INTERNATIONAL FOOD
POLICY RESEARCH INSTITUTE
sustainable solutions for ending hunger and poverty

Supported by the CGIAR

IFPRI Discussion Paper 00885

August 2009

Mapping South African Farming Sector Vulnerability to Climate Change and Variability

A Subnational Assessment

Glwadys Aymone Gbetibouo
Claudia Ringler

Environment and Production Technology Division

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI) was established in 1975. IFPRI is one of 15 agricultural research centers that receive principal funding from governments, private foundations, and international and regional organizations, most of which are members of the Consultative Group on International Agricultural Research (CGIAR).

FINANCIAL CONTRIBUTORS AND PARTNERS

IFPRI's research, capacity strengthening, and communications work is made possible by its financial contributors and partners. IFPRI receives its principal funding from governments, private foundations, and international and regional organizations, most of which are members of the Consultative Group on International Agricultural Research (CGIAR). IFPRI gratefully acknowledges the generous unrestricted funding from Australia, Canada, China, Finland, France, Germany, India, Ireland, Italy, Japan, Netherlands, Norway, South Africa, Sweden, Switzerland, United Kingdom, United States, and World Bank.

AUTHORS

Glwadys Aymone Gbetibouo, Centre for Environmental Economics and Policy in Africa
Department of Agricultural Economics, University of Pretoria
glwadys.gbetibouo@up.ac.za or gbetibouo@yahoo.fr

Claudia Ringler, International Food Policy Research Institute
Senior Research Fellow, Environment and Production Technology Division
International Food Policy Research Institute

Notices

[1] Effective January 2007, the Discussion Paper series within each division and the Director General's Office of IFPRI were merged into one IFPRI–wide Discussion Paper series. The new series begins with number 00689, reflecting the prior publication of 688 discussion papers within the dispersed series. The earlier series are available on IFPRI's website at www.ifpri.org/pubs/otherpubs.htm#dp.

[2] IFPRI Discussion Papers contain preliminary material and research results. They have not been subject to formal external reviews managed by IFPRI's Publications Review Committee but have been reviewed by at least one internal and/or external reviewer. They are circulated in order to stimulate discussion and critical comment.

Copyright 2008 International Food Policy Research Institute. All rights reserved. Sections of this material may be reproduced for personal and not-for-profit use without the express written permission of but with acknowledgment to IFPRI. To reproduce the material contained herein for profit or commercial use requires express written permission. To obtain permission, contact the Communications Division at ifpri-copyright@cgiar.org.

Contents

List of Tables

List of Figures

ACKNOWLEDGMENTS

This work was supported by the Federal Ministry for Economic Cooperation and Development (Germany) as part of the "Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa" project, which forms part of the CGIAR Challenge Program on Water and Food. Support was also received under the IFPRI DGO Small Grants Initiative Program.

ABSTRACT

This paper analyzes the vulnerability of South African farmers to climate change and variability by developing a vulnerability index and comparing vulnerability indicators across the nine provinces of the country. Nineteen environmental and socio-economic indicators are identified to reflect the three components of vulnerability: exposure, sensitivity, and adaptive capacity. The results of the study show that the region's most vulnerable to climate change and variability also have a higher capacity to adapt to climate change. Furthermore, vulnerability to climate change and variability is intrinsically linked with social and economic development. The Western Cape and Gauteng provinces, which have high levels of infrastructure development, high literacy rates, and low shares of agriculture in total GDP, are relatively low on the vulnerability index. In contrast, the highly vulnerable regions of Limpopo, KwaZulu Natal and the Eastern Cape are characterized by densely populated rural areas, large numbers of small-scale farmers, high dependency on rainfed agriculture and high land degradation. These large differences in the extent of vulnerability among provinces suggest that policy makers should develop region-specific policies and address climate change at the local level.

Keywords: climate change and variability, agriculture, vulnerability, adaptive capacity, exposure, sensitivity

ABBREVIATIONS AND ACRONYMS

IPCC	Intergovernmental Panel on Climate Change
SAR	Second Assessment Report
TAR	Third Assessment Report
USAID	United States Agency for International Development
GDP	growth domestic product
VAD	value added
NOAA	National Oceanic and Atmospheric Administration
PCA	principal component analysis
SRES	Special Report on Emissions Scenarios

1. INTRODUCTION

In Southern Africa, the manifestations of climate change are predicted to be greatest in the northern regions. Temperature increases in the range of 10C to 30C are expected by the mid 21st century, with the highest increases expected for the most arid parts of Southern Africa. Of greater consequence for South Africa, as a semi-arid country, is the prediction of broad rainfall reductions (in the range 5 to 10 percent) for the summer rainfall region of the country. This rainfall reduction is predicted to be accompanied an increasing incidence of both droughts and floods, with prolonged dry spells followed by intense storms. A marginal increase in early rainfall is predicted for the winter rainfall region of the country (DEAT 2004).

These predictions raise concerns that climate change could have a significant adverse impact on crop 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 analyze the impact of global climate change on agriculture in South Africa. These studies focus on the implications of future climate change scenarios for crop yields and production, and largely emphasize the physical impacts of climate change on crop yields (Schulze et al. 1993; Du Toit et al. 2002; Kiker 2002; Kiker et al. 2002) and the economic impacts derived from yields losses (Erasmus et al. 2000; Poonyth et al. 2002). Other studies develop a more comprehensive analysis of the economic impacts by including adaptation options (Deressa 2003; Gbetibouo 2004; Gbetibouo and Hassan 2005; Benhin 2006). Based on predictions regarding the physiological responses of affected plants, these studies predict that climate change will adversely impact the agricultural sector, induce (or require) major shifts in farming practices and patterns in different regions of the country, and have significant effects on crop yields (e.g., some of the marginal western areas are predicted to become unsuitable for the production of maize, the main staple crop).

While it is increasingly accepted that the vulnerability of agricultural populations to climatic conditions cannot be solely understood through the quantification of biophysical impacts, no previous climate change study in South Africa has explored the social aspects of vulnerability to climate change with an in depth examination of the underlying socio-economic and institutional factors that determine how farmers respond to and cope with climate hazards.

The degree to which climatic events affect an agricultural system depends on a wide variety of factors, including (among other things) the types of crops or livestock produced, the scale of the operation, the farm's orientation towards commercial or subsistence purposes, the quality of the natural resource base, and specific human variables of the farm's 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.

With a developed commercial farming sector functioning alongside a large subsistence farming sector and a wide variety of crops geographically distributed across the country due to variations in climate patterns, the agricultural sector of South Africa displays a diverse range of social, economic, political and environmental conditions. As this suggests that vulnerability is not evenly distributed across the regions and social groups in South Africa, it becomes more challenging to develop a methodology for vulnerability assessment that accurately captures the spatial dimension of vulnerability in the country. We therefore need to identify the agricultural areas, production systems, and populations that are most vulnerable to climate change.

The aim of this paper is to examine the vulnerability of South Africa's farming sector to climate change by developing a nationwide province-level vulnerability profile that will identify the most vulnerable farming areas in South Africa.

The remainder of this paper is organized as follows. The next section outlines the conceptual framework for this research. Section 3 gives an overview of the analytical tools available for vulnerability assessment. Section 4 describes the methods applied in the various stages of creating the vulnerability index. Section 5 presents the results of the study. Section 6 concludes, discusses policy implications, and outlines some directions for further research.

2. THE CONCEPTUAL FRAMEWORK OF VULNERABILITY

Vulnerability in Climate Change Research

Although the scientific use of the word "vulnerability" has its origins in geography, natural hazards research, and the analysis of food insecurity and famine, the concept of vulnerability has gained increasing importance within the global change research community in recent years. Vulnerability is conceptualized in different ways across different disciplines. Liverman (1990) noted that vulnerability has been equated to concepts such as resilience, risk, marginality, adaptability, and exposure. This diversity of conceptualization is due to the fact that the term "vulnerability" has been used in different policy contexts, referring to different systems exposed to different hazards.

The climate change literature provides two main distinct epistemological approaches to conceptualizing vulnerability. One approach views vulnerability as the "end point," in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard. 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 (Kelly and Adger 2000; Brooks 2003).

The end point approach is found in earlier studies of integrated assessment modeling 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. This approach emphasizes the physical dimensions of vulnerability. According to O'Brien et al. (2004a), in this approach, assessment of vulnerability is the end point of an analytic sequence that begins with projections of future emission trends, moves on to the development of climate scenarios, and then progresses through biophysical impact studies and the identification of adaptive options. 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 terms of both impacts and adaptations.

On the other hand, the "starting point" approach to the assessment of vulnerability to climate change has its origins in studies assessing the vulnerability of social groups to food insecurity and famine (Sen 1981; Watts and Bohle 1993; Bohle et al. 1994) and vulnerability to natural hazards (Blaikie et al. 1994, Cutter, 1996). This approach also draws on the entitlement literature regarding access to resources, on the political economy literature in explaining the factors that lead to vulnerability, and on the social capital literature for the means of claiming entitlements and pursuing coping mechanisms (Adger 1996).

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 existent state, which is their capacity to respond to that hazard, rather than by what may or may not happen in the future. Vulnerability is determined by the internal properties of a system, and is a variable condition generated by multiple environmental and social processes, including climate change. Vulnerability depends on the context; the factors that make a system vulnerable to a hazard will depend on the nature of the system and the type of hazard in question. Thus, the starting point approach diagnoses inherent social and economic processes of marginalization and inequalities as the causes of climate vulnerability, and seeks to identify ways to address these processes (O'Brien et al. 2004a). As viewed through the starting point approach, the inability to cope with or adapt to climate variability and change may be termed "social vulnerability," since we are concerned about social systems.

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. (2004a) argue that by viewing vulnerability as an end point, adaptations 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. Table 1 summarizes the main differences between the two approaches to vulnerability currently being utilized in the field of climate change research.

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 prioritize political and research efforts toward particularly vulnerable sectors and regions, and develop adaptation strategies that reduce climate-sensitive risks independent of their attribution (Füssel and Klein 2006; O'Brien et al. 2004a).

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, any assessment of the consequences of climate change will rest on a combination of these two approaches; indeed, the contrast drawn in the previous paragraphs 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 conceptualization. In an effort to find a compromise between these two approaches, 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 (2003a) vulnerability/sustainability framework and Cutter's hazards-of-place model of vulnerability (Cutter 1996; Cutter et al. 2000). Thus far, most of these frameworks remain relatively untested. According to Turner et al. (2003b), 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), O'Brien et al. (2004b), Thornton et al. (2006) and Hebb and Mortsch (2007) are examples of case studies that attempt to use reduced and integrated frameworks of vulnerability. These approaches are detailed in Appendix Table A.1.

