Climate Change Adaptation Strategies

Water Resources Management Options for Smallholder Farming Systems in Sub-Saharan Africa

Stephen N. Ngigi

The Earth Institute AT COLUMBIA UNIVERSITY

The MDG Centre EAST & SOUTHERN AFRICA

Climate Change Adaptation Strategies:

Water Resources Management Options for Smallholder Farming Systems in Sub-Saharan Africa

A Study supported by the Rockefeller Foundation

By

Stephen N. Ngigi
Associate Research Scientist / MVP Water Coordinator
The MDG Centre, East and Southern Africa
The Earth Institute at Columbia University

With contributions from:

Glenn Denning, Christopher Graham, Tapsoba Ludovic, Amos Majule, Cheryl Palm, Maimbo Malesu, Matayo Indeje, Damaris Mungai, Waithera Gaitho, Jacob Tumbulto, Amadou Balima and Oliver Hounkou

The Study report was peer reviewed by:

Douglas Merrey, Bancy Mati, Herbert Blank, Kithinji Mutunga, Isaya Sijali, John Ogwang, Henry Mahoo, Abdou-Salam Savadogo, Philip Langat, Ephraim Alamerew, Cosmos Muli and Sharon Gordon

December 2009

Published by
The MDG Centre for East and Southern Africa of the Earth Institute at Columbia University, New York with financial support from the Rockefeller Foundation.

Design and Layout
Lucy Cherogony

Cover photos
Courtesy of Self Help Africa (SHA) formerly Self Help Development International (SHDI) project in Gilgil Division, Naivasha District of Kenya.

Cataloguing in publication data:
Ngigi, S.N. 2009. Climate Change Adaptation Strategies: *Water Resources Management Options for Smallholder Farming Systems in Sub-Saharan Africa*. The MDG Centre for East and Southern Africa, The Earth Institute at Columbia University, New York. 189p

ISBN 978-92-9059-264-8

Printing: UNON, Publishing Services Section, Nairobi, ISO 14001:2004 - certified.

TABLE OF CONTENTS

EXECUTIVE SUMMARY v

ACKNOWLEDGEMENTS ix

LIST OF ABBREVIATIONS AND ACRONYMS xi

1 INTRODUCTION 1
- 1.1 Background 1
- 1.2 Climate Change and Water Resources for Agriculture 3
- 1.3 Why Focus on Smallholder Farmers? 6
- 1.4 Gender Perspective 8

2 STUDY METHODOLOGY 11
- 2.1 Data Collection and Analysis 11
- 2.2 Scope of the Study 12
  - 2.2.1 Study limitations 13

3 CURRENT TRENDS AND PAST EXPERIENCE 15
- 3.1 Water Resources and African Agriculture 15
  - 3.1.1 Water resources 16
  - 3.1.2 Agricultural water use 23
  - 3.1.3 Anticipated impacts of climate change on agricultural water resources 26
  - 3.1.4 Upgrading rainfed agriculture 28
  - 3.1.5 Conflicts over water resources 35
- 3.2 Adaptation Strategies 37
- 3.3 Adaptation Initiatives 44
  - 3.3.1 Collective action 44
  - 3.3.2 Agricultural Water Management 48
  - 3.3.3 Research programs 54
  - 3.3.4 Governance interventions 59
- 3.4 Challenges and Constraints 62
  - 3.4.1 Economic capacity 63
  - 3.4.2 Technology 63
  - 3.4.3 Technology dissemination 64
  - 3.4.4 Information and skills 65
  - 3.4.5 Infrastructure 66
  - 3.4.6 Land tenure 66

3.4.7 Gender issues ... 67
3.4.8 Governance structures ... 68

4 FEASIBLE INTERVENTIONS ... 73

4.1 Technical Interventions ... 73
4.1.1 Smallholder irrigation development ... 73
4.1.2 Micro-irrigation systems ... 80
4.1.3 Greenhouses for smallholder farmers ... 81
4.1.4 Rainwater harvesting and management ... 84
4.1.5 Energy sources for pumping water ... 88
4.1.6 Integrated AWM ... 93

4.2 Crop Varieties and Diversification ... 94
4.2.1 Crop varieties ... 94
4.2.2 Crop diversification ... 96

4.3 Crop Insurance ... 97

4.4 Information Management ... 101
4.4.1 Hydro-climatology ... 102
4.4.2 Climatic variability prediction and forecasting ... 103
4.4.3 Data collection and management ... 106

4.5 Capacity Building ... 108
4.5.1 Strengthening local innovation systems ... 109
4.5.2 Enhancing capacity in research and technology development ... 111

5 POLICY AND INSTITUTIONAL ISSUES ... 113

5.1 Policy and Institutional Framework ... 113
5.2 Necessary Governance Reforms ... 117
5.3 Farmer Support Services ... 121
5.4 Stakeholders and Collaborators ... 127

6 CONCLUSIONS AND RECOMMENDATIONS ... 129

6.1 Conclusions ... 129
6.2 Recommendations ... 133

7 REFERENCES ... 139

8 ANNEXES ... 165

Annex 1: List of Study Interviewees ... 165
Annex 2: Interviewee Checklist ... 171
Annex 3: Stakeholders in SSA ... 173

EXECUTIVE SUMMARY

Climate change, population growth, increasing water demand, overexploitation of natural resources and environmental degradation have significantly degraded the world's freshwater resources. In sub-Saharan Africa (SSA), the number of countries where water demand outstrips available resources is increasing. Many African countries experience either water stress (less than 1,700 m^3 per capita per annum) or water scarcity (less than 1,000 m^3 per capita per annum) or both. Moreover, food insecurity remains endemic throughout much of Africa, with climatic factors such as rainfall variability a major cause. For example, in 2006, 25 African countries required food aid, largely due to recurring drought. Poverty and food insecurity are linked to low agricultural productivity aggravated by climate change and variability. As 1970 Nobel Peace Prize Laureate Norman Borlaug stated, 'Humankind in the 21st century will need to bring about a Blue Revolution to complement the Asian Green Revolution of the 20th century… New science and technology must lead the way.'

