CPWF Project Report

Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa

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Governance and Modeling Author Team

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Disclaimer

Program Preface

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase water productivity for agriculture—that is, to change the way water is managed and used to meet international food security and poverty eradication goals—in order to leave more water for other users and the environment.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface

Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa

The project "Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa" aimed to provide farmers, policymakers, and other stakeholders in Ethiopia and South Africa with tools to make better adaptive decisions in the face of climate-related risk. The project combined household surveys and stakeholder forums, which examined local perceptions of the long-term effects of global warming and adaptive responses, with climate change impact analysis. The results of the study showed that vulnerability to climate change is dependent on a number of factors including the degree to which farmers are exposed to climate change, their sensitivity to climate changes, and their adaptive capacity. Given that the nature of vulnerability will vary depending on these factors and given large spatial differences across regions, policymakers should tailor strategies to reduce vulnerability to local conditions. 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. Moreover, early warning of extreme climatic events, such as droughts and floods, can alert farmers to the shocks, enabling them to take action to reduce their vulnerability, such as selling livestock and increasing food stocks. The findings indicate that adaptation strategies need to go beyond improved water storage, additional irrigation, and new crop varieties to include a focus on improving farmers' access to information, credit, and markets. Information on climate changes and appropriate adaptation responses is critical to ensure that farmers are able to make the necessary adjustments to their farming practices. To ensure that the right information gets to the right people, proactive investments, policies, and extension services must explicitly target those who are most vulnerable to climate change: subsistence farmers, women, children, and marginalized or less-educated groups. Additional investments of US$2 billion per year in public agricultural R&D, rural roads, female secondary education, irrigation, and access to clean water could significantly reduce the adverse effects of climate change in Sub-Saharan Africa. US$5 billion per year could help reduce the number of malnourished children to one-third of its current level over the next fifty years.

CPWF Project Report Series

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ARC	Agricultural Research Council (South Africa)
ARI	Advanced Research Institute
BMZ	Germany Ministry for Cooperation and Economic Development (donor)
CDM	Clean Development Mechanism
CEEPA	Center for Environmental Economics and Policy in Africa, University of Pretoria
CGIAR	Consultative Group on International Agricultural Research
CPWF	Challenge Program on Water and Food
DEAT	Department of Environmental Affairs and Tourism (South Africa)
EDRI	Ethiopian Development Research Institute
EEA	Ethiopian Economics Association
EEPF	Environmental Economics Policy Forum of the Ethiopian Development Research Institute associated with Addis Ababa University
IFPRI	International Food Policy Research Institute
NARES	National Agricultural Research and Extension
NGO	Non-Government Organization
NMA	National Meteorology Agency (Ethiopia)
UH	University of Hamburg
UNFCCC	United Nations Framework Convention on Climate Change

RESEARCH HIGHLIGHTS

The project exceeded expectations in terms of both output and outreach. This was the first scientific, in-depth analysis of climate change impacts and adaptation options at the farm and national-level for Ethiopia and, while there is much more research and information available for South Africa, project insights were also deeply appreciated in South Africa.

This project generated research results on vulnerability, adaptation and climate change impacts using a variety of methods including household surveys, stakeholder workshops, econometric analyses, and simulation modeling, using both partial agricultural equilibrium and general equilibrium models.

Vulnerability assessment showed that while exposure to climate change is greater in the case of South Africa, farmers in Ethiopia can be considered more vulnerable given a lack of coping or adaptive capacity due to extreme poverty. In the case of Ethiopia, vulnerability to climate change is highly related to poverty. Integrated rural development schemes aimed at alleviating poverty can play the double role of reducing poverty and increasing adaptive capacity to climate change. To counteract the adverse impact of climate change, special emphasis will need to be placed on the relatively less-developed regions of the country (i.e., Afar and Somali), as well as the relatively more populated regions (e.g., Oromia and Tigray), in terms of investment in technology, institutions, and infrastructure.

The results for South Africa show that the regions deemed to be most exposed to climate change and variability do not always overlap with the most vulnerable populations. Rather, 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.

An analysis of the determinants of adaptation yielded the following key findings: In order to successfully promote adaptation, action is necessary in a number of areas, including climate change awareness, access to rural services such as credit and extension, secure land rights, agricultural technology, and communication. Development efforts to strengthen the economic position of households would also facilitate adaptation by enabling farmers to invest in changes to their farming practices.

As climate change continues to worsen farming conditions in Sub-Saharan Africa, governments will also need to improve monitoring systems to provide early warnings so farmers can prepare for potential crises. While it is important that governments share information and communicate with rural communities, this information must be communicated in a way that is useful to farmers. Greater communication between smallholder farmers, policymakers, and development workers will ensure that the information provided is relevant and useful on the ground.

Global change assessments and scenario analyses revealed that water resources in the basin are already stressed under today's climate condition. Projected water management and infrastructure improvements, including water use efficiency, storage and conveyance facilities, are expected to improve the situation by 2030 if current climate continues into the future. However, once climate change considerations are taken into account, future water supply conditions are expected to worsen considerably out to 2030. Assessing hydrological impacts of climate change is crucial given that expansion of irrigated areas has been postulated as one key adaptation strategy for Sub-Saharan Africa. Such expansion will need to take into account changes in availability of water resources in African river basins.