Table 1. 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).

Basic Components of Vulnerability

Chambers (1989) defines vulnerability as exposure to 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 defenselessness 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 Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR) and Moser (1998) change the focus of vulnerability from emphasizing internal/coping and external/exposure, and examine 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 (Watson et al. 1996). According to Moser (1998), any definition of vulnerability requires the identification of two components: 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.

The IPCC Third Assessment Report (TAR) reconciles 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" (McCarthy et al. 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 (Füssel and Klein 2006). The IPCC Fourth Assessment Report (AR4), which reports recent advances in our understanding of climate change, contains a 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.

Others authors also characterize vulnerability using these three dimensions. 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 mobilize 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) recognize 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 is understood as a function of three components: exposure, sensitivity and adaptive capacity, which are influenced by a range of biophysical and socio-economic factors (TERI 2003).

3. VULNBERABILITY ASSESSMENT: ANALYTICAL TOOLS

Approaches to vulnerability assessment attempt to explore questions about who and what are vulnerable, to what are they vulnerable, their degree of vulnerability, the causes of their vulnerability, and 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). Despite the many challenges that exist in quantifying vulnerability, several quantitative and semi-quantitative metrics have been proposed and applied. These may be classified into two main approaches: the indicator approach and vulnerability variable assessments.

Vulnerability variable assessments measure and assess the vulnerability of selected variables of concern to specific sets of stressors. Vulnerability is defined in terms of the changes that have occurred or will occur in these selected variables (e.g., household assets or income) or stressors. This method can assess relationships across a wide range of stressors. To the extent that the selected stressors characterize a given place, they provide an important indication of its vulnerability (Luers et al. 2003). A few generic vulnerability metrics have been proposed. For example, the variability of selected variables of concern has been applied as a metric of vulnerability, especially in economic and agricultural studies (Pritchett et al. 2000; Heitzmann et al. 2002; Luers et al. 2003). Another generic metric is the probability that a variable of concern will cross a threshold (Schimmelpfennig and Yohe 1999; Mansuri and Healy 2002). While these metrics are useful, they are not sufficient to fully capture all the dimensions of vulnerability. Indeed, no single measure can fully capture the multiple dimensions of vulnerability (Luers et al. 2003).

The indicator approach 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. This approach can be applied at any scale (e.g., household, county/district, national, system). The major limitation of the indicator approach is its inability to capture the complex temporal and social dynamics of the various systems being measured. In addition, the application of indices is limited by considerable subjectivity in the selection of variables and their relative weights, by the availability of data at various scales, and by the difficulty of testing or validating the different metrics (Luers et al. 2003). However, the indicator approach is valuable for monitoring trends and exploring conceptual frameworks. According to Leichenko and O’Brien (2002), composite indices capture the multi-dimensionality of vulnerability in a comprehensible form. Vulnerability indicators are needed for practical decision-making processes, such as to provide policy makers with appropriate information about where the most vulnerable individuals are located. The identification of zones of vulnerability provides a systematic rationale for targeting proactive measures aimed at protecting populations. Thus, policy makers use indicators not only for understanding vulnerability, but also for direct decision making (knowledge of action). According to Vogel and O’Brien (2004), capturing the differential elements of vulnerability is a prerequisite for the formulation and implementation of policies that will promote equitable and sustainable development. The indicator approach is the most common method adopted for quantifying vulnerability in the global change community. It is used to develop a better understanding of the socio-economic and biophysical factors contributing to vulnerability (Hebb and Mortsch 2007). Several composite indicators are known from the field of sustainable development; these include the Human Development Index of the United Nations Development Programme (UNDP, 1990), the United States Agency for International Development (USAID) Food Emergency Warning Systems program, the Food Security Index by Downing (1992), the Genuine Progress Indicator (Venetoulis and Cobb 2004) and the State of the Future Index (Glenn and Gordon 2004). Examples of composite indicators related to vulnerability mapping include the Index of Vulnerability of Lonergan et al. 1998 and the climate globalization vulnerability maps of The Energy Research Institute (TERI) 2003).

In the present paper, we use the indicator approach to identify vulnerable agricultural regions in South Africa.

4. CONSTRUCTING AN INDEX OF SOUTH AFRICAN FARMING SECTOR VULNERABILITY TO CLIMATE CHANGE

Study Area

There are approximately 100 million hectares of agricultural land in South Africa, of which 14 million receive sufficient rainfall for viable arable farming. The remainder of the land is used for extensive grazing (72 million hectares), nature conservation (11 million hectares), and forestry (1 million hectares). Dry land cultivation is practiced on 11.2 million hectares and irrigated agriculture occupies slightly more than 1.2 million ha that produce 25 to 30 percent of the country's agricultural output (AAS 2007).

Agriculture contributed about 3.5 percent of the country's growth domestic product (GDP) in 2002. KwaZulu Natal province made the largest contribution to agricultural value added (VAD) (28.3 percent) followed by the Western Cape (22.6 percent). Three categories of products contributed to the agricultural GDP, namely: (1) field crops; (2) horticultural products; and (3) livestock. Over the past two decades, the average contribution to gross VAD of the agricultural sector was about 37 percent, 20 percent, and 43 percent from field crops, horticulture and livestock, respectively (AAS, 2007).

South Africa may be subdivided into a number of farming regions according to climate, natural vegetation, types of soil, and the type of farming practiced. The principal cropping regions are the summer highveld plateaus of Gauteng and Free State, as well as the highveld and midlands of KwaZulu Natal and winter rainfall region of the Western Cape. The Joint Agriculture and Weather Facility of the National Oceanic and Atmospheric Administration (NOAA) of the United States determined four climatic zones for South Africa based on crop areas and climate profiles: the steppe (arid), desert, sub-tropical wet and sub-tropical winter rain zones (Appendix 2).

Due to the history of apartheid policies, agriculture in South Africa is highly dualistic; a commercial sector located in the "former white South Africa" is run predominately by white farmers, while a subsistence sector is located in the former homeland areas and run by black farmers. The institutional infrastructure of agriculture differs in quality, availability and accessibility between commercial and subsistence farms (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 percent of total VAD in agriculture and covers 87 percent 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, labor-intensive production. Despite the land reform initiatives put in place since 1995, the estimated 3.4– 4.8 million smallholders are predominantly settled in the former homelands and produce on the remaining 13 percent of the agricultural land (17 million hectares) (Feynes and Meyer 2003) for semi-subsistence purposes. Land holdings in the former homelands are generally very small (Groenewald and Nieuwoudt 2003) and are under a communal land tenure system. Only 3.7 percent (47,486 hectares) of the total irrigated land in South Africa is under smallholder agriculture. While there is high potential for veld grazing in these areas, stocking currently exceeds the carrying capacity of the land in most areas, and overgrazing has severely affected the quality of arable land in many areas. Poverty in rural areas is associated with agricultural policies, which have persistently marginalized small-scale black farmers by curtailing their access to resources such as land, credit and technical know-how (Coetzee and Van Zyl 1992).

The Causal Model: The Choice of Indicators

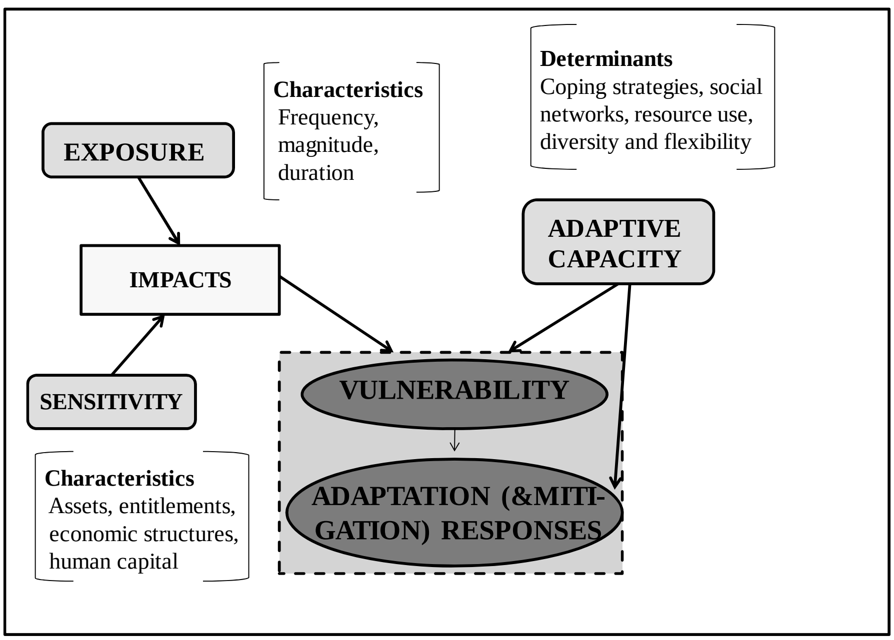
For this study, we base our definition of vulnerability on the Intergovernmental Panel on Climate Change's definition, where a region's vulnerability to climate change and variability is described by three elements: exposure, sensitivity, and adaptive capacity (IPCC 2001), as follows:

- Exposure can be interpreted as the direct danger (i.e., the stressor), and the nature and extent of changes to a region's climate variables (e.g., temperature, precipitation, extreme weather events).
- Sensitivity describes the human–environmental conditions that can worsen the hazard, ameliorate the hazard, or trigger an impact.
- Adaptive capacity represents the potential to implement adaptation measures that help avert potential impacts (see also Figure 1).

Exposure and sensitivity are intrinsically linked and together affect potential impact. To assess farming vulnerability to climate change, we look at exposure to climate change, sensitivities to those changes, and societal coping and adaptive capabilities (which might include mitigation options). 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.

The selection of indicators was done through an extensive review of previous reports; in particular, we draw from Aandahl and O'Brien (2001), Moss et al. (2001), Cutter et al. (2000 and 2003), TERI (2003), O'Brien et al. (2004b), Lucas and Hilderink (2004), Brenkert and Malone (2005), Brooks et al. (2005), Patnaik and Narayanan (2005), and Thornton et al. (2006). Further, we were guided by a list of indicators that were developed in a workshop setting,[1] and then pragmatically assessed in relation to data availability.

Figure 1. Vulnerability framework



Source: Authors

[1] A national stakeholder's forum was held on November 21, 2007, at the University of Pretoria. This meeting was organized by the Center for Environmental Economics and Policy in Africa (CEEPA) in collaboration with the International Food Policy Research Institute (IFPRI) to discuss the nature of South Africa's vulnerability and assess stakeholders' perceptions of vulnerability to climate change and options for adaptation. This forum was supported by the "Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa" project, which forms part of the CGIAR Challenge Program on Water and Food.