A key challenge for decision makers, policy makers, and development partners is to understand the strategies adopted by farmers and other stakeholders in their efforts to address climate change-induced water stress. Smallholder farmers are the most vulnerable to climate change, and they have no alternative but to adapt their livelihood systems to changing climatic conditions. Fortunately, several practical options for adaptation exist. All efforts should therefore be made to refine, augment and deploy them appropriately and urgently.

Water resources management strategy is thus key to ensuring that agricultural production can withstand the stresses caused by climate change. It is against this background that the MDG Centre (East and Southern Africa), decided to embark on a thorough study to assess appropriate strategies for smallholder farmers in sub-Saharan Africa (SSA). The study identified improved agricultural water management (AWM) as one of the 'best bets' for adapting agricultural production to climate change and variability. The study concurred with Borlaug that a Blue Revolution must be designed to complement a Green Revolution in Africa. However, accomplishing this Blue Revolution is a significant challenge. At present, only about 6 percent of African agricultural land is under irrigation, and according to the Intergovernmental Panel on Climate Change (IPCC), by 2020 rainfed crop yields in some countries will decrease by half, with as many as 250 million Africans facing critical water stress. The impact of climate change on farmers and their livelihoods could be catastrophic.

The study points out that current poor performance in terms of water-use efficiency, plus competition over diminishing water resources, suggests the need for investment in better water management systems. Also, where access to irrigation is limited, smallholder farmers need to develop water conservation and rainwater harvesting systems to maximize on-farm water management.

Among the strategies recommended by the study is smallholder irrigation development. The study showed that the performance of smallholder irrigation schemes – in terms of improved water management, food security and income – is encouraging, with net earnings ranging between USD 200 and 1200 per month for single-crop enterprises in Kenya. Rainwater harvesting complements smallholder irrigation and enhances farmers' profitability. Rainwater harvesting for supplemental irrigation, for example, yielded net profits of USD 150-600 per ha in Burkina Faso and USD 110-500 in Kenya. But despite evidence of good returns on investment, large-scale national programs on water management have not been realized.

Smallholder AWM is emphasized for a number of reasons. The performance of large public irrigation schemes in Africa is associated with poor governance and insecure land tenure, leading to low farmer investment and exploitation by government agencies. This partly explains the low cost recovery, poor performance, low water use efficiency, poor crop yields, low water productivity and weak sustainability that typify public irrigation schemes.

A key policy change would be to support increased investment in smallholder irrigation as opposed to large-scale irrigation projects. Apart from the obvious lower start-up cost and high economic impact, smallholder irrigation systems often have strong local community governance, are relatively free of political intervention, and have lower operation and maintenance costs. Water management is also improved by having a greater diversity of options for water sources, such as small streams, shallow wells, boreholes and rainwater storage. Other irrigation options also exist. These include surface irrigation methods (furrows and small basins), pressurized systems (sprinkler and both high- and low-head drip) and water lifting technologies (gravity, manual and pumps – motorized, wind-driven and solar).

The rehabilitation and improvement of existing smallholder irrigation systems that have fallen into disarray provides another source of potential. For a number of reasons – inadequate management or technical skills, socio-political instability, inadequate funding for maintenance, land degradation – systems initiated by smallholders frequently fall into disuse. In SSA, an estimated two million hectares of land equipped for irrigation are unused. These lands could be developed along with another 13 million hectares with irrigation potential.

Another management strategy is the upgrading of rainfed agriculture through integrated rainwater harvesting systems and complementary technologies such as low-cost pumps and water application methods, such as low-head drip irrigation kits. Rainwater harvesting systems include two broad categories:

- In-situ soil moisture conservation – technologies that increase rainwater infiltration and storage in the soil for crop use
- Run-off storage for supplemental irrigation using storage structures such as farm ponds, earth dams, water pans and underground tanks

The realization of the African Green Revolution is threatened by climate change. While the recommended interventions may answer many of the needs for improved water management as an adaptation to climate change at the farm level, political and financial investment is a prerequisite. To realize the benefits of proposed interventions, necessary steps must be taken to ensure adoption, replication, up-scaling and sustainability. The study therefore also made it a point to identify the necessary steps to enhance adoption and sustainability of proposed AWM strategies. These include capacity building at various levels, research and technology development, appropriate policy and institutional reforms and the provision of farmers' support services such as micro-credit, revolving grants, crop insurance, marketing infrastructure and value addition. It is envisaged that the study's findings will form the basis of increased investment (including grants) to promote improved agriculture water management as a climate change adaptation for smallholder farmers in SSA.

The report is divided into six chapters. Chapter 1 presents an overview and background of the problem, the study objectives and expected outputs. It also reflects on climate change and water resources for agriculture and provides a justification for focusing on smallholder farmers. Highlights from a gender perspective are also included, focusing on gender roles in AWM. Chapter 2 focuses on the study methodology, in particular data collection and analysis, as well as the scope of the study.

Chapter 3 includes an assessment of current trends and past experience with particular focus on water resources and their utilization in Africa. A review of climate change adaptation strategies is presented, as well as an overview of current practices in terms of pilot projects, research agenda and governance interventions. The chapter concludes with a discussion of the challenges and constraints that must be addressed to increase the adoption of identified options.

Chapter 4 discusses some of the feasible interventions identified in Chapter 3. It outlines a number of technical interventions and supporting instruments to enhance their implementation, such as crop diversification and insurance, information management and capacity building.

Chapter 5 highlights governance issues, with emphasis on existing policy and institutional frameworks, necessary reforms to enhance adaptation to climate change, required farmers' support services, and some of the key stakeholders and actors addressing, either directly or indirectly, climate change adaptation strategies in SSA.

