical aggregation of three components: exposure, sensitivity and adaptive capacity which are complex concepts and difficult to measure and quantify directly. As a result, it is necessary to identify proxy variables, or indicators. According to Leichenko and O'Brien (2002), composite indices provide a framework to capture comprehensively the multi-dimensionality of vulnerability. Secondly, the policy relevance of the indicator approach is indisputable. The identification of zones of vulnerability provides a systematic rationale for targeting proactive measures aimed at protecting populations. Currently, requests to develop generic indices of vulnerability to climate change are expressed in international climate change forums to prioritise efforts toward the most vulnerable countries and assess adaptation needs (Fussler 2010).

South Africa is a country of large diversity with nine provinces, each with its own legislation, premier and executive council and distinctive landscape, population, economy and climate. In preparing for climate change, it is also worthwhile to know how different regions may differ in terms of vulnerability such that scarce resources are efficiently allocated to the areas that need them most. The indicator approach is valuable for understanding the construction of a place's vulnerability where results of studies are presented in the form of relative values or scaled degrees of vulnerability, which make the comparison between different places possible.

Gbetibouo G. A. (2011)

The present study selects the indicator approach to develop a climate change and variability vulnerability index for South African farming regions.

4.2.2 Empirical studies for vulnerability indices

4.2.2.1 General composites indices

A review of existing composite indicators lists over 130 such measures from the fields of economy, society, environment, globalisation, and technology (Bandura 2005). During the past 20 years, with the emergence of the field of sustainable development, a number of indices related to environmental and economic vulnerability gained prominence in the literature. Indices encompass a large variety of indicators from health, economy, education, environment, institutions, geography, population, etc. Each index has its own underlined theory and choices of variables are mainly made from literature review and expert consultation. Generally, equal weighting schemes are applied. Most well-known indicators are generally produced by and for the United Nations Organisations and other international agencies. Even though there is considerable variability within country in terms of the exposure, susceptibility, and impact, these indices are generally used for cross-national comparisons, with little focus on variation at the sub-national level (Cutter et al. 2009). Among well-known vulnerability composite indicators, we can cite: i) the Human Development Index of the United Nations Development Programme (UNDP 1990); ii) the Environmental Vulnerability Index (SOPAC and UNEP 2005); and iii) the Environmental Sustainability Index (Esty et al. 2005).

The Human Development Index (HDI) is a measure of human development, developed by the United Nations Development Programme (UNDP) in 1990. The HDI is annually updated and compares the relative levels of development and improvement in well-being among 177 countries. The HDI is based on three main components, namely: i) health measured by life expectancy at birth; ii) education measured with the combination of two indicators (adult literacy rate: weight of 2/3) and gross enrolment ratio: weight of 1/3); and ii) income measured by GDP per capita. For each of these three components a sub-index is constructed: the GDP index, the education index and the life expectancy index. A standardisation formula that normalised each

Gbetibouo G. A. (2011)

sub-index to a range of 0 to 1 is performed. The HDI is an average of these three sub-indices. All countries included in the HDI are classified into three clusters by achievement according to human development: high human development (with an HDI of 0.8 or above), medium human development (0.5–0.79) and low human development (less than 0.5).

The Environmental Vulnerability Index (EVI) is designed to reflect the extent to which the natural environment of a country is prone to damage and degradation. It has been developed by the South Pacific Applied Geosciences Commission (SOPAC) and the United Nations Environment Programme (UNEP). The EVI provides insights into the processes that can negatively influence sustainable development of countries. The EVI uses 50 biophysical or natural environment indicators grouped into three sub-indices (hazards, resistance, damage) and also into seven policy-relevant sub-indices (climate change, biodiversity, water, agriculture and fisheries, human health, desertification, and exposure to natural disasters). There are 32 indicators of hazards, 8 indicators of resistance and 10 indicators that measure damage. The hazard indicators relate to the frequency and intensity of hazardous events. The resistance indicators refer to the inherent characteristics of a country that would tend to make it more or less able to cope with natural and anthropogenic hazards. Damage indicators relate to the vulnerability that has been caused by loss of ecological integrity or increasing levels of degradation of ecosystems (SOPAC and UNEP 2005). For most indicators, signals are based on average levels observed over the past 5 years and all indicators are transformed to a common scale so that they can be combined by averaging, and to facilitate the setting of thresholds of vulnerability. The EVI scale was defined as ranging between a value of 1 (indicating high resilience / low vulnerability) and 7 (indicating low resilience / high vulnerability). According to Cutter et al. (2009), the EVI excludes the human system hence is more like an exposure assessment rather than an integrated vulnerability assessment.

The Environmental Sustainability Index (ESI) is a composite index tracking a diverse set of socio-economic, environmental, and institutional indicators that characterise and influence environmental sustainability at the national scale for 146 nations. It has been developed through the collaborative effort of the Yale Centre for Environmental Law and Policy; the Centre for International Earth Science Information Network of Columbia University (CIESIN), the Joint Research Centre (JRC), European Commission and the World Economic Forum. The ESI is

Gbetibouo G. A. (2011)

based on five core components: environmental systems, environmental stresses, human vulnerability to environmental stresses, social and institutional capacity, and global stewardship (Esty et al. 2005). Its basic model builds on a broad base of theory in the ecological sciences and environmental policy. The ESI score represents an equally weighted average of the 21 indicator scores. Each indicator builds on between 2 and 12 data sets for a total of 76 underlying variables.

The review of literature on composite indices development in South Africa reveals nine studies: i) the poverty maps of Alderman et al. (2000); ii) the development indices of Hirschowitz et al. (2000); iii) the deprivation indices at magisterial level by McIntyre et al. (2000); iv) the living standard by Klasen (2000); v) the Lived Poverty Index by Mattes et al. (2003); vi) the multiple deprivation provincial indices by Noble et al. (2006); vii) the growth potential indices by Zietsman et al. (2006) for the towns of Western Cape province; viii) the non-economic quality of life by Rossouw and Naudé (2008); and ix) the local vulnerability index by Naudé et al. (2008).

The majority of these studies relate mainly to the levels of economic development, poverty and inequality in post-apartheid era. These studies all concur that South Africa is characterised by significant sub-national variation in poverty, deprivation and quality of life. While these studies varied in the extent of the indicators they used, they generally depict peoples' ability to obtain basic necessities. Common sub-indices are the Infrastructure index, Health index, Education index, Economic index. For example, Hirschowitz et al. (2000) used the Alderman et al. (2000) methodology for their construction of provincial level development indices with two sub-indices Household Infrastructure Index and a Household Circumstances Index. The Infrastructure Index was based on eight variables relating to the state of housing, access to services, education and expenditure. The Circumstances Index was based on the remaining three variables relating to unemployment, household size and number of children. Using principal component analysis (PCA) of a number of variables relating to socio-economic, demographic and physical household characteristics, McIntyre et al. (2000) produced four alternative deprivation indices at magisterial district level using data from the 1996 Census. Noble et al. (2006) defined five domains of provincial deprivation by assigning equal weights: Income and Material Deprivation, Employment Deprivation, Health Deprivation, Education Deprivation, and Living Environment Deprivation. Zietsman et al. (2006) compiled three composite indices to measure growth

Gbetibouo G. A. (2011)

potential of towns in Western Cape: a resource index, an infrastructure index and an economic index.

Useful as these studies are to the understanding of the spatial patterns of poverty and deprivation in South Africa, these indices are strongly correlated to per capita income. The concept of vulnerability is not largely adopted in these indices, except for the recent study of Naudé et al. (2008), which try to measure vulnerability not poverty. Indeed, Naudé et al. (2008) capture subnational vulnerability by integrating five domains: economic vulnerability, vulnerability of environment, governance, demographic and health fragilities with ten indicators selected via principal component analysis. Their local vulnerability index construct revealed that the high vulnerability areas are characterised by the remoteness, dominance of primary (agricultural) production in the economy, and low population densities. Thus, Naudé et al. (2008) made a contribution to the development of composite indices in South Africa that operationalise the concept of vulnerability.

However, the term vulnerability can only be used meaningfully with reference to a particular vulnerable situation (Brooks 2003; Luers et al. 2003; Downing and Patwardhan 2004; Metzger et al. 2005; Fussel 2007). Vulnerability is a relative term and they fail to clearly answer the question of “vulnerability to what?”. Indeed, Tol and Yole (2007) show that there is no such thing as a general adaptive capacity for all stresses because of the substitutability of different component indicators.

4.2.2.2 Climate change and climate variability vulnerability indices

The development of vulnerability indicators related to climate change and climate variability is still in its infancy, although there is considerable research and policy interest (Cutter et al. 2009). The methodological development of climate change and climate variability vulnerability indices focus on around four crucial points: i) the underlined theory; ii) scale of the index; iii) choice of variables; and iv) the method of aggregation and weighting.

The underlying theory of vulnerability determined the number of components or sub-indices that composed the overall vulnerability indices. Vulnerability is conceptualised as: i) social construct

Gbetibouo G. A. (2011)

(Cutter et al. 2003; Cutter and Finch 2008); ii) integration of two types of vulnerability, the biophysical and social vulnerability (Adepetu and Berthe 2007; Brooks et al. 2005; Cutter et al. 2000; Hebb and Mortsch 2007; Hegglin and Huggel 2008; Rygel et al. 2006; Sullivan and Meigh 2005; Vincent 2004); iii) depending on two or three components: exposure, sensitivity and coping capacity (Brenkert and Malone 2005; Lucas and Hilderink 2004; Moss et al. 2001; Patnaik and Narayanan 2005; Perch-Nielsen 2009; Pulhin et al. 2006; Swanson et al. 2007; Yusuf and Francisco 2009); and iv) builds on the sustainable livelihood framework (Dasgupta and Baschieri 2010; Hahn et al. 2009; Thornton et al. 2008).

Climate change vulnerability indices have multiple scales of analysis. There are vulnerability indices developed at national level in order to perform cross country comparisons (Brooks et al. 2005; Lucas and Hilderink 2004; Moss et al. 2001; Perch-Nielsen 2009; Sullivan and Meigh 2005; Thornton et al. 2008; Vincent 2004). Also sub-national level indices for cross regions comparisons are developed (Brenkert and Malone 2005; Cutter et al. 2000 & 2003; Cutter and Finch 2008; Hebb and Mortsch 2007; Hegglin and Huggel 2008; O'Brien et al. 2004; Patnaik and Narayanan 2005; Rygel et al. 2006; Swanson et al. 2007; Yusuf and Francisco 2009). In contrast with the general use of secondary data, more empirically-based household level data indices of climate change and variability vulnerability have also been developed (Adepetu and Berthe 2007; Dasgupta and Baschieri 2010; Hahn et al. 2009; Pulhin et al. 2006).

Generally, the variables or proxies to represent the indicators are selected by the researcher via literature review and based on theoretical foundations. Some studies in addition, used expert consultations (Brooks et al. 2005; Yusuf and Francisco 2009) or statistical test (Brooks et al. 2005; Cutter et al. 2003; Cutter and Finch 2008; Moss et al. 2001; Rygel et al. 2006) to select the variables.

The review of climate change and variability vulnerability indices development indicates that three methods are used to assign weights to indicators: i) expert judgment or local consultation (Adepetu and Berthe 2007; Brooks et al. 2005; Hegglin and Huggel 2008; Pulhin et al. 2006); ii) arbitrary choice of equal weights (Cutter et al. 2000; Cutter et al. 2003; Cutter and Finch 2008; Hahn et al. 2009; Hebb and Mortsch 2007; Lucas and Hilderink 2004; Moss et al. 2001; O'Brien et al. 2004; Patnaik and Narayanan 2005; Swanson et al. 2007; Yusuf and Francisco 2009); and

Gbetibouo G. A. (2011)

iii) statistical methods such as principal component analysis, factor analysis or pareto ranking (Dasgupta and Baschieri 2010; Rygel et al. 2006; Thornton et al. 2008).

There is a wide range of variables selected and sub-indices mostly related to the sector of interest (agriculture, water, whole economy, etc.). Appendix 4.1 presents a review of methods and variables used to construct climate change vulnerability indices. For example, Moss et al. (2001) identified ten proxies for five sectors of climate sensitivities which are settlement sensitivity, food security, human health sensitivity, ecosystem sensitivity and water availability and seven proxies for three sectors of coping and adaptive capacity, economic capacity, human resources and environmental or natural resources capacity. Proxies were aggregated into sectoral indicators, sensitivity indicators and coping or adaptive capacity indicators and finally constructed vulnerability resilience indicators to climate change.

Vincent (2004) created an index to empirically assess relative levels of social vulnerability to climate change induced variations in water availability and allow cross country comparison in Africa. An aggregated index of social vulnerability were formed through the weighted average of five composite sub-indices, which are economic wellbeing and stability, demographic structure, institutional stability and strength of public infrastructure, global interconnectivity and dependence on natural resources. The results indicate that using the current data, Niger, Sierra Leone, Burundi, Madagascar and Burkina Faso are the most vulnerable countries in Africa. Swanson et al. (2007) selected twenty indicators to represent adaptive capacity. The indicators were organised into six determinants (based on Smit et al. (2001), namely: i) economic resources; ii) technology; iii) infrastructure; iv) information, skills and management; v) institutions and networks; and vi) equity. The scores for each indicator were normalised and aggregated to a determinant value and then aggregated into an overall index of adaptive capacity for each of the 53 agricultural Census Divisions.

Gbetibouo G. A. (2011)

4.3 Assessment of adaptation to climate change in agriculture

4.3.1 Methods to the study of adaptation

The analytical methods used by researchers are commonly classified into two main categories: a “top-down” approach and a “bottom-up” approach. The top-down mode starts with climate change scenarios, and estimates impacts through scenario analysis, based on which possible adaptation practices are identified. The bottom-up approach, on the other hand, takes on a contextual perspective where adaptation strategies are considered more as a process involving the socio-economic and policy environments, producers’ perceptions, and elements of decision-making (Belliveau et al. 2006; Bryant et al. 2000; Wall and Smit 2005).

4.3.1.1 Top-down approach

The top-down approach is referred to as the traditional adaptation research that largely focused on the question of ‘what are we adapting to?’ yielding a large body of work on climate impacts mainly directed to the mitigation side of climate policy. This top-down research essentially contributes to the debate on trade-offs between mitigation and adaptation (Burton et al. 2002). Adaptations are considered to assess the degree to which they can moderate or reduce negative impacts of climate change, or realise positive effects, to avoid danger. This approach is also named the scenario-based approach largely because adaptations are assumed or hypothetical are invariably treated as primarily technical adjustments (for example, changing to different crops, adopting efficient irrigation systems, or altering production systems) to the impacts identified. Most of these adaptations represent possible or potential adaptation measures, rather than measures that have actually been adopted. Indeed, there is no evidence that these adaptation options are feasible, realistic, or even likely to occur. Furthermore, they would only be possible with complete and accurate knowledge of future climatic conditions, which is why they have been aptly named “clairvoyant farmer” scenarios (Risbey et al. 1999).

A second body of research in the top down approach relates to the question of ‘what do they want to achieve?’ and aims to evaluate alternative adaptations. Evaluations are intended to assess the overall merit, suitability, utility or appropriateness of potential adaptation strategies or

Gbetibouo G. A. (2011)

measures. It is expected that evaluation methods or frameworks will at least assist in screening potential adaptation options, and provide direction as to which adaptations should be encouraged or implemented. Some generic evaluation frameworks have been proposed to judge the merit of planned adaptations to climate change generally (Smith and Lenhart 1996; Klein and Tol 1997) and in agriculture specifically (Mizina et al. 1999) in order to identify suitable adaptation options.

Using the top-down approach, the following models have been used:

- 1) regional structural (agronomic-economic) models (Adams et al. 1990; 1995; 1998);
- 2) integrated assessment models (Yates et al. 1998; Crosson and Rosenberg 1993; Rosenzweig and Parry 1994);
- 3) cross sectional models such as the Future Agricultural Resources Model (FARM) (Darwin et al. 1994; 1995) and Ricardian models (Mendelsohn et al. 1996; Gbetibouo and Hassan 2005; Dinar et al. 2008).

4.3.1.2 Bottom-up approach

With the emergence of vulnerability, as contextual or starting point, in climate change research, attention has shifted to some of the more neglected questions of ‘who or what adapt?’ (agents) and their decision-making processes; and ‘how do they adapt?’ (determinants of adaptation, such as capital and entitlements). This approach is called bottom up because analyses of adaptation processes tend to start with the system of interest. It employs the experience and knowledge of community members to characterise pertinent conditions, community sensitivities, adaptive strategies, and decision making process (Smit and Wandel 2006).

The bottom-up approach for adaptation in the climate change research stills at its infancy. According to Smit and Skinner (2002), five old schools of research approaches could give insights to climate change research field for a better understanding of adaptation in agriculture: i) natural hazards; ii) agrarian political economy; iii) innovation adoption; iv) agricultural systems and farm decision-making; and v) risk management.

Gbetibouo G. A. (2011)

Indeed natural hazards research can inform climate change studies of agriculture, especially by raising the questions of how farmers perceive the risks associated with climate change and by recognition that adaptation is directly related to the perception of risks and involves conscious decision-making. The role of government policies, institutions and macro level social and economic conditions are increasingly recognised in the literature as forces or stimuli that either constrain or facilitate the adaptation process. However, these non-climatic forces have been vaguely defined and not yet fully study in the climate change research.

The agrarian political economy with a long history of dealing with transformations taking place in agriculture and decision making process affected by political and economic variables, could provide crucial insights for this purpose. Innovation adoption research recognises that adaptation is a multi-faceted decision making process, is function of the personal and situational circumstances of the decision maker and the characteristics of the innovation under consideration, that occurs within a context of changing economic, social, political and biophysical conditions.

The innovation adoption research could therefore inform climate change adaptation research on the understanding of the processes by which adaptation options are implemented and their likelihood of adoption. Furthermore, studies have shown that decisions involving changes in agriculture are made at different levels that are interrelated, and as a result, patterns of agricultural activity, including adaptation, are the product of many individual decisions (government, agri-business and individual producers). Agricultural systems and farm decision-making research by emphasising the interconnections among various levels within the agricultural system is also a research approach on which climate change adaptation may gain constructive insights. Lastly, Smit and Skinner (2002) argue that risk management research by recognising that decisions in agriculture involve both risk assessment, could guide climate change adaptation research in understanding uncertainties associated with climate change, especially those associated with variability and extremes.

The bottom-up approach, usually assess adaptation through a more qualitative way via survey data analysis with in-depth interviews, and focus group discussions with farmers and other farms experts (Belliveau et al. 2006; Brklacich et al. 1997; Chiotti et al. 1997; Smit et al. 1996).

Gbetibouo G. A. (2011)

Building on the adoption literature, a number of recent studies have adopted quantitative discrete choice (probit, logit, multinomial logit, multivariate probit) models (Deressa et al. 2009; Hassan and Nhemachena 2008; Kurukulasuriya and Mendelsohn 2008; Maddison 2006; Seo and Mendelsohn 2009) to analyse adaptation.

The vulnerability – adaptation framework of this study (see section 2.4.2) adopted vulnerability from a starting point of view and is concerned with the key adaptation question “how do they adapt?” Accordingly, the bottom-up approach of adaptation is adopted.

4.3.2 Empirical adaptation studies⁷

Although, the bottom-up approach of agricultural adaptation has only been developed recently, we already found a number of empirical studies. These empirical studies treated the questions of the perceptions of rural households and the factors influencing their decision making process.

Studies on local knowledge and perception of climate change are scattered across the globe. These studies often used in depth survey analysis and compared meteorological data with farmers’ perceptions using trends and descriptive statistics. For example, Vedman and Rhoades (2001) examine how apple farmers in the western Himalayas of India perceive climatic change. This is done by comparing the locally idealised traditional weather cycle with climate change as perceived by the farmers of the region using snowfall and rainfall data to measure the accuracy of perceptions. Hageback et al. (2005) assess small-scale farmers’ perceptions of climate change in the Danagou watershed in China by comparing the local rainfall and temperature data trend with the responses given by farmers to the question “Do you feel any changes in the weather now compared to 20 years?”

Another study by Maddison (2006), using data for over 9,500 farmers from eleven African countries, compared the probability that the climate has changed, as revealed by an analysis of the statistical record, with the proportion of individuals who believe that such a change has in fact occurred to assess farmers’ perceptions of climatic change. In general, the studies confirmed

⁷ This review is only limited to studies that have taken the bottom up approach of climate change adaptation and analyse farmers’ actual climate change adaptations and perceptions.

Gbetibouo G. A. (2011)

that perceived climate changes and impacts differed significantly even within a small geographic area. However, two contrasting views emerge in their results. Some authors suggest that farmers' perceptions of changing climate are shaped by events rather than observations of meteorological trends (Bryant et al. 2000); that perception of climate is linked to the utilitarian aspect of it (Meze-Hausken 2004; Ovuka and Lindquist 2000) and farmers, memories of past climatic events tend to decrease significantly after 3 years (Brondizio and Moran 2008; Thomas et al. 2007).

Others suggest that farmers do detect meteorological trends and that these perceptions can be correlated with meteorological records (Battaglini et al. 2009; Hageback et al. 2005; Maddison 2006; Vedman and Rhoades 2001; West et al. 2008; West and Vasquez-Leon 2003). Another trend in perceptions studies is to investigate local knowledge in terms of the understanding of the climate change phenomenon and the exact drivers of change. For example Byg and Salick (2009) found that climate change was seen as a moral and spiritual issue and therefore these interpretations affect how people deal with climate change and its impacts.

A number of studies investigated the different adaptation strategies that farmers employed in response to climate change and the factors that influence their decision to adapt to climate change at the farm level. These studies reveal that there is a body of knowledge and experience within local communities on coping with climate change and climatic variability and extreme weather events. In South Africa, Thomas et al. (2007) shows that dry spells caused farmers to reduce cropping efforts and focus on livestock. In Aribinda, and in most other areas of Burkina Faso with limited rainfall (Ramert et al. 2002), farmers seek optimal crop yield by growing both long and short growth cycle crops on the same plot, such as millet and sorghum. This practice allows spreading the risk over a large number of varieties and therefore to increase the probability for a successful yield.

Kurukulasuriya and Mendelsohn (2008), and Seo and Mendelsohn (2009) used multinomial logit models to analyse respectively crop and livestock choice as adaptation options. The study on crop choice shows that crop type is climate sensitive and farmers adapt to changes in climate by switching crops. The results from the choice models in the livestock study show that farmers in warmer temperatures tend to choose goats and sheep as opposed to beef cattle and chicken. Goats and sheep can do better in dry and harsher conditions than beef cattle.

Gbetibouo G. A. (2011)

A summary of the AIACC case studies (Leary et al. 2007) find out that in most cases, adaptations strategies have been adopted in response to multiple sources of risk and only rarely to climate risk alone. General strategies in use in the study areas include among others: i) increasing the capacity to bear losses by accumulating food surpluses; ii) livestock, financial savings and other assets; iii) hedging risks by diversifying crops, income sources, food sources and locations of production activities; iv) reducing exposures to climate hazards by relocating, either temporarily or permanently; v) spreading risks through kinship networks, pooled community funds, insurance and disaster relief; vi) reducing the sensitivity of production and incomes derived from natural resources by restoring degraded lands, using drought resistant seed varieties, harvesting rainfall, adopting irrigation and using seasonal forecasts to optimise farm management; vii) preventing climate impacts through flood control, building standards and early warning systems; and viii) increasing the capacity to adapt through public sector assistance such as extension services, education, community development projects, and credit services.

Furthermore, the study by Dinar et al. (2008) reveal that large numbers of farmers in Africa have already perceive that the climate has become hotter and that the rains have become less predictable and shorter in duration. In response to these changes several adaptations measures have been apply (Table 4.1).

Looking into the determinants of farmers adaptations strategies, many studies underscore the importance of formal and informal institutions and social relationships in facilitating or hindering adaptation to climate change (Agarwal and Perrin 2008; Deressa et al. 2009; Eakin 2005; Hassan and Nhemachena 2008; Isham 2002; Maddison 2006). Supporting the notion that personal characteristics and conditions influence adaptation, few studies also make use of household datasets to empirically examine these factors. They found that farming experience, socio-economic position, and access to resources, credit, and extension services increase the probability of uptake of adaptation measures to climate change (Deressa et al. 2009; Hassan and Nhemachena 2008; Maddison 2006).