Exposure

Exposure relates to the degree of climate stress upon a particular unit of analysis; it may be represented by either long-term changes in climate conditions or changes in climate variability, including the magnitude and frequency of extreme events (O'Brien et al. 2004).

In this study, exposure is represented by two elements:

- Frequency of climate extremes: In South Africa, one of the key constraints to agriculture is a high climate variability that has historically included numerous droughts and floods (e.g., the 2000 floods and the 2002/2003 drought). In regions with a higher frequency of droughts or floods, crop production is more risky.
- Predicted change in temperature and rainfall by 2050: This metric gives the predicted level of climate change that regions will experience. The larger the changes, the more difficulty the regions are expected to 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.

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. This measure, which herein reflects the responsiveness of a system to climatic influences, is shaped by both socio-economic and ecological conditions and determines the degree to which a group will be affected by environmental stress (SEI, 2004). 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, crop models are ecology- and management-sensitive. Because each crop requires extensive experiments for successful modeling, 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. 2002).

In the present study framework, sensitivity describes the human–environmental conditions that can either worsen the hazard or trigger an impact. We examine five factors that may influence the sensitivity of a farming region:

- Irrigation rate: If we compare two agricultural regions that grow the same crops and have similar climates, their exposure to climate variability might be similar, but their sensitivity could be very different. For example, an irrigated system would have low sensitivity to short-term precipitation variability, whereas a rainfed system would have greater sensitivity to the same exposure.
- Land degradation index: Land degradation reduces the productive capacity of land. Contributors to land degradation include natural disasters and human activities (e.g., agricultural mismanagement, overgrazing, fuelwood consumption, industry and urbanization). This indicator represents the "combined degradation index," which considers soil degradation (erosion, salinization and acidification) and veld or vegetation degradation (loss of cover and changes in species composition, bush encroachment, alien plant invasions, and deforestation). Areas with higher land degradation indices will experience greater negative impacts of climate variability and change.

- Crop diversification index: Farmers themselves commonly identify diversification as an effective strategy for managing business risks, particularly climatic risks (Bathia 1965). An agricultural region with more diversified crops will be less sensitive to climatic variations.
- Percent small-scale: Small-scale farmers, generally subsistence farmers, are more sensitive to climate change and variability because they have less capital-intensive technologies and management practices. Thus, a region with a large number of small-scale farmers will be more climate-sensitive than a region with fewer small-scale farmers.
- Rural population density: A region with high population density is more sensitive to climate because more people are exposed and therefore the region will need greater humanitarian assistance.

Adaptive Capacity

Adaptive capacity is a significant factor in characterizing 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 (2003), the adaptive capacity of a system or society reflects its ability to modify its characteristics or behavior 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). 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). Adaptive capacity is considered to be "a function of wealth, technology, education, information, skills, infrastructure, access to resources, and stability and management capabilities" (McCarthy et al. 2001).

Analyzing vulnerability involves identifying not only the threat, but also the "resilience," or the responsiveness of the system and its ability to exploit opportunities and resist or recover from the negative effects of a changing environment. The means of resistance are the assets and entitlements that the individuals, households, or communities can mobilize and manage in the face of hardship. There are close linkages between vulnerability and livelihoods, and building resilience is a question of expanding and sustaining these assets (Moser 1998). 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.

Here, adaptive capacity is described as being dependent upon four[2] livelihoods assets:

1. Social capital is represented by farm organizations (the number of farmers in organized agriculture). This indicator is a proxy for private social networks. First, social networks act as conduits for financial transfers that may relax the farmer's credit constraints. Second, they act as conduits for information about new technology. Third, social networks can facilitate cooperation to overcome collective action dilemmas, where the adoption of technologies involves externalities (Deressa et al. 2008). It is hypothesized that social capital positively influences adaptation to change.
2. Human capital is represented by literacy rate and HIV prevalence.
3. According to Leichenko et al. (2002), increased overall literacy levels reduce vulnerability by increasing people's capabilities and access to information, thereby enhancing their ability to cope with adversities. HIV prevalence is used as indicator under the assumption that areas with higher rates of HIV/AIDS are more vulnerable. Drimie (2002) states unequivocally that

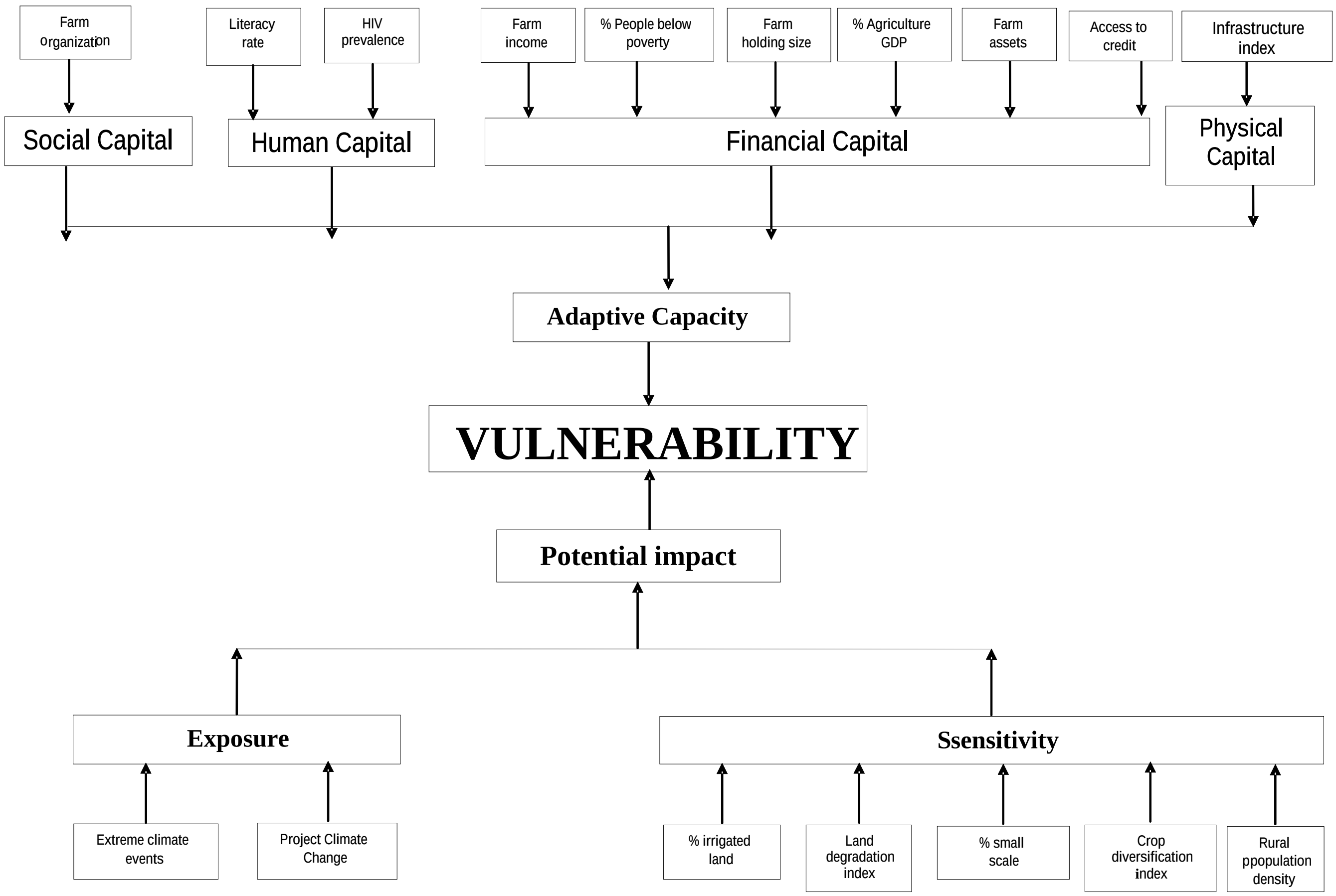
[2] We also include a fifth asset, that of natural capital; however, this is classified under the sensitivity component of vulnerability which describes the human–environmental conditions that can either worsen the hazard or trigger an impact. The indicator of natural capital is the "land degradation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

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 labor productivity and supply, and puts a brake on economic growth.

4. Financial capital is represented by (1) farm income; (2) farm holding size; (3) farm assets; (4) percentage of people below the poverty line; (5) share of agricultural GDP; and (6) access to credit. These indicators provide a general picture of the financial situation of the province. Regions with higher farm income, larger farms, greater farm value assets, and more access to credit are wealthier and are therefore better able to prepare for and respond to adversity. In contrast, regions with a higher dependence on agriculture (higher share of agriculture in total GDP) are assumed to be less economically diversified and thus more susceptible to climatic events and changes.
5. Physical capital is related to infrastructure and access to markets. 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. Improved infrastructure may reduce transactions costs, and strengthen the links between labor and product markets. Markets may be important for a variety of reasons, including their abilities to spread risk and increase incomes. According Zhang et al. (2007), markets are a means of linking people both spatially and over time. That is, they allow shocks (and risks) to be spread over wider areas. In particular, markets should make households less vulnerable to (localized) covariate shocks. Furthermore, pre-existing coping strategies (e.g. the sale of productive assets) will be more effective, thereby avoiding the potentially irreversible effects of these actions. 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. Infrastructure may also facilitate migration and remittances, which are important ex ante and ex post mechanisms for reducing vulnerability. Here, we construct an infrastructure index to represent the physical capital of the agricultural regions.

The utilized indicators and their inter-linkages, which are geared towards reflecting overall vulnerability, are graphically presented in Figure 2 below.

Figure 2. The aggregation of the different indicators towards the overall vulnerability



Source: Authors

Data

Data on the selected indicators for the nine provinces of the country are taken from various secondary sources. Socio-economic data covering the four livelihood assets (social, financial, human and physical) come from the South African Statistical Agency (Census, 2001 and Agricultural Census, 2004). Data on agriculture (irrigation rate, land size, etc.) come from the Agricultural Census of 2004. Data on drought and flood frequencies come from the International Disaster Data Base for 1906 to 2006 (Emergency Events Database (EM-DAT) 2006). Predicted changes in temperature and rainfall come from the Climate Systems Analysis Group at the University of Cape Town (Table 2).