Chapter 6 summarizes the study's conclusions and recommendations. The chapter underscores the fact that the effects of climate change are already identified, and that these impact negatively on most livelihood systems in SSA. It calls for increased attention and investment to enhance adaptation, especially by the vulnerable smallholder farmers. The recommendations focus on interventions to improve AWM and complementary strategies that can enhance their implementation and sustainability. Finally, it calls for increased investments to support the resilience of smallholder farmers to cope with climate change and variability.

ACKNOWLEDGEMENTS

The study was accomplished with the assistance of many contributors. I would like to single out the support of the persons and institutions highlighted in the list of interviewees in Annex 1, as well as the stakeholders listed in Annex 3, all of whom provided useful information for the study. In particular, I wish to thank the United Nations Development Programme (UNDP), the Nile Project of the Food and Agriculture Organization of the United Nations (FAO), the Lake Victoria Initiative (LVI), the Nile Basin Initiative (NBI), the Global Water Partnership (East Africa), the World Conservation Union (IUCN), the African Centre of Meteorological Application for Development (ACMAD), the Economic Community for West African States (ECOWAS), the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), the Regional Centre for Research on Water and Sanitation (CREPA), the International Water Management Institute (IWMI), Improved Management of Agricultural Water in Eastern and Southern Africa (IMAWESA), the Senegal River Basin Development Organization (OMVS), the Institute of Research for Development (IRD), the Council of NGOs for Development Support (CONGAD), the Challenge Program on Water and Food (CPWF), the Greater Horn of Africa Rainwater Partnership (GHARP), the focal points of the National Action Plan for Climate Change Adaptation (NAPA) and related government ministries.

I extend special thanks to my colleagues at the MDG Centres in Nairobi and Bamako, which coordinated the study in the four sub-regions of SSA (Eastern, Southern West and Central Africa). The Millennium Villages Project (MVP), which is implemented in tripartite partnership between the Earth Institute, UNDP, and the Millennium Promise, provided useful lessons for science-based local-scale initiatives for coping with climate change-induced water stress. IMAWESA's Third Regional Conference in Addis Ababa (15-19 September 2008) also provided insight to both technical and policy interventions that were useful to the study.

Due to the nature and scope of the study, a number of persons directly contributed in information gathering and data analysis. In this regard, I am grateful to the following persons: Dr Glenn Denning, Mr Christopher Graham, Dr Tapsoba Ludovic, Dr Amos Majule, Dr Cheryl Palm, Mr Maimbo Malesu, Dr Matayo Indeje, Ms Damaris Mungai, Ms Waithera Gaitho, Dr Jacob Tumbulto, Mr Amadou Balima, and Mr Oliver Hounkou. In addition, the contributions of a panel of peer reviewers made remarkable contributions to the finalization of the study by critically evaluating the first draft report and presenting their feedback during a three-day workshop at the

MDG Centre in Nairobi (22-24 October 2008). The panel of reviewers, drawn from different institutions and government departments, included Dr Douglas Merrey, Prof Bancy Mati, Dr Herbert Blank, Mr Kithinji Mutunga, Mr Isaya Sijali, Mr John Ogwang, Prof Henry Mahoo, Mr Abdou-Salam Savadogo, Mr Philip Langat, Mr Ephraim Alamerew, Mr Cosmos Muli, and Ms Sharon Gordon. My sincere thanks also go to Ms Caroline Nyanjui, the MDG Centre (Nairobi) Administrative Assistant for her logistical support and for successfully organizing the peer reviewers' workshop. I am also thankful to Robert Huggan, Alison Rose, Eric McGaw and Cindy Paladines for their assistance in editing the final report.

Finally, I would like to express my appreciation for the financial support from The Rockefeller Foundation, which enabled the MDG Centre (East and Southern Africa) to undertake this study. Support and critique from a number of Rockefeller Foundation staff was invaluable in finalizing this report. In particular, I recognize the contributions of Gary Toenniessen, Wiebe Boer, Suman Sureshbabu, Veronica Olazabal and Cristina Rumbaitis del Rio. Last but not least, I acknowledge the role that played by Joe DeVries of the Alliance for a Green Revolution in Africa (AGRA) in initiating this collaboration during an AGRA-MDG Centre meeting in Nairobi.

LIST OF ABBREVIATIONS AND ACRONYMS

ACMAD	-	African Centre of Meteorological Application for Development
ACT	-	African Conservation Tillage Network
AEZ	-	Agro-ecological Zone
AFK	-	Amiran Farmer 's Kit
AFRACA	-	African Rural and Agricultural Credit Association
AGMP	-	Agriculture Meteorology Program
AGRA	-	Alliance for Green Revolution in Africa
AGRHYMET	-	Center for Agro Hydro Meteorology
AKIS	-	Agricultural knowledge and information system
AMCOW	-	African Ministers ' Council on Water
ASARECA	-	Association for Strengthening Agricultural Research in Eastern and Central Africa
AWDR	-	Africa Water Development Report
AWM	-	Agricultural Water Management
CAADP	-	Comprehensive Africa Agriculture Development Programme
CAIT	-	Climate Analysis Indicators Tool
CBO	-	Community-based Organization
CCAA	-	Climate Change Adaptation in Africa
CGIAR	-	Consultative Group on International Agricultural Research
CICOS	-	International Commission for the Congo Oubangui Sangha
CIG	-	Common Interest Groups
CILSS	-	Permanent Interstate Committee for Drought Control in the Sahel
CIMMYT	-	International Maize and Wheat Improvement Center
ClimDev	-	Climate for Development in Africa
CLIPS	-	Climate Information and Prediction Services
CONGAD	-	Council of NGOs for Development Support
COP15	-	15th Conference of Parties
CPWF	-	Challenge Program on Water and Food
CREPA	-	Regional Centre for Research on water and Sanitation
CSE	-	Ecological Monitoring Center (Senegal)
CMI	-	Crop Moisture Index
CPR	-	Common Property Resource
CSO	-	Civil Society Organization
DAT	-	Draught Animal Technology
DFID	-	Department for International Development