Table 4.1: List of identified adaptations options across Africa

Gbetibouo G. A. (2011)

Different varieties	Change from livestock to crops	Decreased use of water conservation techniques
Different crops	Adjustments to livestock management	Soil conservations techniques
Crop diversification	Change from farming to non-farming activity	Shading and sheltering/tree planting
Different planting dates	Change from non-farming to farming activity	Use of insurance or weather derivatives
Shortening growing season	Increased use of irrigation/groundwater/watering	Prayer or ritual offering
Lengthening growing season	Decreased use of irrigation/groundwater/watering	Other
Moving to a different site	Change use of capital and labour	No adaptation
Changing quantity of land under cultivation	Changed use of chemicals and fertilizers	
Change from crops to livestock	Increased use of water conservation techniques	

Source: Dinar *et al.* (2008)

4.3.3 The choice of adaptation approach for the present study

It has been identified that there is no study that captures the determinants of perceptions and adaptations to climate change of farmers in South Africa (see section 3.3.3). The use of multivariate techniques has recently emerged in the literature to study adaptation and has proven to be a useful tool to determine factors explaining the heterogeneity of farmers and farmers' responses across and within geographical areas.

Accordingly, following others (Deressa *et al.* 2009; Hassan and Nhemachena 2008; Kurukulasuriya and Mendelsohn 2008; Maddison 2006; Seo and Mendelsohn 2009), this study adopts the multinomial logit to investigate factors affecting the perceptions and choice of adaptation strategies to climate change at farm level.

Gbetibouo G. A. (2011)

4.4 Concluding remarks

This chapter presented the main methodological approaches and empirical studies to assessing vulnerability and adaptation to climate change.

There are two main methods for vulnerability assessment, namely: i) vulnerability variable assessment; and ii) indicator approach. The vulnerability variable assessment approach captures vulnerability by measuring welfare loss for selected variables of concern due to specific sets of stressors, such as climate change. The indicator approach measures vulnerability by computing indices, averages or weighted averages for selected variables or indicators. Although the vulnerability variable assessment has an advantage of reliable results because it is based on strong mathematical and econometric calculations, the present study does not adopt this approach due to its inability to fully: i) capture the multidimensionality of the term vulnerability and ii) characterise the vulnerability of a place. Alternatively, the study adopts the indicator approach to develop a climate change and variability vulnerability index for South African farming regions and therefore identify the most vulnerable areas and social groups in the country.

Assessment of adaptation has evolved from a “top-down” to a “bottom-up” approach. The top-down focuses on predicting impacts of climate change scenarios, and identifies potential adaptation practices to these scenarios. The bottom-up approach, on the other hand, focuses on existing biophysical and socio-economic environments and adaptations are processes involving several aspects including the policy environment, producers’ perceptions and other elements of decision making. This study adopts the bottom-up approach and uses multivariate techniques to investigate factors affecting the perceptions and choice of adaptation strategies at farm level in the Limpopo Basin in South Africa.

CHAPTER 5

SOUTH AFRICAN FARMING SECTOR VULNERABILITY TO CLIMATE CHANGE: A SUB-NATIONAL LEVEL ASSESSMENT⁸

5.1 Introduction

The impacts of climate change are predicted to be scale dependent, in that they will be unevenly distributed among and within regions, communities and individuals as a result of differential exposure and vulnerabilities (Clark et al. 1998). In preparing for climate change, it is therefore worthwhile to know how different regions may differ in terms of vulnerability such that scarce resources are efficiently allocated to the areas that need them most.

This chapter assesses the relative distribution of South African agriculture's vulnerability to climate change and variability. Based on the framework presented in chapter two which defined vulnerability as a function of exposure, sensitivity and adaptive capacity, the indicator approach is adopted to construct a vulnerability index and compares vulnerability indicators across the nine provinces of the country.

The next section presents the selection of indicators for creating the vulnerability index and section 3 describes the methods applied in the various stages of creating the vulnerability index. Section 4 presents the results of the study and the conclusions and policy implications are drawn in the final section 5.

⁸Earlier version of this chapter has been published as:

Gbetibouo G.A and C. Ringler, 2009. Mapping South African farming sector vulnerability to climate change and variability: A subnational level assessment. International Food Policy Research Institute, Discussion Paper 885, Washington, DC.

A shorter version of this chapter has been published as:

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Gbetibouo G. A. (2011)

5.2 The causal model of vulnerability: choice of indicators

The framework of analysis is based on the causal chain of vulnerability presented in chapter two (section 2.4.2) in which vulnerability is understood as a hierarchical aggregation of three components: exposure, sensitivity and adaptive capacity. To therefore assess farming vulnerability to climate change, we look at exposure to climate change, sensitivities to those changes, and societal coping and adaptive capabilities.

Our vulnerability indicator approach is integrated, in that the selected indicators represent both the biophysical conditions of the farming regions and the socio-economic conditions of the farmers.

As indicated earlier (section 4.2.1.3), a number of criticisms challenged the application of the indicator approach to assess vulnerability. Particularly, the robustness of the index is constrained by the level of subjectivity on the selection of indicators and weights. To therefore reduce subjectivity in the selection procedure, two steps were followed. Firstly, a survey of the literature on climate change vulnerability assessment identified a list of commonly used social and biophysical indicators of vulnerability. Secondly, this list of indicators was submitted to a panel of participants in a workshop setting,⁹ to identify which of the indicators they felt were most important in terms of defining or predicting vulnerability at the regional level. A ranking exercise was then performed by the participants based on a set of four well defined criteria:

- 1) **relevancy**: theoretically well founded within the vulnerability framework;
- 2) **ease**: easy to grasp by policymakers;
- 3) **adequacy**: really measures what it should and the direction of influence between the indicator and vulnerability is not ambiguous; and
- 4) **data availability**: data that is publicly and easily available at the level of analysis.

⁹ A national stakeholder forum was held on November 21, 2006, at the University of Pretoria. This meeting was organized by the Centre for Environmental Economics and Policy in Africa (CEEPA) in collaboration with the International Food Policy Research Institute (IFPRI) to assess the determinants of vulnerability and adaptive capacity of rural populations to climate change in the context of South Africa. The forum gathered a spectrum of representatives of 30 organisations from five key sectors: (1) government departments; (2) research institutes; (3) community-based organisations; (4) private sector and (5) universities.

Gbetibouo G. A. (2011)

5.2.1 Exposure

Exposure may be defined as the shocks and stress to which a system may be subject. It is the risk that an event may occur (Adger 1996). Chambers (1989) defined it as the external side of vulnerability. Exposure relates to the influences or stimuli that impact on a system. The IPCC fourth Assessment Report describes “exposure as the nature and degree to which a system is exposed to significant climatic variations”. Exposure represents the background climate conditions against which a system operates, and any changes in those conditions. Exposure is different across the globe, regions, and countries or even at lower scales because the climate is a multi-dimensional phenomenon that exhibits variations on various spatio-temporal scales.

Climate change is expected to expose farmers to new and, in many cases, unfamiliar conditions (Watts and Goodman 1997) through long-term changes in average climate conditions (such as annual mean temperature, rainfall, and sea-level rise) and also changes in the frequency and intensity of extreme climate events such as droughts and heavy rains.

We therefore select two indicators to characterise the exposure of South Africa’s regions to climate change:

- *Frequency of past climate extremes*: as proxy for future climate extremes. The assumption is that farming regions with a higher frequency of droughts or floods are more vulnerable.
- *Predicted change in temperature and rainfall by 2050*: to represent expected changes in mean climate conditions. The assumption is that the larger the changes, the more difficulty regions will have in adjusting to these changes. More importantly, if increased temperature and decreased rainfall are predicted we would expect to see negative impacts on farm production in already hot and water-scarce regions.

Gbetibouo G. A. (2011)

5.2.2 Sensitivity

Sensitivity, in its general sense, is defined by Gallopín (2003) as the degree to which a system is modified or affected by an internal or external disturbance or set of disturbances. It is impossible to directly predict crop yields under potential future climates on a decadal timescale (Challinor et al. 2007). This may only be done through crop simulation models, which are complicated because they deal with the complex physiological relationships between crop and climate. Moreover, crops models are ecology and management-sensitive. Because each crop requires extensive experiments for successful modelling, such models have only been developed thus far for major crops. Also, due to the cost implications of the necessary experiments and the location specificity of the models, the developed models can only be applied to a few locations. For aggregate analyses, inferences must be made from relatively few sites and crops, and then applied to large areas and diverse production systems. In South Africa, only the CERES-maize model has been widely applied (Schulze et al. 1993; Du Toit et al. 2000).

In the present study framework, sensitivity reflects the responsiveness of a system to climatic influences and is shaped by both socio-economic and environmental conditions (SEI 2004). We examine five human–environmental factors that may influence the sensitivity of a farming region to climate change:

- *Irrigation rate*: Having access to water for irrigation purposes increases the resilience of farmers to climate variability (O'Brien et al. 2004). Indeed studies have shown that in Africa dryland farms are sensitive to rainfall changes whereas net revenues of irrigated farms are barely affected (Gbetibouo and Hassan 2005; Benhin 2008; Kurukulasuriya and Mendelsohn 2006). Thus, agricultural regions with more land under irrigation will be less sensitive compared to those regions with low irrigation access.

- *Land degradation index*: Land quality is an important determinant of agricultural productivity. Studies have shown that differences in land quality contribute to significant differences in agricultural productivity among countries (Wiebe 2003). Consequently, farming areas already experiencing land degradation will be more sensitive to climate change. To capture the diversity of land quality in South Africa, we used the soil and veld degradation indices

Gbetibouo G. A. (2011)

developed by Hoffman et al. (1999) who attempt to integrate the major degradation features associated with the deterioration of soil and vegetation conditions.

- *Crop diversification index:* Farmers themselves commonly identify diversification as an effective strategy for managing business risks, particularly climatic risks (Bathia 1965). Moreover, as different crops respond differently to climate change greater crop diversity can decrease the vulnerability of farming areas to climate change (Kandji et al. 2006; Reidsma and Ewert 2008).

- *Share small-scale:* Many studies report that subsistence or smallholder farmers in developing countries will be most affected by climate change (Jones and Thornton 2003; IPCC 2007; Benhin 2008). Although smallholder farmers' resilience factors such as family labour, existing patterns of diversification, including non-farm activities, and possession of a store of indigenous knowledge should not be underestimated, their socio-economic characteristics, such as small farm sizes, low capitalisation, limited technologies, and diverse other nonclimate stressors will tend to increase vulnerability (Morton 2007). The specific socio-political situation in South Africa, where past agricultural policies have persistently marginalised small-scale black farmers by curtailing their access to resources such as land, water, credit and technical know-how (Coetzee and van Zyl 1992; Kirsten and van Zyl 1998), is a further indication of increased sensitivity of South Africa's smallholders to climate change.

Rural population density: We used rural population density as a proxy for human sensitivity to climate-hazard exposure. Population density provides an indication of the number of people that are possibly affected by disasters and related human loss (Hegglin and Huggel 2008; Yusuf and Francisco 2009). The assumption here is that regions that are relatively less inhabited are less sensitive in terms of adverse climate change outcomes compared to regions with high population densities, given the same degree of exposure to climate hazards.

Gbetibouo G. A. (2011)

5.2.3 Adaptive capacity

Adaptive capacity is a significant factor in characterising vulnerability. In the climate change literature, adaptive capacity is similar or closely related to a host of other commonly used concepts such as adaptability, coping ability, management capacity, stability, robustness, flexibility, and resilience (Smit and Wandel 2006). According to Brooks (Brooks 2003), the adaptive capacity of a system or society reflects its ability to modify its characteristics or behaviour in order to better cope with existing or anticipated external stresses and changes in external conditions. The IPCC (2001) describes adaptive capacity as the potential or ability of a system, region, or community to adjust to the effects or impacts of climate change (including climate variability and extremes). It therefore characterises the responsiveness of the system and its ability to exploit opportunities and resist or recover from the negative effects of a changing environment” (IPCC 2007). The capacity to adapt is context-specific and varies from country to country, from community to community, among social groups and individuals, and over time (IPCC 2001; Smit and Wandel 2006).

According to Moser and Satterthwaite (2008), the key determinant of individuals, households, or communities’ adaptive capacity both to reduce risk and to cope with and adapt to increased risk levels is their asset-portfolio. There are close linkages between vulnerability and livelihoods, and building resilience is a question of expanding and sustaining these assets (Moser 1998; Thornton et al. 2008). Vulnerability is therefore closely linked to asset ownership. The more assets people have, the less vulnerable they are; conversely, the greater the erosion of people’s assets, the greater their insecurity (Moser 1998).

We characterise adaptive capacity as dependent upon four¹⁰ livelihoods assets:

- *Social capital is represented by share of farmers in farm organisations*¹¹: This indicator is a proxy for social networks for farm areas. Social networks act as conduits for financial

¹⁰ We also include a fifth asset, that of natural capital; however, this is classified under the sensitivity component of vulnerability which describes the human–environmental conditions that can either worsen the hazard or trigger an impact. The indicator of natural capital is the land degradation index.

¹¹ In South Africa there are two large farm associations: 1) Agri South Africa (AgriSA), a mainly commercial farmers’ union with about 70,000 members and 2) the National African Farmers’ Union (NAFU) representing small-scale black farmers. These associations are organised into district and provincial level farmers’ associations and commodity sector organisations.

Gbetibouo G. A. (2011)

transfers that may relax a farmer's credit constraints. Second, they act as conduits for information about new technologies. Third, social networks can facilitate cooperation to overcome collective action dilemmas, where the adoption of technologies involves externalities (Deressa et al. 2009). It is hypothesised that social capital positively influences adaptation to change.

- *Human capital is represented by literacy rate:* The assumption is that higher literacy rates increase adaptive capacity by increasing people's capabilities and access to information, thereby enhancing their ability to cope with adversities (Bhadwal 2005; Brooks et al. 2005).

- *Human capital is also represented by HIV prevalence:* This indicator was added given the high prevalence levels in South Africa. The assumption is that higher prevalence rates reduce adaptive capacity. Drimie (2002) states that HIV/AIDS is "...the major development issue facing Sub-Saharan Africa." The epidemic deepens poverty, reverses human development achievements, worsens gender inequalities, erodes the ability of governments to maintain essential services, reduces labour productivity and supply, and puts a brake on economic growth. Furthermore HIV/AIDS has been cited among the main driver of food insecurity and poverty in rural southern Africa undermining family structures and creating increasingly vulnerable and socially unstable communities (Misselhorn 2005).

- *Financial capital is represented by farm income, farm holding size, farm assets, share of people below the poverty line, share of agricultural GDP, and access to credit.* These indicators provide a general picture of the rural financial situation of each province. Regions with higher farm income, larger farms, greater farm value assets, and more access to credit are wealthier. Indeed wealth generally provides access to markets, technology, and other resources that can be used to adapt to climate change and variability (Brenkert and Malone 2005). In contrast, regions with a higher dependence on agriculture (higher share of agriculture in total GDP) are assumed to be less economically diversified and more susceptible to climatic events and changes (Thornton et al. 2008). Furthermore, the presence of alternative economic activities provides an indicator of the ability of farmers in a region to shift to other economic activities in response to reduced agricultural income resulting from adverse climatic conditions such as drought (O'Brien et al. 2004).

Gbetibouo G. A. (2011)

- *Physical capital is represented by an infrastructure index:* The quality of infrastructure is an important measure of the relative adaptive capacity of a region. Regions with better infrastructure are presumed to be better able to adapt to climatic stresses (Moss et al. 2001; Adger et al. 2004; IPCC 2007). According to Adger et al. (2004) quality and density of roads and other transport routes will determine the ability of rural populations to access markets in order to sell livestock and other commodities in times of crisis, and also influence the feasibility and efficacy of aid distribution programs in response to disasters such as droughts, floods and famines. Improved infrastructure may reduce transactions costs, and strengthen the links between labour and product markets. Moreover, improved infrastructure should encourage the formation of non-farm enterprises as a source of diversification in the short run and, eventually, a transition out of agriculture. Rural infrastructure may also facilitate migration and remittances, which are important ex ante and ex post mechanisms for reducing vulnerability (Zhang et al. 2007).

The indicators used and their inter-linkages, which are geared towards reflecting overall vulnerability, are graphically presented in Figure 5.1 below and Table 5.1 provides a brief description of the indicators and data sources.

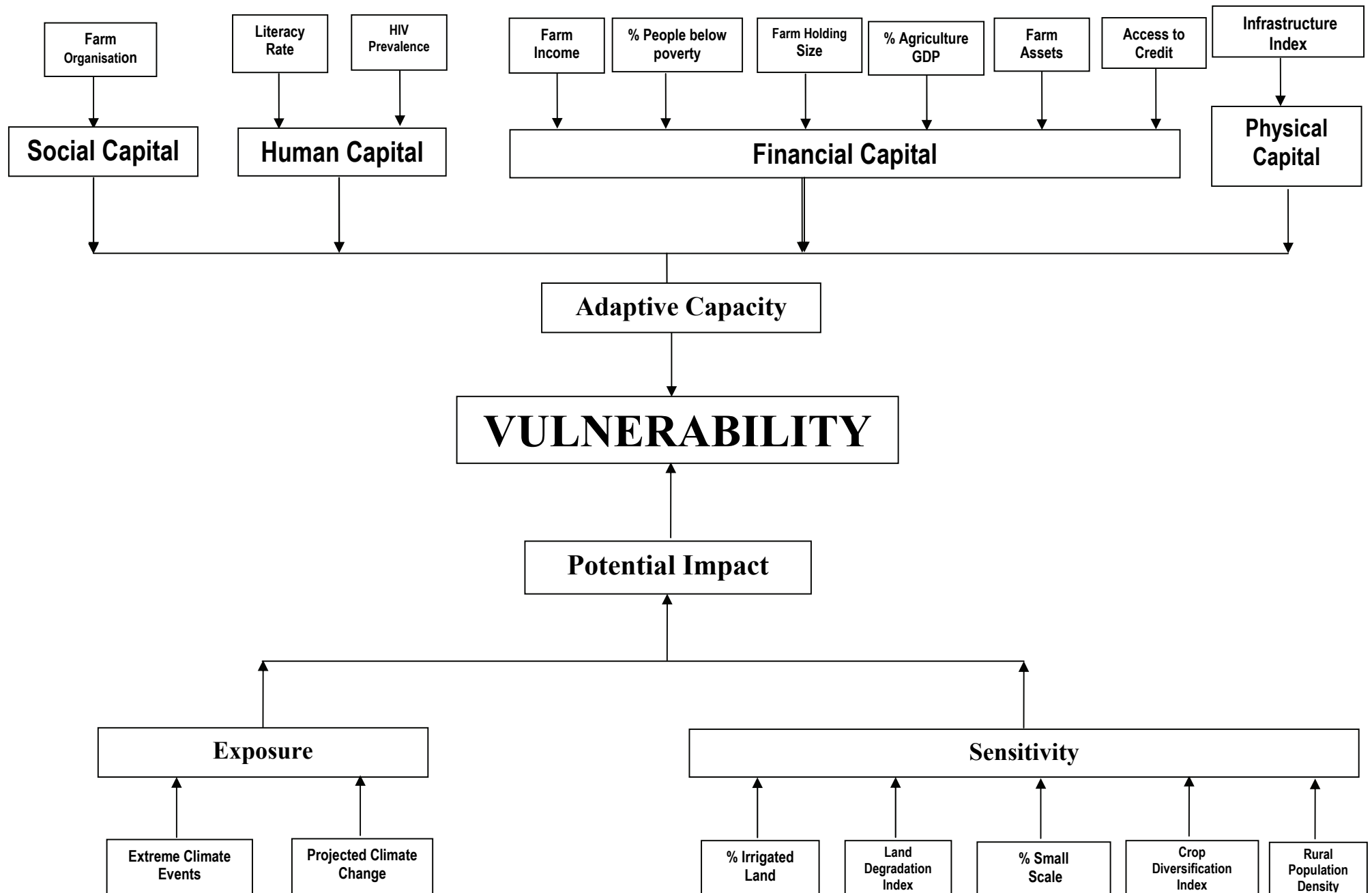


Figure 5.1: Contribution of different indicators to vulnerability

Gbetibouo G. A. (2011)

Table 5.1: Vulnerability indicators, variables and data sources

Determinants of vulnerability	Component indicators	Description of the indicator	Unit of measurement	Hypothesized functional relationship between indicator and vulnerability	Data source
EXPOSURE	Extreme climate events: floods/droughts	Frequency of droughts or floods	Number of occurrence of droughts/floods events from 1960 to 2006	The higher the frequency, the higher the vulnerability	EM-DAT(2006)
	Change in climate ¹²	Change in temperature from base (1961 -2000) Change in rainfall from base (1961-2000)	Degrees Celsius Percentage change	The higher the changes from present climate normal, the higher the vulnerability	CSAG (2008)
SENSITIVITY	% Irrigated land	Percentage of irrigated land	Percentage	The higher the land under irrigation, the lower the vulnerability	SSA (2005)
	Land degradation index	Combined soil and veld degradation	No unit	The higher the land degradation index the higher the vulnerability	Hoffman et al. (1999)
	% Small-scale farming operations	Percentage	Percentage	The higher the % of small-scale farming, the higher the vulnerability	SSA (2002)
	Rural population density	Total rural population/area	Population/km ²	The higher the rural population density, the higher the vulnerability	SSA (2008)
	Crop diversification index ¹³	Following Bathia (1965), Index of crop diversification = (Percentage of sown area under x crops)/Number of x crops	Percentage	The higher the crop diversification index, the lower the vulnerability	SSA (2005)
ADAPTIVE CAPACITY	Farm organization	share of farmers members of farmers associations	Percentage	The higher the share of participating farmers, the lower the vulnerability	SSA (2005)
	Literacy rate	Proportion of persons aged 15 years or older who are able to read and write	Percentage	The higher the literacy rate, the lower the vulnerability	SSA (2008)
	HIV prevalence	Percentage of people infected by HIV	Percentage	The higher the HIV prevalence, the higher the vulnerability	SSA (2008)
	Access to credit	Amount of credit received	Rand	The higher access to credit, the lower the vulnerability	SSA (2005)
	Farm income	Net farm income	Rand	The higher the farm income, the lower the vulnerability	SSA (2005)
	Percentage of people below poverty	Proxy unemployment rate	Percentage	The higher the proportion of people below the poverty line, the higher the vulnerability	SSA (2008)
	Farm holding size	Average farm size	Hectares	The larger the size of land, the lower the vulnerability	SSA (2005)
	Share Agricultural GDP	Percentage	Percentage	The higher the share, the higher the vulnerability	SSA (2008)
	Farm assets	Total value of farm assets	Rand	The higher the farm assets, the lower the vulnerability	SSA (2005)
	Infrastructure index	Computation of infrastructure index ¹³	No unit	The higher the infrastructure index, the lower the vulnerability	SSA (2005)

¹²Data is produced by a complex statistical downscaling model. Future climate states are derived from three global climate models (GCMs): HadCM3, ECHAM4.5, CSIRO Mk2. forced by the SRES A2 emissions scenario. For further reading about the downscaling methodology see Hewitson and Crane (2006).

Gbetibouo G. A. (2011)

5.3 Calculating the vulnerability indices

Having considered the theoretical determinants of farming sector vulnerability and selected appropriate indicators for its capture, we must now carry out some form of standardisation to ensure that all the indicators are comparable (Vincent 2004). Based on the method of the United Nations Development Programme's (UNDP) Human Development Index (UNDP 1990), all of the variables in the vulnerability indices are normalised to a range of 0 to 100. To ensure that high index values indicate high vulnerability in all cases, we reverse the index values by using $[100 - \text{index value}]$ for indicators hypothesised to decrease vulnerability. The values of each variable are normalised to the range of values in the data set by applying the following general formula:

$$\text{Index value} = \frac{(\text{Actual value} - \text{minimum value}) * 100}{(\text{Maximum value} - \text{minimum value})} \quad (5.1)$$

After standardising the data, we next attach weights to the indicators. Among the three methods identified by our review (see section 4.2.2.2), we selected a statistical method, the principal component analysis (PCA) to generate weights for the indicators. We do not assign equal weights because this strategy is too subjective, and the literature shows that indicators do not equally affect vulnerability (Hebb and Mortsch 2007). The development of weights via expert judgment is often constrained by the availability of expert knowledge in smaller communities and difficulties in reaching a consensus on the weights among expert panel members (Lowry et al. 1995).