Table 2. 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 level	EM-DAT: The OFDA/CRED International Disaster Database
	Change in climate	Change in temperature Change in precipitation	Change (delta T) in degrees from base value (2000) Percentage change from base value (2000)	The higher the changes from present climate normal, the higher the vulnerability level	Climate Systems Analysis Group University of Cape Town
SENSITIVITY	% Irrigated land	Percentage of irrigated land	Percentage	The higher the land under irrigation, the lower the vulnerability level	SSA 2005
	Land degradation index	Combined soil degradation and veld or vegetation degradation	No unit	The higher the land degradation index the higher the vulnerability level	Meadows and Hoffman (2002)
	% Small-scale farming operations	Percentage	Percentage	The higher the % of small-scale farming, the higher the vulnerability level	SSA 2002
	Rural population density	Total rural population/area	Population/km2	The higher the rural population density, the higher the vulnerability level	SSA, 2008
	Crop diversification index[3]	Percentage of snow area under x crops/ number of x crops	percentage	The higher the crop diversification index, the lower the vulnerability level	SSA 2005

[3] The computations of the crop diversification index and infrastructure index are illustrated in the appendix section.

Table 2. (Continued)

Determinants of vulnerability	Component indicators	Description of the indicator	Unit of measurement	Hypothesized functional relationship between indicator and vulnerability	Data source
ADAPTIVE CAPACITY	Farm organization	Number of farmers members of organized agriculture	Number	The higher the number of farmers, the lower the vulnerability level	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 level	SSA, 2008
	HIV prevalence	Percentage of people infected by HIV	Percentage	The higher the HIV prevalence, the higher the vulnerability level	SSA, 2008
	Access to credit	Amount of credit received	Rand	The higher access to credit, the lower the vulnerability level	SSA 2005
	Farm income	Net farm income	Rand	The higher the farm income, the lower the vulnerability level	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 level	SSA, 2008
	Farm holding size	Average farm size	Hectares	The higher the size of land, the lower the vulnerability level	SSA 2005
	Share Agricultural GDP	Percentage	Percentage	The higher the share, the higher the vulnerability level	SSA, 2008
	Farm assets	Total value of farm assets	Rand	The higher the farm assets, the lower the vulnerability level	SSA 2005
	Infrastructure index	Computation of infrastructure index[3]	No unit	The higher infrastructure index, the lesser the vulnerability level	SSA 2005

Source: Authors

Calculating the vulnerability indices

From our conceptual framework, we see that the vulnerability of a given system largely depends on its exposure and sensitivity, which combined provides the potential impact and the potential for effectively coping with the impacts and associated risks. Vulnerability may be formulated mathematically as follows:

$$V = f\,(\underset{(-)}{I} - \underset{(+)}{AC})$$

where V is vulnerability, I is potential impact, and AC is adaptive capacity. A higher adaptive capacity is associated with a lower vulnerability, while a higher impact is associated with a higher vulnerability. Given the above equation, vulnerability is defined as a function of a range of biophysical and socio-economic factors, commonly aggregated into three components that estimate the adaptive capacity, sensitivity, and exposure to climate variability and change.

Having considered the theoretical determinants of provincial farming sector vulnerability and selected appropriate indicators for its capture, we must now carry out some form of standardization to ensure that all the indicators are comparable (Vincent 2004). Based on the method in the United Nations Development Programme (UNDP)'s Human Development Index (UNDP 2002), all of the variables in the vulnerability indices are normalized to a range of 0 to 100. The values of each variable are normalized to the range of values in the data set by applying the following general formula:

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

To ensure that high index values indicate high vulnerability in all cases, we reverse the index values by using [100 – index value] for indicators hypothesized to decrease vulnerability.

After standardizing the data, we next attach weights to the vulnerability indicators. A review of the literature indicates that three methods are used to assign weights to indicators: (1) expert judgment (Brooks et al. 2005; Moss et al. 2001); (2) arbitrary choice of equal weight (Lucas and Hilderink 2004; O'Brien et al. 2004b; Patnaik and Narayanan 2005) and (3) statistical methods such as principal component analysis or factor analysis (Cutter et al. 2003; Thornton et al. 2006). 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). Therefore, we herein use principal component analysis (PCA) to generate weights for the indicators.

PCA is a technique for extracting from a set of variables those few orthogonal linear combinations of variables that most successfully capture the common information. Following Filmer and Pritchett (2001), 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 normalized by its mean and standard deviation. For instance, a1j = (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:

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

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 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 nth 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 (1). This yields a set of estimates for each of the *A*-principal components:

$$
\begin{aligned}
&A_{1j} = f_{11}\, a_{1j} + f_{12}\, a_{2j} + \ldots + f_{1N}\, a_{Nj} \\
&\ldots \qquad\qquad\qquad\qquad j = 1 \ldots J \\
&A_{Nj} = f_{N1}\, a_{1j} + f_{N2}\, a_{2j} + \ldots + f_{NN}\, a_{Nj}
\end{aligned}
\tag{2}
$$

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:

$$A_{1j} = f_{11}\,(a^*_{1j} - a^*_1)/(s^*_1) + \ldots + f_{1N}\,(a^*_{Nj} - a^*_N)/(s^*_N) \tag{3}$$

5. RESULTS AND DISCUSSION

Descriptive Statistics

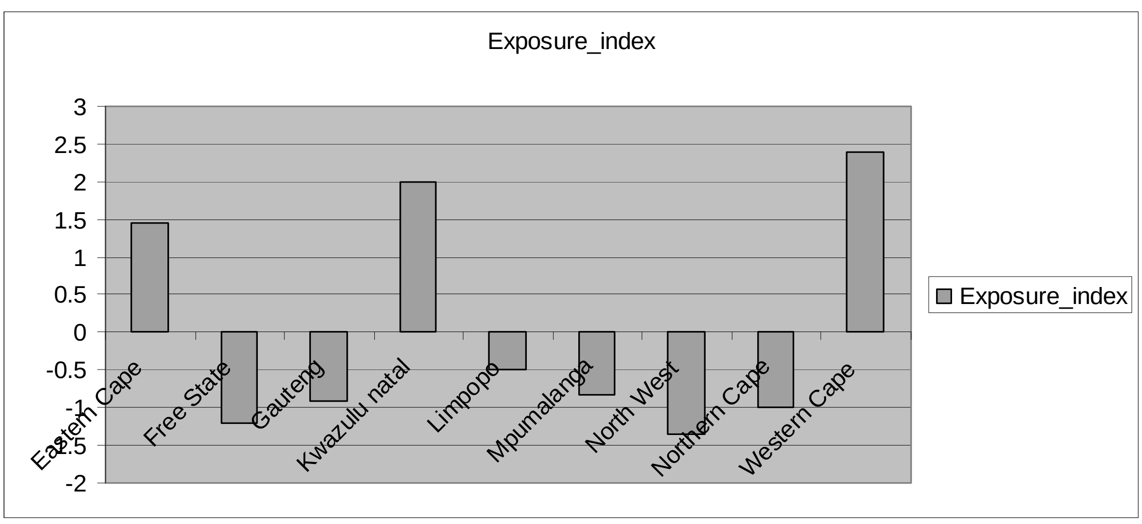
Our preliminary analyses show that provinces in South Africa demonstrate a vast diversity in terms of environmental and socio-economic conditions (see Appendix 4, Table A.3 to Table A.6). The coastal provinces of KwaZulu Natal, the Eastern Cape and the Western Cape show the highest frequency of extreme events (droughts/floods) over the last century. The highest incremental increase in temperature by 2050 is found 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 the Gauteng and North West provinces. Concerning the sensitivity indicators, 65 percent of the crop area in the Northern Cape (the desert region) is irrigated. The regions showing the highest levels of soil and veld degradation are the Eastern Cape, KwaZulu Natal and Limpopo. The Western Cape and Limpopo are the most diversified regions; in these areas, 5 or 6 different types of crops occupy around 70 percent of the crop land. The most populated rural areas are the Eastern Cape, KwaZulu Natal, Mpumalanga and North West, where small farmers comprise more than 70 percent of the farming population. The most developed provinces are Gauteng and the Western Cape, which have infrastructure index scores of 2.95 and 2.92, respectively. They also have the highest literacy rates and lower unemployment rates. In contrast, the 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.

The Three Dimensions of Vulnerability

The Exposure Index

The results of the exposure index are depicted in Figure 3 below:

Figure 3. The exposure indices across provinces in South Africa



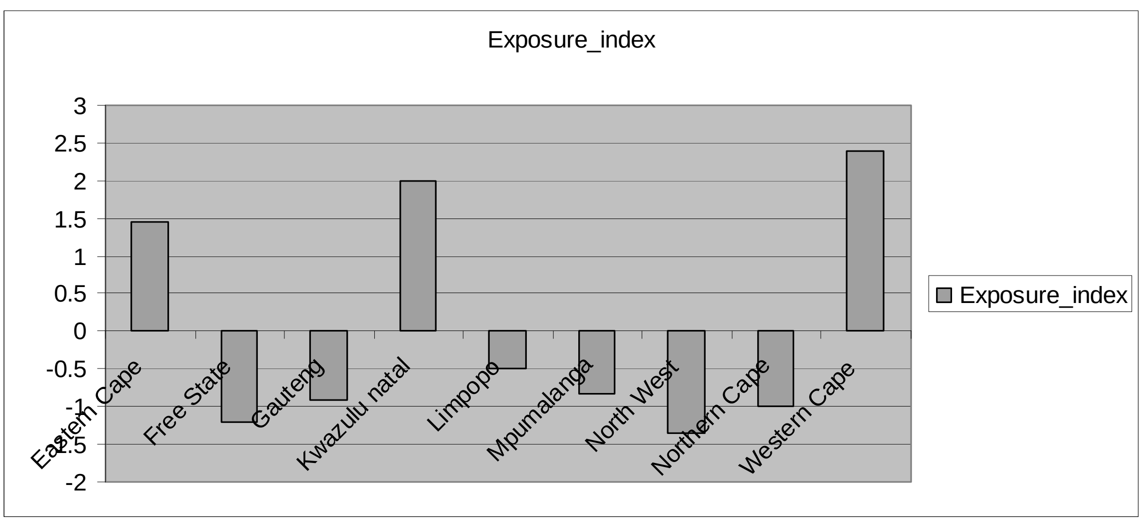
Source: Authors

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 and Alder (2005), who conclude that coastal ecosystems are the most highly threatened systems in the world. In very recent assessments of the potential flood risks that may arise by 2080 across a range of scenarios from the Special Report on Emissions Scenarios (SRES) and climate change projections, three of the five regions shown to be at risk of flooding in coastal and deltaic areas of the world are located in Africa: North Africa, West Africa and Southern Africa (see Nicholls and Tol 2006; for a more detailed assessment, see 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.