DTMA	-	Drought-tolerant Maize for Africa
ECOWAS	-	Economic Community for West African States
ESCWA	-	Economic and Social Commission for West Asia
FAO	-	Food and Agriculture Organization of the United Nations
FFS	-	Farmer Field School
GCM	-	Global Circulation Model
GDP	-	Gross Domestic Product
GEF	-	Global Environment Facility
GIS	-	Geographical Information System
GWA	-	Gender and Water Alliance
ICARDA	-	International Center for Agricultural Research in the Dry Areas
ICID	-	International Commission on Irrigation and Drainage
ICLEI	-	International Council for Local Environmental Initiatives
ICRAF	-	World Agroforestry Centre
ICRISAT	-	International Crops Research Institute for the Semi-Arid Tropics
IDRC	-	International Development Research Centre (Canada)
IER	-	Institut d'Economie Rurale (Mali)
IFAD	-	International Fund for Agricultural Development
IFPRI	-	International Food Policy Research Institute
IGAD	-	Inter-Governmental Authority on Development
IISD	-	International Institute for Sustainable Development
IITA	-	International Institute for Tropical Agriculture
IMAWESA	-	Improved Management of Agricultural Water in Eastern and Southern Africa
INERA	-	Environment and Agricultural Research Institute
IPIA	-	Improving the Performance of Irrigation in Africa
IPCC	-	Intergovernmental Panel on Climate Change
IRD	-	Institute of Research for Development
IRI	-	International Research Institute for Climate and Society
ISESCO	-	Islamic Educational, Scientific and Cultural Organization
IRRI	-	International Rice Research Institute
IWM	-	Irrigation Water Management
IWMI	-	International Water Management Institute
IWRM	-	Integrated water resources management
IUCN	-	World Conservation Union
JICA	-	Japan International Cooperation Agency
KRA	-	Kenya Rainwater Association
LHLCD	-	Low-head Low-cost Drip

MDG	-	Millennium Development Goals
MHP	-	Moneymaker Hip Pump
MVP	-	Millennium Villages Project
NAPA	-	National Action Plan for Climate Change Adaptation
NARS	-	National Agricultural Research System
NBI	-	Nile Basin Initiative
NDVI	-	Normalized Difference Vegetation Index
NEPAD	-	New Partnership for Africa's Development
NERICA	-	New Rice for Africa
NGO	-	Non-governmental Organization
NOAA	-	National Oceanic and Atmospheric Administration
NREL	-	National Renewable Energy Laboratory
O&M	-	Operation and Maintenance
OECD	-	Organization for Economic Cooperation and Development
OFWM	-	On-farm Water Management
OMVS	-	Senegal River Basin Development Organization
ORS	-	Segou Office for Rice Development
PRDA	-	Participatory Rapid Diagnosis and Action Planning
PRESAO	-	Prévisions Saisonnières pour l'Afrique de l'Ouest
PRSP	-	Poverty Reduction Strategy Paper
PVP	-	Photo-voltaic Pump
RCCC	-	Rice and Climate Change Consortium
RF	-	The Rockefeller Foundation
RHM	-	Rainwater Harvesting and Management
SADC	-	Southern African Development Community
SASE	-	Semi-arid Savannah Environment
SIDA	-	Swedish International Development Agency
SMP	-	Super Moneymaker Pump
SSA	-	Sub-Saharan Africa
UNCCD	-	United Nations Convention to Combat Desertification
UNDP	-	United Nations Development Programme
UNECA	-	United Nations Economic Commission for Africa
UNEP	-	United Nations Environment Programme
UNESCO	-	United Nations Education, Scientific and Cultural Organization
UNFCCC	-	United Nations Framework Convention on Climate Change
USAID	-	United States Aid for International Development
WARDA	-	Africa Rice Center
WCASP	-	World Climate Applications and Services
WCDMP	-	World Climate Data and Monitoring Programme

WFP	-	World Food Programme
WHYCOS	-	World Hydrological Cycle Observing Systems
WMO	-	World Meteorological Organization
WRI	-	World Resources Institute
WRSI	-	Water Requirement Satisfaction Index
WUA	-	Water Users Association

1. INTRODUCTION

1.1 Background

The realization of the African Green Revolution and its contribution to food security and economic growth in sub-Saharan Africa is threatened by climate change. The Fourth Assessment Report of the IPCC highlighted the vulnerability of African agriculture and all who depend on it for food security and livelihoods (IPCC 2007). Agriculture will be affected by reduced growing seasons and higher temperatures. The IPCC predicted that rainfed crop yields in some countries will decrease by 50 percent, and that an estimated 50-250 million Africans will face increased water stress by 2020. With only about 6 percent of African crop lands irrigated, the impacts on smallholders could be catastrophic. These direct effects on agricultural production and food security will be exacerbated by greater exposure to malaria and other climate-influenced diseases that reduce labor productivity and employment opportunities. According to FAO (2007), agricultural production and the biophysical, political and social systems that determine food security in Africa are expected to be placed under considerable additional stress by climate change. It is anticipated that adverse impacts on agriculture sector will exacerbate the incidence of rural poverty (Dinar *et al*. 2008).

African smallholder farmers have no alternative but to adapt to climate change and climate variability. This will require an unprecedented level of political commitment, increased investments and financial resources, and enhanced local and national capacity. Fortunately, several practical options for adaptation exist, and these must be refined, augmented and deployed appropriately as a matter of urgency. Following is a list of some of these options:

- Intensification of food production by smallholders through better access to improved seed, soil fertility management (eg, fertilizer application) and reliable water supply
- Improved AWM[1] (smallholder irrigation, rainwater harvesting, sustainable extraction of groundwater and other underutilized water resources), conservation agriculture and improved on-farm water use efficiency

---

1. Agricultural water management (AWM) refers to farming system interventions aimed at increasing water availability and utilization for productive use (crops, fishery and livestock) in both rainfed and irrigated agriculture. It includes land and water management, soil and water conservation, rainwater harvesting and management, irrigation and drainage, aquaculture and agricultural watershed management. Holistic and multi-sectoral interventions that are appropriate in smallholder farming systems can be termed Integrated AWM. According to Mati (2007), "AWM is the management of all water put into agriculture in the continuum from rainfed systems to irrigated agriculture."