Moreover, under a scenario of moderate climate change the world's crop harvested area and food production would decrease by 0.3 and 2.7 percent, respectively, by 2050. Both rainfed and irrigated harvested areas decrease in Sub-Saharan Africa under climate change, whereas rainfed production increases by 0.7 percent, and irrigated production drops by 15.3 percent. This sharp decrease in irrigated productivity occurs because some irrigated crops, such as wheat and sugarcane, are more susceptible to heat stress and as well as due to reduced availability of water for irrigation. Under climate change, only 4.4 percent of the total crop harvested area is expected to be under irrigation by 2050, whereas irrigated production is expected to constitute 12.1 percent of total agricultural production in the region by 2050.

These results show that without specific adaptation, climate change would have a negative impact on agriculture in Sub-Saharan Africa. Total food production would fall by 1.6%, with heavy losses in sugarcane (-10.6%) and wheat (-24.1%). The number of malnourished children would increase by almost 2 million.

Adaptation strategies need to go beyond improved water storage, additional irrigation, and new crop varieties to include a focus on improving farmers' access to information, credit, and markets. Information is the key to adaptation. To ensure that the right information gets to the right people, proactive investments, policies, and extension services must explicitly target those who are most vulnerable to climate change: subsistence farmers, women, children, and marginalized or less-educated groups.

Additional investments of US$2 billion per year in public agricultural R&D, rural roads, female secondary education, irrigation, and access to clean water could significantly reduce the adverse effects of climate change in the region. US$5 billion per year could help reduce the number of malnourished children to one-third of its current level over the next fifty years. Agricultural mitigation also presents an opportunity, through carbon credits and the like, to provide poor farmers with the economic resources they need to adapt.

EXECUTIVE SUMMARY

Background

Over the coming decades, global change will have an impact on food and water security in significant and highly uncertain ways, and there are strong indications that developing countries will bear the brunt of the adverse consequences, particularly from climate change. This is largely because poverty levels are high, and developing-country capacity to adapt to global change is weak. Furthermore, the rural populations of developing countries—for whom agricultural production is the primary source of direct and indirect employment and income—will be most affected due to agriculture's vulnerability to global change processes. The agricultural sector is the largest consumer of water resources, and variability in water supply has a major influence on health and welfare in poor areas. With water scarcity and extreme weather events expected to increase under climate change, water security could decline significantly in rural areas. Consequently, it is important to understand the impacts of global change (in terms of climate, demography, technology, and so on) on agriculture and natural resources in developing countries and to develop adaptive capacity to respond to these impacts. Moreover, there is a need to develop informed and effective adaptation measures and investment options that can be taken now to alleviate adverse impacts of global change in the future.

Objectives

The project aimed to provide policymakers and stakeholders in Ethiopia and South Africa, particularly farmers and other rural stakeholders who face the largest impact from global change, with tools to better understand, analyze, and form policy decisions that will allow them to adapt to global change. Results are also useful to other areas in Africa and elsewhere that face similar impacts from global climate change. The project produced outputs in 6 areas: (1) Characterization of Vulnerability and Adaptive Capacity with Local Partners and Stakeholders (Ethiopia and South Africa); (2) Identification of Determinants of Adaptive Capacity with Partners and Stakeholders; (3) Development of Integrated Policy Analysis Tools with Partners; (4) Global Change Assessment and Scenario Analysis - Assessment of the impacts of global change on rural Africa, in general, and on Ethiopia and South Africa, in particular, and analysis of response options developed in Ethiopian and South African study sites based on the integrated policy analysis tool; (5) Development of General Directions for Adaptation and Mitigation Strategies for Rural Africa and the Developing World; and Specific Strategies for Ethiopia and South Africa Together with Local Partners and Wide Dissemination of Research Results; and (6) Enhanced National and International Capacity for climate change and economic policy analysis through training of PhD students.

Research regions

To develop these outputs, research under this project was conducted in two river basins in two countries in Sub-Saharan Africa; the Limpopo Basin in South Africa and the Nile River Basin in Ethiopia. Additional research activities were implemented at the national levels in Ethiopia and South Africa and at the regional level for all of Sub-Saharan Africa.

Methods

At the local level, farm household surveys were implemented in the Nile River Basin of Ethiopia and the Limpopo River Basin of South Africa to examine vulnerability to shocks, perceptions of long-term changes in climate (precipitation and temperature), and the determinants of adaptation to long-term climate change. Policymakers are generally

more interested in the development of adaptation measures following political rather than hydrologic boundaries. Therefore, vulnerability and adaptation measures were also developed at the province/state level for these two countries. In parallel, stakeholder forums were held in Ethiopia and South Africa to discuss measures of vulnerability, adaptation options and constraints, and the role of information and various actors—the state, the private sector, and civil society—in shaping adaptation to climate change. Finally, the impact of climate change on crop production in the survey sites was simulated based on crop yield and production function models to assess the implications of climate change for local food security.