¹³Computations of crop diversification index and infrastructure index are illustrated in appendix 5.1 and appendix 5.2 respectively.

Gbetibouo G. A. (2011)

PCA¹⁴ is a technique used to reduce multidimensional datasets to lower dimensions for analysis. The use of PCA is sometimes limited by the fact that weights assigned to sub-indicators are based on correlations which do not necessarily correspond to the underlying relationships between the indicators and the phenomena being measured. Thus, the validity of the PCA to predict weights is entirely dependent on the nature of data and the relationships between variables that are being considered, the validity of the variables included and also their reliability (Vyas and Kumaranayake, 2006). However, the strength of the PCA is the considerable reduction of the influence of the researcher subjectivity in the index computation. Empirically, the PCA technique has shown to be robust in constructing socio-economic status indices (Filmer and Pritchett 2001; Mckenzie 2005; Sumarto et al. 2006, Labonne et al. 2007).

Following Filmer and Pritchett (2001), Mckenzie (2005); Sumarto et al. (2006), Labonne et al. (2007) and other studies, we define the first principal component of a set of variables as the linear index of all the variables that captures the largest amount of information common to all the variables.

Let us suppose we have a set of N -variables (a^*_{1j} to a^*_{Nj}) that represents the N -variables (indicators) of each province j . PCA starts by specifying each variable normalised by its mean and standard deviation. For instance, $a_{1j} = (a^*_{1j} - a^*_1)/s^*_1$, where a^*_1 is the mean of a^*_{1j} across regions and s^*_1 is its standard deviation. The selected variables are expressed as linear combinations of a set of underlying components for each region j :

$$\begin{aligned}
 a_{1j} &= \gamma_{11} A_{1j} + \gamma_{12} A_{2j} + \dots + \gamma_{1N} A_{Nj} \\
 &\dots \qquad \qquad \qquad j=1 \dots J \\
 a_{Nj} &= \gamma_{N1} A_{1j} + \gamma_{N2} A_{2j} + \dots + \gamma_{NN} A_{Nj}, \qquad \qquad \qquad (5.2)
 \end{aligned}$$

Where the A 's are the components and the γ 's are the coefficients on each component for each variable (and do not vary across regions). Because only the left side of each line is observed, the solution to the problem is indeterminate. PCA overcomes this

¹⁴ A detailed description on constructing indices using PCA can be found in Nardo *et al.* (Nardo et al. 2008).

Gbetibouo G. A. (2011)

indeterminacy by finding the linear combination of the variables with maximum variance (usually the first principal component W_{1j}), then finding a second linear combination of the variables orthogonal to the first and with maximal remaining variance, and so on. Technically, the procedure solves the equation $(\mathbf{R} - \lambda_n \mathbf{I})\mathbf{v}_n = 0$ for λ_n and $\mathbf{v}_n$, where $\mathbf{R}$ is the matrix of correlations between the scaled variables (the a 's) and $\mathbf{v}_n$ is the vector of coefficients on the n th component for each variable. Solving the equation yields the characteristic roots of $\mathbf{R}$, λ_n (also known as eigenvalues), and their associated eigenvectors, $\mathbf{v}_n$. The final set of estimates is produced by scaling the $\mathbf{v}_n$ s so the sum of their squares sums to the total variance; this is another restriction imposed to achieve determinacy of the problem.

The scoring factors from the model are recovered by inverting the system implied by equation (5.3). This yields a set of estimates for each of the A -principal components:

$$A_{1j} = f_{11} a_{1j} + f_{12} a_{2j} + \dots + f_{1N} a_{Nj} \dots \quad j = 1 \dots J$$

$$A_{Nj} = f_{N1} a_{1j} + f_{N2} a_{2j} + \dots + f_{NN} a_{Nj} , \quad (5.3)$$

Where the f 's are the factor scores. Therefore, the first principal component, expressed in terms of the variables, is an index for each province based on the following expression:

$$A_{1j} = f_{11} (a^*_{1j} - a^*_{1})/(s^*_1) + \dots + f_{1N} (a^*_{Nj} - a^*_{N})/(s^*_N) \quad (5.4)$$

For more insights into the three dimensions of vulnerability: an exposure index, sensitivity index and adaptive capacity index were calculated separately and an overall vulnerability index was constructed as well.

For each index construction, the first principal component is used to assign weights by applying the following formula:

$$v_j = \sum_{i=1}^k [b_i (a_{ji} - x_i)] / s_i \quad i = 1 \dots k ; j = 1 \dots J \quad (5.5)$$

Gbetibouo G. A. (2011)

Where v is the vulnerability index, b is the weights from PCA 1, a is the indicator value, x is the mean indicator value, s is the standard deviation of the indicators, i is the indicators and j is the specific province.

5.4 Results and discussion

5.4.1 Descriptive statistics

Descriptive analyses show that provinces in South Africa demonstrate a wide diversity in terms of both environmental and socio-economic conditions (see Appendix 5.3, Table A5.3 to Table A5.6). The coastal provinces of Kwazulu-Natal, Eastern Cape and Western Cape show the highest frequency of occurrence of extreme events (droughts/floods) over the last century. The highest projected incremental increase in temperature by 2050 is in the desert region of the Northern Cape and the steppe arid regions of Free State and Mpumalanga, whereas changes in rainfall are predicted to be greatest in Gauteng and North West provinces.

Concerning the sensitivity indicators, 65% of the crop area in Northern Cape, the desert region, is irrigated. The regions showing high levels of soil and veld degradation are Eastern Cape, Kwazulu-Natal and Limpopo. Western Cape and Limpopo are the most diversified regions where 5 to 6 different types of crops occupy around 70% of the crop land. The most populated rural areas are Eastern Cape, Kwazulu-Natal, Mpumalanga and North West where small farmers comprise more than 70% of the farming population. The most developed provinces are Gauteng and Western Cape with infrastructure index scores of 2.95 and 2.92, respectively. They also have the highest literacy rates and lower unemployment rates. In contrast, Eastern Cape and Limpopo have the highest share of agricultural GDP, the lowest average value of farm assets, the lowest literacy rate, and the highest unemployment rate.

Gbetibouo G. A. (2011)

5.4.2 The three dimensions of vulnerability

A. The exposure index

The results of the exposure index are depicted in Figure 5.2 below:

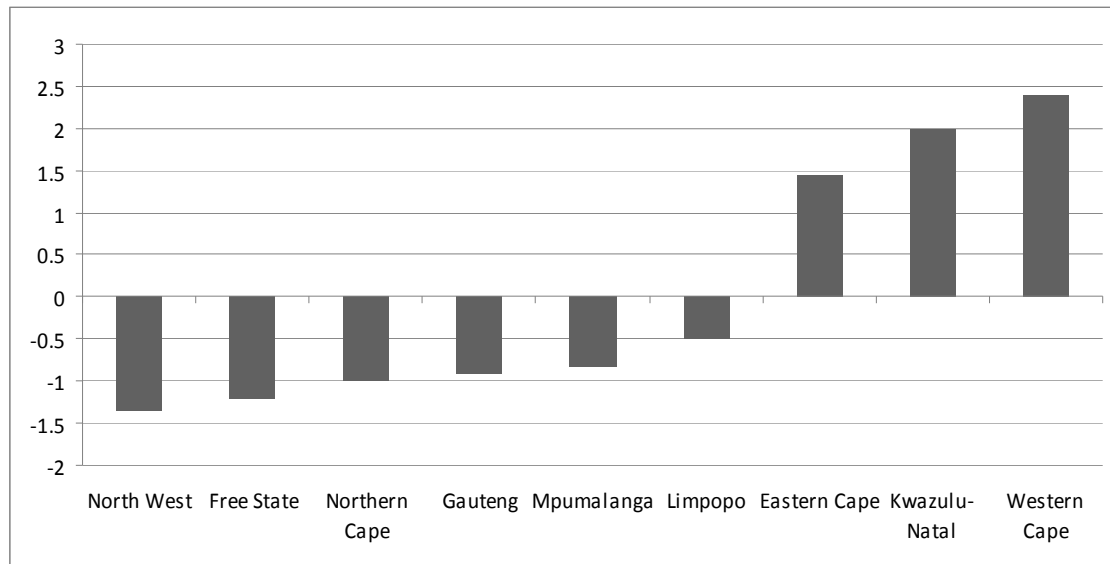


Figure 5.2: Exposure index across the provinces in South Africa

Source: Own analysis

We find that the coastal regions of the Western Cape, Kwazulu-Natal and the Eastern Cape are the most highly exposed to the risk of droughts/floods and predicted climate change. These results are in accordance with those of Agardy et al. (2005), who conclude that coastal ecosystems are the most highly threatened systems in the world. North Africa, West Africa and Southern Africa are three of the five regions shown to be at risk of flooding in coastal and deltaic areas of the world predicted by 2080 across a range of scenarios from the Special Report on Emissions Scenarios (SRES) and climate change projections (Nicholls and Tol 2006; Warren et al. 2006). Thus the South African coastal regions' exposure risk is almost twice as high as that of inland regions of Limpopo, Mpumalanga, and Gauteng. The least exposed regions are the desert region of the Northern Cape, and the steppe arid regions of the North West and Free State provinces.

Gbetibouo G. A. (2011)

B The sensitivity index

The overall sensitivity of the farming sector across the nine provinces of South Africa is presented in Figure 5.3. The most sensitive regions are Limpopo, KwaZulu-Natal and the Eastern Cape. These regions are characterised mainly by a large subsistence, low technology, and rainfed agriculture. Furthermore, these regions have suffered from inappropriate land uses, which created severe land degradation and reduced the natural production capacity. According to Meadows and Hoffman (Meadows and Hoffman 2002), Eastern Cape, Kwazulu-Natal and Limpopo possess a combination of physical and socio-economic factors (both contemporary and historical) that have led to significant and, probably in certain extreme cases, irreversible levels of deterioration in the rural environment.

Although the Northern Cape is an arid region, land degradation index is not the highest in the country and agriculture relies heavily on irrigation, making it comparatively a medium sensitive to climate change. The least sensitive regions are the Western Cape, Gauteng, and Free State. A common feature of these regions is that they have a low percentage of subsistence farmers and the least populated rural areas. The Western Cape is the least sensitive, due largely to a high degree of crop diversification and low levels of land degradation.

The combined effect of the sensitivity and exposure indicators together produce give us the potential impact of climate change and variability on the various provinces. Figure 5.4 shows that Kwazulu-Natal, Limpopo, and the Eastern Cape are predicted to suffer the largest potential impacts. These regions, with the exception of Limpopo, have both the largest exposures and the largest sensitivities. A mid-range potential impact is seen for Mpumalanga and the North West provinces. The Northern Cape, the Western Cape, Free State, and Gauteng show the lowest potential impacts.

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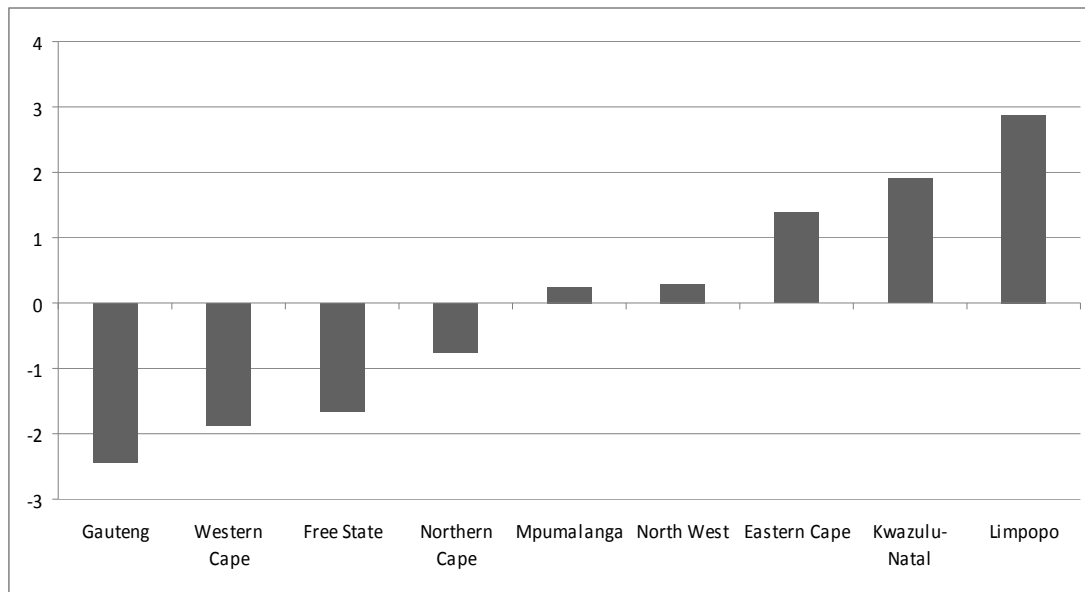


Figure 5.3: Sensitivity index across the provinces in South Africa

Source: Own analysis

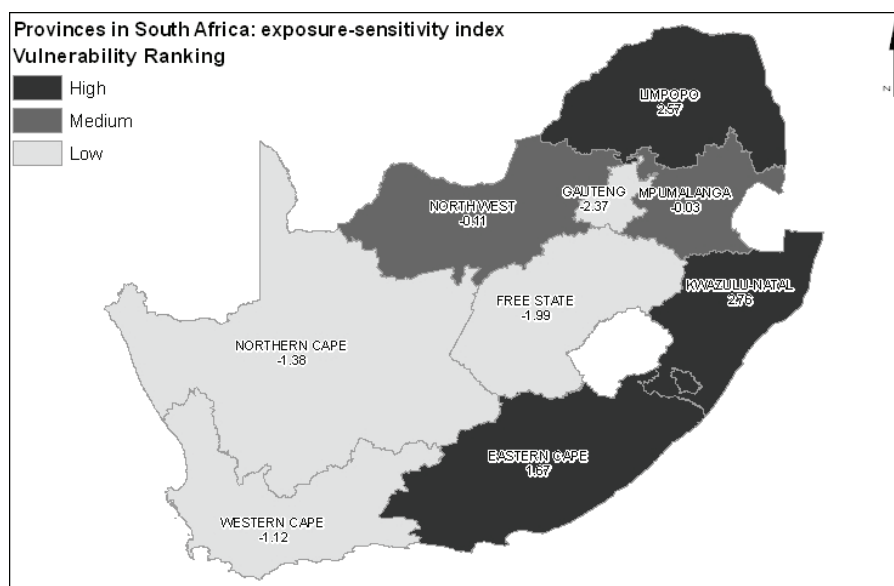


Figure 5.4: Map of exposure-sensitivity index across the farming provinces in South Africa

Source: Own analysis

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C The adaptive capacity index

Figure 5.5, which presents the adaptive capacity index, shows that there are large differences across the nine provinces. Coping capacity is greatest in the Western Cape, with an index value of 4.4. Gauteng ranks a distant second with an index value of less than 1. The Western Cape has the highest adaptive capacity because of the combined effects of a well-developed infrastructure network, high levels of literacy and income, and low levels of unemployment and HIV prevalence. The wealth capital of the region is also relatively high. For Gauteng and the Northern Cape, we see a mid-range coping capacity, while low coping capacities are seen for Kwazulu-Natal, the Eastern Cape, Free State, Limpopo, and North West. These regions are unlikely to cope effectively with the potential impact of climate change and variability. These regions suffer from high agricultural dependency, unemployment and HIV prevalence, and low infrastructure development.

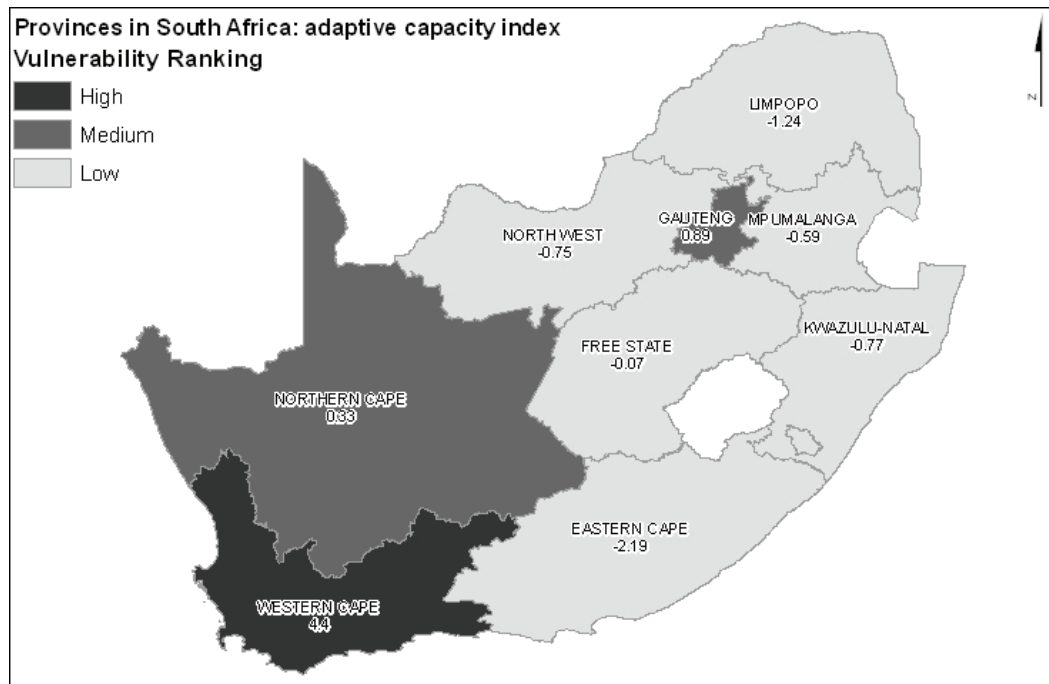


Figure 5.5: Map of adaptive capacity index across the provinces in South Africa

Source: Own analysis

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D The overall vulnerability index

Comparing regions based on their potential impacts and coping capacities, keeping in mind that these parameters increase and decrease vulnerability, respectively, we can predict the most vulnerable areas. The matrix of vulnerability displayed in Table 5.2 shows that Limpopo, the Eastern Cape and Kwazulu-Natal are the most vulnerable regions. Mpumalanga, North West, Gauteng, and the Northern Cape have mid-range vulnerabilities. Free State vulnerability falls into an indeterminate zone because of its combined low exposure and low adaptive capacity, while the Western Cape has the lowest level of vulnerability because of its low potential impact and high adaptive capacity.

Table 5.2: The matrix of vulnerability to climate change and variability for provinces in South Africa

		Adaptive capacity		
		High	Medium	Low
Potential impact [Exposure-Sensitivity]	Low	<i>Low vulnerability</i> Western Cape	<i>Medium vulnerability</i> Gauteng Northern Cape	? Uncertainty Free State
	Medium	<i>Low vulnerability</i>	? Uncertainty	<i>Medium vulnerability</i> Mpumalanga North West
	High	? Uncertainty	<i>High vulnerability</i>	<i>High vulnerability</i> Limpopo Eastern Cape Kwazulu-Natal

Source: Own analysis

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Ranking



We ran a Principal Component Analysis with all 19 indicators listed in Table 5.1 using data analysis and statistical software (STATA). Nineteen components were extracted in the first stage of the PCA but only the first five were significant.¹⁵ These five components explain 91% of the total variation in the dataset. The first principal component explained most of the variation (33%), the second principal component explained 23%, the third explained 16%, the fourth explained 12%, and the fifth explained only 6%.

The first principal component is, therefore, used to construct the vulnerability index (Table 5.3). As expected, all indicators with the exception of change in rainfall and irrigated land are loaded positive. Soil degradation, share small-scale operations, rural population density, literacy rate, unemployment rate and infrastructure index are the variables with the highest weight, above 0.3. The results show that most populated rural areas seem to have: i) large number small scale farmers; ii) higher soil degradation; iii) higher unemployment rate; and iv) lower infrastructure index.

The results of the overall vulnerability index for each province are depicted in Figure 5.6.

We further classify provinces with an index range below -2 as “low vulnerability”; those with an index range from -2 to 0 as “low-medium vulnerability”; those with a range from 0 to 2 as “medium vulnerability”; and those with an index above 2 as “high vulnerability”

¹⁵ The Kaiser criterion states that unless a principal component has an eigenvalue equal to or greater than 1, it should be dropped from further analysis (Filmer and Pritchett 2001). The Eigenvalue is a measure of standardized variance, with a mean of 0 and standard deviation of 1.

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(Figure 5.7). The results show that Western Cape and Gauteng have a low vulnerability index, scoring -4.44 and -2.49, respectively. Free State and Northern Cape are low-medium vulnerability provinces scoring -1.22 and -1.04, respectively. Provinces with a medium vulnerability index include North West (0.92) and Mpumalanga (0.6). Finally, the three most vulnerable provinces are Eastern Cape, Kwazulu-Natal and Limpopo, scoring 2.49, 2.11 and 3.09, respectively.

Thus, our results show that those provinces with the highest climate exposure index do not rank highest on the vulnerability index. Farmers in the Western Cape will be confronted with high exposure to extreme events and climate change with expected adverse impact on the farming sector. However, the well-developed infrastructure network, high levels of literacy and income, and low levels of unemployment and HIV prevalence in the province result in the highest adaptive capacity score, which should help the province to adapt more quickly to the negative impacts of climate change. In contrast, Limpopo with the lowest climate exposure index has the highest vulnerability index score. It will take only moderate climate changes to disrupt the livelihoods and wellbeing of the province's rural inhabitants, who are largely subsistence farmers. The results show that the most vulnerable provinces are those with a high share of small-scale farmers relying on rain-fed agriculture, a high level of soil degradation, a high rural population density, high unemployment, low literacy levels, and a low infrastructure index.