- Shifts towards crop and livestock types/varieties/breeds with greater drought and heat tolerance and improved pest and disease resistance
- Enterprise diversification towards higher value crops, value adding (processing), off-farm employment, and marketing infrastructure
- Grain storage improvements (from household to national levels) to ensure security of carryover stocks and access to surpluses
- Climate forecasting and provision of timely advice to governments, private sector (agro-dealers), extension services and farmers
- Weather-related crop and livestock insurance

The potential and limitations of these and other interventions are explored in this report.

The MDG Centre for East and Southern Africa (of the Earth Institute at Columbia University, New York) requested for financial assistance from the Rockefeller Foundation to undertake an assessment and comparative analysis of opportunities for investing in water resources management for smallholders in adapting to climate change in SSA.

The main objectives of the study were sixfold:

- Review information on supply and demand for renewable and non-renewable water resources and assess the roles and potential contributions of a range of small-scale AWM interventions for coping with climate change and variability.
- Identify best practices/interventions and quick impact initiatives within water resources management, and highlight adaptive strategies for climate change in each intervention.
- Assess how technical, policy and institutional interventions enable smallholders to adapt to changes in water availability due to climate variability (droughts and floods).
- Undertake an inventory of major programs and institutions currently engaged in water resources management in SSA.
- Apply internationally identified principles to recommend appropriate AWM strategies and programs in Africa.
- Synthesize data and make recommendations for consideration by development partners and other stakeholders, as appropriate, in preparing for investments in improving AWM in SSA.

1.2 Climate Change and Water Resources for Agriculture

Agriculture and climate change are inextricably linked. Nelson (2009) stated that "Agriculture is part of the climate change problem, contributing about 13.5 percent of annual greenhouse gas emissions (with forestry contributing an additional 19 percent), compared with 13.1 percent from transportation. Agriculture is, however, also part of the solution, offering promising opportunities for mitigating emissions through carbon sequestration, soil and land use management, and biomass production. Climate change threatens agricultural production through higher and more variable temperatures, changes in precipitation patterns and increased occurrences of extreme events like droughts and floods".

The challenges of water resources development in SSA will be aggravated by ensuing climate change, with serious implications on socio-economic development. IPCC (2001) noted that "these challenges include population pressure, problems associated with land use such as erosion/siltation and possible ecological consequences of land-use change on the hydrological cycle. Climate change – especially changes in climate variability through droughts and flooding – will make addressing these problems more complex. The greatest impact will continue to be felt by the poor, who have the most limited access to water resources". In the savanna regions, the incidence of seasonal flow cessation may be on the increase, as shown by some streams in Zimbabwe (Magadza 2000). Southern Africa has experienced more recurrent drought and flood episodes in recent times. Drought periods now translate into periods of critical water shortages for industrial and urban domestic supplies (Magadza 1996). The frequent droughts and floods in most parts of SSA – leading to severe food shortages, food insecurity, water scarcity, hunger/famine and acute shortage of hydropower – signify the region's vulnerability to climate change. Reduced hydropower also affects energy supply for pumping water.

There is a general consensus that the African continent is particularly susceptible to the onset of climate change (Boko *et al*. 2007). A variety of factors exacerbate susceptibility to the effects of climate variability but, in focusing on strictly physical elements, the range of ecosystems present on the continent poses particular challenges in developing mitigation and adaptation mechanisms. FAO (2008b) identified 16 distinct ecosystems (agro-ecological zones (AEZs)) in which various farming systems exist, and which would be affected differently by climate change. However, according to Greenfacts[2], over the past 40 years, some general climatic trends have emerged on a more regional scale.

2 See,www.greenfacts.org

The IPCC Fourth Assessment Report noted that, since the 1960s, the African continent has experienced a general warming trend with certain regions experiencing more warming than others (Boko *et al*. 2007). Since 1900, warming has occurred in Africa at approximately 0.5°C per century (Hulme et al. 2001). Precipitation is also highly variable across the continent, although much of the continent has experienced decreases in annual precipitation. An increase in inter-annual variability has been noted with the indication that extreme precipitation events (floods, droughts) are on the rise (Boko *et al*. 2007). Notwithstanding the inconsistency of predictions about climate change, the effects of the phenomenon are being experienced throughout SSA, especially in areas typified by variable rainfall shifting growing seasons (IPCC 2001). Most African farmers, particularly those working in rainfed agriculture, have been affected in one way or another.

It is important to delineate expected regional differences in determining and assessing mitigation strategies for future water stresses resulting from the onset of climate change in Africa. Some African countries are much more economically dependent on agriculture, leaving them more vulnerable than others (Kurukulasuriya *et al*. 2006). The precarious state of water resources in Africa is such that water stress (use exceeds renewable supply) is relatively high for the majority of the continent's population. Yet nearly two thirds of Africans rely on limited water sources prone to high yearly variability (Vörösmarty *et al*. 2000). In total, about a quarter of the continent's entire population lives in water-stressed regions (UNEP 1999).

Because the amount of available fresh water is relatively finite, increases in population result in corresponding decreases in the per capita water supply, while rising temperatures exacerbate an already alarming situation in Africa (Human Impact Report 2009). In terms of fresh water, annual run-off and water availability are projected to increase by 10-40 percent at high latitudes but to decrease by 10-30 percent over some dry regions at mid-latitudes and in the dry tropics (Falkenmark 2007). This means that drought-affected areas will likely increase in extent. Agricultural production is projected to be severely compromised in many regions by these trends (UNFCC 2008).

Agriculture accounts for more than 70 percent of global water use (FAO 2008a, World Bank 2006a). According to projections, there will be increasing challenges in terms of increased water stress and areas suitable for agriculture along the margins of semi-arid and arid areas are expected to decrease significantly (Falkenmark 2007).