At the basin level, the impact of climate change on water availability, water demands, and irrigation was simulated to identify basin-level adaptation strategies. Moreover, alternative investment strategies at the basin level were identified for Ethiopia taking into account climate variability and change, and broader impacts on the economy. A different but similar approach was used to study the impact of climate change and adaptation strategies on river basin units in South Africa. To capture the interactions of climate change and adaptation at the national and regional (Sub-Saharan Africa) levels, a water-food projections model was updated to take into account the impacts of climate change in addition to other drivers of global change. Using the integrated analysis tool, the impact of global change on water and food security, and poverty was assessed for case study countries and Sub-Saharan Africa. Alternative adaptation strategies developed at workshops were assessed using the modeling framework and taking into account local-level constraints to adaptation and basin-level challenges identified.

These sets of analyses were complemented with papers on the role of climate change mitigation for the region, the importance of taking risk into account in devising adaptation options, and the role of collective action and property rights in community adaptation.

Research findings

- Characterization of Vulnerability and Adaptive Capacity with Local Partners and Stakeholders (Ethiopia and South Africa)

In the case of Ethiopia, vulnerability to climate change is highly related to poverty. Integrated rural development schemes aimed at alleviating poverty can play the double role of reducing poverty and increasing adaptive capacity to climate change. To counteract the adverse impact of climate change, special emphasis will need to be placed on the relatively less-developed regions of the country (i.e., Afar and Somali), as well as the relatively more populated regions (e.g., Oromia and Tigray), in terms of investment in technology, institutions, and infrastructure.

Moreover, early warning of extreme climatic events, such as drought, can alert farmers to sell their livestock and buy food and other items. Without such warning systems, extreme events can deplete the assets of farmers with long-term adverse consequences for income and poverty alleviation. In addition, investment in irrigation in places with high potential for irrigation (e.g., SNNPR—Southern Nations, Nationalities and People's Region) can increase the country's food supply. This supply could then be stored and sold during drought events and thus reduce food aid dependence. Strengthening the ongoing micro-level adaptation methods of governmental and nongovernmental organizations, such as water harvesting and other natural resource conservation programs, can also boost the adaptive capacities of farmers.

The results for South Africa show that the regions deemed to be most exposed to climate change and variability do not always overlap with the most vulnerable populations. Rather, 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. The findings indicate that farmers in the Western Cape will be confronted with high exposure to climate change and 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 change 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.

Given the large spatial differences across province-level vulnerability, policymakers should tailor policies to local conditions. 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, policymakers should enact measures to support the effective management of environmental resources (e.g., soil, vegetation and water resources); promote increased market participation, especially within the large subsistence farming sector; stimulate both agricultural intensification and diversification of livelihoods away from risky agriculture; and enact social programs and spending on health, education and welfare, which can help maintain and augment both physical and intangible human capital. Finally, policymakers 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.

- Identification of Determinants of Adaptive Capacity with Partners and Stakeholders

Participants at the stakeholder forums in Ethiopia and South Africa discussed the adaptation options available to farmers in the study regions. According to workshop participants in Ethiopia, households have only a limited set of adaptation options at their disposal given generally high levels of poverty and low levels of education and knowledge. Common adaptation measures communities adopt when confronted with climate change include diversification of livelihood sources, migration, participation in non-farm activities, sale of assets, settlement and resettlement activities, and the adoption of improved water management systems. In South Africa, participants identified improving water management, irrigation and water harvesting, delaying planting, diversifying livelihood sources, shifting to non-farm activities, environmental conservation, and decreasing the area of land under cultivation as appropriate adaptations.

Stakeholders also made several policy recommendations designed to facilitate adaptation. In Ethiopia, stakeholders argued that greater efforts should be made to promote economic development, encourage the participation of all stakeholders in decision-making, strengthen coordination and information exchange among stakeholders, integrate adaptation into sustainable development strategies, draw on local knowledge and experience, create awareness, strengthen data collection and analysis, and build capacity for policymaking and implementation of adaptation strategies. In South Africa, participants also identified several measures the government should undertake to support adaptation, including developing the land market, providing market opportunities for small-scale farmers, Investing in infrastructure development including the transport system, providing training (and re-training) of extension officers, investing in education and capacity building of farmers, investing in irrigation systems, and promoting off-farm income earning activities.

The descriptive and econometric analyses yielded the following key findings: In order to successfully promote adaptation, action is necessary in a number of areas, including

climate change awareness, access to rural services such as credit and extension, secure land rights, agricultural technology, and communication systems (such as monitoring and early warning systems). Development efforts to strengthen the economic position of households would also facilitate adaptation by enabling farmers to invest in changes to their farming practices. Providing incentives for agricultural technology could make adaptation far easier for many farmers, giving them access to small-scale irrigation systems or enabling them to plant high-yielding or drought-resistant crop varieties. Social networks also support adaptation by acting as conduits for financial transfers that may ease farmers' credit constraints, provide information about new technologies, and facilitate cooperation among farmers to allow the costs and benefits of adaptation to be shared.