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Table 5.3: Factors scores from PCA1 and associated statistics

Indicators	Mean	Standard Deviation	Scoring factor: PCA1
Change in temperature	63.94	38.39	0.04
Change in rainfall	35.90	32.64	-0.13
Frequency of droughts/floods	36.67	29.15	0.13
Irrigated land	71.94	32.56	-0.11
Soil degradation	48.20	36.07	0.34
Veld degradation	53.87	32.32	0.27
Crop diversification	47.31	39.70	0.03
Small-scale	52.27	44.28	0.37
Rural population density	45.09	33.91	0.37
Access to credit	64.85	28.92	0.23
Farm organization	52.59	43.26	0.13
Literacy rate	65.88	37.37	0.34
HIV prevalence	58.50	34.24	0.10
Net farm income	59.06	35.34	0.20
Unemployment rate	70.37	30.37	0.31
Farm holding size	77.22	32.43	0.21
Share agricultural GDP	65.53	30.51	0.06
Farm assets	79.81	31.072	0.00
Infrastructure index	51.57	32.93	0.34

Source: Own analysis

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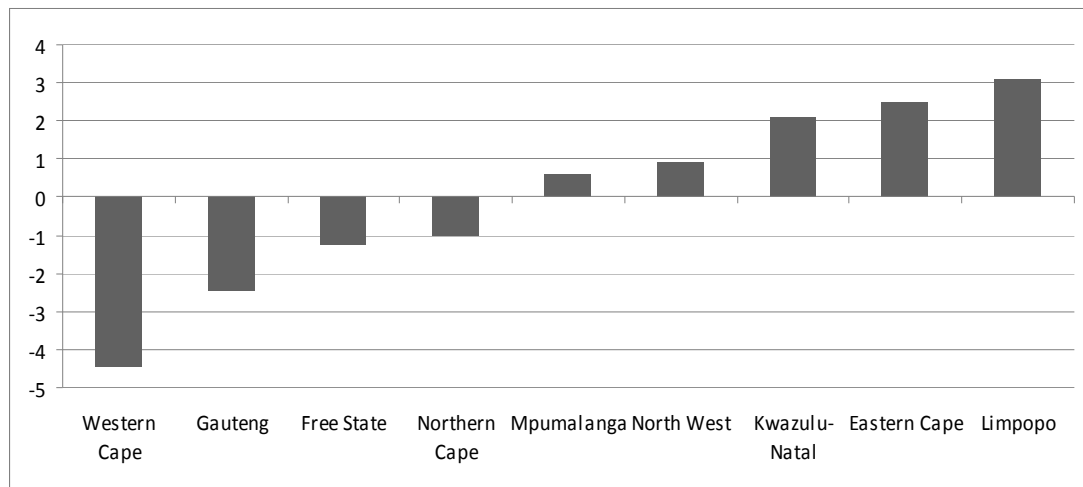


Figure 5.6: Vulnerability index across the farming regions in South Africa

Source: Own analysis

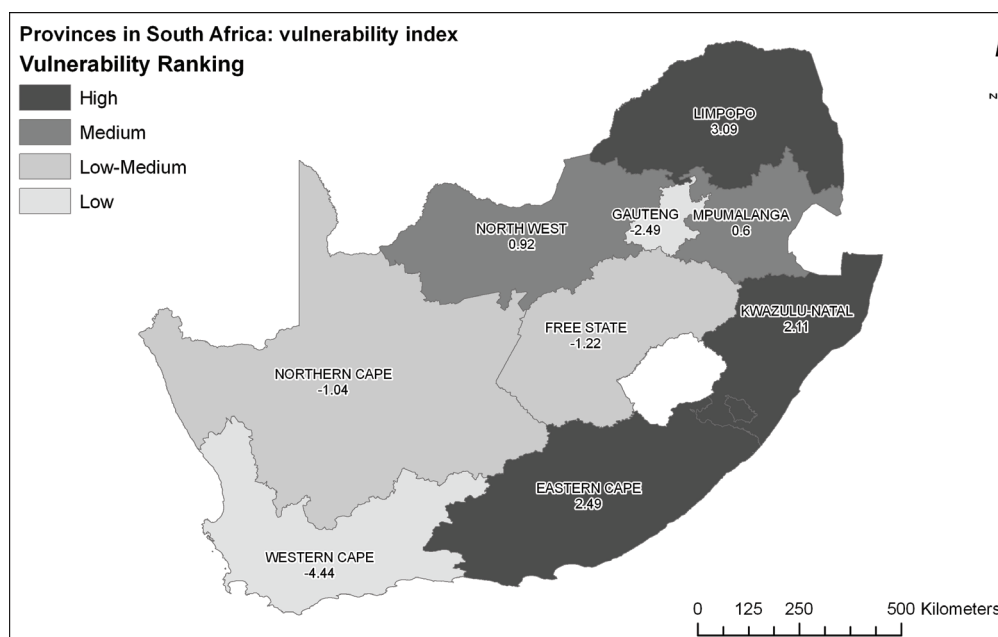


Figure 5.7: Map of vulnerability index across South Africa's provinces

Source: Own analysis

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5.5 Summary and policy implications

We have quantitatively evaluated the relative distribution of South African farming sector vulnerability to climate change and variability across the country's nine provinces. Vulnerability is assessed through its three components of exposure, sensitivity, and adaptive capacity. We assessed the relevance of 19 environmental and socio-economic indicators to reflect these three components of vulnerability and construct a vulnerability index using principal components analysis.

Our analyses put forward three main features of the vulnerability of South Africa's farming sector to climate change. First and foremost, vulnerability to climate change is spatially differentiated across the farming areas in the country. Thus, although a national climate change adaptation policy is necessary, policymakers should develop region-specific policies and address climate change at the provincial level (and below). For example, the study reveals that coastal regions have a higher exposure index compared to the inland regions. In such regions, priority should be given to the development of more drought-resistant crops varieties, improved monitoring and weather forecasts, as well as appropriate relief programs and agricultural insurance.

Secondly, the study shows that vulnerability to climatic change is intrinsically linked with level of socio-economic development. Indeed the regions identified as most vulnerable (Limpopo, Kwazulu-Natal, and the Eastern Cape) are characterised by a large number of small-scale farmers, a high rural population density, high unemployment, low literacy levels, and limited rural infrastructure. The overall climate change adaptation policy for such provinces should be placed within the broader developmental context. In regions found to be highly vulnerable as a result of poor socio-economic development, policymakers should enact measures to support the effective management of environmental resources (e.g., soil, vegetation and water resources); promote increased market participation, especially within the large subsistence farming sector; stimulate both agricultural intensification and diversification of livelihoods away from risky agriculture; and enact social programs and spending on health, education and welfare, which can help maintain and augment both physical and intangible human capital. Policymakers should also target these provinces for rural infrastructure investments.

Vulnerability and adaptation of farming to climate change in South Africa

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Thirdly, the results show that the regions most exposed to extreme events and climate change are not necessarily those that are the most vulnerable. Rather, our study results are similar to those of Cutter et al. (2000) for Georgetown (South Carolina), in that the most vulnerable regions are characterised by a combination of medium-level risk exposure and medium to high levels of social vulnerability. Both climate risk exposure and pre-existing environmental and socio-economic conditions are important factors to determine overall vulnerability. Therefore an integrated approach to climate change adaptation is needed.

It should be noted that this paper is a first attempt to analyse South African farming sector vulnerability to climate change. It allows us to trace vulnerable regions back to their underlying determinants. However, our assessment holds adaptive capacity and sensitivity indicators to the 2002 levels, assuming that current trends continue. Alternative scenarios of future social and economic conditions across provinces in South Africa are needed. Furthermore, there is enormous heterogeneity within provinces and districts with regard to household-level resource access, poverty level, and ability to cope with climate change and variability. Examination of vulnerability can certainly be guided by macro-level analyses, but ultimately future work should be done at more disaggregate levels, such as the district and village level. However, data availability at this level of analysis is limited.

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CHAPTER 6:

SOUTH AFRICAN FARMERS' PERCEPTIONS AND ADAPTATIONS TO CLIMATE CHANGE AND VARIABILITY¹⁶

6.1 Introduction

A better understanding of the autonomous adaptation process of farmers is a prerequisite for promoting successful adaptation of the agriculture sector.

This chapter analyses the determinants of perceptions regarding long-term changes in local climate, and adaptation responses of farmers surveyed in the arid Limpopo river basin in South Africa.

The primary hypothesis is that farmers adapt to perceived climate change and variability. The analysis is therefore conducted in two stages based on the two stage adaptation process framework presented in section 2.4.2. First, it is determined whether the climate has changed, whether the farmers perceive climate change and variability, and what characteristics differentiate farmers who perceived changes from those who did not. Second, the determinants of adaptation are examined. It is assumed that not all of the farmers who perceived climate change will respond by taking adaptation measures. Here it is argued that farmers who perceived climate changes and responded share some

¹⁶ Earlier version of this chapter has been published as:

Gbetibouo G. A., (2009). Understanding farmers' perceptions and adaptations to climate change and variability: the case of the Limpopo Basin, South Africa. IFPRI Discussion Paper 849, International Food Policy Research Institute, Washington, DC.

Sections of this chapter have also been published as:

- (1) Gbetibouo G. A., R. M. Hassan, and C. Ringler, 2010b. Modelling farmers' adaptations strategies to climate change and variability: The case of the Limpopo Basin, South Africa. *Agrekon*, 49 (2): 217- 234.
- (2) Bryan, E.; Deressa, T.T., Gbetibouo G.A., and C. Ringler, 2009. Adaptation to Climate Change in Ethiopia and South Africa: Options and Constraints, *Environmental Science & Policy* 12: 413-426.

Gbetibouo G. A. (2011)

common characteristics. Therefore, there is a need to understand the reasons underlying their response (or failure to respond for those who did not adapt).

Next section describes the study area and data used. Section 3 presents the assessment of farmers' perceptions of climate change and variability. Section 4 examines the determinants of farmers' adaptation options. Finally, Section 5 concludes and outlines the policy implications of the study.

6.2 The study area and sources of data collection

The Limpopo River is one of the major river systems in Southern Africa. Originating in South Africa's Witwatersrand region, the Limpopo River is about 1,700 kilometres long, drains an area of about 415,500 square kilometres, and is shared by Botswana, Mozambique, South Africa, and Zimbabwe. South Africa occupies about 46% of the total area of the basin (Table 6.1). In South Africa, the Limpopo River Basin extends over four administrative provinces (Limpopo, Mpumalanga, Gauteng, and North West) and five water management areas (WMAs)¹⁷. These are the: i) Limpopo; ii) Luvuvhu/Letaba; iii) Crocodile (west) and Marico; iv) Olifants; and v) Inkomati (Figure 6.1).

The climate in the basin ranges from temperate and semiarid in the south of the Limpopo WMA and the east of the Crocodile (west) and Marico WMA to arid in the extreme north of the Limpopo WMA. Mean annual rainfall ranges from 200 mm per year in the Limpopo WMA to more than 2,300 mm annually in the Luvuvhu/Letaba WMA, with temperatures ranging from 8°C to more than 30°C in the northern parts of the Limpopo WMA. Among the five WMAs, Inkomati has the highest mean annual runoff with 3,539 million cubic meters, followed by Olifants (2,040 million), Luvuvhu/Letaba (1,185 million), Limpopo (986 million) and Crocodile (west) and Marico (855 million). The

¹⁷ To facilitate the management of the scarce water resources, the country has been divided into 19 catchment-based water management areas (WMAs). All except one WMA are interlinked with other areas through inter-catchment transfers. The interlinking of catchments gives effect to one of the main principles of the country's National Water Policy Acts, which designates water as a national resource (DWA 2004).

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diverse climate in the basin influences the vegetation and agricultural activities in the five WMAs and the four provinces.

Farming activities range from dry farming to intensive irrigation and livestock production. For example, farming in the Limpopo WMA mainly focuses on livestock and irrigation, while the Olifants WMA is favourable for dry-land farming and livestock as well as extensive irrigation. Intensive irrigation is prevalent in the Crocodile (west) and Marico, where the irrigation sector is the second largest water consumer in the WMA, using an estimated 33% of the total water use. In the Limpopo WMA, crops grown include cotton, grain sorghum, and tobacco, as well as considerable subsistence production. In the Luvuvhu/Letaba WMA, citrus and a variety of fruits plus commercial forestry are prevalent. The Olifant WMA features trout and game farming. South Africa and the Limpopo Basin feature both large commercial agricultural farms as well as small-scale agriculture.

Table 6.1: Limpopo basin areas

Country	Total area of the country (km ²)	Area of the country within the basin (km ²)	Percentage of total area of basin (%)	Percentage of total area of country (%)	Irrigation potential (hectares)	Area under irrigation (hectares)	Average annual rainfall in the basin area (mm)		
							min	max	mean
Botswana	581,730	80,118	19.9	13.8	5,000	1,381	290	555	425
Zimbabwe	390,760	51,467	12.38	13.2	10,900	200	300	635	465
Mozambique	801,590	84,981	21.1	10.6	148,000	40,000	355	865	535
South Africa	11,221,040	185,298	46.31	15.2	131,500	198,000	290	1,040	590
Total	12,995,120	401,864	100.0		295,400	241,381	290	1,040	530

Source: Food and Agriculture Organization of the United Nations, www.fao.org/documents/show_cdr.asp?url_file=/docrep/W4347E/w4347e0p.htm.

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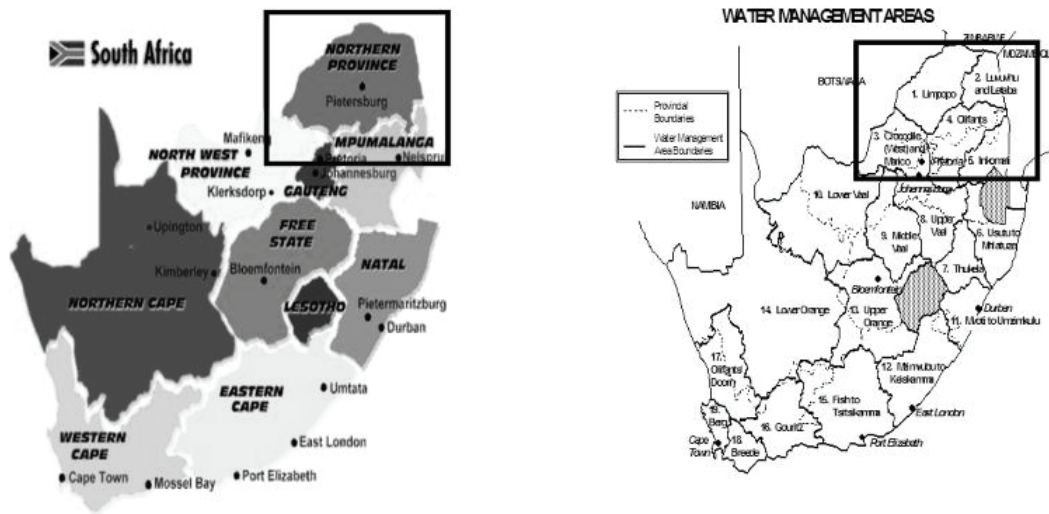


Figure 6.1: Provinces and water management areas in the Limpopo River Basin

Source: http://www.exittoafrika.com/media/images/maps/m-sa_provinces.gif and <http://www.dwaf.gov.za/Documents/Notices/Water%20Management%20areas%20enl.doc>

The empirical analyses of this chapter used data obtained from a project entitled Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa, funded by the German's Advisory Service on Agricultural Research for Development. Under the project, a survey was carried out by the Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, in collaboration with the International Food Policy Research Institute (IFPRI) to analyse the potential impact of climate variability and climate change on household vulnerability and farm production. The survey period was between August and November 2005 covering the April/May 2004 to April/May 2005 agricultural season. In total, 794 surveys were completed in 19 districts of four provinces in South Africa (Limpopo, North West, Mpumalanga and Gauteng). Farmers were carefully selected with the assistance of producers' associations and the National Department of Agriculture.

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While the survey collected data on a wide range of attributes of the studied community and region, this study used the sections of the survey on perceptions of climate change, adaptations made by farmers, and barriers to adaptation. Open-ended questions were used to ask farmers whether they had noticed long-term changes in mean temperature, mean rainfall and the direction of the change over the past 20 years. Farmers were also asked about their adaptation responses and constraints faced. The exact formulation of the questions is included in Appendix 6.1.

Monthly rainfall and temperature data was obtained from the South African Weather Service (SAWS). The data covers the period from January 1960 to October 2003. To capture the provincial temperature, a mean of all stations in each province was calculated. For the whole Limpopo River Basin the same analysis was conducted.

6.3 Assessing farmers' perceptions to climate change

6.3.1 Comparison between perceptions of changes and meteorological stations' recorded data

To assess farmers' perceptions of climate change and variability, we first look at how climate data recorded at meteorological stations evolved (trends and variability) and how farmers perceived these changes. Tests were undertaken for linear trend in annual means and seasonal¹⁸ means of temperature, and total annual and seasonal rainfall both at the Limpopo River Basin level and at the provincial level. Descriptive statistics based on summary counts of the questionnaire structure are used to provide insights into producers' perceptions of climate change and variability.

¹⁸ In this study, the year has been divided in two seasons according the agricultural seasons in the country.

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6.3.1.1 Temperature perceptions

About 95% of the farmers interviewed perceived long-term changes in temperature. Most of them (91% or 686 farmers) perceive the temperature in the Limpopo Basin to be increasing. Only 1.5% noticed the contrary, a decrease in temperature. Across the four provinces of the basin, the same pattern is noticed with the exception of Gauteng, where 16%, which represents 7 farmers interviewed, have not noticed any changes in the temperature (Figure 6.2 and Table 6.2).

The statistical record of temperature data from the Limpopo River Basin between 1960 and 2003 shows an increasing significant trend. However, this rise in temperature is not uniform across the seasons. The plot of temperature data points shows a linear trend with a slope of 0.02 for both annual and summer temperature, whereas the slope of winter temperature is 0.03. The goodness of the linear fit is stronger for annual and winter temperature with respectively an R square of 0.26 and 0.33 compare to summer which has R square of 0.09 (Figure 6.3).

Disaggregating the data at the provincial level shows that a trend of increasing temperature could be observed. However, the magnitude of change is not uniformly distributed across the provinces. In the North West province, the slope of the trend is at a minimal value of 0.009 and is not statistically significant. Mpumalanga province exhibits a higher increase in temperature with a significant trend with a slope of at 0.04. Total change in temperature over the 43 years period is estimated at approximately 1°C for the whole basin and Mpumalanga at 1.83°C. In Limpopo, Gauteng, and Mpumalanga provinces, the increased trend is occurring mostly during the winter season (Table 6.3).

Thus, farmers' perceptions appear to be in accordance with the statistical record in the region.

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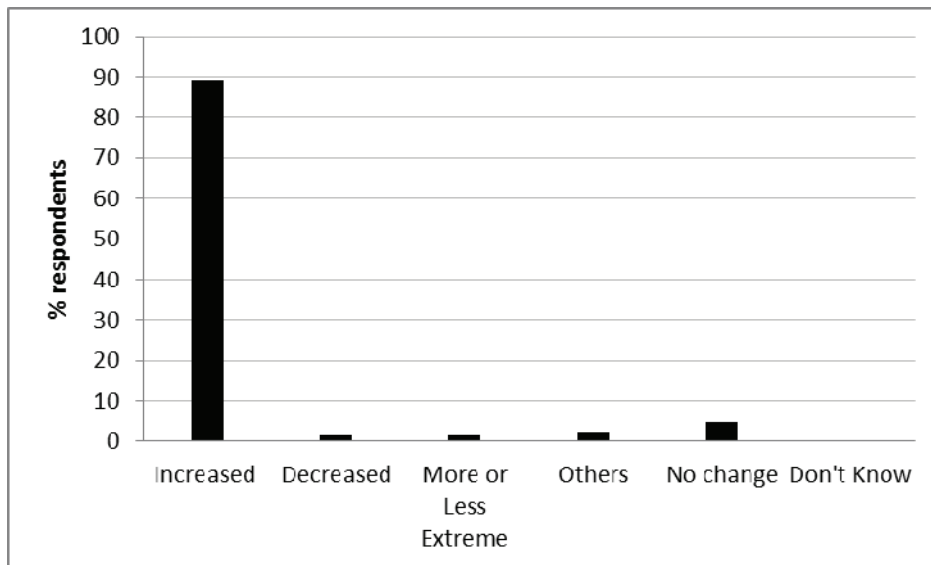


Figure 6.2: Farmers' perceptions of changes in temperature in the Limpopo River Basin South Africa

Source: Own analysis

Table 6.2: Farmers' perception of changes in temperature at provincial level (%)

	Increased	Decreased	More or less Extreme	Others	No change	Don't know
Total Basin	89.32	1.56	1.56	2.21	5.08	0.26
Limpopo	90.67	1.20	1.67	1.44	4.78	0.24
Gauteng	66.67	4.44	4.44	8.89	15.56	0.00
North West	89.52	2.86	0.00	4.76	2.89	0.00
Mpumalanga	91.52	1.00	1.50	1.00	4.50	0.50

Source: Own analysis

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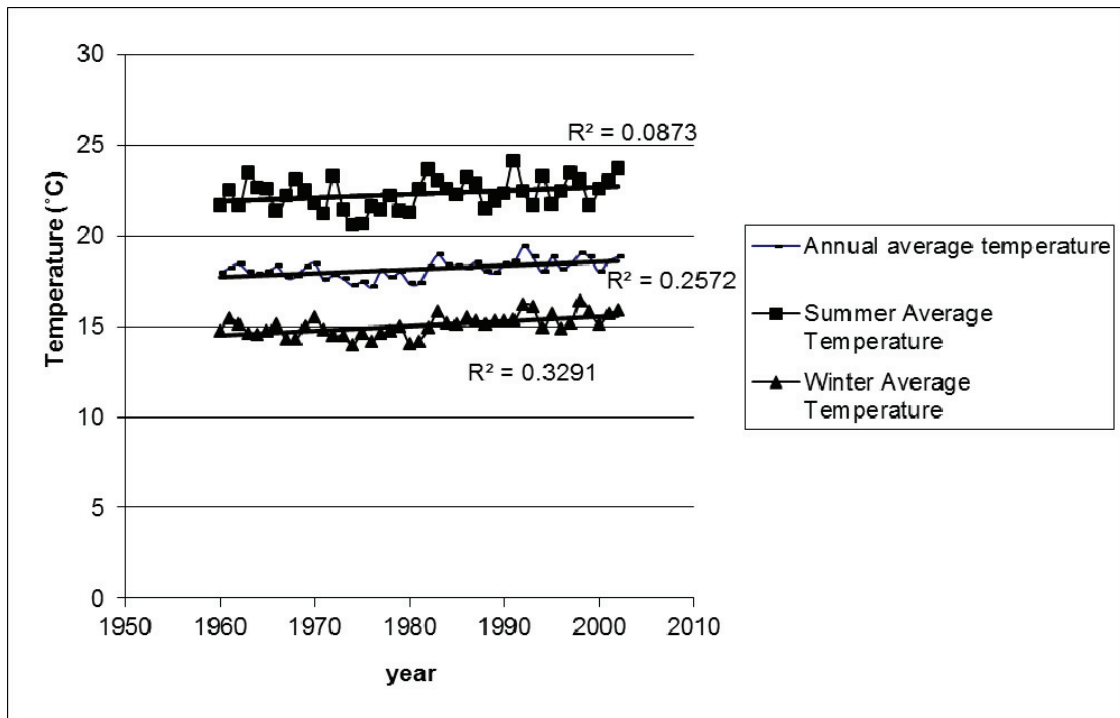


Figure 6.3: Trend temperature data for the Limpopo River Basin: 1960-2003

Source: Own analysis

Table 6.3: Analysis of temperature data: 1960-2003

Temperature	Yearly	Summer	Winter
Data for the total Limpopo River Basin			
Mean (°C)	18.15	22.31	15.04
Standard deviation (°C)	0.52	0.85	0.59
Minimum temperature (°C)	17.15	20.6	13.93
Maximum temperature (°C)	19.43	24.09	16.41
Trend (°C/year or season)	0.02*	0.02*	0.03*
Correlation	0.51	0.30	0.60
Total change calculated from the trend (°C/43 years)	0.94	2.04	1.15
Data for the Limpopo province			
Mean (°C)	20.83	23.93	17.75
Standard deviation (°C)	0.57	0.64	0.68
Minimum temperature (°C)	19.18	22.67	16.58
Maximum temperature (°C)	22.18	25.35	19.15
Trend (°C/year or season)	0.02*	0.01*	0.03*
Correlation	0.47	0.29	0.55

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Temperature	Yearly	Summer	Winter
Total change calculated from the trend ($^{\circ}\text{C}/43$ years)	0.83	0.76	1.02
Data for the North West province			
Mean ($^{\circ}\text{C}$)	18.39	22.31	14.49
Standard deviation ($^{\circ}\text{C}$)	0.48	0.68	0.47
Minimum temperature ($^{\circ}\text{C}$)	17.28	20.98	13.64
Maximum temperature ($^{\circ}\text{C}$)	19.51	23.86	15.45
Trend ($^{\circ}\text{C}/\text{year}$ or season)	0.009	0.007	0.01*
Correlation	0.24	0.14	0.32
Total change calculated from the trend ($^{\circ}\text{C}/43$ years)	0.28	0.85	0.41
Data for the Gauteng province			
Mean ($^{\circ}\text{C}$)	9.91	14.15	5.71
Standard deviation ($^{\circ}\text{C}$)	0.48	0.46	0.63
Minimum temperature ($^{\circ}\text{C}$)	8.56	12.11	4.53
Maximum temperature ($^{\circ}\text{C}$)	10.75	15.09	6.85
Trend ($^{\circ}\text{C}/\text{year}$ or season)	0.02*	0.01*	0.03*
Correlation	0.58	0.38	0.58
Total change calculated from the trend ($^{\circ}\text{C}/43$ years)	1.03	0.31	1.68
Data for the Mpumalanga province			
Mean ($^{\circ}\text{C}$)	17.52	20.59	13.90
Standard deviation ($^{\circ}\text{C}$)	0.77	0.80	0.91
Minimum temperature ($^{\circ}\text{C}$)	16.08	18.94	12.22
Maximum temperature ($^{\circ}\text{C}$)	19.17	22.15	15.66
Trend ($^{\circ}\text{C}/\text{year}$ or season)	0.04*	0.03*	0.05*
Correlation	0.63	0.57	0.65
Total change calculated from the trend ($^{\circ}\text{C}/43$ years)	1.83	1.80	2.26

*P < 0.05 Student's t-test, N=43. Total change is the difference between the trend line value of the first and last year.