The Sensitivity Index

The overall sensitivity of the farming sector across the nine provinces of South Africa is presented in Figure 4. The most sensitive regions are Limpopo, KwaZulu Natal and the Eastern Cape, mainly due to the very large proportion of small-scale farmers that produce primarily for subsistence purposes, use very low technology, and are highly dependent on 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 (2002), the 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 is not a serious problem and agriculture relies heavily on irrigation, making it less 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.

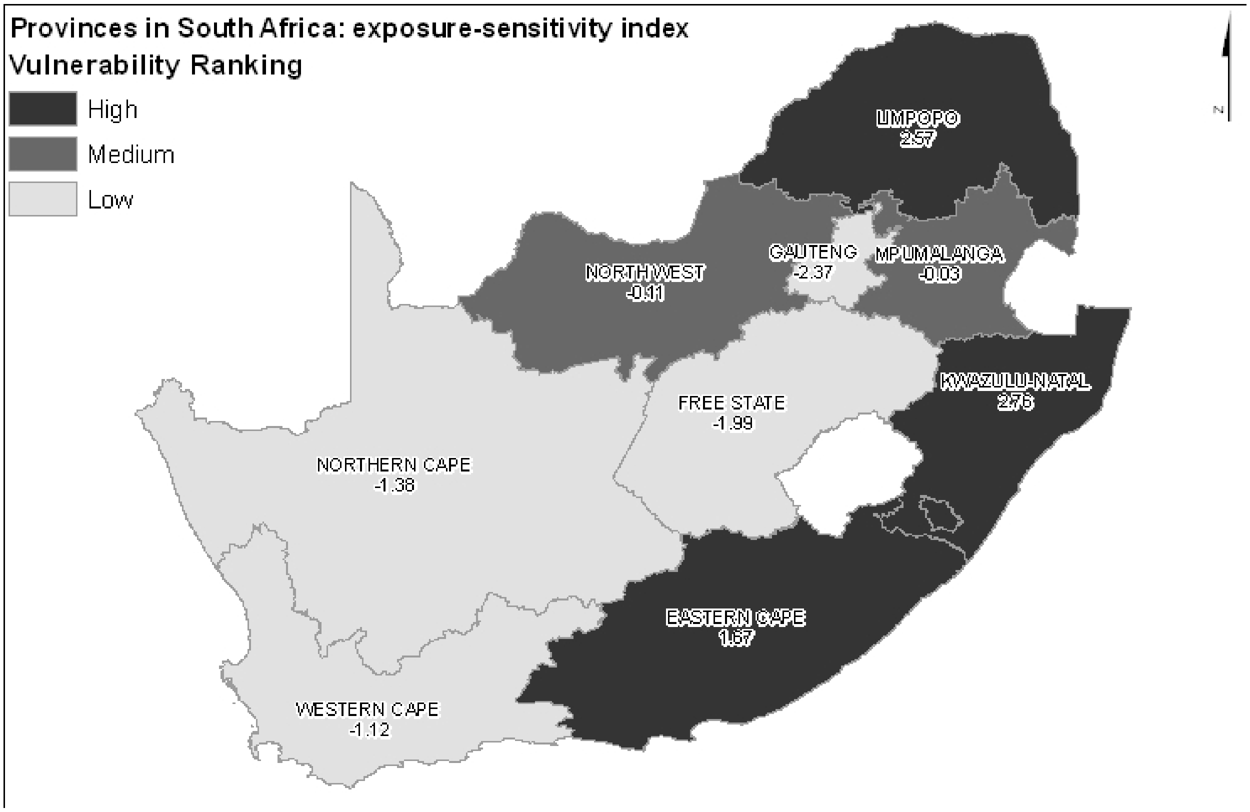
Figure 4. The sensitivity indices across the farming provinces in South Africa



Source: Authors

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 shows that KwaZulu Natal, Limpopo, and the Eastern Cape are predicted to suffer have 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, as they are largely composed of large commercial farms and do not suffer from too much land degradation.

Figure 5. Map of exposure-sensitivity indices across the farming provinces in South Africa

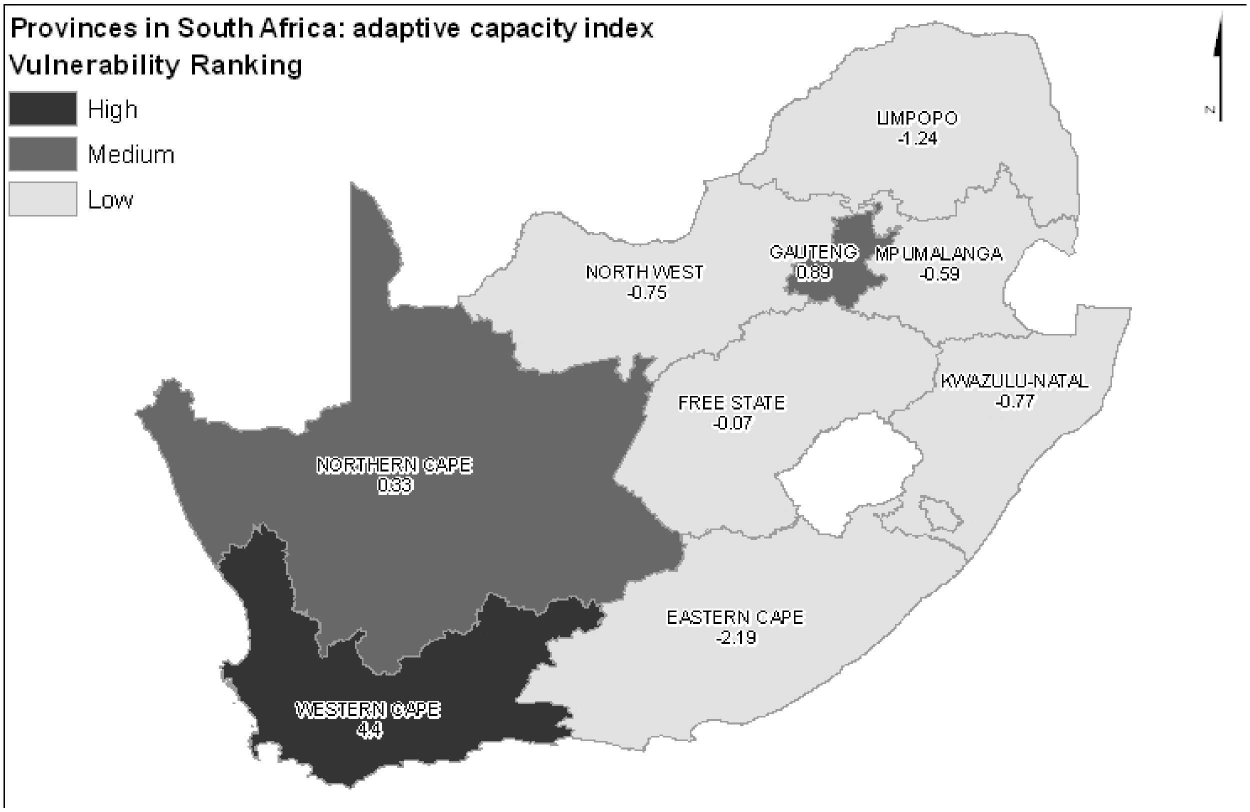


Source: Authors

The Adaptive Capacity Index

Figure 6, 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 6. Adaptive capacity indices across the farming provinces in South Africa



Source: Authors

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 3 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 3. The matrix of vulnerability to climate change and variability for provinces in South Africa

		Adaptive capacity		
		High	**Medium**	**Low**
Potential impact [Exposure-Sensitivity]	Low	Low vulnerability Western Cape	Medium vulnerability Gauteng Northern Cape	? Uncertainty Free State
	Medium	Low vulnerability	? Uncertainty	Medium vulnerability Mpumalanga North West
	High	? Uncertainty	High vulnerability	High vulnerability Limpopo Eastern Cape KwaZulu Natal

Ranking

High Vulnerability → Low Vulnerability

KwaZulu Natal, Limpopo, Eastern Cape — North West, Mpumalanga, Gauteng — Free State — Western Cape

Source: Authors

To quantitatively assess the overall vulnerability index, we run a PCA with the 19 indicators listed in Table 3, using data analysis and statistical software (STATA). Nineteen components are extracted in the first stage of the PCA but only the first five are significant (based on the Kaiser criterion of an eigenvalue greater than 1[4]). These five components explain 91 percent of the total variation in the data set. The first principal component explains most of the variation (33 percent), the second principal component explains 23 percent, the third explains 16 percent, the fourth explains 12 percent, and the fifth explains only 6 percent. The first component is then used to construct the vulnerability index. Each variable is normalized to take a value between 0 and 100 (see Appendix Table A.7). The weights (or scores) assigned to the indicators on component 1 are shown in Table 4, along with their associated statistics. Following Filmer and Pritchett (2001), the assigned weights are then used to construct an overall vulnerability index by applying the following formula:

$$v_j = \sum_{i=1}^{k} \left[b_i \left(a_{ji} - x_i \right) \right] / s_i \qquad (4)$$

[4] The eigenvalue is a measure of standardized variance, with a mean of 0 and standard deviation of 1. Each standardized variable (here, each of the 19 indicators) contributes at least the variance of 1 to the principal component extraction. The Kaiser criterion states that unless a principal component extracts at least as much as one of the original variables (i.e. has a standardized variance equal to or greater than 1), it should be dropped from further analysis (Filmer and Pritchett 2001).

where *v* is the vulnerability index, *b* is the weight from PCA 1, *a* is the indicator value, *x* is the mean indicator value, and *s* is the standard deviation of the indicators.

Figure 7a/b depicts the results of the vulnerability index for each province in South Africa. The results show that Western Cape and Gauteng, the most developed provinces, have low vulnerability indices, ranging from -4 to -2.5. Provinces with medium vulnerabilities (ranging from -1.2 to +1) are Free State, the Northern Cape, Mpumalanga and North West. The three most vulnerable provinces are the Eastern Cape, KwaZulu Natal and Limpopo. The low vulnerabilities of the Western Cape and Gauteng are associated with high levels of infrastructure development, high literacy rates, and low shares of agricultural GDP. The most vulnerable regions are those with more small-scale farmers, high dependencies on rainfed agriculture, high land degradation, and populated rural areas where most people rely on agriculture for their livelihoods.