Further evidence from Ethiopia suggests that farmers' risk perceptions may also play an important role in their choice of adaptation strategy. Farmers appear to select soil and water conservation technologies that reduce risk in terms of the impact on the variance of crop production. The riskiness of technology varies according to level of rainfall as well as geographic region underscoring the importance of careful targeting when promoting and scaling up soil and water conservation technologies.

- Development of Integrated Policy Analysis Tools with Partners

The following policy analysis tools were developed: vulnerability indicators (PhD students with partners in country), econometric models (PhD students and partners in country), country-level CGE model (for South Africa, IFPRI with partners in country), combining climate change impact analysis with a multi-market model (for Ethiopia, consultants and IFPRI), extension of a partial agricultural equilibrium model to incorporate the impacts of climate change (IFPRI), and adding climate change impact analysis capacity to a Global General Equilibrium Model (German partner, with developing-country PhD student and IFPRI).

- Global Change Assessment and Scenario Analysis - Assessment of the impacts of global change on rural Africa, in general, and on Ethiopia and South Africa, in particular, and analysis of response options developed in Ethiopian and South African study sites based on the integrated policy analysis tool

Global change assessments revealed that climate change impacts vary significantly, depending on the scenario and Global Circulation Model chosen. This is particularly true for Sub-Saharan Africa where model results indicate raising temperatures but results differ significantly regarding changes in precipitation (for example, for East Africa, with results ranging from a much drier to much wetter outcomes).

When climate change scenarios are incorporated into a global hydrological model to assess implications from climate change on water and irrigation, results showed that water resources of the Limpopo River Basin are already stressed under today's climate condition. Projected water management and infrastructure improvements, including water use efficiency, storage and conveyance facilities, are expected to improve the situation by 2030 if current climate continues into the future. However, once climate change considerations are taken into account, future water supply conditions are expected to worsen considerably out to 2030. Assessing hydrological impacts of climate change is crucial given that expansion of irrigated areas has been postulated as one key adaptation strategy for Sub-Saharan Africa. Such expansion will need to take into account changes in availability of water resources in African river basins.

The major impact of climate change on Ethiopia's economy will result from more frequent occurrence of extreme hydrologic events, which cause losses in both the agricultural and nonagricultural sectors. To adapt to these long-term changes, Ethiopia

should invest in enhanced water control to expand irrigation and improve flood protection.

An analysis of green (precipitation-based) and blue (irrigation-based) water resources in the Limpopo and Nile River Basins found that growing water scarcity in the Limpopo basin suggests a need for investment in technologies to enhance both irrigated and rainfed crop yields. In the Nile River basin, on the other hand, irrigated crop productivities are fairly high and achieved with little complementary precipitation. In this basin, the focus needs to be on both an expansion of irrigated areas and improvement in rainfed crop productivity.

Linking the global hydrologic model with IFPRI's IMPACT water and food projections model and a Computable General Equilibrium model developed at the University of Hamburg showed that without specific adaptation, climate change would have a negative impact on agriculture in Sub-Saharan Africa. Total food production would fall by 1.6%, with heavy losses in sugarcane (-10.6%) and wheat (-24.1%). The number of malnourished children would increase by almost 2 million.

Two adaptation scenarios—the first doubles irrigated area in Sub-Saharan Africa and the second scenario increases both rainfed and irrigated crop yields by 25 percent for all countries in Sub-Saharan Africa—show improved outcomes, however. Because of the relatively low share of irrigated area in total agricultural area in Sub-Saharan Africa, an increase in agricultural productivity achieves much larger benefits for the region than a doubling of irrigated area. Because agriculture in Sub-Saharan Africa is far below its potential, substantial productivity gains are technically feasible. An increase in irrigated area and agricultural productivity leads to a decrease in the production cost of agricultural products, and consequently to a reduction in market prices. Even though Sub-Saharan Africa is not a key contributor to global food production or irrigated food production, both adaptation scenarios help lower world food prices.

As a result of lower food prices, the number of malnourished children in Sub-Saharan Africa is projected to decline by 0.3 million children by 2050 under the doubling of irrigated area scenario and by 1.6 million children under the increased agricultural productivity scenario. Both adaptation scenarios enable farmers to achieve higher yields and revenues from crop production.

- Development of General Directions for Adaptation and Mitigation Strategies for Rural Africa and the Developing World; and Specific Strategies for Ethiopia and South Africa Together with Local Partners and Wide Dissemination of Research Results

Key conclusions that extend to all of Sub-Saharan Africa include that adaptation strategies need to go beyond improved water storage, additional irrigation, and new crop varieties to include a focus on improving farmers' access to information, credit, and markets. Information is the key to adaptation. To ensure that the right information gets to the right people, proactive investments, policies, and extension services must explicitly target those who are most vulnerable to climate change: subsistence farmers, women, children, and marginalized or less-educated groups.

The analysis on investments needed for climate change adaptation for Sub-Saharan Africa have shown that additional investments of US$2 billion per year in public agricultural R&D, rural roads, female secondary education, irrigation, and access to clean water could significantly reduce the adverse effects of climate change in the region. US$5 billion per year could help reduce the number of malnourished children to one-third of its current level over the next fifty years.