Seasonal variability in water availability is also critical for agricultural production. For instance, a comparatively small decrease in rainfall during one season may have more severe consequences than a much larger precipitation decrease in another season. Although many past studies have revealed different climate change scenarios in Africa (Christensen *et al*. 2007), here are some of the expected climate changes that would affect water resources for agriculture:

- Warming is very likely to be larger than the global annual mean warming in all seasons, with drier sub-tropical regions warming more than the moister tropics.
- Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall toward the Mediterranean coast.
- Rainfall in southern Africa is likely to decrease in much of the winter rainfall region and western margins, leading to longer dry seasons and more uncertain rainfall.
- An increase in annual mean rainfall in East Africa is likely.
- A warmer and drier environment is expected in the Sahelian region (Falkenmark 2007).

IPCC 2007 stated that "Africa is one of the most vulnerable continents because of multiple stresses and low adaptive capacity. The multiple stresses may arise from current climatic hazards, poverty and unequal access to resources, food insecurity, globalization trends, social and political conflicts and incidences of diseases such as malaria, tuberculosis and HIV/AIDS". Nevertheless, the overall climate will largely be defined by the change in precipitation corresponding to what appears to be a marked increase in temperature. This will lead to extreme rainfall events with dire consequences to agricultural production, especially for the vulnerable smallholder farmers. The impact of climate change on AWM will be aggravated by demographic change. In eastern and southern Africa, climate change vulnerability is heightened by the large number of people who depend on the already marginalized natural resource base for their livelihoods (Ziervogel et al. 2008). Moreover, within the next 15 to 20 years, the area considered to have relative water security in Africa will fall from 53 percent to 35 percent (Ashton 2002). Therefore, due to the current population growth, many SSA countries are expected to experience a severe increase in water stress, with or without climate change. Population changes could in fact nullify any increases in precipitation/available water. The situation will be aggravated by over-dependence on natural resources (Raleigh and Urdal 2007). Overdependence on surface water, especially for irrigation, will aggravate the impacts of climate change and variability on agricultural development.

The predicted impacts of climate change must be introduced into development planning, including land-use planning, natural resources management, infrastructure design and measures to reduce vulnerability in disaster reduction strategies. According to Falkenmark (2007), the array of adaptation options is very large, ranging from purely technological measures to managerial adaptation and policy reform. For developing countries, availability of resources and adaptive capacity building are particularly important. Based on anticipated climate change and impacts on water resources in Africa, IPCC (2001) identified four necessary adaptive strategies.

a. *"Adaptive measures.* Measures should be adopted that would enhance flexibility, resulting in net benefits in water resources (irrigation and water reuse, aquifer and groundwater management, desalinization), agriculture (crop changes, technology, irrigation, husbandry), and forestry (regeneration of local species, energy-efficient cook stoves, sustainable community management)."
b. *"Risk sharing.* A risk-sharing approach between countries will strengthen adaptation strategies, including disaster management, risk communication, emergency evacuation, and cooperative water resources management."
c. *"Enhancement of adaptive capacity.* Local empowerment is essential in decision-making in order to incorporate climate adaptation within broader sustainable development strategies. Most countries in Africa are particularly vulnerable to climate change because of limited adaptive capacity as a result of widespread poverty, recurrent droughts, inequitable land distribution and dependence on rainfed agriculture."
d. *"Diversification.* To minimize sensitivity to climate change, African economies should be more diversified, and agricultural technology should optimize water usage through efficient irrigation and crop development. "

1.3 Why Focus on Smallholder Farmers?

Smallholder farmers are particularly vulnerable to changes in the climate that reduce productivity and negatively affect their weather-dependent livelihood systems. For instance, in Malawi, frequent droughts and floods have eroded assets and knowledge, leaving people more vulnerable to disasters (Gandure and Alam 2006) such as water and food insecurity, diseases and land degradation. Evidence strongly suggests that increased droughts and floods may be exacerbating poverty levels, leaving many rural farmers trapped in a cycle of poverty and vulnerability to diminishing resources (Phiri *et al*. 2005). Water scarcity is already a major problem in arid and semi-arid areas of SSA (Rijsberman 2006) – areas mainly inhabited by smallholder farmers in both agro-pastoral and pastoral communities.

Climate change and increasing population contribute to water scarcity and limit its availability for irrigation (Turner 2006) and other productive uses. Although the potential to invest in irrigation in much of Africa is high, poor performance of large-scale irrigation schemes in Africa and competition for diminishing water resources suggest that smallholder irrigation is preferable. Smallholder farmers must develop water conservation and water harvesting systems in order to maximize rainfall use efficiency on their own farms. Beside lower investment costs and higher rates of returns, smallholder irrigation development is easier to manage and operate than large-scale centrally managed irrigation schemes. However, despite the low development cost and high rate of returns, there have been inadequate investments, mainly due to misplaced government priorities, declining external support, poor marketing infrastructure, and non-conducive policy and institutional frameworks. However, as the potential of irrigated agriculture continues to gain recognition as an adaptation strategy to climate change, the pattern appears to be changing.

Virtually all large-scale irrigation schemes in SSA have been undertaken by government agencies. While some farmer groups have grown more active in operating these projects, government agencies have largely been responsible for maintenance and operation, often with little cost recovery (Peacock *et al.* 2007) and poor performance. The experience of Mali irrigation parastatals like the Segou Office for Rice Development (ORS) and similar government-controlled schemes in SSA attest to this. In such government-controlled schemes, farmers rarely pursue an active role in improving these irrigation systems. Some reasons include insignificant incentive for individual users, lack of cohesion among users, isolation and poor means of communication, and reforms that often reduce subsidies and increase individual expenses (Aw and Diemer 2005). However, reforms in government-controlled schemes, which give farmers more responsibility in water management, operation and maintenance, have shown positive results. A good model is the case of the Mwea Irrigation Scheme in Kenya (Blank *et al*. 2002). In Mali, reform of the *Office du Niger* irrigation scheme over a period of 20 years led to a quadruple increase in rice yields, a six-fold increase in total rice production (Aw and Diemer 2005).