Table 4. Factor scores from PCA and associated statistics

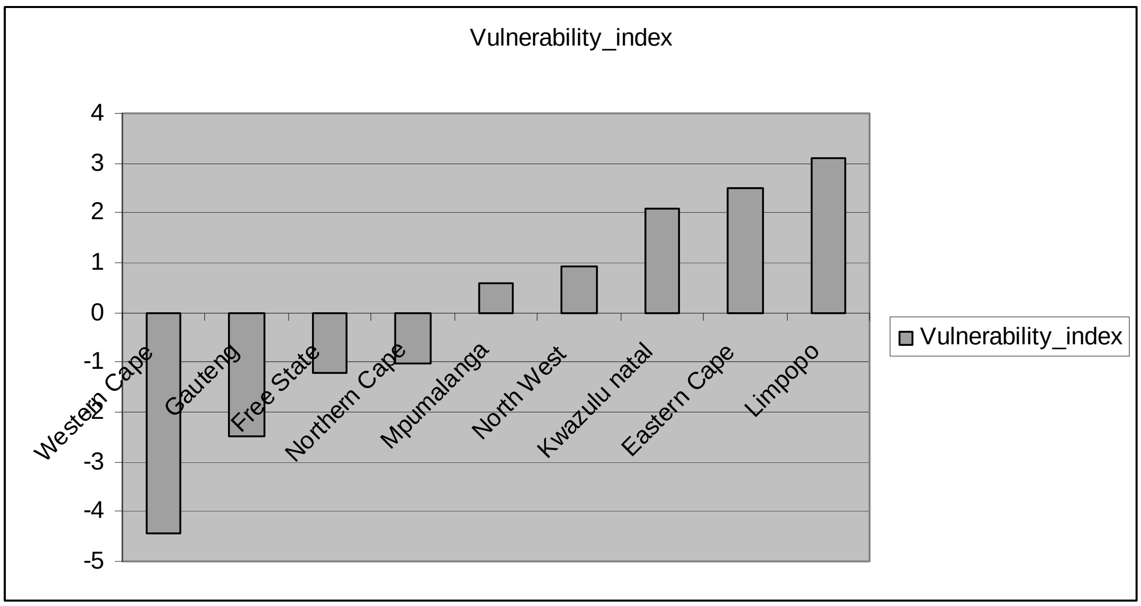
Indicators	Eigenvalue	Proportion	Cumulative	Mean	Standard Deviation	Scoring factor: PCA1
Change in temperature	6.22896	0.3278	0.3278	63.93909	38.38529	0.0355
Change in rainfall	4.43806	0.2336	0.5614	35.89761	32.63587	-0.1334
Frequency of droughts/floods	3.13086	0.1648	0.7262	36.66667	29.15476	0.1278
Irrigated land	2.42104	0.1274	0.8536	71.93974	32.55948	-0.11
Soil degradation	1.10933	0.0584	0.912	48.20182	36.07274	0.3391
Veld degradation	0.850657	0.0448	0.9568	53.86779	32.31948	0.2691
Crop diversification	0.509999	0.0268	0.9836	47.31183	39.70495	0.0261
Small-scale	0.311103	0.0164	1	52.26757	44.27848	0.3701
Rural population density	0	0	1	45.09044	33.90975	0.3672
Access to credit	0	0	1	64.8487	28.92462	0.2273
Farm organization	0	0	1	52.59259	43.26205	0.1253
Literacy rate	0	0	1	65.8835	37.37238	0.3424
HIV prevalence	0	0	1	58.50067	34.24387	0.1037
Net farm income	0	0	1	59.05648	35.34395	0.1951
Unemployment rate	0	0	1	70.37037	30.36557	0.3115
Farm holding size	0	0	1	77.22207	32.42789	0.2079

Table 4. (Continued)

Indicators	Eigenvalue	Proportion	Cumulative	Mean	Standard Deviation	Scoring factor: PCA1
Share agricultural GDP	0	0	1	65.53288	30.51335	0.062
Farm assets	0	0	1	79.81361	31.07182	0.0028
Infrastructure index	0	0	1	51.57343	32.93298	0.3393

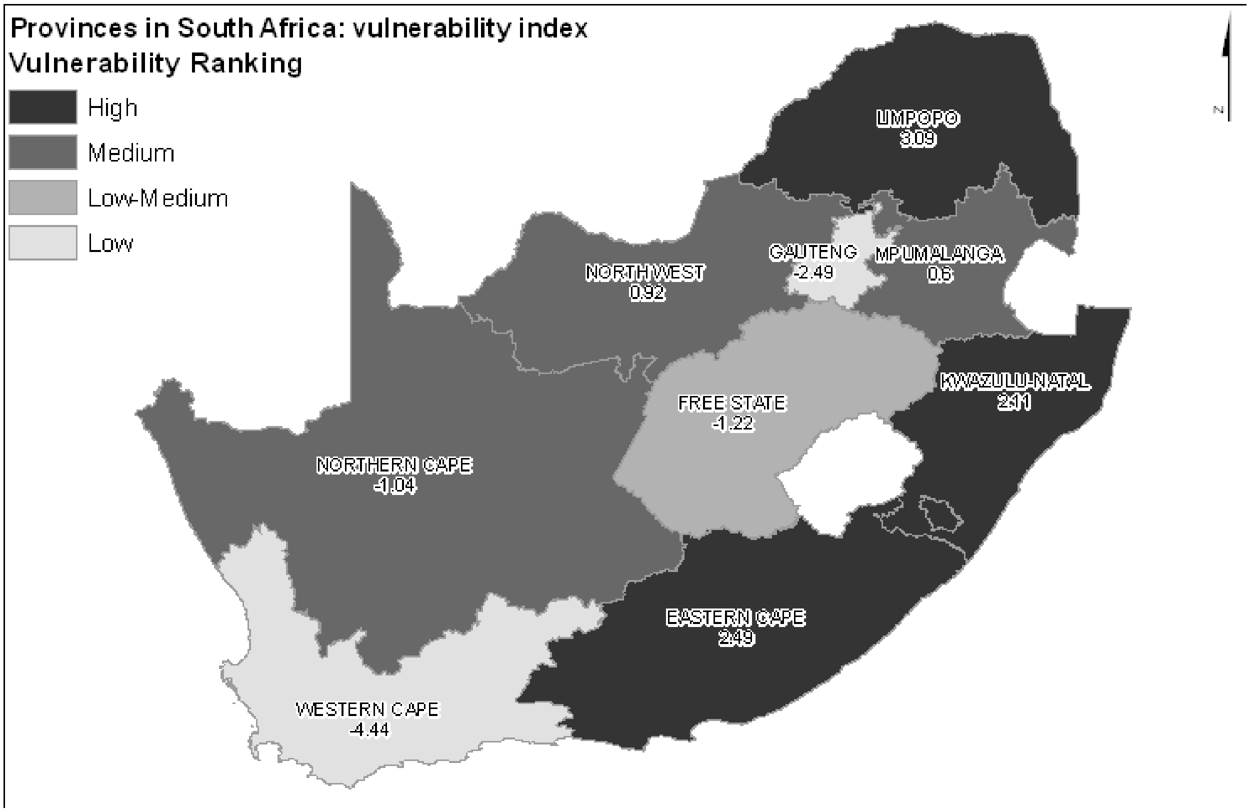
Source: Authors

Figure 7. Overall vulnerability indices across the farming provinces in South Africa



Source: Authors

Figure 8. Map of the overall vulnerability indices across the farming provinces in South Africa



Source: Authors

6. CONCLUSION

We herein report the quantitative operationalization of climate change vulnerability across the nine provinces of South Africa. Vulnerability has three components: exposure, sensitivity, and adaptive capacity. We examine the use of 19 environmental and socio-economic indicators to reflect these three components of vulnerability. Our framework combines exposure with sensitivity to give the potential impact, which is then compared with the adaptive capacity to yield an overall measure of vulnerability. Principal component analysis is used to generate weights for the different indicators, and an overall vulnerability index is calculated.

The methodology used herein has both limitations and strengths. The macro-profiles are limited in that mapping vulnerability at the provincial level may lead to a false sense of precision. 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 higher resolutions, such as the district and villages levels. Currently, to our knowledge there is only limited data available for the district level, necessitating a macro approach at this time. The advantages of this approach are the transparency of the indicator framework that allows us to trace vulnerable regions back to their underlying determinants. Another key strength of our approach is that it provides a means for evaluating the relative distribution of vulnerability at a sub-national level.

Our results show that the regions deemed to be most vulnerable to exposure to extreme events and climate change/variability do not always overlap with the most vulnerable populations. Rather, our study confirms the findings of Cutter et al. (2000 on the vulnerability of Georgetown, that the overall vulnerability of the South African farming sector is characterized by a combination of medium-level risk exposure coupled with medium to high levels of social vulnerability. Our findings indicate that farmers in the Western Cape will be confronted with high exposure to extreme events and climate change/variability. They will therefore incur great economic losses. However, the adaptive capacity of this province is high due to its greater wealth, high infrastructure development, and good access to resources. In contrast, for Limpopo, KwaZulu Natal and the Eastern Cape, it will take only moderate climate changes to disrupt the livelihoods and wellbeing of the rural inhabitants, who are largely subsistence farmers. Thus, climate change will increase the burden of those who are already poor and vulnerable.

General policy recommendations can be drawn from the above results. First, given large spatial differences across province-level vulnerability, policy makers should tailor policies to local conditions. In addition, climate change should be placed within the broader developmental context. An effective way to address the impacts of climate change would be to integrate adaptation measures into sustainable development strategies, thereby reducing the pressure on natural resources, improving environmental risk management, and increasing the social wellbeing of the poor. In regions found to be highly vulnerable, such as Limpopo, KwaZulu Natal, and the Eastern Cape, policy makers 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. Finally, policy makers should invest in the development of infrastructure in rural areas, while in high exposure regions, especially the coastal zones, priority should be given to the development of more accurate systems for early warning of extreme climatic events (e.g., drought or floods), as well as appropriate relief programs and agricultural insurance.

REFERENCES

Aandahl, G., and K. O'Brien. 2001. Vulnerability to climate changes and economic changes in India agriculture. Paper presented at the biannual conference of the Nordic Association for South Asian Studies "Waters of Hope. The role of water in South Asian development," Voss, Norway, September 20–22.

AAS (Abstract of Agricultural Statistics). 2007. Directorate Agricultural Information, National Department of Agriculture, Pretoria, South Africa.

Adger, W.N. 1996. *Approaches to vulnerability to climate change*. Centre for Social and Economic Research on the Global Environment Working Paper GEC 96–05. Norwich, U.K.: University of East Anglia.

Adger, W.N, and P.M. Kelly. 1999. Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change* 4: 253–266.