The project also analyzed the potential for Sub-Saharan African countries to contribute to climate change mitigation through agriculture and land use change. The review found

that while there has been little recognition of the role of agriculture and land use change in contributing to climate change significant potential exists in these countries to reduce climate change. By recognizing and financing these mitigation opportunities through carbon credits and the like, developed countries would also be providing poor farmers with the economic resources they need to adapt.

Outcomes and impacts

The main aim of this project was to influence the policymaking process at the national level, thus, policymakers and researchers were the main audience for research results. To ensure that research results are used by policymakers and researchers, policy briefs were developed for all major research papers and reports. Policy briefs relating to topics of importance for Ethiopia were translated into Amharic. All policy briefs have been made available over the internet or as hardcopy when requested. Moreover, we disseminated research results through several policy workshops in our partner countries, as well as through various media outlets (see selected media reports below), and through presentations in international conferences, and publication of working papers that can be easily accessed over the internet. The data collected for this project have been made available for use by all our in-country collaborators, and they, in turn, have passed the data on to new students and researchers.

However, the results have implications for other stakeholders at a more micro-level including extension agents, farmers, and community leaders. It is assumed that information provided to policymakers at the national level will influence decision-making in the formation of adaptation strategies, which will then influence changes at the farm level. However, it will be important to monitor the impact of policy decisions on the ground at the farm and community levels.

We received several requests for the household questionnaire that has since been adapted to other studies in other African countries and beyond. We also received many requests for presentation of our research results and for papers, articles, and short summaries that we have gladly provided. We hope to also present our final results at the Copenhagen Climate Change Negotiations.

International public goods

Apart from the knowledge generated through the research, the project produced two important international public goods: 2 large household datasets with vulnerability, climate change perception, and adaptation modules. Household datasets will be made available on the IFPRI website following IFPRI data policy; moreover, the project, for the first time, combined a global CGE model with both irrigation analysis and climate change impact analysis.

Recommendations and Future Research Needs

The study highlighted the need for more research on the effectiveness, risks, and benefits of adaptation options in different contexts. IFPRI and collaborating research institutes should further explore and assess the implications of different adaptation options. In addition, more research is needed on the synergies and tradeoffs between adaptation responses, climate change mitigation activities, and efforts to increase agricultural productivity so that priority may be given to activities which meet multiple objectives.

Finally, more research is needed on the impacts of extreme events (droughts, floods, hailstorms), and not just impacts of climate change as measured by Global Circulation Models (increasing temperatures and changing patterns of precipitation). Furthermore, impacts of sea-level rise, glacier melt, extreme events, increasing temperatures and

changing rainfall patterns need to be assessed simultaneously to assess potential impacts on agricultural production and food security more in-depth.

The study also highlighted the need for targeted investments based on disaggregated vulnerability analysis--given the large heterogeneity among local biophysical and socioeconomic conditions and projected changes of these conditions under climate change--to ensure that scarce budgetary resources are not wasted. This will require more spatially disaggregated projections of climate change impacts and more information on the long-term benefits and risks of various adaptation options. Further research on community-based adaptation strategies is also warranted.

The research results have several implications for end users. The results show that farm-level adaptation involves more than adopting new agricultural technologies such as improved water storage facilities, additional irrigation, and new crop varieties. Given the importance of having access to extension services and formal sources of credit on farmers' decisions to adapt, policy-makers should extend and improve upon such services, ensuring that they reach small-scale subsistence farmers.

Providing support to the poorest farmers is critically important, given that this group is the most vulnerable to long term climate change, and least-equipped to make the changes needed to sustain their livelihoods in the face of such a threat. Addressing market imperfections, including lack of access to information and credit, and ensuring effective targeting requires strong leadership and involvement of the government in planning for adaptation and implementing measures to facilitate adaptation at the farm level.

Government investments in enhanced and expanded water control, development of better crop varieties, and improved crop management practices, such as agro-forestry also require government support to be taken up by a larger number of farmers. Ultimately, given the constraints to adaptation highlighted in this study, many farmers may turn to adaptation options outside the agriculture sector, including migration, or finding wage employment.

1. INTRODUCTION

1.1 Impacts of global change on the poor

Over the coming decades, global change will have an impact on food and water security in significant and highly uncertain ways, and there are strong indications that developing countries will bear the brunt of the adverse consequences, particularly from climate change. This is largely because poverty levels are high, and developing-country capacity to adapt to global change is weak. Furthermore, the rural populations of developing countries—for whom agricultural production is the primary source of direct and indirect employment and income—will be most affected due to agriculture's vulnerability to global change processes. The agricultural sector is the largest consumer of water resources, and variability in water supply has a major influence on health and welfare in poor areas. With water scarcity and extreme weather events expected to increase under climate change, water security could decline significantly in rural areas. Consequently, it is important to understand the impacts of global change (in terms of climate, demography, technology, and so on) on agriculture and natural resources in developing countries and to develop adaptive capacity to respond to these impacts. Moreover, there is a need to develop informed and effective adaptation measures and investment options that can be taken now to alleviate adverse impacts of global change in the future (Figure 1).