In addition to low costs and high economic impact, many factors support additional investments in smallholder irrigation development over large-scale irrigation projects.

Smallholder irrigation systems have strong local community governance, are relatively free of political intervention, have relatively low operation and maintenance cost (FAO 2008a), and sometimes constitute a means of poverty alleviation. Water management is also improved by the relatively low number of users and the diverse options for water sources (small streams, shallow wells, boreholes, rainwater storage, etc.), many irrigation technological options (surface irrigation methods like the furrow and small basin methods, and pressurized systems (sprinkler and drip – both high head and low head systems), and water-lifting technologies (gravity, manual and motorized pumps, wind and solar pumps).

The potential is high for rehabilitation and improvement of existing smallholder irrigation systems, some of which have been initiated by farmers on their own, but have fallen into disarray. According to the FAO (2005), about 2 million ha of land equipped for irrigation are unused. This potential farmland could be developed along with approximately 13 million ha of additional land with irrigation potential, of which about 9 million ha are in West Africa (FAO 2008a). Given smallholder farmers' vulnerability to climate change, the low development costs and high economic performance of smallholder irrigation schemes underscore the need for investments in these AWM farming systems.

1.4 Gender Perspective

Emerging evidence shows that women and girls will experience even greater inequality through the impacts of climate change. It is evident that women suffer disproportionately in nearly all disasters. Young (2008) stated that "disasters shortened women's life expectancy significantly more than men's but encouragingly, this association was reduced where women's status was more equal. Many women are made vulnerable by their reduced access to sources of emergency information, as well as their lack of decision-making power in disaster prevention and preparedness programs; they are also often excluded from disaster recovery operations and from planning at the national level".

Young (2008) noted that "the unequal impact on women is not only evident in major disaster events – it also affects everyday life and opportunities, since in many low-income countries, women already work more hours each day than men. Additionally, in Africa, women are more involved in agriculture than men – an estimated 80 percent of smallholder farmers are women". FAO (2001a) estimated that women produce 60-80 percent of food grown in the developing world – often small-scale crops critical to family sustenance. In SSA, women are responsible for 65 percent of farming activity in the smallholder irrigation sector (FAO 2001b). In addition, women and girls are responsible for collecting and carrying water, among many other domestic activities. Young (2008) stated that "as communities cope with the effects of changes in climate, demands on women's time and workloads are likely to increase. To compensate for increased demands on their time, poor families may pull girls out of school". The added stresses incurred by a changing climate compound the many risks already faced by women in developing countries.

Consideration and integration of gender issues is therefore important in any assessment of how smallholder water resources management relates to climate change in Africa. The equal inclusion of men and women in all aspects of water resources management is imperative. Gender mainstreaming must focus on a holistic approach to ensure sustainability of climate change adaptation strategies and programs in Africa. Gender-sensitive water governance should address the institutions, policies, legal frameworks and technologies that perpetuate gender inequalities. A gender approach in governance should be an integral part of setting up broader governance structures and mechanisms. This means promoting the involvement of both women and men in consultation and decision making from the community level to the highest management levels. Gender-focused approaches in water governance depend on the skills, knowledge and commitment of staff involved in implementation and management.

2. STUDY METHODOLOGY

2.1 Data Collection and Analysis

The study reviewed information on the status of both renewable and non-renewable water resources and assessed the roles and potential contributions of a range of interventions in infrastructure and services. These included:

- Surface water capture (dams, reservoirs, weirs)
- Groundwater extraction (both shallow and deep reservoirs)
- Rainwater harvesting and distribution
- On-farm water-use efficiency
- Seasonal forecasting and advisory services

The study reviewed relevant literature and web-based resources on current trends and past experiences. This review was followed by focused interviews with selected informants. These included policy makers, non-governmental organizations (NGOs), heads of government departments, private sector representatives, researchers, scientists from CGIAR centers and other international research organizations, international development organizations (UNDP, and FAO), meteorological organizations and representatives of interest groups – in short, anyone with experience and responsibilities in water resources management and agriculture.[3] The results of these interviews were used to develop a consensus of expert opinion on the opportunities and priorities for investment in various water resources management interventions. The study focused on selected countries in SSA: five in West Africa (Burkina Faso, Ghana, Mali, Nigeria and Senegal); four in East Africa (Ethiopia, Kenya, Rwanda and Uganda) and three in Southern Africa (Malawi, South Africa and Tanzania). Country selection was based on data availability, past experiences on smallholder AWM and coverage of related activities. To some extent, the MVP also influenced the selection of the countries due to existing study related activities, research networks and resource persons. Central Africa was given less attention because of logistical constraints and less vulnerability to predicted drought related climate change scenario.

The study highlighted climate change adaptation components for each set of assessed interventions. This analysis included assessments of how technical, policy and

3 See Annexes 1 and 2 for a list of people interviewed for the study and a checklist of the guiding questions for the interviews conducted.

institutional interventions will enable smallholders to adapt to increased climate change and variability – both excess and scarcity – in water availability. The assessment also undertook an inventory of major programs and institutions currently engaged in water resources management in SSA. This inventory documented important ongoing and planned work by national governments, regional and sub-regional institutions, international funding institutions and donors, and research institutions.

The study identified feasible 'best bet' interventions that can be promoted by various development partners to enhance AWM by smallholder farmers as a coping and adaptation strategy for climate change and variability in SSA. The interventions focused mainly on feasible investment options in AWM, which encompasses both upgrading rainfed agriculture (improved on-farm management of rainwater) and smallholder irrigation systems geared toward improving land and water productivity.

Drawing on this synthesis and comparative analysis of current trends and practices, and with an understanding of the institutional landscape, the assessment developed key findings and recommendations for consideration by development partners and other stakeholders in preparing for a development/investment program in this important area. The draft report was subjected to critical expert review by correspondence and finally through a peer review feedback consultation workshop in Nairobi in October 2008. The peer reviewers' comments and recommendations were incorporated in the report.