Source: Own analysis

6.3.1.2 Rainfall perceptions

In total, 97% of the respondents observed changes in rainfall patterns over the past 20 years, and 81% (or 624) noticed a decrease in the amount of rainfall or a shorter rainy season. Almost 5% of the informants noticed a change not in the total amount of rainfall but in the timing of the rains, with rains coming either earlier or later than expected. The

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same pattern is observed across the four provinces with slight differences (Figure 6.4 and Table 6.4). A change in the timing of rainfall was mentioned by 7% of the farmers in Mpumalanga, 12% in North West, and 24% in Gauteng. Many respondents observed that the main rainfall season, which is the summer, is coming late and is also becoming shorter.

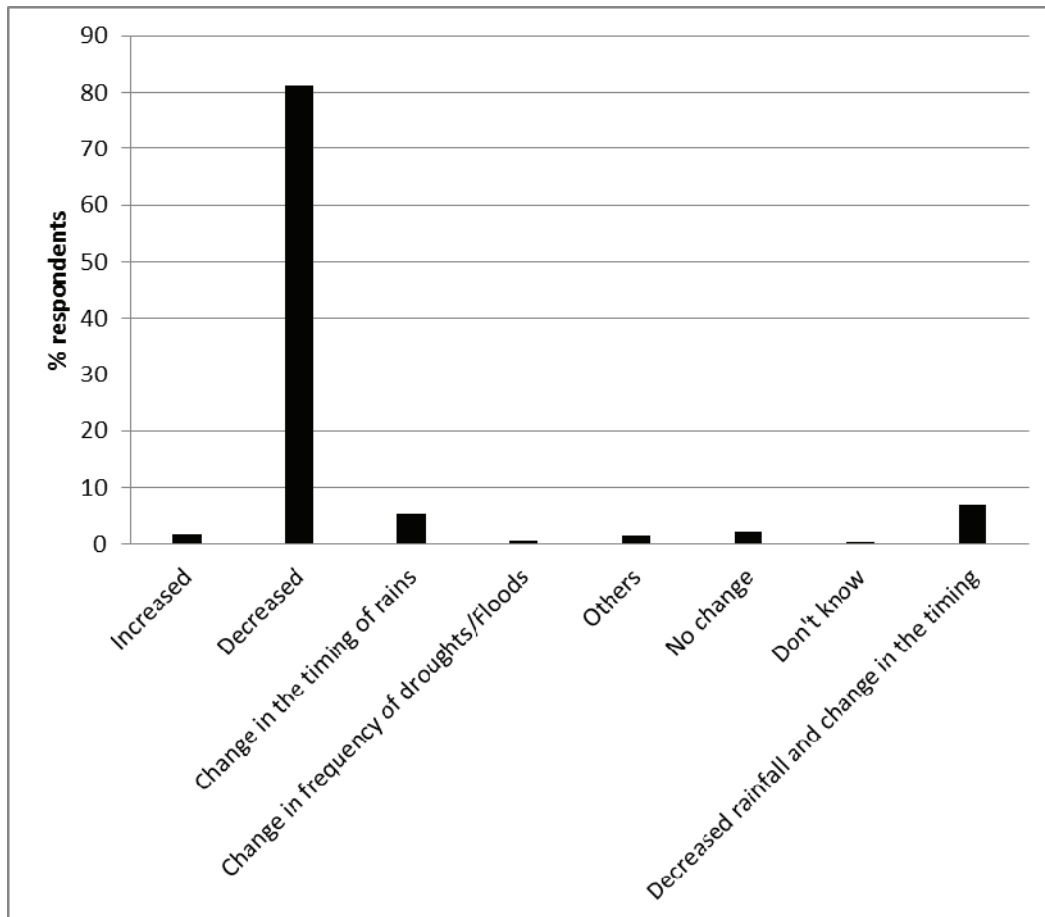


Figure 6.4: Farmers' perceptions of changes in rainfall in the Limpopo River Basin

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Source: Own analysis

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Table 6.4: Farmers' perceptions of changes in rainfall at provincial level (%)

	Increased	Decreased	Change in timing of rains	Change in frequency of droughts/floods	Others	No change	Don't know	Decreased rainfall and change in the timing
Total Basin	1.69	81.25	5.34	0.65	1.43	2.21	0.39	7.03
Limpopo	1.68	91.61	0.72	0.72	0.96	2.40	0.24	1.68
Gauteng	2.22	57.78	24.44	0.00	2.22	4.44	0.00	8.89
North West	0.94	62.26	12.26	1.89	3.77	2.83	0.94	15.09
Mpumalanga	2.00	75.00	7.00	0.00	1.00	1.00	0.50	13.50

Source: Own analysis

The plot of the rainfall data shows that rainfall does not exhibit a linear trend. The R square for all annual, summer and winter rainfall is minimal at less than 0.10. Indeed, there is a large variability in the amount of rainfall from year to year (Figure 6.6).

The recorded data on rainfall from 1960 to 2003 shows that about 85% of the rainfall occurs during summer months (October to March). Also, there is no statistically significant trend in the rainfall data. An analysis at provincial level, also confirms the same pattern. The correlation between rainfall and time is insignificant for all provinces. However, we found that winter rainfall has a correlation of less than 30% and displays as well a statistically significant decreasing trend (Table 6.5).

The high proportion of farmers noticing a decrease in precipitation could be explained by the fact that during the last few years of the study (2001 to 2003), there was a substantial decrease in the amount of rainfall (Figure 6.5). Thus, farmers' perceptions of a reduction in rainfall over the 20-year period are explained by the fact that, as Maddison (2006) noticed, some farmers place more weight on recent information than is efficient.

Gbetibouo G. A. (2011)

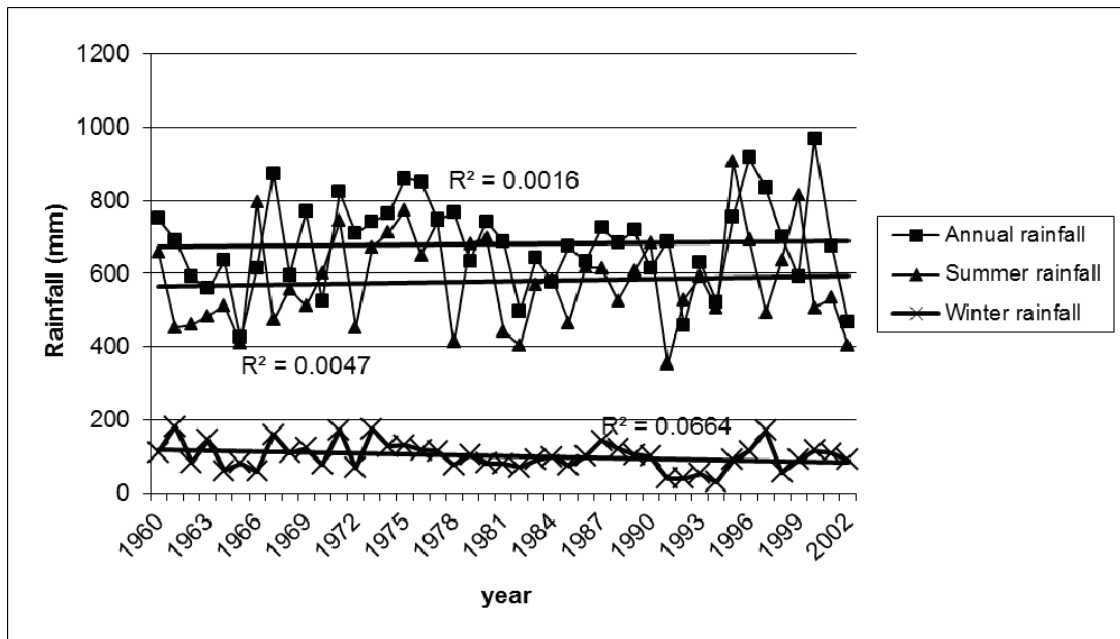


Figure 6.5: Trend rainfall data for the Limpopo River Basin: 1960-2003

Source: Own analysis

Table 6.5: Analysis of the rainfall data: 1960-2003

Rainfall	Yearly	Summer	Winter
Data for the Limpopo River Basin			
Mean (mm)	681.76	579.89	99.36
Percentage of yearly total		85	15
Standard deviation (mm)	123.53	128.97	38.16
Minimum rainfall (mm)	425.858	352.97	30.65
Maximum rainfall (mm)	967.09	906.25	181.94
Trend (mm/year or season)	0.38	0.7	-0.76*
Correlation	0.04	0.07	-0.27
Total change calculated from the trend (mm/43 years)	-242.84	-255.87	-20.97
Total change calculated from the trend (%)	-37.64	-38.77	-18.79

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Rainfall	Yearly	Summer	Winter
Data for the Limpopo province			
Mean (mm)	612.39	525.00	85.64
Percentage of yearly total		85.78	14.22
Standard deviation (mm)	143.15	153.44	33.108
Minimum rainfall (mm)	364.64	271.48	26.50
Maximum rainfall (mm)	1000.36	900.54	159.56
Trend (mm/year or season)	1.92	1.61	-0.37
Correlation	0.17	0.13	-0.09
Total change calculated from the trend (mm/43 years)	-304.59	-308.35	-23.22
Total change calculated from the trend (%)	-45.26	-47.23	-22.56
Data for the North West province			
Mean (mm)	605.83	513.80	89.95
Percentage of yearly total		84.8	15.2
Standard deviation (mm)	133.61	133.10	52.11
Minimum rainfall (mm)	341.85	320.96	17.30
Maximum rainfall (mm)	922.01	879.78	224.006
Trend (mm/year or season)	-1.09	-0.4	-1.25*
Correlation	-0.10	-0.03	-0.26
Total change calculated from the trend (mm/43 years)	-272.86	-242.69	0.93
Total change calculated from the trend (%)	-39.51	-39.88	1.07
Data for Gauteng province			
Mean (mm)	687.71	588.58	97.67
Percentage of yearly total		85.58	14.42
Standard deviation (mm)	133.91	135.72	43.37
Minimum rainfall (mm)	429.36	353.65	18.43
Maximum rainfall (mm)	971.45	965.29	212.59
Trend (mm/year or season)	0.33	0.85	-1.11*
Correlation	0.03	0.08	-0.27
Total change calculated from the trend (mm/43 years)	-190.62	-162.17	-8.37

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Rainfall	Yearly	Summer	Winter
Total change calculated from the trend (%)	-28.26	-26.73	-8.55
Data for Mpumalanga province			
Mean (mm)	821.11	692.16	124.19
Percentage of yearly total		84.29	15.71
Standard deviation (mm)	140.03	137.95	44.46
Minimum rainfall (mm)	554.93	442.57	41.20
Maximum rainfall (mm)	1197.05	1077.90	255.27
Trend (mm/year or season)	0.37	0.7	-1.25*
Correlation	0.03	0.07	-0.22
Total change calculated from the trend (0C/43 years)	-361.70	-310.26	-53.25
Total change calculated from the trend (%)	-37.56	-40.22	33.70
*P <0.05 Student's t-test, N=43. Total change is the difference between the trend line value of the first and last years			

Source: Own analysis

6.3.2 Spatial clustering of climate change perceptions

As shown in the above section, a large number of farmers believe the climate has become hotter and drier. As suggested by Maddison (2006), this perception might be a case of prominence bias in questionnaires dealing with climate change. It is likely that some respondents provided answers during the interview that the enumerators were more interested in hearing. Thus, validation of the respondent's assessment of climate change with his/her neighbours' responses would provide more confidence that the responses were objective and not subjective.

We employed Moran's I^{19} test for spatial autocorrelation with an inverse distance weights matrix on the portion of farmers who perceive particular types of climate change within a given area. The results (Table 6.6) suggested that neighbouring farmers agree that

¹⁹ For further details on Moran I test see Cliff and Ord (1981)
Ho: spatial independence.

Gbetibouo G. A. (2011)

temperature is increasing and rainfall is decreasing with a change in the timing. These results are evidence that farmers are capable of perceiving changes in climate. Thus, neighbouring farmers tell a consistent story.

Table 6.6: Moran's I test for spatial correlation of climate change perception

Perception of temperature	Moran I statistics	Perception of rainfall	Moran I statistics
Increased temperature	0.044**	Increased rainfall	-0.013
Decreased temperature	0.002	Decreased rainfall	0.125**
More or less extreme	0.001	Change in the timing	0.051**
No change	-0.003	Change in frequency of droughts/floods	-0.007
** Significant at 1% level * significant at 5% level		No change	0.003

Source: Own analysis

6.3.3 Factors influencing farmers' perceptions

According to Hansen et al. (2004): "...farmers' memory of past climatic variability may be distorted in systematic ways, reflecting wishful thinking by distortions consistent with decision goals as well as being shaped by personality characteristics and pre-existing beliefs...". We therefore investigate which factors besides actual climate events may have shaped the perceptions of the respondents in our study.

The adaptation process framework presented in section 2.4.2 distinguishes two main categories of factors which influence farmers' perceptions:

- i) exogenous factors: social, economic and cultural setting and provision of climate information

Gbetibouo G. A. (2011)

ii) endogenous factors: risk perception, attitudes and beliefs (based on age, gender, education, etc.) and farms characteristics (crop type, irrigation, soil, etc.)

Firstly, farmers' perceptions of climate change have been classified according to their years of experience and their level of education. Both were selected as proxies to represent risk perception and attitudes and beliefs. In Appendix 6.2, we distinguish the responses of farmers in three categories: i) having less than 10 years; ii) between 10 and 30 years; and iii) 30 or more years of experience. For the level of education, we distinguish four classes: i) no formal education; ii) standard education; iii) secondary education; and iv) tertiary education.

Using the Kruskal-Wallis test, a nonparametric test, we assess if the perceptions of climate according experience level and education level differed significantly. We hypothesised that the perception of experienced farmers and educated farmers would be in line with the actual changes in the climate. Experienced farmers have a better knowledge of the area and have a longer time span to assess long-term changes. Also educated farmers are expected to base their perception on available climate information.

The results show that a slightly higher proportion of farmers with more than 30 years of experience claimed that temperature is increasing and rainfall is decreasing, and noted change in the frequency of droughts and floods. Farmers with more than 30 years of experience are also less likely to claim no change in temperature and no change in rainfall. However, the Kruskal-Wallis test indicated that the views between experienced and inexperienced farmers are statistically not significant. The results also indicated that there is statistically no difference between the views of the educated and less-educated farmers.

The above results do not indicate whether the results are sensitive to other factors; therefore, we analyse which types of farmers are likely to notice climate change (temperature and/or rainfall changes) by running a probit model. Rather than present results for each category of climate change perception, we limit the analysis to explaining the twin perception of change in both temperature and rainfall. Because these two perceptions are likely to be correlated, we run a seemingly unrelated bivariate probit model. The

Gbetibouo G. A. (2011)

independent variables are education, farming experience, farm size, whether or not a crop farm, soil characteristics, irrigation, access to extension services, access to climate information, and region dummy for Gauteng. These results are adjusted for clustering at the district level on the assumption that the responses from farmers in the same district are likely to be related anyway.

The results displayed in Table 6.7 below show the following:

1. Education seems to decrease the probability that the farmer will perceive long-term changes in rainfall. Thus, educated farmers are more likely to see that rainfall does not have a significant trend over the long run.
2. With experience, farmers are more likely to perceive change in temperature.
3. Farmers who have access to water for irrigation purposes are unlikely to perceive any change in the climate whether in temperature or rainfall. Indeed, having access to water increases the resilience of farmers to climate variability.
4. Access to extension, on the other hand, increases the probability of perceiving change in temperature.
5. The results also confirm that being in Gauteng (the biggest province where agriculture is a small part of the economy) decreases the probability of perceiving climate change.
6. Farmers with highly fertile soil are less likely to perceive change in temperature but more likely to perceive change in rainfall. Indeed farmers with highly fertile soil, temperature are not a determining factor of their productivity. However, they may be constrained by water availability.

Gbetibouo G. A. (2011)

Table 6.7: Results of the seemingly unrelated bivariate probit of farmers' perception of change in the climate, Limpopo River Basin

	Perceive change in temperature	Perceive change in rainfall
Education	-0.0049	-0.0371***
Farming experience	0.0136*	0.0048
Farm size	0.2900	-0.3474
Crop farm	0.0822	-0.0219
Infertile soil	-0.3838	0.0994
Highly fertile soil	-0.3231**	0.6542**
Access to water for irrigation	-0.5917**	-0.7279**
Access to extension services	0.3361**	0.2271
Access to climate information	-0.0101	0.2044
Gauteng dummy	-0.6374***	0.2454
Intercept	1.91923 ***	2.4828***
Log likelihood: -186.0339		Number of observations: 632
Athrho: 0.8027***		Rho: 0.6655
Clustering at district level Wald test of rho=0: $\chi^2(1) = 28.5094$ Prob > $\chi^2 = 0.0000$		
.*** significant at 1% level; ** significant at 5% level; * significant at 10% level		

Source: Own analysis

Gbetibouo G. A. (2011)

6.4 Determinants of farmers' adaptation options to climate change and variability

6.4.1 The adaptation choices in the study area

A number of studies note a disconnection between farmers' perceptions of climate change and actual adaptation responses (Smit et al. 1996; Brklacich et al. 1997; Granjon 1999). This study gives similar findings. Although a large number of interviewed farmers indicated they noticed long term changes in mean temperature and rainfall levels, about two-thirds failed to take remedial actions. Majority of the farmers surveyed perceived an increase in temperature and a decreasing trend in rainfall (89% and 81%, respectively) over the past 20 years (section 6.3.1).

Table 6.8 describes farmers' adaptation strategies in the Limpopo River Basin. Common responses of those farmers who managed to adapt, included among others: i) planting different crops changing crop varieties; iii) changing planting dates; iv) increasing use of irrigation; v) changing area of land grazed or cultivated; and vi) supplementing livestock feed. While adopting a new crop variety was one of the main strategies used to adapt to increasing temperature, building water-harvesting schemes was a popular strategy for coping with decreased rainfall. Adaptation measures taken by South African farmers are similar to those reported in other studies in the climate change adaptation literature (Bradshaw et al. 2004; Deressa et al. 2009; Hassan and Nhemachena 2008).

Gbetibouo G. A. (2011)

Table 6.8: Farmers' adaptation strategies in the Limpopo River Basin (%)

Variable	Total Basin	Limpopo	North West	Gauteng	Mpumalanga
Adaptation to long-term changes in temperature (% respondents)					
Change crop variety	3.03	1.21	3.92	2.27	6.57
Increasing irrigation	3.96	3.38	1.96	6.82	5.56
Plant different crops	6.86	9.66	3.62		4.04
Change planting date	3.69	3.62	0.98	6.82	4.55
Change amount of land	3.43	4.11	1.96	2.27	3.03
Livestock feed supplements	3.69	3.62	5.88	4.55	2.53
Crop diversification/mixing	0.53	0.97			
Other	5.01	4.83	2.94	6.82	6.06
No adaptation	69.39	67.87	78.43	70.45	67.68
Adaptation to long-term changes in rainfall (% respondents)					
Change crop variety	0.66	0.72			1.01
Increasing irrigation	7.75	4.82	13.99	4.55	11.56
Plant different crops	4.99	6.75	2.91	2.27	3.02
Change planting date	4.73	3.13	3.88	9.09	7.54
Change amount of land	2.76	4.43			1.51
Livestock feed supplements	2.23	2.41	3.88	2.27	1.01
Water-harvesting scheme	3.81	3.61	1.94	4.55	5.03
Other	5.12	4.34	4.85	4.55	7.04
No adaptation	67.94	69.88	68.06	72.73	62.31

Source: Own analysis

The reported barriers to adaptation are shown in table 6.9. Farmers cited a number of barriers to adaptation including poverty, lack of access to credit, water and markets and low savings. Insecure property rights were also cited as an important barrier to

Gbetibouo G. A. (2011)

adaptation. A few farmers also reported lack of information and knowledge of appropriate measures as barriers to adaptation.

Table 6.9: Barriers to adaptation in the Limpopo River Basin (%)

	Lack of information about long-term climate change	Lack of knowledge concerning appropriate adaptations	Lack of credit or savings / poverty	No access to water	Insecure property rights	Lack of market access poor transport links	Other	No barriers to adaptation
Total Basin	6.03	1.95	53.9	20.75	9.57	6.21	10.99	0.78
Limpopo	4.32	2.65	24.24	32.58	14.27	10.3	7.97	8.31
North West	10.47	0.00	54.65	3.49	3.49	1.16	9.3	22.09
Gauteng	0.00	0.00	32	12	0.00	4	20	10
Mpumalanga	8.56	1.98	48.04	8.56	5.92	1.32	13.10	23.03

Source: Own analysis

6.4.2 The analytical framework

The decision of whether or not to use any adaptation option is analysed under the general framework of utility and profit maximisation²⁰.

Consider a rational farmer who seeks to maximise the present value of expected benefits of production over a specified time horizon, and must choose among a set of J adaptation options. The farmer i decides to use j adaptation option if the perceived benefit from option j is greater than the utility from other options (say, k) depicted as

$$U_{ij}(\beta'_j X_i + \varepsilon_j) > U_{ik}(\beta'_k X_i + \varepsilon_k), k \neq j, \quad (6.1)$$

²⁰ This study follows the same approach as earlier studies on climate change adaptation in Africa: Maddison 2006; Kurukulasuriya and Mendelsohn 2008; Seo and Mendelsohn 2009; Hassan and Nhemachena 2008; Deressa et al. 2009.

Gbetibouo G. A. (2011)

Where U_{ij} and U_{ik} are the perceived utility by farmer i of adaptation options j and k , respectively; X_i is a vector of explanatory variables that influence the choice of the adaptation option; β_j and β_k are parameters to be estimated; and ε_j and ε_k are error terms.

Under the revealed preference assumption that the farmer practices an adaptation option that generates net benefits and does not practice an adaptation option otherwise, we can relate the observable discrete choice of practice to the unobservable (latent) continuous net benefit variable as $Y_{ij} = 1$ if $U_{ij} > 0$ and $Y_{ij} = 0$ if $U_{ij} < 0$. In this formulation, Y is a dichotomous dependent variable taking the value of 1 when the farmer chooses an adaptation option in question and 0 otherwise.

The probability that farmer i will choose adaptation option j among the set of adaptation options could accordingly be defined as follows:

$$\begin{aligned}
 P(Y = 1 / X) &= P(U_{ij} > U_{ik} / X) \\
 &= P(\beta'_j X_i + \varepsilon_j - \beta'_k X_i - \varepsilon_k > 0 / X) \\
 &= P((\beta'_j - \beta'_k) X_i + \varepsilon_j - \varepsilon_k > 0 / X) \\
 &= P(\beta^* X_i + \varepsilon^* > 0 / X) = F(\beta^* X_i),
 \end{aligned}
 \tag{6.2}$$

Where ε^* is a random disturbance term, β^* is a vector of unknown parameters that can be interpreted as the net influence of the vector of explanatory variables influencing adaptation, and $F(\beta^* X_i)$ is the cumulative distribution of ε^* evaluated at $\beta^* X_i$.