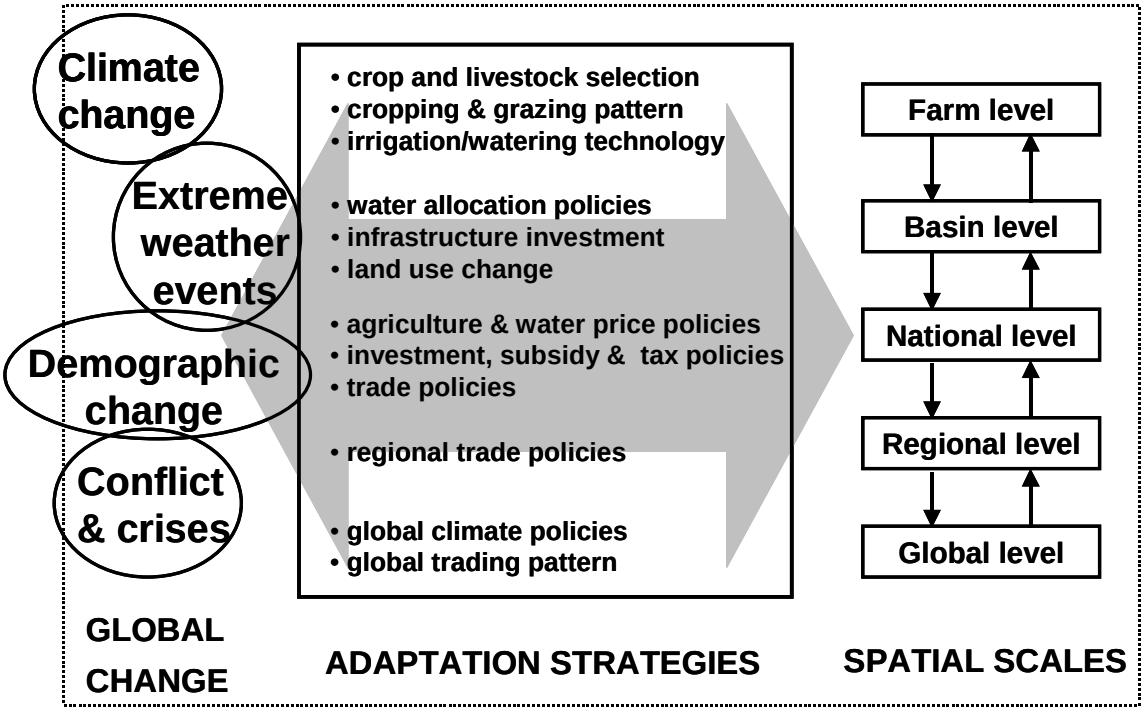

Figure 1. Global Change, Spatial Scales, and Adaptation Strategies

A project supported by the Federal Ministry for Economic Cooperation and Development, Germany, titled "Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa," has attempted to work on these various scales with a focus on adaptation to climate change. This project, which is associated with the CGIAR Challenge Program on Water and Food, involved close collaboration with researchers at the

Center for Environmental Economics and Policy in Africa, the Ethiopian Development Research Institute, the Ethiopian Economics Association, and the University of Hamburg.

At the local level, farm household surveys were implemented in the Nile River Basin of Ethiopia and the Limpopo River Basin of South Africa to examine vulnerability to shocks, perceptions of long-term changes in climate (precipitation and temperature), and the determinants of adaptation to long-term climate change. Policymakers are generally more interested in the development of adaptation measures following political rather than hydrologic boundaries. Therefore, vulnerability and adaptation measures were also developed at the province/state level for these two countries. In parallel, stakeholder forums were held in Ethiopia and South Africa to discuss measures of vulnerability, adaptation options and constraints, and the role of information and various actors—the state, the private sector, and civil society—in shaping adaptation to climate change. Finally, the impact of climate change on crop production in the survey sites was simulated based on crop yield and production function models to assess the implications of climate change for local food security.

At the basin level, the impact of climate change on water availability, water demands, and irrigation was simulated to identify basin-level adaptation strategies. Moreover, alternative investment strategies at the basin level were identified for Ethiopia taking into account climate variability and change, and broader impacts on the economy. A different but similar approach was used to study the impact of climate change and adaptation strategies on river basin units in South Africa. To capture the interactions of climate change and adaptation at the national and regional (Sub-Saharan Africa) levels, a water-food projections model was updated to take into account the impacts of climate change in addition to other drivers of global change. Using the integrated analysis tool, the impact of global change on water and food security, and poverty was assessed for case study countries and Sub-Saharan Africa. Alternative adaptation strategies developed at workshops were assessed using the modeling framework and taking into account local-level constraints to adaptation and basin-level challenges identified.

These sets of analyses were complemented with papers on the role of climate change mitigation for the region, the importance of taking risk into account in devising adaptation options, and the role of collective action and property rights in community adaptation.