Agardy, T, J. Alder , P. Dayton, S. Curran, A. Kitchingman, M. Wilson, A. Catenazzi, J. Restrepo, C. Birkeland, S. Blaber, S. Saifullah, G. Branch, D. Boersma, S. Nixon, P. Dugan, N. Davidson and C. Vörösmarty. 2005. Coastal systems. Chapter 19 in Ecosystems and Human Wellbeing: Volume 1, Current State and Trends. The Millennium Ecosystem Assessment, online at http://www.millenniumassessment.org

Bathia, S.S. 1965. Patterns of crop concentration and diversification in India. *Economic Geography* 41 (1): 39–56.

Benhin, J.K.A. 2006. *Climate change and South Africa agriculture: impacts and adaptation options.* CEEPA Discussion Paper No. 21. Centre for Environmental Economics and Policy in Africa. Pretoria, South Africa: University of Pretoria.

Blaikie, P., T. Cannon, I. Davis and B. Wisner. 1994. *At risk: Natural hazards, people's vulnerability and disasters.* London: Routledge.

Bohle, H.G. 2001. Vulnerability and Criticality: Perspectives from social geography. *IHDP Update, Newsletter of the International Human Dimension Programme on Global Environmental Change* (IHDP) 2:1–4.

Bohle, H.G., T.E. Downing and M.J. Watts.1994. Climate change and social vulnerability: Toward a sociology and geography of food insecurity. *Global Environmental Change* 4(1):37–48.

Brenkert, A.L. and E.L. Malone. 2005 Modeling vulnerability and resilience to climate change: a case study of India and Indian States. *Climatic Change* 72: 57–102.

Brooks, N., 2003. *Vulnerability, risk and adaptation: A conceptual framework.* Working paper 38. Norwich, U.K.: Tydall Centre for Climate change Research, University of East Anglia.

Brooks, N., W.N. Adger and P.M. Kelly, 2005. The determinants of vulnerability and adaptive capacity at the national and the implications for adaptation. *Global Environmental Change* 15 (2005): 151–162.

Challinor, A., T. Wheeler, C. Garforth, P. Craufurd and A. Kassam. 2007. Assessing the vulnerability of food crop systems in Africa to climate change. *Climatic Change* 83: 381–399.

Chambers, R. 1989. Editorial introduction: Vulnerability, coping and policy. *IDS Bulletin* 20 (2): 7.

Coetzee, G.K. and J. Van Zyl. 1992. An assessment of food security in South Africa. In: Csaki, C., T.J. Dams, D. Metzger and J. Van Zyl (eds). *Agricultural restructuring in Southern Africa*. Association of Agricultural Economics of Namibia, Windhoek Printers & Publishers, Namibia: 496 – 504.

Cutter, S.L.1996. Vulnerability to environmental hazards. *Progress in Human Geography* 20(4): 529–539.

Cutter, S.L., B.J. Boruff and W.L. Shirley. 2003. Social vulnerability to environmental hazards. *Social Science Quarterly* 84 (2): 242–261.

Cutter, S.L., J.T. Mitchell and M.S. Scott. 2000. Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers* 90 (4):713–737.

DEAT (Department of Environmental Affairs and Tourism), 2004. *South African National Climate Change Response Strategy Report*, Pretoria.

Deressa, T.T., 2003. *Measuring the impact of climate change on South African agriculture: The case of sugarcane growing regions.* MSc. Thesis, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria, South Africa.

Deressa, T.T. 2008. *Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia.* IFPRI Discussion Paper 798. Washington, D.C.: International Food Policy Research Institute (IFPRI).

Downing, T.E., 1992.Vulnerability and global environmental change in the semi–arid tropics: Modeling regional and household agricultural impacts and responses. Oxford University Environmental Change Institution: 1–26.

Downing, T.E., Butterfield, R., Cohen, S., Huq, S., Moss, R., Rahman, A., Sokona, Y. and L. Stephen. 2001. *Vulnerability indices: Climate change impacts and adaptation*. United Nations Environment Programme, Policy Series 3. New York: United Nations.

Drimie, S. (2002) HIV/Aids and land: Case studies from Kenya, Lesotho and South Africa. *The African communist*. 162:1–8.

Du Toit, A.S., Prinsloo, M.A., Durand, W. and Kiker, G., 2002. Vulnerability of maize production to climate change and adaptation in South Africa. Combined Congress: South African Society of Crop Protection and South African Society of Horticultural Science, Pietermaritzburg, South Africa.

Emergency Events Database (EM–DAT). 2006. OFDA/CRED International Disaster Database. Country profile for South Africa. Universite Catholique de Louvain– Brussels– Belgium www.em–dat.net. Accessed September 15, 2006.

Erasmus, B., A. van Jaarsveld, J. van Zyl and Vink, N., 2000. The effects of climate change on the farm sector in Western Cape. *Agrekon* 39 (4): 559–573.

FAO/GIEWS (Food and Agriculture Organization of the United Nations /Global Information and Early Warning System on Food and Agriculture), 2001. www.fao.org/giews/english/basedocs/saf.htm.

Feynes, T. and N. Meyer. 2003. Structure and production in South African Agriculture. In *The challenge of change: Agriculture land and the South African economy,* L. Nieuwoudt, and J. Groenewald, eds. Pietermaritzburg, South Africa: The University of Natal Press.

Filmer, D. and L.H. Pritchett, 2001. Estimating wealth effects without expenditure data—or tears: An application to educational enrolments in States of India. *Demography* 38 (1): l15–131.

Füssel, H.M. 2007. Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change* 17: 155–167.

Füssel, H.M. and R.J.T. Klein. 2006. Climate change vulnerability assessments: An evolution of conceptual thinking. *Climatic Change* 75 (3): 301–329.

Gallopín, G.C., 2003. Box 1. A systemic synthesis of the relations between vulnerability, hazard, exposure and impact, aimed at policy identification. In Economic Commission for Latin American and the Caribbean (ECLAC). Handbook for estimating the socio-economic and environmental effects of disasters. Mexico, D.F.: ECLAC.

Gbetibouo, G.A. 2004. Economic impact of climate change on major South African field crops: A ricardian approach. MSc. Thesis. Pretoria, South Africa: Faculty of Natural and Agricultural Sciences, University of Pretoria.

Gbetibouo, G.A., and R.M. Hassan. 2005. Measuring the economic impact of climate change on major South African field crops: A Ricardian approach, *Global and Planetary Change* 47 (2005) 143–152.

Glenn, J.C., and T.J. Gordon (eds.). 2004. State of the future. Millennium assessment publication, UNEP.

Groenewald, J., and L. Nieuwoudt. 2003. Demands on and challenges for South African agriculture. In *The challenge of change: Agriculture land and the South African economy,* L. Nieuwoudt, and J. Groenewald, eds. Pietermaritzburg, South Africa: The University of Natal Press.

Hebb, A. and L. Mortsch. 2007. *Floods: Mapping vulnerability in the Upper Thames watershed under a changing climate.* Final Report of the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) Project: Assessment of Water Resources Risk and Vulnerability to Changing Climatic Conditions.

Heitzmann, K., R.S. Canagarajah, and P.B. Siegel. 2002. *Guidelines for assessing risk and vulnerability*. SP Discussion Paper 0218. Social Protection Unit, Human Development Network. Washington, D.C.: World Bank.

IPCC (Intergovernmental Panel on Climate change). 2001. *Climate change 2001: Impacts, adaptation, and vulnerability,* J. J. McCarthy, et al., eds. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

IPCC (Intergovernmental Panel on Climate change). 2007. *Climate Change 2007: Impacts, adaptation and vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds. Cambridge, UK: Cambridge University Press.

Kelly, P.M., and W.N. Adger. 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47: 325–352.

Kiker, G.A., 2002. CANEGRO-DSSAT linkages with geographic information systems: applications in climate change research for South Africa. Proceedings of International CANGRO Workshop, Mount Edgecombe, South Africa.

Kiker, G.A., Bamber, I.N., Hoogenboom, G., Mcgelinchey, M., 2002. Further Progress in the validation of the CANEGRO-DSSAT model. Proceedings of International CANGRO Workshop, Mount Edgecombe, South Africa.

Leichenko, R.M. and K.L. O'Brien, 2002. The dynamics of rural vulnerability to global change: the case of Southern Africa. *Mitigation and Adaptation Strategies for Global Change* 7: 1–18.

Liverman, D.M., 1990. Vulnerability to global environmental change. In *Understanding global environmental change: The contributions of risk analysis and management,* R.E. Kasperson, K. Dow, D. Golding, and J.X. Kasperson, eds. Worcester, MA: Clark University.

Lonergan, S. 1998. *The role of environmental degradation in population displacement, Global environmental change and human security project.* International Human Dimensions Programme on Global Environmental Change, Research Report I., British Columbia, Canada: University of Victoria.

Lowry, J., H. Miller and G. Hepner. 1995. A GIS-based sensitivity analysis of community vulnerability to hazardous contaminants on the Mexico/U.S. Border. *Photogrammetric Engineering &Remote Sensing* 61 (11): 1347–1359.

Lucas, P.L., and H.B.M Hilderink. 2004. *The vulnerability concept and its application to food security*. Report 550015004/2004. Netherlands: National Institute for Public Health and the Environment (RIVM).

Luers, A.L., D.B. Lobell, L.S. Skar, C.L. Addams and P.A. Matson. 2003. A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Global Environmental Change* 13: 255–267.

Mansuri, G., Healy, A., 2002. Vulnerability prediction in rural Pakistan. Paper Presented at IFPRI-World Bank Conference on Risk and Vulnerability: Estimation and Policy Implications, Washington D.C., September 23–24. Available online: http://www.ifpri.org/events/conferences/2002/092302/mansuri.pdf .

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S., eds. 2001. *Climate change 2001: Impacts, adaptation and vulnerability.* Cambridge, UK: Cambridge University Press.

Meadows, M.E and M.T. Hoffman. 2002. The nature, extent and causes of land degradation in South Africa: Legacy of the past, lessons for the future? *Area* 34 (4): 428–437.

Moser, C.O.N. 1998. The asset vulnerability framework: Reassessing urban poverty reduction strategies. *World Development* 26 (1): 1–19.

Moss, R.H., A.L. Brenkert and E.L. Malone. 2001. *Vulnerability to climate change: a quantitative approach*. Research report Prepared for the U.S. Department of Energy.

Nicholls, R.J. and R.S.J. Tol. 2006: Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the 21st century. Philos. T. Roy. Soc. A, 361:1073–1095.

O'Brien, K.L., S. Eriksen, A. Schjolden and L. Nygaard. 2004a. *What's in a word? Conflicting interpretations of vulnerability in climate change research.* CICERO Working Paper 2004:04. Oslo, Norway: Centre for International Climate and Environmental Research.