Given that we investigate several adaptation choices, the multinomial logit (MNL) model is employed to analyse climate change adaptation behaviour of farmers. Thus, the probability that household i with characteristics X chooses adaptation option j is specified as follows:

$$P_{ij} = \text{prob}(Y = 1) = \frac{e^{x'\beta}}{1 + \sum_{j=1}^J e^{x'\beta}}, j=1 \dots J,
 \tag{6.3}$$

Gbetibouo G. A. (2011)

Where β is a vector of parameters that satisfy $\ln(P_{ij}/P_{ik}) = X'(\beta_j - \beta_k)$ (Greene 2003). Unbiased and consistent parameters estimates of the MNL model in Equation 6.3 require the assumption of independence of irrelevant alternatives (IIA) to hold (Greene 2003). Specifically, the IIA assumption requires that the likelihood of a household's using a certain adaptation measure needs to be independent of alternative adaptation measures used by the same household. Thus, the IIA assumption implies independent and homoscedastic disturbance terms of the adaptation model in Equation 1. The validity of the IIA assumption could be tested using the Hausman's specification, which is based on the fact that if a choice set is irrelevant, eliminating a choice or choice sets from the model altogether will not change parameter estimates systematically (Hausman 1978).

Differentiating Equation 6.3 with respect to each explanatory variable provides measures of the marginal effects of these variables:

$$\frac{\partial P_j}{\partial x_k} = P_j \left(\beta_{jk} - \sum_{j=1}^{j-1} P_j \beta_{jk} \right). \quad (6.4)$$

Using the MNL model for our analysis gives rise to a sample selectivity problem²¹ because only those who perceive climate change will adapt. Indeed, adaptation to climate change begins with two processes: first, perceiving change, and then, deciding on a particular adaptation choice. Therefore, the correct modelling of the adaptation behavioural to climate change implies the use of a sample selectivity model or a two-period framework ($t=0$, observation of the climate change; and $t=1$, adaptation choice is made). However, the two-period choice model is a complicated model to estimate (Dagsvik 2000). Also, a review of applied literature²² on selectivity bias correction methods did not reveal a two-stage model that uses a multivariate choice model as the

²¹ Also the usual endogeneity-related limitations of household-level empirical methods are present and therefore undermine claims of causal relationships. Specifically, simultaneity bias causes endogeneity. Therefore, the estimates in this study provide suggestive evidence between a household's decision and various characteristics but not necessarily definitive proof of causal relationships.

²² We found in the literature that following the seminal insight of Heckman (1979), two traditional approaches suggested by Lee (1983) and Dubin and McFadden (1984) are applied when the selection model is a multinomial logit, and in the outcome equation the dependent variable is a continuous variable. We also found that Dagsvik (2000) has developed a theoretical model where the two stages are MNL model; however, a successful application of this model still has to be verified.

Gbetibouo G. A. (2011)

outcome equation. Therefore, both the Heckman sample selectivity probit model and the MNL model are used to study the determinants of adaptation to climate change.

Following Maddison (2006), Heckman's sample selectivity probit model is based on the following two latent variables:

$$Y_1 = b'X + U_1 \quad (6.5)$$

$$Y_2 = g'Z + U_2, \quad (6.6)$$

where X is a k -vector of regressors; Z is an m -vector of regressors, possibly including 1's for the intercepts; and the error terms U_1 and U_2 are jointly normally distributed, independently of X and Z , with zero expectations. Although we are primarily interested in the first model, the latent variable Y_1 is only observed if $Y_2 > 0$. Thus, the actual dependent variable is:

$$Y = Y_1 \text{ if } Y_2 > 0, Y \text{ is a missing value if } Y_2 \leq 0. \quad (6.7)$$

The latent variable Y_2 itself is not observable, only its sign. We only know that $Y_2 > 0$ if Y is observable, and $Y_2 \leq 0$ if not. Consequently, we may without loss of generality normalise U_2 such that its variance is equal to 1. If we ignore the sample selection problem and regress Y on X using the observed Y 's only, then the ordinary least squares (OLS) estimator of b will be biased, because:

$$E[Y_1 | Y_2 > 0, X, Z] = b'X + rsf(g'Z)/F(g'Z), \quad (6.8)$$

where F is the cumulative distribution function of the standard normal distribution, f is the corresponding density, s^2 is the variance of U_1 , and r is the correlation between U_1 and U_2 . Hence,

$$E[Y_1 | Y_2 > 0, X] = b'X + rsE[f(g'Z)/F(g'Z)|X]. \quad (6.9)$$

The latter term causes sample selection bias if r is nonzero. In order to avoid the sample selection problem, and to get asymptotically efficient estimators, the model parameters are estimated by maximum likelihood.

Gbetibouo G. A. (2011)

6.4.3 Empirical specification of the variables

Based on the information about adaptation choices in section 6.4.1, the choice set considered in the adaptation model includes 10 variables:

1. Change crop variety
2. Intensification irrigation
3. Water-harvesting scheme
4. Plant different crops
5. Crop diversification/mixing
6. Change planting date
7. Change amount of land
8. Livestock feed supplements
9. Other
10. No adaptation

Explanatory variables were chosen based on data availability and the literature. A review of literature on adoption of new technologies and adaptation studies suggest the importance of a number of households and farm characteristics as well as institutional factors and other determinants in influencing farmers' adaptation choices.

i) Household characteristics

Adesina and Forson (1995) cited in Teklewold et al. (2006) did not find agreement in the adoption literature on the effect of farmer's *age* which was generally location- or technology-specific.

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

On the other hand higher levels of *education* of farmers often were found to increase the probability of adopting new technologies (Daberkow and McBride 2003; Adesina and Forson 1995). Education is expected to increase one's ability to receive, decode, and understand information relevant to making innovative decisions (Wozniak 1984).

Gender of the household head was also found to influence adoption decisions. A number of studies in Africa have shown that women have lesser access to critical resources (land, cash, and labour), which often undermines their ability to carry out labour-intensive agricultural innovations (De Groote and Coulibaly 1998; Quisumbing et al. 1995). However, a study by Nhemachena and Hassan (2007) found that female-headed households are more likely to take up climate change adaptation methods.

Wealth is believed to reflect past achievements of households and their ability to bear risks. Thus, households with higher income and greater assets are in better position to adopt new farming technologies (Shiferaw and Holden 1998).

Farming experience is hypothesised to increase the probability of uptake of all adaptation options because experienced farmers have better knowledge and information on changes in climatic conditions and crop and livestock management practices (Nhemachena and Hassan 2007).

The influence of *household size* on the decision to adapt has been ambiguous. Household size as a proxy to labour availability may influence adoption of a new technology positively as its availability reduces labour constraints (Teklewold et al. 2006). However, the study of Tizale (2007) suggests that there is a possibility that households with many family members may be forced to divert part of the labour force to off-farm activities in an attempt to earn income to ease the consumption pressure imposed by a large family size.

ii) Farm characteristics

The literature suggests that adoption of an innovation tends to take place earlier on larger farms than on smaller ones. Daberkow and McBride (2003) show that given the uncertainty and the fixed transaction and information costs associated with innovation

Gbetibouo G. A. (2011)

there may be a critical lower limit on *farm size* that prevents smaller farms from adapting. As these costs increase, the critical size also increases. It follows that innovations with large fixed transaction and/or information costs are less likely to be adopted by smaller farms.

Fertility of the farm land is also considered an important element as farmers' perceptions that their lands are infertile may be a first step in the adaptation process. They may therefore be more likely to adopt any adaptation techniques that will help improve their productivity.

iii) Institutional factors

In the world of less-than-perfect information, the introduction of new technologies creates a demand for information useful in deciding on adopting new technologies (Wozniak 1984). Of the many sources of information available to farmers, agricultural extension is the most important for analysing the adoption decision.

Based on the innovation-diffusion literature it is hypothesised that *access to extension services* is positively related to adoption of new technologies by exposing farmers to new information and technical skills (Adesina and Forson 1995).

Also, in the specific case of climate change adaptation, *access to climate information* may increase the likelihood of uptake of adaptation measures.

Access to credit is another variable that has received attention, which was commonly found to have positive effect on adaptation (Caviglia-Harris 2002; Sain and Barreto 1996; Napier 1991; Hansen et al. 1987). Any fixed investment requires the use of owned or borrowed capital. Hence, the adoption of a technology requires a large initial investment, which may be hampered by lack of borrowing capacity (El-Osta and Morehart 1999).

The occupation of the farmer is an indication of the total amount of time available for farming activities. *Off-farm employment* may present a constraint to adoption of technology because it competes for on-farm work (McNamara et al. 1991).

Gbetibouo G. A. (2011)

Similarly, *land tenure* can contribute to adaptation, because landowners tend to adopt new technologies more frequently than tenants, an argument that has justified numerous efforts to reduce tenure insecurity (Lutz et al. 1994; Shultz et al. 1997). Land tenure is widely believed to encourage the adoption of technologies linked to land such as irrigation equipment or drainage structures. Land ownership is likely to influence adoption if the innovation requires investments tied to land.

iv) **Other factors**

Local climatic and agro-ecological conditions are expected to influence the decision to adapt. We therefore included *district level climate variables* (temperature and rainfall). Also, to take into account spatial autocorrelation and neighbourhood effects, we include location attributes (latitude and longitude coordinates) of each household. A dummy variable is also included to control for the fixed *province effects* reflecting any specific institutional arrangements with bearing on the ability of farmers to adapt to climate change in a particular province.

Table 6.10 provides a brief description of each explanatory variable and expected direction of its influence on adaptation choices.

Gbetibouo G. A. (2011)

Table 6.10: Variables hypothesised to affect adaptation decisions of farmers in the Limpopo River Basin

Variable name	Description	Unit	Expected sign
Household characteristics			
Age	Age of the head of the farm household	Years	Cannot be signed a priori (+ or -)
Education	Number of years of formal schooling attained by the head of the household	Years	Positive
Gender	Gender of the head of the farm household	1= male, 0= female	Cannot be signed a priori (+ or -)
Household size	Number of family members of a household	Number	Cannot be signed a priori (+ or -)
Farming experience	Number of years of farming experience for the household head	Years	Positive
Wealth	An index ²³ was constructed using household ownership of seven households' assets: television, radio, flushing toilet, cell phone, brick house, refrigerator, and car.	number	Positive
Farm characteristics			
Farm size	Determine if the farm is large-scale or small-scale	1= large scale 0= small scale	Positive
Soil fertility	Farmer's own perception of the fertility level of his land. Three dummies: infertile, fertile, and highly fertile.	0 or 1	Positive
Institutional factors			
Extension	If household has access to extension services	1=yes, 0= no	Positive
Climate information	If household gets information about weather, climate from any source (extension officers, TV, radio, etc.)	1=yes, 0= no	Positive
Credit	If household has access to credit from any sources	1=yes, 0= no	Positive
Off-farm employment	Income from off-farm activities during the survey year		Cannot be signed a priori (+ or -)
Land tenure	If the land used is owned or rented/share-cropped, etc.	1= owned 0= otherwise	Positive
Others factors			
Temperature	Average temperature between 1960 and 2003	degree Celsius	Positive
Rainfall	Average rainfall between 1960 and 2003	Mm	Negative
Latitude		degree	
Longitude		degree	
Limpopo	If household farm in Limpopo province	1=yes, 0= no	Cannot be signed a priori (+ or -)

²³ Following Filmer and Pritchett (2001), principal component analysis (PCA) was used to assign weights to each asset. The overall wealth index is calculated by applying the following formula:

$$w_j = \sum_{i=1}^k [b_i (a_{ji} - x_i)] / s_i$$

where w is the wealth index, b is the weights from PCA 1, a is the asset value, x is the mean asset value, and s is the standard deviation of the assets.

Gbetibouo G. A. (2011)

6.4.4 Results and discussions

In this section, two models for adaptation choices to climate change in the Limpopo River Basin are estimated by using the statistical software Stata version 9.0: the Heckman probit and the MNL model. Before initial runs of the model, the data were checked for the presence of any multicollinearity in the data set. Among the variables hypothesised to influence adaptation, age of the head of household was found to be correlated inversely with education ($\rho = -0.39$) and positively with farming experience ($\rho = 0.30$) and extension and climate information ($\rho = 0.25$). Although these correlations coefficients do not suggest incidence of strong collinearity, age was dropped from the model (see Appendix 6.3).

Farmers have an average of 7 years of education. Household size is relatively large with an average of 6 household members. Farmers aged in average 55 years, with 12 years' experience in farming. However, age is not a proxy for experience because many farmers in South Africa began farming much later in life. The standard deviation of years of experience is about 12 with minimum of 1 and a maximum of 60 years. 92% of farmers surveyed are small scale and only 44% have a land tenure title. 69% of farmers perceive that they have medium to highly fertile soils. 22% of farmers have access to credit and 60% of farmers have access to extension services. Appendix 6.4 provides the summary statistics of the independent variables included in the analysis.

6.4.4.1 The Heckman Probit model results

This section presents the results of the Heckman probit adaptation model. The model determines the likelihood of perceiving any change in the climate as well as the likelihood of farmers' adapting to these changes. The dependent variable for the selection equation is binary indicating whether or not a farmer perceives climate change; the dependent variable for the outcome equation is also binary indicating whether or not a farmer responded to the perceived changes by adapting farming practices. The explanatory variables are those discussed in the previous section, and "access to water for irrigation" is also included in the selection equation.

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

The likelihood function for the Heckman probit model was significant (Wald $\chi^2 = 36.26$ with $P < 0.001$), showing a strong explanatory power. Furthermore, the rho different from zero (Wald $\chi^2 = 12.7$ with $P < 0.001$) confirms the appropriateness of the model over the standard probit model and that there is a selectivity bias in adapting to climate change. Thus, perception is a prerequisite before adapting.

As shown in Table 6.11, access to water for irrigation, access to irrigation services, and living in Gauteng influence the likelihood of perceiving climate change. On the other hand, farming experience, farm size, soil fertility, access to extension, access to credit, land tenure status, and region influence the probability of adapting to climate change.

As expected, experienced farmers are more likely to adapt. Indeed, experienced farmers have better knowledge about agricultural practices and techniques. Likewise, farm size positively and significantly leads to an increase in the likelihood of adapting to climate change. Larger farms are generally better equipped to take on new technologies. Farmers' perception of having highly fertile soil decreases the probability of taking up adaptation in response to changes in the climate. Indeed, the productivity of farms with highly fertile soils, are less sensitive to climatic changes and therefore the need for adaptation is reduced.

Access to extension services increases the likelihood of perceiving changes in climate as well as the likelihood of adaptation. This suggests that extension services help farmers to take climate changes and weather patterns into account and help advise them on how to tackle climatic variability and change. The results also show important regional variation. Farmers in Limpopo province are more likely to adapt compared with farmers in the other provinces. Indeed, in Limpopo, the population is largely rural (82 %), and the main rural economic activity is agriculture

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Table 6.11: Results of the Heckman probit model of adaptation behaviour, Limpopo River Basin

Variables	Estimated coefficients outcome equation: adaptation model	Estimated coefficients selection equation: perception model
Access to water for irrigation		-0.621***
Gender	0.134	-0.088
Education	-0.011	-0.012
Farming experience	0.01***	0.006
Wealth	0.114	0.051
Farm size	0.649***	-0.036
Soil fertility	-0.142*	-0.005
Extension	0.179*	0.364***
Climate information	-0.1	-0.115
Credit	0.232*	-0.0650
Off-farm employment	0.127	0.0472
Land tenure	0.268***	0.0359
Mpumalanga	-0.006	-0.031
Gauteng	-0.603***	-0.527**
North West	-0.445***	-0.029
Intercept	-0.6615***	1.83***
Wald test (zero slopes):36.26***		
Wald test (independent equations): 12.7*** Total observations: 577 Censored observations:43		

Note: *** significant at 1% level ** significant at 5% level * significant at 10% level

Source: Own analysis

Gbetibouo G. A. (2011)

6.4.4.2 The Multinomial Logit model results

This section presents the empirical results of the MNL adaptation model. The MNL, as specified in section 6.4.3 with 10 adaptation options, failed to produce satisfactory results in terms of the significance level of the parameters estimates and also in terms of the validity of the independence of irrelevant alternatives (IIA) assumption. The model was thus restructured by grouping three closely related choices together in the same category. The replacement of plant-type cultivars with new varieties, the adoption of new crops, and multicropping and mixed farming systems of crops and livestock were grouped in the same category, labelled “portfolio diversification.” Indeed, these three choices are closely related because they are considered for the same purpose of risk-spreading. Also, we aggregate intensification irrigation and water-harvesting scheme into the same category, irrigation, because both are related to the use of water for the purpose of increasing productivity and withstanding rainwater shortages.

Accordingly, the choice set in the restructured MNL model included the following adaptation options:

1. Portfolio diversification
2. Irrigation
3. Change planting date
4. Change amount of land
5. Livestock feed supplements
6. Other
7. No adaptation

The above restructured MNL adaptation model was tested for the IIA assumption using the Hausman specification test. The test failed to reject the null hypothesis of independence of the included choices suggesting there is no evidence against the current specification of the adaptation model giving a $\chi^2 = -0.375$ with P value of 0.9311. Therefore, the application of the MNL specification to the data set for modelling climate change adaptation behaviour of farmers is justified.

Gbetibouo G. A. (2011)

Table 6.12 and Table 6.13 present the estimated coefficients and the marginal effects, respectively. The likelihood ratio statistics ($\chi^2 = 291.07$) are highly significant at 1%, suggesting a strong explanatory power of the model. It is important to note that the estimated coefficients should be compared with the base category of not adopting any of the adaptation choices. There is a 70% probability that farmers will not adapt to climate change.

The results show that a large household will be more willing to choose the “Other” category as an adaptation option, which includes adaptations such as use of soil conservation techniques and chemical treatments that are labour-intensive especially in small-scale farming.

Experienced farmers have an increased likelihood of using portfolio diversification, changing planting dates, and changing the amount of land under production. These results confirm the findings of Nhemachena and Hassan (2007) in a similar study of adaptation in the Southern Africa region. Experienced farmers have high skills in farming techniques and management and are able to spread risk when facing climate variability by exploiting strategic complementarities between activities such as crop-livestock integration. Wealthier households were found to be more willing to adapt by changing their planting dates. Surprisingly, the results suggested that education level and gender did not have a significant impact on the probability of choosing any adaptation technique.

The coefficient on farm size is significant and positively correlated with the probability of choosing irrigation as an adaptation measure. Indeed, large-scale farmers are more likely to adopt irrigation as they have more capital and resources to invest in irrigation technologies. The perception of having highly fertile soil increases the probability that farmers will change their amount of land under cultivation.

Having access to extension increases the probability of choosing portfolio diversification by 4%. It appears therefore that extension messages in the study area emphasized risk spreading and farm-level risk management. The implementation of the land reform has increased the number of new, emerging farmers who did not have the skills and

Gbetibouo G. A. (2011)

information gathered by experienced farmers; therefore, extension is of great need in South Africa.

As expected, access to credit increases the likelihood of adaptation. Poverty or lack of financial resources is one of the main constraints to adjustment to climate change. In a study on Tanzania, O'Brien et al. (2000) report that despite numerous adaptation options that farmers are aware of and willing to apply, the lack of sufficient financial resources to purchase the necessary inputs and other associated equipment (e.g., purchasing seeds, acquiring transportation, hiring temporary workers) is one of the key constraints to adaptation. In our study, 60% of the respondents who did not adapt cited lack of financial resources as the main constraint to adaptation. The results show that access to credit increases the likelihood that farmers will take up portfolio diversification and buy feed supplements for their livestock.

Having secure property rights increases the probability of farmers to adapt by 9%. With proper property rights, farmers may be able to change their amount of land under cultivation to adjust to new climatic conditions. While off-farm employment may present a constraint to adaptation because it competes for on-farm work (McNamara et al. 1991), the empirical results suggest that off-farm activities increase the likelihood of buying feed supplements for the livestock. This suggests that expanding smallholder farmers' access to off-farm income and employment opportunities increases the probability that they will invest in farming activities.

Households living in regions with high temperatures have an increased likelihood of adapting. These households are more likely to choose the following adaptation options: i) portfolio diversification, such as changing their types of crops (e.g., from maize to sorghum, a more heat-tolerant crop); ii) intensify irrigation; and iii) change planting dates. A decrease in rainfall is likely to push farmers to delay planting.

Gbetibouo G. A. (2011)

Table 6.12: Coefficient estimates of the multinomial logit adaptation model, Limpopo River Basin

	Portfolio diversification	Irrigation	Changed planting dates	Changed the amount of land	Livestock feed supplements	Other
Education	-0.0256 (0.45)	0.015 (0.56)	-0.0072 (0.84)	0.0239 (0.54)	-0.02606 (0.63)	0.0274 (0.51)
Gender	-0.0381 (0.90)	0.390 (0.24)	0.4163 (0.39)	-0.2365 (0.61)	0.5869 (0.41)	-0.0687 (0.89)
Household size	-0.0256 (0.62)	0.045 (0.34)	-0.0065 (0.92)	0.0235 (0.80)	-0.1032 (0.23)	-0.1206 (0.09)*
Farming experience	0.0283 (0.01)***	0.011 (0.36)	0.0362 (0.01)***	0.0478 (0.00)***	-0.0159 (0.55)	0.0015 (0.92)
Wealth	-0.0439 (0.66)	0.152 (0.09)*	0.7200 (0.00)***	0.3255 (0.07)*	0.1524 (0.32)	0.1223 (0.43)
Farm size	0.7903 (0.09)*	0.994 (0.03)**	0.3967 (0.65)	0.8507 (0.26)	0.2231 (0.86)	0.3850 (0.58)
Highly fertile soil	0.4521 (0.10)*	0.335 (0.29)	-0.1061 (0.823)	1.0011 (0.05)**	0.7963 (0.19)	-0.3737 (0.50)
Infertile soil	-0.4928 (0.44)	-0.120 (0.81)	0.2631 (0.658)	1.0477 (0.14)	-0.3601 (0.71)	0.9341 (0.09)*
Extension	0.5876 (0.09)*	0.016 (0.95)	0.4915 (0.27)	0.5658 (0.22)	0.2494 (0.62)	0.0001 (0.99)
Climate information	-0.3225 (0.33)	-0.009 (0.97)	-0.3602 (0.42)	0.2471 (0.61)	-0.1404 (0.80)	0.4426 (0.29)
Credit	0.4903 (0.08)*	0.348 (0.26)	0.0860 (0.87)	-0.9608 (0.13)	1.2228 (0.02)**	0.5648 (0.22)
Off-farm employment	0.4091 (0.19)	0.050 (0.87)	0.1044 (0.80)	-0.7191 (0.31)	2.1167 (0.00)***	0.2936 (0.50)
Land tenure	0.2672 (0.36)	0.304 (0.31)	0.4309 (0.28)	1.1490 (0.02)**	-0.3775 (0.49)	1.3012 (0.00)***
Latitude	0.4806 (0.05)**	-0.142 (0.25)	-0.2132 (0.17)	0.7003 (0.09)*	-0.3234 (0.07)*	0.0809 (0.58)
Longitude	-0.1496 (0.45)	-0.016 (0.92)	0.5093 (0.03)**	0.5458 (0.23)	-0.4082 (0.09)*	-0.1312 (0.54)

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

	Portfolio diversification	Irrigation	Changed planting dates	Changed the amount of land	Livestock feed supplements	Other
Rainfall	0.0062 (0.12)	0.004 (0.13)	-0.0071 (0.04)**	0.0079 (0.269)	0.0001 (0.97)	-0.0007 (0.86)
Temperature	0.1851 (0.02)**	0.144 (0.08)*	-0.2957 (0.00)***	0.0783 (0.53)	0.0855 (0.60)	0.2502 (0.03)**
Intercept	6.1086 (0.49)	-11.102 (0.05)**	-14.0650 (0.09)*	-10.6187 (0.53)	-2.6090 (0.75)	-2.3139 (0.74)
Base category: No Adaptation No. observations: 591 LR chi-square (90): 291.07*** Log pseudo likelihood : -676.2506 Pseudo R-Square: 0.1320						

Notes: *** significant at 1% probability level, ** significant at 5% probability level, * significant at 10% probability level

Source: Own analysis

Table 6.13: Estimate of the marginal effects of the MNL adaptation model, Limpopo River Basin