1.2 Conceptual framework for vulnerability and adaptation to climate change

Figure 2 presents the conceptual framework for vulnerability and adaptation to climate change used for this report. An individual, community's or country's ability to become resilient to climate change is determined by the nature of the impacts and the capacity to adapt. The magnitude of impacts is influenced by exposure and sensitivity to climatic variability and change. In addition, varied factors determine adaptive capacity, from social networks to the level of access to economic resources. Therefore, building adaptive capacity through increasing access to knowledge and resources and reducing the severity of impacts through emissions abatement are key entry points for reducing vulnerability and building resilience to climate change.

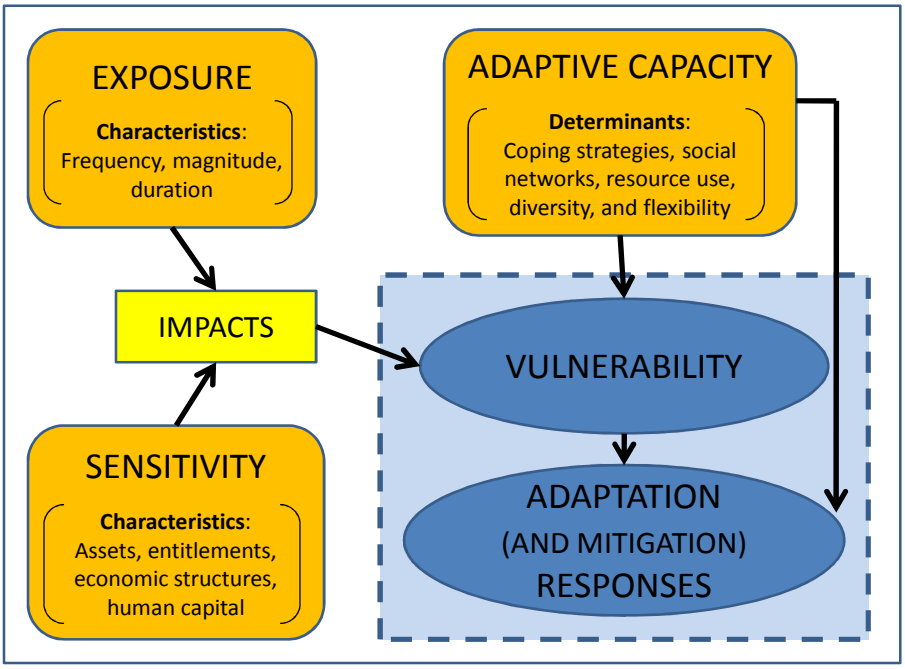

Figure 2. Climate change vulnerability, adaptation, and resilience
Source: Adapted from Gbetibouo (2009).

1.2.1 Exposure and sensitivity

Exposure and sensitivity have been used in the literature to characterize the biophysical impacts of climate change on agroecological systems (Tubiello and Rosenzweig 2008; Moss et al. 2001). Exposure encompasses the spatial and temporal dimensions of climate variability, such as droughts, and sensitivity refers to the resiliency of the agroecological system to withstand the impacts, without conscience efforts by manages at adaptation. Levels of exposure and sensitivity to climate change will affect crop yields, water availability, pest populations, and crop calendars.

Vulnerability to climate change depends not only on exposure to climate events but also on physical, environmental, socioeconomic, and political factors that influence how sensitive countries will be to a changing climate and how they will be able to cope. Each of the three components defining vulnerability to climate change—exposure, sensitivity, and adaptive capacity—requires several strategies in order to reduce vulnerabilities of agriculture. Mitigation and adaptation measures are essential to reduce the extent of global warming, to reduce the sensitivity of countries, and to improve countries' capacity to adapt to a changing climate.

Several results have been developed on the vulnerability of Ethiopia and South Africa using composite indicators reflecting exposure, sensitivity, and adaptive capacity.

1.2.2 Adaptive capacity

The third dimension of vulnerability weighs the biophysical impacts against the capacity of a society or human system to manage those impacts. This aspect of vulnerability is most

difficult to conceptualize, because many socioeconomic variables determine adaptive capacity. Institutional factors such as property rights and political stability will influence the extent to which farmers and other stakeholders can mobilize and gain access to pooled resources and knowledge. For example, government-provided extension services will influence a farmer's knowledge of alternative technologies, and property rights provide an incentive for continued investment. Economic aspects will shape the level of investment and planning, as well as how much access to inputs such as fertilizer and irrigation a farmer may have. Achieving enhanced resilience in the face of climate change will require enhancing the adaptive capacity of countries in Sub-Saharan Africa as well as implementing appropriate adaptation investments, policies, and institutions. Moreover, mitigation measures can support adaptation options and provide much-needed funds for further adaptation (Bryan et al. 2008; FAO 2009). Adaptation measures should be targeted to countries, sectors, and people most vulnerable to the adverse impacts of climate change—that is, those most exposed to and most sensitive to the adverse impacts of climate change and those with the least adaptive capacity (Figure 1.2).