O'Brien, K.L., R.M. Leichenko, U. Kelkar, H.M. Venema, G. Aandahl, H. Tompkins, A. Javed, S. Bhadwal, S. Barg, L. Nygaard and J. West. 2004b. Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change* 14: 303–313.

Patnaik U. and K. Narayanan. 2005. Vulnerability and climate change: An analysis of the eastern coastal districts of India. Paper presented at the "Human Security and Climate Change International Workshop," Asker, Norway, June 21–23.

Poonyth, D., Hassan, R.M., Gbetibouo, G.A., Ramaila, J.M. and Letsoalo, M.A., 2002. Measuring the impact of climate change on South African agriculture: A ricardian approach. Paper presented at the "40th Annual Agricultural Economics Association of South Africa Conference," Bloemfontein, South Africa, September 18–20.

Pritchett, L., Suryahadi, A., Sumarto, S., 2000. Quantifying vulnerability to poverty: a proposed measure with application to Indonesia. Social Monitoring and Early Response Unit Research Institute (SMERU) Working Paper, May 2000. Available online: www.smeru.or.id.

Schimmelpfennig, D., Yohe, G., 1999. Vulnerability of crops to climate change: A practical method of indexing. In: *Global Environmental Change and Agriculture,* Frisvold, G., Kuhn, B. eds. UK: Edward Elgar Publishing.

Schulze, R.E., G.A. Kiker and R.P. Kunz. 1993. Global climate change and agricultural productivity in Southern Africa. *Global Environ. Change* 3 (4): 330–349.

Sen, A. 1981. *Poverty and famines: An essay on entitlement and deprivation.* Oxford: Clarendon Press and New York: Oxford University Press.

SEI (Stockholm Environment Institute). 2004. *Choosing methods in assessments of vulnerable food systems*. Risk and Vulnerability Programme, SEI Briefing Note, Stockholm: SEI.

Smit, B. and J. Wandel. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16 (3):282–292.

SSA (Statistics South Africa). 2002. *Report on the survey of large and small scale agriculture. Central Statistical Service.* South Africa: Pretoria.

SSA (Statistics South Africa). 2005. *Census of commercial agriculture 2002: Financial and production statistics. Central Statistical Service. Report No. 11–02–01,* Pretoria, South Africa: Statistics South Africa.

SSA (Statistics South Africa). 2008. *General household survey 2007: Central Statistical Service.* Pretoria, South Africa: Statistics South Africa.

TERI (The Energy Research Institute). 2003. Coping with global change: Vulnerability and adaptation in Indian agriculture. Delhi, India: The Energy and Resource Institute.

Thornton P.K., Jones P.G., Owiyo T., Kruska R.L., Herrero M., Kristjanson P., Notenbaert A., Bekele N. and Omolo A., with contributions from Orindi V., Otiende B., Ochieng A., Bhadwal S., Anantram K., Nair S., Kumar V. and U. Kulkar. 2006. *Mapping climate vulnerability and poverty in Africa*. Report to the Department for International Development (ILRI) Nairobi, Kenya.

Turner B.L., R.E. Kasperson, P.A. Matson, J.J. McCarthy, R.W. Corell, L. Christensen, N. Eckley, J.X. Kasperson, A. Luers, M.L. Martello, C. Polsky, A. Pulsipher and A. Schiller. 2003a. Framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences, USA. PNAS 100: 8074–8079.

Turner B.L., R.E. Kasperson, P.A. Matson, J.J. McCarthy, R.W. Corell, L. Christensen, N. Eckley, G.K. Hovelsrud-Broda, J.X. Kasperson, R.E. Kasperson, A. Luers, M.L. Martello, S. Mathiesen, R. Naylor, C. Polsky, A. Pulsipher, A. Schiller and N. Tyler. 2003b. Illustrating the coupled human-environment system for vulnerability analysis: Three case studies. . Proceedings of the National Academy of Sciences, USA. PNAS 100: 8080–8085.

UNDP (United Nations Development Programme). 2002. Human development report. United Nations Development Programme. New York.: United Nations.

UNDP (United Nations Development Programme). 1990. Human development report: Concept and measurement of human development. United Nations Development Programme. New York.: United Nations.

Vincent, K., 2004. *Creating an index of Social vulnerability to climate change for Africa*. Working paper 56. Norwich, U.K.: Tydall Centre for Climate change Research, University of East Anglia.

Venetoulis, J., and C. Cobb. 2004. Genuine Progress Indicator (GDI): Measuring the real state of the economy. Oakland: Redefining Progress.

Vogel, C., and K. O'Brien. 2004. Vulnerability and global environmental change: Rhetoric and reality. *AVISO Bulletin* 13:1–8.

Watson, R.T., M.C., Zinyowera, and R.H. Moss, eds. 1996. Climate change 1995: Impacts, adaptations and mitigation of climate change: Scientific-Technical analyses, contribution of Working Group II to the second assessment report of the Intergovernmental Panel on Climate Change. Cambridge, U.K.: Cambridge University Press.

Warren, R., N. Arnell, R. Nicholls, P. Levy and J. Price. 2006. *Understanding the regional impacts of climate change: Research report prepared for the Stern Review on the Economics of Climate Change. Tyndall Centre for Climate Change Research.* Working Paper 90. Norwich: University of East Anglia.

Watts, M.J. and H.G. Bohle. 1993. The space of vulnerability: the causal structure of hunger and famine. *Progress in Human Geography* 17 (1): 43–67.

Zhang, X., M. Rockmore and J. Chamberlin. 2007. *A typology for vulnerability and agriculture in Sub-Saharan Africa.* IFPRI Discussion Paper 00734. Development Strategy and Governance Division. Washington, D.C.: International Food Policy Research Institute.

RECENT IFPRI DISCUSSION PAPERS

For earlier discussion papers, please go to www.ifpri.org/pubs/pubs.htm#dp.
All discussion papers can be downloaded free of charge.

884. *How does food price increase affect Ugandan households? An augmented multimarket approach.* John M. Ulimwengu and Racha Ramadan. 2009.

883. *Linking urban consumers and rural farmers in India: A comparison of traditional and modern food supply chains.* Bart Minten, Thomas Reardon, and Anneleen Vandeplas. 2009.

882. *Promising Approaches to Address the Needs of Poor Female Farmers: Resources, Constraints, and Interventions.* Agnes R. Quisumbing and Lauren Pandolfelli. 2009

881. *Natural Disasters, Self-Insurance, and Human Capital Investment: Evidence from Bangladesh, Ethiopia, and Malawi.* Futoshi Yamauchi, Yisehac Yohannes, and Agnes Quisumbing. 2009.

880. *Risks, ex-ante actions, and public assistance: Impacts of natural disasters on child schooling in Bangladesh, Ethiopia, and Malawi.* Futoshi Yamauchi, Yisehac Yohannes, Agnes Quisumbing. 2009.

879. *Measuring child labor: Comparisons between hours data and subjective measures.* Andrew Dillon. 2009.

878. *The effects of political reservations for women on local governance and rural service provision: Survey evidence from Karnataka.* Katharina Raabe, Madhushree Sekher, and Regina Birner. 2009.

877. *Why is the Doha development agenda failing? And what can be Done? A computable general equilibrium-game theoretical approach.* Antoine Bouët and David Laborde. 2009.

876. *Priorities for realizing the potential to increase agricultural productivity and growth in Western and Central Africa.* Alejandro Nin-Pratt, Michael Johnson, Eduardo Magalhaes, Xinshen Diao, Liang You, and Jordan Chamberlin. 2009.

875. *Rethinking China's underurbanization: An evaluation of Its county-to-city upgrading policy.* Shenggen Fan, Lixing Li, and Xiaobo Zhang. 2009.

874. *Agricultural trade liberalization and poverty in Brazil.* Joachim Bento de Souza Ferreira Filho. 2009.

873. *Economywide impacts of climate change on agriculture in Sub-Saharan Africa.* Alvaro Calzadilla, Tingju Zhu, Katrin Rehdanz, Richard S.J. Tol, and Claudia Ringler. 2009.

872. *Decentralization and local public services in Ghana: Do geography and ethnic diversity matter?* Kamiljon T. Akramov Felix Asante. 2009.

871. *Soil and water conservation technologies: A buffer against production risk in the face of climate change? Insights from the Nile Basin in Ethiopia.* Edward Kato, Claudia Ringler, Mahmud Yesuf, and Elizabeth Bryan. 2009.

870. *Validation of the World Food programme's food consumption score and alternative indicators of household food security*. Doris Wiesmann, Lucy Bassett, Todd Benson, and John Hoddinott. 2009

869. *Rebuilding after emergency: Revamping agricultural research in Sierra Leone after civil war*. Kwadwo Asenso-Okyere, Sindu Workneh, Edward Rhodes, John Sutherland. 2009.

868. *Farmers' health status, agricultural efficiency, and poverty in rural Ethiopia.* John M. Ulimwengu. 2009

867. *Joint water quantity/quality management analysis in a biofuel production area: Using an integrated ecomomic hydrologic model.* Márcia Maria Guedes Alcoforado de Moraes, Ximing Cai, Claudia Ringler, Bruno Edson Albuquerque, Sérgio P. Vieira da Rocha, Carlos Alberto Amorim. 2009.

866. *Economywide economic impact of Avian flu in Ghana: A dynamic CGE model analysis.* Xinshen Diao. 2009

865. *Brazil: Shadow WTO agricultural domestic support notifications.* Andre M. Nassar and Diego Ures, 2009**.**

864. *HIV/AIDS, growth and poverty in KwaZulu-Natal and South Africa: Integrating firm-level surveys with demographic and economywide modeling*. James Thurlow, Gavin George, and Jeff Gow, 2009.

863. *The short-run macroeconomic impact of foreign aid to small states: an agnostic time series analysis*. Henrik Hansen and Derek Headey, 2009.

862. *European Union preferential trade agreements with developing countries and their impact on Colombian and Kenyan carnation exports to the United Kingdom*. Guyslain K. Ngeleza and Andrew Muhammad, 2009.

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

www.ifpri.org

IFPRI HEADQUARTERS

2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org

IFPRI ADDIS ABABA

P. O. Box 5689
Addis Ababa, Ethiopia
Tel.: +251 11 6463215
Fax: +251 11 6462927
Email: ifpri-addisababa@cgiar.org

IFPRI NEW DELHI

CG Block, NASC Complex, PUSA
New Delhi 110-012 India
Tel.: 91 11 2584-6565
Fax: 91 11 2584-8008 / 2584-6572
Email: ifpri-newdelhi@cgiar.org