	Portfolio diversification	Irrigation	Changed planting dates	Changed amount of land	Livestock feed supplements	Other	No Adaptation
Education	-0.0023 (0.39)	0.0019 (0.50)	-0.0003 (0.82)	0.0003 (0.56)	-0.0003 (0.62)	0.0009 (0.49)	-0.0003 (0.94)
Gender	-0.0084 (0.75)	0.0388 (0.22)	0.0115 (0.38)	-0.0034 (0.54)	0.0046 (0.41)	-0.0044 (0.8)	-0.0387 (0.37)
Household size	-0.0021 (0.60)	0.0058 (0.25)	-0.0002 (0.94)	0.0003 (0.79)	-0.0010 (0.25)	-0.0041 (0.09)*	0.0013 (0.85)
Farming experience	0.0020 (0.01)***	0.0007 (0.59)	0.0011 (0.03)**	0.0005 (0.09)*	-0.0002 (0.47)	-0.0001 (0.8)	-0.0039 (0.03)**
Wealth	-0.0083 (0.29)	0.0128 (0.23)	0.0231 (0.00)***	0.0030 (0.22)	0.0010 (0.49)	0.0026 (0.62)	-0.0343 (0.01)***
Farm size	0.0536 (0.32)	0.1176 (0.09)*	0.0034 (0.91)	0.0077 (0.58)	-0.0007 (0.94)	0.0030 (0.9)	-0.1846 (0.05)**
Highly fertile soil	0.0342 (0.21)	0.0314 (0.39)	-0.0066 (0.64)	0.0125 (0.10)*	0.0080 (0.32)	-0.0148 (0.33)	-0.0648 (0.17)

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

	Portfolio diversification	Irrigation	Changed planting dates	Changed amount of land	Livestock feed supplements	Other	No Adaptation
Infertile soil	-0.0375 (0.29)	-0.0168 (0.73)	0.0091 (0.70)	0.0176 (0.30)	-0.0032 (0.64)	0.0471 (0.20)	-0.0162 (0.81)
Extension	0.0434 (0.09)*	-0.0075 (0.80)	0.0138 (0.30)	0.0052 (0.35)	0.0016 (0.73)	-0.0027 (0.84)	-0.0537 (0.08)*
Climate information	-0.0257 (0.32)	0.0018 (0.95)	-0.0112 (0.43)	0.0031 (0.60)	-0.0011 (0.82)	0.0172 (0.26)	0.0161 (0.69)
Credit	0.0355 (0.06)*	0.0289 (0.42)	-0.0014 (0.93)	-0.0093 (0.19)	0.0149 (0.09)*	0.0172 (0.37)	-0.0858 (0.08)*
Off-farm employment	0.0302 (0.27)	-0.0046 (0.88)	0.0006 (0.96)	-0.0077 (0.09)*	0.0339 (0.00)***	0.0074 (0.63)	-0.0597 (0.18)
Land tenure	0.0112 (0.63)	0.0204 (0.52)	0.0102 (0.47)	0.0124 (0.10)*	-0.0048 (0.27)	0.0466 (0.02)**	-0.0960 (0.03)**
Latitude	0.0404 (0.03)**	-0.0208 (0.12)	-0.0082 (0.10)*	0.0074 (0.14)	-0.0034 (0.13)	0.0020 (0.69)	-0.0174 (0.41)
Longitude	-0.0132 (0.39)	-0.0020 (0.91)	0.0175 (0.02)**	0.0060 (0.17)	-0.0039 (0.05)**	-0.0046 (0.52)	0.0002 (0.99)
Rainfall	0.0005 (0.12)	0.0004 (0.16)	-0.0003 (0.03)**	0.0001 (0.36)	0.0000 (0.87)	-0.0001 (0.68)	-0.0006 (0.12)
Temperature	0.0133 (0.04)**	0.0136 (0.09)*	-0.0114 (0.00)***	0.0005 (0.73)	0.0005 (0.72)	0.0075 (0.07)*	-0.0240 (0.03)**
Probability	0.09	0.12	0.035	0.01	0.01	0.035	0.7

Notes: *** significant at 1%, ** significant at 5%, * significant at 10%

Source: Own analysis

6.5 Summary and policy implications

Our study reveals that for the most part, farmers' perceptions of climate changes appear to be in line with actual climate data. However, there is some evidence that farmers' perceptions of climate change may not be based entirely on actual changes in climate. Statistical records of actual temperature data in South Africa show that temperatures have

Gbetibouo G. A. (2011)

in fact increased over the period from 1960 to 2003. However, in contrast to farmers' perceptions, there is no clear statistically significant trend of declining rainfall over the 1960–2003. The survey year followed a three years period (2001–2003) of substantial drop in the volume of rainfall. Therefore, this could explain the high proportion of farmers noticing a decrease in rainfall. Thus, farmers' perceptions may be based more on recent, short-term trends rather than long-term changes.

The study also finds that having access to water for irrigation decreases the likelihood that the farmer perceives climate change in South Africa. On the other hand, having access to extension services increases the likelihood of perceiving climate change. This could suggest that extension services provide information about climate and weather. Furthermore, experienced farmers are more likely to perceive change in temperature. This study confirms therefore that perceptions are not entirely based on actual climate conditions and changes but are influenced by other factors as well.

The study further reveals that although farmers are well aware of long term climatic trends, few seem to take steps to adjust their farming activities. Farmers in the Limpopo River Basin practiced switching of crops and varieties, changing planting dates, increasing irrigation, building water-harvesting structures, changing land area under cultivation, and buying livestock feed supplements to cope with climate change.

The Heckman Probit and the Multinomial Logit analyses of determinants of adaptation to climate change indicated that household size, wealth, farm size, farming experience, perception of soil fertility, access to credit, extension and off-farm activities, tenure security, high temperature, and low rainfall tend to enhance adaptive capacity to climate change.

Government policies are needed to ensure that farmers have access to affordable credit and therefore increase their ability and flexibility to change production strategies in response to changing climate conditions. Also, more investments in irrigation infrastructure are encouraged to increase the resilience of farmers to shortfall in water due to climate variability. However, to promote efficient water use, emphasis should be

Gbetibouo G. A. (2011)

given to reforming water pricing and clearly defined property rights, as well as strengthening of farm-level irrigation efficiency.

The implementation of land reform policy has increased the number of new, emerging farmers who did not have the same skills and information compared to their more experienced counterparts. This implies that improved access to extension services is critical for to increase farmers' awareness of climate change and enhance the adaptive capacity of emerging farmers in South Africa.

Study results also suggest that diversification of livelihoods through providing off-farm income and employment opportunities are an important adaptation strategy for rural households.

Finally, factors such as household size, wealth, farm size and soil fertility provide good indication of households' adaptive capacity level. Therefore these factors are well defined criteria for the selection of beneficiaries' household for government support.

Gbetibouo G. A. (2011)

CHAPTER 7:

SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS

7.1 Introduction

This thesis made an attempt to improve understanding of the interrelations between climate change and agriculture in South Africa with special focus on the role of human agency in determining vulnerability to climate change. The study addressed research questions related to which farming areas are most vulnerable to climate change in South Africa, how farmers have responded to that and what factors influenced their adaptive responses. This chapter provides a summary of the methods used for the intended analysis and obtained results as well as derives policy implications and recommendations for further research.

7.2 Mapping South African farming sector vulnerability to climate change

The study adopted a vulnerability indicator approach to assess the relative distribution of vulnerability across the nine farming provinces of the country. By adopting the indicator approach this study has comprehensively operationalised the concept of vulnerability defined as exposure, sensitivity and adaptive capacity at sub-national level. Nineteen indicators drawn from an extensive review of the literature have been selected to represent both the biophysical socio-economic conditions of studied regions. The selected indicators provide measures of the three components of vulnerability. Frequency of past climate extremes and predicted change in temperature and rainfall by 2050, were selected to characterise the exposure component. The sensitivity component, which reflects the responsiveness of a system to climatic influences, was represented by five human and environmental factors: i) irrigation rate; ii) land degradation index; iii) crop diversification index; iv) share of small-scale and v) rural population density.

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Building on the proposition that adaptive capacity is closely linked to asset ownership ten indicators were selected to represent social, human, financial and physical capital, whereas natural capital was defined under the sensitivity component. Social capital was measured as the share of farmers in farm organisations. Literacy rate and HIV prevalence were used to represent human capital whereas farm income, farm holding size, farm assets, share of people below poverty line, share of agricultural GDP, and access to credit were used to represent financial capital. Physical capital was measured using an infrastructure index.

The principal components analysis (PCA) was then used to assign weights to the selected indicators to construct the overall vulnerability index. Based on the derived index, provinces were classified into stages of vulnerability: i) “low vulnerability” for an index score below -2; ii) “low-medium vulnerability” for an index score between -2 and 0; iii) “medium vulnerability” for an index score between 0 and 2; and iv) “high vulnerability” for an index score above 2.

This analysis revealed that vulnerability to climate change is spatially differentiated across the farming areas in the country. Provinces most exposed to climate change and variability, do not always overlap with those experiencing high sensitivity or low adaptive capacity. The overall vulnerability of the South African farming sector is characterised by a combination of medium-level risk exposure and medium to high levels of social vulnerability. Thus both climate risk exposure and pre-existing environmental and socio-economic conditions are important factors to determine overall vulnerability. Coastal provinces have higher exposure index compared to inland provinces. Vulnerability to climate change is intrinsically linked with the level of socio-economic development. The results show that the most vulnerable agricultural provinces to climate change in South Africa are those provinces with a high number of small scale farmers relying on rain-fed agriculture, a high level of soil and land degradation, a high level of rural population density, high unemployment, low literacy levels and a low infrastructure index.

Gbetibouo G. A. (2011)

7.3 Understanding farmers' perceptions and adaptation to climate change

Analysis of farmers' perception and adaptation responses to climate change was based on data collected from a survey of 794 farmers sampled from the four provinces covered by the study in the Limpopo River Basin. The analysis was conducted in two stages. In the first stage characteristics differentiating farmers who perceived changes in climate from those who did not were investigated. Then determinants of adaptation were analysed. The accuracy of farmers' perceptions of climate change was assessed by comparing their perceptions of long-term changes in temperature and rainfall with climate trends recorded at nearby meteorological stations. A seemingly unrelated biprobit model was then employed to investigate factors influencing farmers' perceptions of climate change.

About 89% of the surveyed farmers perceived an increase in temperature over the past 20 years. This perception was confirmed by metrological statistical records for the Limpopo River Basin between 1960 and 2003, which showed a warming trend occurring mostly in the summer months (October to March). However, despite a majority perception of a decreasing rainfall trend, climate records show no statistically significant trend over the past 40 years. Overall metrological records show large inter-annual variability in the amount of rainfall, and the same pattern was observed in each province.

The seemingly unrelated biprobit model of the twin perception of change in both temperature and rainfall suggests that perceptions are not based entirely on actual climate conditions and changes but are also influenced by other factors such as education, experience and access to extension services.

Even though a large number of farmers interviewed noticed changes in climate, almost two-thirds chose not to undertake any remedial action. Among those farmers who did adapt, common responses included planting different crops, changing crop varieties, changing planting dates, increasing irrigation, diversifying crops, changing the amount of land grazed or under cultivation, and supplementing livestock feed. While adopting a new crop variety was the main strategy used to adapt to increasing temperature, building water-harvesting schemes was a popular strategy for coping with decreased rainfall.

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Farmers cited a number of barriers to adaptation including poverty, lack of access to credit, and lack of savings. Insecure property rights and lack of markets were also cited as significant barriers to adaptation. A few farmers also reported lack of information and knowledge of appropriate adaptation measures as barriers to adaptation.

Both a Heckman probit model and a Multinomial logit model were applied to investigate the determinants of farmers' adaptations strategies to climate change. The results from these models indicate that experienced farmers are more likely to adapt to perceived climate change. In particular, the likelihood of diversifying portfolios (that is, adopting new crops or crop varieties, or using mixed farming systems), changing planting dates, and changing the amount of land under production increases with farm experience. This suggests that farmers with greater management and technical skills are better able to cope with climate change and variability, and to spread risk by exploiting strategic complementarities among activities, such as crop–livestock integration.

Large households were more likely to adapt, indicating that additional household labour may facilitate the adoption of more labour-intensive adaptation options. Large-scale farmers were also more likely to adapt as a result of greater financial resources and access to capital, which enable them to invest in more costly technologies, such as irrigation. Likewise, wealthier households were more likely to change their planting dates in response to perceived climate change. Access to rural services such as extension and credit also increases the likelihood of adaptation. Farmers with access to extension services and therefore more likely to have knowledge of management practices to address climate changes, were more likely to diversify their portfolios in an effort to reduce risk. Access to credit also increases the likelihood that farmers will diversify their portfolios and buy feed supplements for their livestock.

Given that lack of financial resources is one of the major constraints to adaptation, access to credit enables farmers with limited financial resources to purchase the necessary inputs and equipment associated with many adaptation options. Having secure property rights also increases the probability of adaptation. With clear property rights farmers are able to make adaptation decisions involving their land, such as changing the amount of land under cultivation. Access to fertile soil also increases the likelihood that farmers will

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

increase the amount of land under cultivation in response to climate change. While off-farm employment could present a constraint to adaptation by reducing time spent managing farms, the results show that farmers who engage in off-farm activities are more likely to supplement livestock feed.

7.4 Conclusions and implication for research and policy

Three main hypotheses were advanced to be tested in the present study (section 1.4), namely:

- 1) The most exposed provinces to the physical manifestations of climate change (change in average conditions and/ or occurrence of extreme climate events) are not necessary the most vulnerable agricultural provinces to climate change in South Africa when socio-economic conditions are taken into account.
- 2) Farmers' perceptions of climate change correspond with climate data recorded at meteorological stations.
- 3) Improved access to resources such as (credit, extension, information, water, etc.) enhances farm-level use of adaptation measure.

The empirical results presented in this study were found to provide substantial support of the validity of hypothesis 1 and hypothesis 3. However, for hypothesis 2, the results revealed that farmers' perceptions are not entirely based on observed changes in climate conditions but are also influenced by other socio-economic factors. The general conclusions from the study and their policy implications are presented below.

The study reveals that vulnerability to climate change is spatially differentiated across farming areas in South Africa. Even within a same regional setting, farmers have different capacity to adapt to climate change. Thus, although a national climate change adaptation policy is necessary, policymakers should develop region-specific policies and address climate change at provincial level as well as at a lower scale to really tailor to local conditions.

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

The study demonstrated the multifaceted nature of vulnerability that demands consideration of both climate risk exposure and pre-existing environmental and socio-economic conditions. Climate change adaptation policy should be addressed in concomitance with all pre-existing developmental problems and placed within the broader development context. Policy makers should enact measures to support the effective management of environmental resources (e.g., soil, vegetation and water resources); the development of rural infrastructure, promote increased market participation, especially among subsistence farmers, stimulate both agricultural intensification and diversification of livelihoods out of agriculture, and enact social programs and spending on health, education and welfare, which can help maintain and augment both physical and intangible human capital.

The study revealed that perceptions are not only based on observed changes in climate conditions but are also influenced by other factors such as farmers' experience, availability of extension services and access to irrigation and fertile soil. Accordingly, improved farmer education and awareness about climate change could enhance adaptive capacities. Extension services capabilities to provide accurate climate information to farmers are also necessary for reducing vulnerability to climate change.

Investment in improving farmers' access to affordable credit is also expected to give them greater flexibility to modify production strategies in response to climate change. Because access to water for irrigation increases farmers' resilience to climate variability, greater investments in smart irrigation are needed. Reforming pricing, clearly defining property rights, and strengthening farm-level managerial capacity should also impact positively on farmers' capacity to cope with climate risks. More importantly, major efforts are required to create sufficient off-farm employment and income opportunities, and facilitate a smooth transition from subsistence to commercial farming.

Although this thesis made valuable contributions to the literature on vulnerability to climate change and variability the methodology applied has some limitations that call for further research.

Gbetibouo G. A. (2011)

Firstly, the scale of our analysis for the vulnerability assessment is highly aggregated at a regional level. Indeed, there is enormous heterogeneity within provinces in South Africa with regard to household-level resource access, poverty level, and ability to cope with climate change and variability. Although examination of vulnerability can certainly be guided by macro-level analyses, ultimately future work should be done at more disaggregate levels, such as district and village level. Secondly, vulnerability is dynamic in nature, changing overtime with new opportunities and conditions. However, we present a static view of vulnerability holding adaptive capacity and sensitivity indicators constants to the 2002 levels. To capture potential changes over time in indicator approach models, alternative scenarios of future social and economic conditions across provinces in South Africa are needed.

Thirdly, in the study of farmers' adaptation responses, we try to isolate climate change specific adaptations in the agriculture sector. In the real world, farmers faced simultaneously multiple stresses or stimuli (market, policy, environment, etc.), with climate change and variability only one of them. Therefore, research to assess how farmers are currently responding to multiple stresses and identify the trade-offs made by farmers is urgently needed and critical to support adaptation to climate change.

Gbetibouo G. A. (2011)

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APPENDIX

APPENDIX 2.1

SELECTED DEFINITIONS OF VULNERABILITY IN OTHER RESEARCH FIELDS

Table A2.1: Selected definitions of vulnerability in other research fields

Author(s)	Definitions
Gabor and Griffith (1980)	Vulnerability is the threat (to hazardous materials) to which people is exposed (including chemical agents and the ecological situation of the communities and their level of emergency preparedness). Vulnerability is the risk context.
Timmerman (1981)	Vulnerability is the degree to which a system acts adversely to the occurrence of a hazardous event. The degree and quality of the adverse reaction are conditioned by a system's resilience (a measure of the system's capacity to absorb and recover from the event).
UNDRO (1982)	Vulnerability is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude.
Susman et al. (1983)	Vulnerability is the degree to which different classes of society are differentially at risk.
Pijawka and Radwan (1985)	Vulnerability is the threat or interaction between risk and preparedness. It is the degree to which hazardous materials threaten a particular population (risk) and the capacity of the community to reduce the risk or adverse consequences of hazardous materials releases.
Bogard (1989)	Vulnerability is operationally defined as the inability to take effective measures to insurance against losses. When applied to individuals, vulnerability is a consequence of the impossibility or improbability of effective mitigation and is function of our ability to detect the hazards.
Mitchell (1989)	Vulnerability is the potential for loss.
Smith (1992)	Risk from a specific hazard varies through time and according to changes in either (or both) physical exposure or human vulnerability (the breadth of social and economic tolerance available at the same site).
Alexander (1993)	Human vulnerability is a function of the costs and benefits of inhabitants' areas at risk from natural disaster.

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Definitions
Cutter (1993)	Vulnerability is the likelihood that an individual or group will be exposed to and adversely affected by a hazard. It is the interaction of the hazards of place (risk and mitigation) with the social profile of communities.
Watts and Bohle (1993)	Vulnerability is defined in terms of exposure, capacity and potentiality. Accordingly, the prescriptive and normative response to vulnerability is to reduce exposure, enhance coping capacity, strengthen recovery potential and bolster damage control (i.e. minimize destructive consequences) via private and public means.
Blaikie et al. (1994)	By vulnerability we mean the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard. It involves a combination of factors that determine the degree to which someone's life and livelihood are put at risk by a discrete and identifiable event in nature or in society.
Cutter (1996)	Vulnerability is conceived as both a biophysical risk as well as a social response, but with a specific area or geographic domain. This can be geographic space, where vulnerable people and places are located, or social space who in those places is most vulnerable?
Moser (1998)	Any definition requires the identification of two dimensions of vulnerability, its sensitivity (the magnitude of a system's response to an external event) and its resilience (the ease and rapidity of a system's recovery from stress).
IFRC (1999)	Vulnerability can be defined as the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of natural or made-man hazards.
Cutter et al. (2000)	Broadly defined vulnerability is the potential for loss of poverty or life from environmental hazards.
Hoddinot and Quisumbing (2003)	Vulnerability is the likelihood that at a given time in the future, an individual will have a level of welfare below some norm or benchmark.
ISDR (2004)	Vulnerability is defined as the set of conditions and processes resulting from physical, social, economic and environmental factors which increase the susceptibility of a community to the impacts of hazards.

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APPENDIX 2.2

TWO APPROACHES TO THE STUDY OF VULNERABILITY IN CLIMATE CHANGE RESEARCH

Table A2.2: Two approaches to the study of vulnerability in climate change research

	End Point Approach	Starting point Approach
Main discipline	Natural sciences	Social sciences
Definition of vulnerability	Expected net damage for a given level of global climate change	Susceptibility of climate change and variability as determined by socio-economic factors
Root problem	Climate change impacts	People's vulnerability to climate stress
Policy context	Climate change mitigation Compensation Technical adaptation	Social adaptation Sustainable development
Policy question	What are the benefits of climate change mitigation?	How can the vulnerability of societies to climate hazards be reduced?
Research question	What are the expected net impacts of climate change in different regions?	Why are some groups more affected by climate hazards than others?
Vulnerability and adaptive capacity	Adaptive capacity determines vulnerability	Vulnerability determines adaptive capacity
Reference for adaptive capacity	Adaptation to future climate change	Adaptation to current climate variability
Starting point of Analysis	Scenarios of future climate change	Current vulnerability to climatic stimuli

Source: Füssel (2007)

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APPENDIX 4.1

A REVIEW OF METHODS AND INDICATORS USED TO CONSTRUCT VULNERABILITY INDEX

Table A4.1: A review of methods and indicators used to construct vulnerability

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
Cutter <i>et al.</i> (2000)	Vulnerability is place specific and encompass biophysical and social dimensions	Sub-national: County level	Literature review	Equal weight	Biophysical Social	Chemical release Palmer Drought Severity Index Earthquake felt Floods Hail Hurricane surge/wind Tornado Wildfire Total population Total housing units Number of females Number of non white residents Number of people under age 18 Number of people over age 65 Mean house value Number of

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						mobile homes
Moss <i>et al.</i> (2001)	Vulnerability has two dimensions: sensitivity of system or process to climate change and adaptability of that system	National	Literature review and statistical test	Equal weight	Settlement /infrastructure sensitivity Food security Ecosystem sensitivity Human health sensitivity Water resource sensitivity Economic capacity Human and civic resources Environmental capacity	Population at flood risk from sea-level rise Population without access to clean water/sanitation Cereals production area Animal protein consumption/capita % land managed Fertilizer use Completed fertility Life expectancy Renewable supply and inflow Water use GDP (market)/capita Gini index Dependency ratio

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						Literacy Population density SO ₂ /area % land unmanaged
Cutter <i>et al.</i> (2003)	Vulnerability as social vulnerability the product of social inequality	Sub-national: County level	Literature review and statistical test	Equal weight		Personal wealth: per capita income Age Density of the built environment: No of commercial establishments/mi ² % of employed in extractive industries % housing units that are home mobiles % African American % Hispanic % Native American % Asian % employed in service occupations % employed in transportation, communication, and

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						public utilities
Lucas and Hilderink (2004)	vulnerability is determined by the potential impact (exposure plus sensitivity) and the coping capacity	National	Literature review	Equal weight	Exposure Sensitivity Coping capacity	Caloric balance index Food diversity index Fraction agricultural value added in total GDP GINI-coefficient GDP per capita (PPP) index Water stress index Water erosion hazard index Desertification risk index Land availability index Literacy rate index GINI-coefficient Life expectancy index Infrastructure density index GDP per capita (PPP) index
O'Brien <i>et al.</i> (2004)	Vulnerability as a function of	Sub-national:	Literature review	Equal weight	Biophysical	Depth of soil cover

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
	double exposure: climate and globalization, sensitivity and adaptive capacity	district level			Socio-economic Technological	Severity of soil degradation Total amount of replenishable groundwater adult literacy rates degree of gender equity % workforce in agriculture % of landless labourers net irrigated area as % of net sown area Infrastructure Development Index
Vincent (2004)	Two vulnerability: biophysical vulnerability is the sensitivity of the natural environment to the exposure and social vulnerability is the sensitivity of the human environment to the exposure	National	Literature review	Unequal weight	Economic well-being and stability Demographic structure Institutional stability and public infrastructure Global interconnectivity Natural resource dependence	% people below poverty line Change in % urban population % population under 18 and over 65 % Adults 21-49 with HIV/AIDS Public health expenditure as % of GDP Number of mainland telephone lines per