1.2.3 Moving from vulnerability to resilience

Resilience is used to describe the magnitude of a disturbance that a system can withstand without crossing a threshold into a new structure or dynamic. A number of factors contribute to a system's ability to become resilient, including economic and natural resources, knowledge, and the level of sophistication of institutional processes, all of which broadly describe a system's adaptive capacity. Building resiliency to climate change requires simultaneously building resilience in human systems and in the interlinked ecosystems upon which they depend. Enacting proactive adaptation measures to build resilience in food production, food security, and the livelihoods of the poor requires an understanding of the strategies that can reduce the vulnerability of the agricultural sector to the effects of climate change and that can build resilience among farmers and those who depend directly on the sector for their livelihoods. For example, key crops and production systems will need to be identified that are important both in maintaining food security and in generating income, as well as those production systems that will respond ideally to defensive investments. The determination of the best-bet investments depends on many factors and is more an art than a science at this point. Given that the location and severity of climatic events are difficult to predict, it will be important to identify strategies that are robust in the face of uncertainty.

2. PROJECT OBJECTIVES AND FINDINGS

The project produced outputs in 6 areas:

1. Characterization of Vulnerability and Adaptive Capacity with Local Partners and Stakeholders (Ethiopia and South Africa);
2. Identification of the Determinants of Adaptive Capacity with Partners and Stakeholders;
3. Development of Integrated Policy Analysis Tools with Partners;
4. Global Change Assessment and Scenario Analysis - Assessment of the impacts of global change on rural Africa, in general, and on Ethiopia and South Africa, in particular, and analysis of response options developed in Ethiopian and South African study sites based on the integrated policy analysis tool;
5. Development of General Directions for Adaptation and Mitigation Strategies for Rural Africa and the Developing World; and Specific Strategies for Ethiopia and South Africa Together with Local Partners and Wide Dissemination of Research Results;
6. Enhanced National and International Capacity for climate change and economic policy analysis through training of PhD students.

3. METHODS

3.1 Household surveys

At the local level, farm household surveys were implemented in the Nile River Basin of Ethiopia and the Limpopo River Basin of South Africa to examine vulnerability to shocks, perceptions of long-term changes in climate (precipitation and temperature), and the determinants of adaptation to long-term climate change. The survey in the Limpopo Basin, South Africa, was carried out in collaboration with the Center for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria between August and November 2005, covering the agricultural season April/May 2004 to April/May 2005. In Ethiopia, the survey was conducted during the 2004/2005-production year in the Nile Basin in collaboration with the Ethiopian Development Research Institute (EDRI).

In order to assess farmer's vulnerability to, perceptions of, and adaptation to climate change, the household survey collected information on demographic characteristics; socioeconomic status (e.g. wealth status, income sources, etc.); social capital (in the case of Ethiopia); land tenure; crop and livestock management; input use and expenses; productive investments; food consumption patterns and expenditures; access to information, extension, technology, markets, and credit; coping responses to climate shocks; perceptions of climate change; adaptation responses; and constraints to adaptation. See Table 1 below for a list of the survey modules.

Table 1: Questionnaire Structure

Section 1: Household Roster--Members of Households, Education, and Employment
Section 2: Household Assets, Basic Services, Disease, Shocks
Section 3: Land Tenure
Section 4: Farm Machinery, Farm Buildings, Wells & Pumps, and Wage Rate
Section 5: Crop Production - Annual and Perennial crops (for annual crops Dec. 2004-Nov. 2005)
Section 6: Livestock Production (Dec. 2004 – Nov. 2005)

Section 7: Access to Extension, Markets and Credit
Section 8: Expenditures on Food and Income
Section 9: Climate Change and Adaptation Options

3.2 ***Ethiopian Nile Basin Household Survey***

The household sampling frame in Ethiopia was developed to ensure representation at the woreda (district) level of rainfall patterns in terms of both annual total and variation; the four classes of traditionally defined agro-ecological zones (AEZs) found in the basin; vulnerability of food production systems through the proxy of frequency of food aid in the past ten years; and irrigation prevalence. All data used in the sample frame is from the *Atlas of the Ethiopian Rural Economy* (Benson et al., 2006).

Each woreda was classified according to the following criteria: agroecological zone (Kolla, Weynadega, Dega, and Bereha), the percent of cultivated land under irrigation (no data, 0-2%, 2-4%, 4-8%, and 8% or greater), average annual rainfall (0-854mm, 854-1133mm, 1133-1413mm, 1413-1692mm, 1692mm or greater), rainfall variability (coefficient of variation for annual rainfall), and vulnerability (number of years of food aid received in the past 10 years).

Twenty woredas were selected such that across each of the above dimensions the proportion falling into each class for the sample matched as closely as possible the proportions for the entire Nile basin. The selected woredas are indicated in Figure XX. Peasant associations (administrative units lower than districts) were also purposely selected to include households that irrigate their farms. One peasant association was selected from every woreda for a total of 20 peasant associations. Random sampling was used in selecting 50 households from each peasant administration within the 20 woredas. Thus, the final dataset contains 1,000 observations from 20 woredas in 5 regions in Ethiopia (Tigray, Amhara, Oromiya, Benishangul Gumuz, and Southern Nations Nationalities and Peoples (SNNP)). Table XX shows the distribution of households by region, district, and peasant association.