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						1000 people Composite index of corruption Trade balance % rural population
Brenkert and Malone (2005)	Vulnerability of a region function of three factors: exposure, sensitivity and coping capacity	Sub-national: region level	Literature review	Equal weight	Settlement /infrastructure sensitivity Food security Ecosystem sensitivity Human health sensitivity Water resource sensitivity Economic capacity Human and civic resources Environmental capacity	Population at flood risk from sea level rise Population without access to clean water/sanitation Cereals production area Animal protein consumption/capita % land managed Fertilizer use Completed fertility Life expectancy Renewable supply and inflow Water use

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						GDP (market)/capita Gini index Dependency ratio Literacy Population density SO₂/area % land unmanaged
Brooks <i>et al.</i> (2005)	Risk is viewed in terms of outcome, and is a function of physically defined climate hazards and socially constructed vulnerability.	National	Shortlist of potential proxies from expert judgment Statistical analysis	Expert judgment	Health status Education Governance	population with access to sanitation maternal mortality calorific intake life expectancy at birth literacy rate, 15–24-year olds literacy rate, over 15 years literacy ratio (female to male) voice and accountability civil liberties political

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						rights government effectiveness
Patnaik and Narayanan (2005)	Vulnerability has two dimensions: sensitivity of system or process to climate change and adaptability of that system	Sub-national: district level	Literature review	Equal weight	Settlement /infrastructure sensitivity Food security Ecosystem sensitivity Human health sensitivity Water resource sensitivity Economic capacity Human and civic resources Environmental capacity	Population at flood risk from sea-level rise Population without access to clean water/sanitation Cereals production area Animal protein consumption/capita % land managed Fertilizer use Completed fertility Life expectancy Renewable supply and inflow Water use GDP (market)/capita Gini index Dependency

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						ratio Literacy Population density SO ₂ /area % land unmanaged
Sullivan and Meigh (2005)	Vulnerability is spatially variable, reflecting local economic, social and cultural characteristics, as well as the local physical conditions.	National	Literature review	Equal weight	Resources Access Capacity Use Environment Geospatial	Surface and groundwater: amount, variability, quality Distance to safe source Time of household water collection Access to water for irrigation Access to water for industrial Income Education Health Domestic use Agricultural use Industrial use Ecological integrity

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						Geographical factors
Pulhin <i>et al.</i> (2006)	Vulnerability to be a function of two major variables: sensitivity of the system to climate-related events and its coping capacity.	Household level data	Literature review	A priori unequal weight cross check with local consultation and statistical test	Food Water Livelihood Health	Seeds availability Crop yield Domestic water Irrigation water Sources of income Sufficiency of income Health problems Access to medical services
Rygel <i>et al.</i> (2006)	Vulnerability is place specific and encompass biophysical and social dimensions	Sub-national: Census block group	Literature review and statistical test	Pareto ranking	Physical exposure Social vulnerability	Storm-surge flood risk zones Poverty Gender Race Ethnicity Age Disability
Adepetu and Berthe (2007)	Vulnerability is place specific and encompass biophysical and social dimensions	Household level data	Literature review and statistical test	local consultation		Acreage under cultivation Crop yield Dependency ratio Livestock

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						ownership Gender household head Livelihood diversification Annual cash income Drought preparedness Education Land tenure Type of house Self-sufficiency in food production Family and social networks Quality of household
Hebb and Mortsch (2007)	Vulnerability is place specific and encompass biophysical and social dimensions	Sub-national: watershed	Literature review	Equal weight	Capacity Access to resources Situational exposure	People over 65 years People under 19 years No knowledge of official languages Females Low income households Singe parent families Rely on public transit

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						Renters Housing type Period of construction
Swanson <i>et al.</i> (2007)	The vulnerability as a function of a system's exposure to climate change effects and its adaptive capacity to deal with those effects	Sub-national: census division	Literature review	Equal weight	Economic resources Technology Information and skills management Infrastructure Institutions and networks	Ratio of gross farm receipts to total capital investment Ratio of income to expenses Off farm earnings Ratio off farm time to on farm time Ratio of value irrigation equipment Ratio of farms with computer Ratio of value in tractors under 100 hp Ratio of technological ly demanding farm types Ratio of farms doing computer reporting Ratio of area of no-till or zero-till seedling Ratio of farm with

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
					Equity	windbreaks and shelter belts Ratio of total farms paying agricultural labour Proportion of area in dependable agricultural land Ratio of surface water area No. and yield of wells Ratio of high capacity roads Ratio of total farms with email Ratio of farms with internet Distance to nearest agricultural education institution Unemployment rate Ratio of labour force in health Ratio of farms reporting sales
Cutter and	Social	Sub-	Literature	Equal		Race

Vulnerability and adaptation of farming to climate change in South Africa

Gbetibouo G. A. (2011)

Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
Finch (2008)	vulnerability temporally and spatially determined	national: County level	review and statistical test	weight		Ethnicity Socio-economic class Gender
Hegglin and Huggel (2008)	Vulnerability is place specific and encompass biophysical and social dimensions	Sub-national: County level	Literature review	Expert judgment	Physical Social	Outburst probability Magnitude Trajectory Population density Age (below 15 and above 64) Poverty mapping Structural prevention and urban planning Existence and implementation of emergency measure
Thornton <i>et al.</i> (2008)	Vulnerability as depending of the five livelihoods assets	National	Literature review	Principal component	Natural capital Physical capital Social Capital Human Capital	Suitability for crop production Soil degradation due to wind, water & human induced erosion Internal water resources by sub-basin Accessibility to markets Human

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Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
					Financial capital	Poverty Index Governance Infant mortality rate % children underweight Malaria risk Public health expenditure HIV/AIDS prevalence Agricultural GDP Global interconnectivity
Hahn <i>et al.</i> (2009)	Vulnerability as depending of the five livelihoods assets	Household level data	Literature review	Equal weight	Socio-demographic Livelihood Health	Dependency ratio % female headed households % household head with no schooling % households with orphans % households with family member working in a different community % households dependent on agricultural income only Average agricultural livelihood diversification

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Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
					Social networks Food Water Natural disaster and climate variability	n Time to health centre % households member with chronic illness % households member miss work or school in the last 2 weeks Average malaria exposure prevention index Average ratio receive /give Average ratio borrow/lend % households with no government assistance in the past 12 months % households dependent on family farm food Average number of months households struggle to find food Average crop diversity index % households that do not save crops % households that do not

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Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						save seeds % households reporting water conflicts % households that utilize natural water source Average time to water source % households that do not have a consistent water supply Inverse of the average number of litres of water stored per household Average number of flood/drought /cyclone in the past 6 years % households that did not received warning % households with injury Standard deviation rainfall Standard deviation temperature
Perch-Nielsen (2009)	Vulnerability based on three factors: exposure,	National	Literature review	Different weighting schemes	Exposure	Frequency/intensity extreme

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Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
	sensitivity and coping capacity				Sensitivity Adaptive capacity	events Rise in sea-level Change in biodiversity Change in precipitation/evapotranspiration Change ins snow security Mitigation policies Climate related tourism Infrastructure (situation, value, robustness) Insurance availability Economic resources Innovation potential Technologies Knowledge Existence and effectiveness of institutions
Yusuf and Francisco (2009)	Vulnerability of a region function of three factors: exposure, sensitivity and coping capacity	Sub-national: district level	Literature review and expert consultation	Equal weight	Exposure Sensitivity Adaptive capacity	Multiple hazard map (cyclone, flood, drought, landslide, sea-level rise) Population density Protected areas

Vulnerability and adaptation of farming to climate change in South Africa

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Author(s)	Conceptual framework of vulnerability	Scale	Method of variables selection	Weighting method	Components	Variables
						Human development index Poverty incidence Income inequality Electricity coverage Extent of irrigation Road density Communication
Dasgupta and Baschieri (2010)	Vulnerability as depending of the five livelihoods assets	Household level data	Literature review	Principal component	Labour capital Human capital Productive assets Social capital	Type of work of household head % of income from agriculture Remittances % food expenditure % household that are dependent Household head education level Access to an hospital care Number of productive assets System of mutual aid Road nearby

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APPENDIX 5.1

CROP DIVERSIFICATION INDEX

Following Bathia (1965), for an objective measurement of crop diversification we calculate the following index:

Index of crop diversification = (Percentage of sown area under x crops)/Number of x crops

where x crops are those crops that individually occupy 5% or more of the sown area in a province. The higher the index value, the lower the degree of crop diversification and vice versa.

Table A5.1: Components of the crop diversification index

Provinces	Percentage of sown area under x crops	Number of x crops	Index value
Eastern Cape	0.63	4	0.16
Free State	0.86	3	0.29
Gauteng	0.76	2	0.38
Kwazulu-Natal	0.78	2	0.39
Limpopo	0.60	5	0.12
Mpumalanga	0.66	2	0.33
North West	0.86	2	0.43
Northern Cape	0.71	4	0.18
Western Cape	0.75	6	0.12

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APPENDIX 5.2

INFRASTRUCTURE INDEX

The following indicators are used in calculating the infrastructure index.

1. Length of all weather road per land area
2. Percentage of households with access to telephone (landline or cell phone)
3. Number of schools per 100000 people
4. Number of hospitals per 100000 people
5. Percentage of households with access to electricity from mains for cooking
6. Percentage of households with access to pipe water

The infrastructure index is calculated using PCA to generate weights:

$$I_{ij} = f_{11} (i^*_{1j} - i^*_{11})/(s^*_{11}) + \dots + f_{1N} (i^*_{Nj} - i^*_{N1})/(s^*_{N1})$$

where I is the infrastructure index, f_{nn} are the scoring factors used as weights, and i are the indicators.

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Table A5.2: Components of the infrastructure index

Provinces	Road_ network (% area)	Telephone_ Access (% hh)	Schools Per 100000pp	Hospitals per 100000pp	Energy (% hh)	Water (% hh)	Infra- structure index
Eastern Cape	0.08	40.1	95	1.46	28.2	20.6	-2.77
Free State	0.38	51.7	91	1.15	57.6	37.8	-0.35
Gauteng	0.45	69.6	25	0.35	85	58.8	2.96
Kwazulu- Natal	0.41	45.7	61	0.77	59.3	34.9	0.11
Limpopo	0.23	45.8	88	0.89	26.1	28.3	-1.69
Mpumalanga	0.32	58.6	62	0.83	13	27.7	-0.52
North West	0.31	51.4	63	0.71	59.3	19.9	-0.25
Northern Cape	0.20	48.2	58	3.28	68.1	48.7	-0.41
Western Cape	0.31	70.8	35	1.19	85.2	99.1	2.93

APPENDIX 5.3

DESCRIPTIVE ANALYSES TABLES

Table A5.3: Exposure indicators

Provinces	Incremental in temperature (degree Celsius)	Percentage change in rainfall (%)	Frequency of floods and droughts
Eastern Cape	1.87	17	7
Free State	2.70	22	3
Gauteng	2.51	25	5
Kwazulu-Natal	1.95	19	12
Limpopo	2.52	23	6
Mpumalanga	2.70	22	5
North West	2.67	25	4
Northern Cape	2.77	18	2
Western Cape	1.67	12	7

Frequency: Number of occurrence of droughts/floods events from 1960 to 2006

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Table A5.4: Sensitivity indicators

Provinces	% Irrigated land	Soil degradation index	Veld degradation Index	Crop diversification index	% Small-scale farmers	% Non-urban population
Eastern Cape	0.37	200	116	0.16	0.96	0.62
Free State	0.06	48	86	0.29	0.30	0.25
Gauteng	0.10	113	31	0.38	0.00	0.04
Kwazulu-Natal	0.24	253	187	0.39	0.88	0.55
Limpopo	0.28	255	189	0.12	0.98	0.9
Mpumalanga	0.18	143	81	0.33	0.82	0.61
North West	0.06	149	122	0.43	0.67	0.59
Northern Cape	0.65	92	140	0.18	0.00	0.19
Western Cape	0.09	77	93	0.12	0.00	0.1

Table A5.5: Adaptive capacity indicators

Provinces	Social capital		Human capital		Financial capital					Physical capital
	Access to credit (R'000)	Farm organisation (%)	Literacy rate (%)	HIV prevalence (%)	Net farm income (R'000)	Unemployment rate (%)	Average farm holding size (ha)	Agricultural GDP (%)	Farm assets (R'000)	Infrastructure index
Eastern Cape	1948108.00	0.05	60.1	21.7	653161.00	0.30	150	5.4	7704486.00	-2.77
Free State	5060522.00	0.19	65.3	30.1	2756739.00	0.29	343	10.4	12477269.00	-0.35
Gauteng	997487.00	0.18	81.4	29.8	962990.00	0.26	1518	0.6	2962276.00	2.95
Kwazulu-Natal	3144070.00	0.06	64.8	33.5	1848480.00	0.29	76	5.6	9900145.00	0.11
Limpopo	2734233.00	0.04	58.7	14.5	998136.00	0.28	372	8	9681405.00	-1.69
Mpumalanga	3164808.00	0.19	60.7	29.2	1574285.00	0.25	239	7.8	9760910.00	-0.52
North West	2808754.00	0.15	62.9	25.2	1379077.00	0.28	361	8.9	84196760.00	-0.24
Northern Cape	3086128.00	0.08	63.7	15.9	909630.00	0.25	3815	10	9698368.00	-0.41
Western Cape	7913782.00	0.06	80.4	8.6	2547461.00	0.18	1475	6.5	27863636.00	2.92

Table A5.6: Normalised value of the indicators for the vulnerability index

Provinces	Incremental in temperature (degrees Celsius)	Percentage change in rainfall (%)	Frequency of floods and droughts	% Irrigated land	Soil degradation index	Veld degradation index	Crop diversification index	% Small -scale farmers	% Non -urban population	Access to credit (R'000)	Farm organisation (%)	Literacy rate (%)
Eastern Cape	18.18	61.54	50	47.46	73.43	53.80	12.90	97.96	100	13.74	6.67	6.17
Free State	93.64	23.08	10	100.00	0.00	34.81	54.84	30.61	36.21	58.75	100.00	29.07
Gauteng	76.36	0.00	30	93.22	31.40	0.00	83.87	0.00	0.00	0.00	93.33	100.00
Kwazulu- Natal	25.45	46.15	100	69.49	99.03	98.73	87.10	89.80	87.93	31.04	13.33	26.87
Limpopo	77.27	15.38	40	62.71	100.00	100.00	0.00	100.00	148.28	25.11	0.00	0.00
Mpumalanga	93.64	23.08	30	79.66	45.89	31.65	67.74	83.67	98.28	31.34	100.00	8.81
North West	90.91	0.00	20	100.00	48.79	57.59	100.00	68.37	94.83	26.19	73.33	18.50
Northern Cape	100.00	53.85	0	0.00	21.26	68.99	19.35	0.00	25.86	30.20	26.67	22.03
Western Cape	0.00	100.00	50	94.92	14.01	39.24	0.00	0.00	10.34	100.00	13.33	95.59

Provinces	HIV prevalence (%)	Net farm income (R'000)	Unemployment rate (%)	Average farm holding size (ha)	Agricultural GDP (%)	Farm assets (R'000)	Infrastructure index
Eastern Cape	47.39	0	0	1.98	51.02	5.84	0
Free State	13.65	100	8.33	7.14	0.00	11.71	42.31
Gauteng	14.86	14.73	33.33	38.57	100.00	0.00	100.00
Kwazulu-Natal	0.00	56.82	8.33	0.00	48.98	8.54	50.35
Limpopo	76.31	16.40	16.67	7.92	24.49	8.27	18.88
Mpumalanga	17.27	43.79	41.67	4.36	26.53	8.37	39.34
North West	33.33	34.51	16.67	7.62	15.31	100.00	44.23
Northern Cape	70.68	12.19	41.67	100.00	4.08	8.29	41.26
Western Cape	100.00	90.05	100	37.42	39.80	30.65	99.48

APPENDIX 6.1

QUESTIONNAIRE ON CLIMATE CHANGE AND ADAPTATIONS OPTIONS

Section 9: Climate change and adaptation options

9.1 Have you noticed any long-term changes in the mean temperature over the last 20 years? (please explain) Please mark ☐ with x if used.

If too difficult: Has the number of hot days stayed the same, increased, or declined over the last 20 years? (please explain) ☐

9.2 Have you noticed any long-term changes in the mean rainfall over the last 20 years? (please explain) ☐

If too difficult: Has the number of rainfall days stayed the same, increased, or declined over the last 20 years? (please explain) ☐

9.3 What adjustments in your farming have you made to these long-term shifts in temperature? Please list below.

9.4 What adjustments in your farming have you made to these long-term shifts in rainfall? Please list below.

9.5 Check the answers for **9.3** and **9.4** and then ask for the ones not yet listed there: What additional measures would you consider in the future?

9.5.1 Why did you not	9.5.2 Reason (key)
1. change crop variety	
2. build a water-harvesting scheme	
3. implement soil conservation techniques	
4. buy insurance	
5. put trees for shading	
6. irrigate more	

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7. change from crop to livestock	
8. reduce number of livestock	
9 migrate to urban area	
10.find off-farm job	
11.lease your land	

Key for 9.5.2: 1: lack of money, 2: lack of information, 3: shortage of labor, 5: Other [write into the lines provided above]

9.6 What were the main constraints/difficulties in changing your farming ways?

9.7 Have you seen any changes in the number of malaria cases over the last 20 years? (please explain)

9.8 Have you seen changes in the vegetation cover over the last 5 years? (please explain)

APPENDIX 6.2

FURTHER DESCRIPTIVE ANALYSES OF FARMERS' PERCEPTION OF CLIMATE CHANGE

Table A6.1: Perceptions of changes in temperature by farmer experience (%)

	Increased	Decreased	More or less extreme	Others	No change	Don't know
Total population	89.32	1.56	1.56	2.21	5.08	0.26
Low experience 0–10 years	89.01	1.76	1.32	2.64	5.05	0.22
Medium experience 10–30 years	87.50	1.39	2.78	1.85	6.02	0.46
High experience 30 years +	94.85	1.03	0	1.03	3.09	0
Test: Equality of populations: The Kruskal-Wallis Test chi-squared = 1.105 with 2 d.f. probability = 0.5755						

Table A6.2: Perceptions of changes in rainfall by farmer experience (%)

	Increased	Decreased	Change in timing of rains (earlier/ later/erratic)	Change in frequency of droughts/floods	Others	No change	Don't know	Decrease in rainfall and change in timing
Total population	1.69	81.25	5.34	0.65	1.43	2.21	0.39	7.03
Low experience 0– 0 years	1.10	78.51	6.14	0.66	1.75	2.41	0.44	8.99
Medium experience 10– 0 years	2.79	86.05	4.19	0.47	0.93	1.86	0.47	3.26
High experience 30 years +	2.06	83.51	4.12	1.03	1.03	2.06	0.00	6.19
Test: Equality of populations: The Kruskal-Wallis Test chi-squared = 1.105 with 2 d.f. probability = 0.5755								

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Table A6.3: Perceptions of changes in temperature by farmer education level (%)

	Increased	Decreased	More or less extreme	Others	No change	Don't know
Total population	89.32	1.56	1.56	2.21	5.08	0.26
No formal education						
0 years	88.00	2.00	2.67	2.00	4.67	0.67
Standard education						
1–7 years	91.06	1.63	0.00	0.81	6.50	0.00
Secondary education						
8–12 years	89.06	1.29	1.80	2.58	4.38	0.26
Tertiary education						
13 years +	87.85	1.87	0.93	2.80	6.54	0.00
Test: Equality of populations: The Kruskal-Wallis Test chi-squared = 0.253 with 3 d.f. probability = 0.9687						

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Table A6.4: Perceptions of changes in rainfall by farmer education level (%)

	Increased	Decreased	Change in timing of rains (earlier/ later/erratic)	Change in frequency of droughts/floods	Others	No change	Don't know	Decreased rainfall change timing
Total population	1.69	81.25	5.34	0.65	1.43	2.21	0.39	7.03
No formal education 0 years	1.33	80.00	6.67	0.67	0.67	0.67	0.00	10.00
Standard education 1–7 years	1.61	83.87	5.65	0.81	0.81	1.61	0.00	6.45
Secondary education 8–12 years	1.80	84.06	3.60	2.06	2.06	2.83	0.77	4.63
Tertiary education 13 years +	1.90	69.52	9.52	0.95	0.95	2.86	0.00	12.38
Test: Equality of populations: The Kruskal-Wallis Test chi-squared = 0.253 with 3 d.f. probability = 0.9687								

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APPENDIX 6.3

CORRELATION MATRIX OF THE INDEPENDENT VARIABLES FOR THE ADAPTATION MODELS

Table A6.5: Correlation matrix of the independent variables for the adaptation models

	Age	Education	Gender	Household size	Farming experience	wealth	Farm size	Soil fertility	Access water for irrigation	extension	Climate Information	credit	Off farm employment	Land tenure
Age	1.00													
Education	-0.39	1.00												
Gender	0.14	0.06	1.00											
Household size	0.08	-0.21	0.02	1.00										
Farming experience	0.29	0.006	-0.007	-0.0002	1.00									
Wealth	0.06	0.07	0.06	0.03	-0.05	1.00								
Farm size	-0.02	0.13	0.10	-0.01	0.05	0.08	1.00							
Soil fertility	-0.03	-0.08	-0.03	0.02	0.06	-0.03	-0.06	1.00						
Access water for irrigation	-0.10	0.04	0.02	-0.07	-0.10	0.08	0.15	-0.05	1.00					
Extension	0.003	-0.02	-0.04	-0.02	-0.12	0.04	0.003	-0.07	0.09	1.00				
Climate Information	0.08	-0.06	0.02	0.03	0.05	-0.02	0.01	0.007	-0.03	0.24	1.00			
Credit	-0.04	0.11	0.03	0.002	-0.03	0.12	0.10	0.008	0.11	-0.03	-0.09	1.00		
Off farm employment	-0.11	0.20	0.05	-0.01	-0.05	0.16	-0.02	0.03	0.05	0.02	-0.09	0.08	1.00	
Land tenure	0.03	0.06	0.14	-0.06	-0.09	0.22	0.12	-0.09	0.17	0.07	-0.04	0.09	0.06	1.00

APPENDIX 6.4

SUMMARY STATISTICS OF THE VARIABLES FOR THE ADAPTATION MODELS

Table A6.6: Summary statistics of the variables for the adaptation models

Variables	Observations	Mean	Standard deviation	Minimum	Maximum
Age	771	55.32	12.87	18	100
Education	775	7.39	5.10	0	33
Household size	784	6.22	2.99	1	24
Farming experience	784	12.51	11.72	1	60
Wealth	781	0.000000653	1.50662	-3.9677	2.123881
	Choices	Frequency	Percent	Cumulative	
Gender	0	216	27.55	27.55	
	1	568	72.45	100	
	Total	784			
Farm size	0	730	91.94	91.94	
	1	64	8.06	100.00	
	Total	794			
Soil fertility	1	231	30.72	30.72	
	2	443	58.91	83.63	
	3	78	10.37	100	
	Total	752	100		
Access water for irrigation	0	201	26.80	26.80	
	1	549	73.20	100	
	Total	750	100		
Extension	0	303	40.08	39.66	

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	1	453	59.92	100
	Total	756	100	
Climate Information	0	455	63.46	63.46
	1	262	36.54	100
	Total	717	100	
Credit	0	616	77.58	77.58
	1	178	22.42	100
	Total	794	100	
Off farm employment	0	516	69.45	69.45
	1	227	30.55	100
	Total	743	100	
Land tenure	0	419	56.17	56.17
	1	327	43.83	100
	Total	746	100	
Limpopo		432	54.48	
North West		110	13.87	
Mpumalanga		202	27.47	
Perceive change in temperature	0	41	5.34	5.34
	1	727	94.66	100
	Total	768	100	
Perceive change in rainfall	0	20	2.60	2.60
	1	748	97.40	100
	Total	768	100	
Adaptation to temperature change	0	494	68.50	68.50
	1	223	31.10	100
	Total	717	100	
Adaptation to rainfall change	0	497	67.34	67.34
	1	241	32.66	100
	Total	738	100	
No Adaptation	0	298	39.16	60.84
	1	463	60.84	100
	Total	761	100	