2.2 Scope of the Study

The study focused on identifying a set of principles to guide improved AWM strategies and programs in Africa, especially for smallholder farming communities. These principles incorporate sustainability and equitable development, water allocation strategies, risk reduction and diversification, and interactions and trade-offs with health and environmental objectives. The study recognizes that sustainable development is hindered by climate change, and this is one of the biggest challenges humanity has ever faced. Climate change appears to threaten progress toward achieving the MDGs because of increased investment uncertainty and associated risks.

The scope of the study was also limited by the predicted impacts of climate change. We recognized that predictions of the effects of climate change often conflict, especially with regard to variations in rainfall patterns in SSA, which have direct impact on water availability and agricultural production. For instance, most climate change predictions anticipate rainfall declines in some places and increases in others (Funk *et al.* 2008, Falkenmark 2007, IPCC 2007, Rijsberman 2006, IPCC 2001).

However, the study focused mainly on anticipated rainfall declines, which are expected in most parts of SSA. In the event of water stress, improved AWM measures – through *in situ* soil moisture conservation, rainwater harvesting, storage and utilization, groundwater exploitation and surface water abstraction for irrigation or adoption of drought-tolerant crops – become predominant, constituting some of the main study highlights. It was therefore by default that areas typified by higher rainfall (where drainage and adoption of hydrophilic crops were adapted as strategies) were not our main focus. However, there are also opportunities for improving AWM since intra-seasonal droughts also affect agricultural production. Thus water storage will be a key adaptation strategy.

The study also considered gender issues related to with climate change and variability. We took cognizance of the fact that women are the main actors in smallholder farming communities and play a major role in ensuring water and food security. Women are more vulnerable and bear most of the consequences of climate change water-induced stresses and conflicts. In this regard, the proposed interventions will strive toward adaptation measures that target but are not limited to enhancing the role of women in AWM and agricultural productivity. Therefore, socio-cultural factors that include gender norms and aspects are critical since they may affect adoption and up-scaling of selected interventions. Country-specific legal, policy and institutional frameworks were also included within the scope of the study.

2.2.1 Study limitations

The wide scope of the study inevitably resulted in several limitations. These included:

- Inadequate interaction with smallholder farmers, since most of the country visits focused on discussions with a number of stakeholders.
- Inadequate information on climate change adaptation case studies in SSA, hence the study relied heavily on few documented cases and contributors' perceptions and experiences.
- The multi-disciplinary nature of climate change and variability, as well as disjointed sector-based interventions, made it difficult to target specific government departments or programs dealing with adaptation strategies. These problems were aggravated by inherent unpreparedness and institutionalization of climate change adaptation in many countries, leading to haphazard policies and strategies.
- Inadequate capacity and technical skills in most countries to deal with climate change, the limited number of contact persons and inadequate knowledge on the subject.

3. CURRENT TRENDS AND PAST EXPERIENCE

This chapter is divided into four sections. Section 3.1 presents the current trend on water resources and AWM in Africa with emphasis on climate and precipitation trends, renewable and non-renewable water resources, agricultural water use and demand, conflict over water resources and anticipated impacts of climate change on water resources. Section 3.2 highlights some of the adaptation strategies developed and attempted by stakeholders. Section 3.3 focuses on the current practices on climate change adaptation in Africa: promising pilot projects, research activities and governance measures such as legal, policy, and institutional issues. Section 3.4 outlines some of the challenges and constraints – factors that affect adoption and up-scaling of adaptation strategies in Africa.

3.1 Water Resources and African Agriculture

As regards water resource abundance and economic development, Africa is a continent of contrast. Although water availability is often directly proportional to economic development in Africa, and especially SSA, this equation does not always apply. The state of agricultural development adds to this contrast at the continental level, but at the country level the scenarios are different. High rainfall areas are more economically developed than the semi-arid savannah environment (SASE). Outside the two extremes – water abundance and water scarcity in the intermediary zone – the countries in the vast SASE have much in common. The region experiences water shortage and population pressure, and is adversely affected by climate change (Figure 1). Most of the livelihoods in SASE are agriculture-based (both crops and livestock) the majority of whom are vulnerable women. Poverty levels in SASE are high, and hence there is less ability to adapt to climate change.

Africa has 36 international river basins spanning 64 percent of the continent and holding 90 percent of all surface water resources (Turton *et al*. 2005). IPCC (2001) noted that "five major river basins – the Congo, Nile, Niger, Chad, and Zambezi – occupy about 42 percent of the geographical area and sustain more than 44 percent of the African population". Other shared basins in the continent are those of the Senegal, Gambia, Limpopo, Orange/Senqu and Cunene river basins. The Congo, Nile, Niger, and Zambezi river basins are each shared by more than eight countries. IPCC (2001) stated that "the dependency ratio[4] is nearly 90 percent for

4 Dependency ratio is defined as the ratio between renewable water produced out of a country and the total renewable water of the same country

Niger and Mauritania in West Africa, while similar transboundary dependencies are also evident in southern Africa and in the Nile basin".

Availability of water in SSA is highly variable and is one of the biggest constraints to socio-economic development. Only the humid tropical zones in Central and West Africa have abundant water (IPCC 2000). In addition, water availability varies considerably within countries as well. According to the United Nations Environment Programme (UNEP), eight countries were suffering from water stress or scarcity in 1990. By 2025, the number of countries expected to experience water stress will rise to 18 – affecting 600 million people (World Bank 1995). As Figure 1 illustrates, between 1990 and 2025 many countries will shift from having water surplus to water scarcity as a result of population growth alone. According to estimates, by 2025, up to 16 percent of Africa's population (230 million) will be living in countries facing water scarcity, and 32 percent (460 million) will be living in water-stressed countries (Johns Hopkins 1998).[5] In the next 15-20 years, the proportion of the continent with water security will fall from nearly 53 percent to 35 percent (Ashton 2002).

3.1.1 Water resources

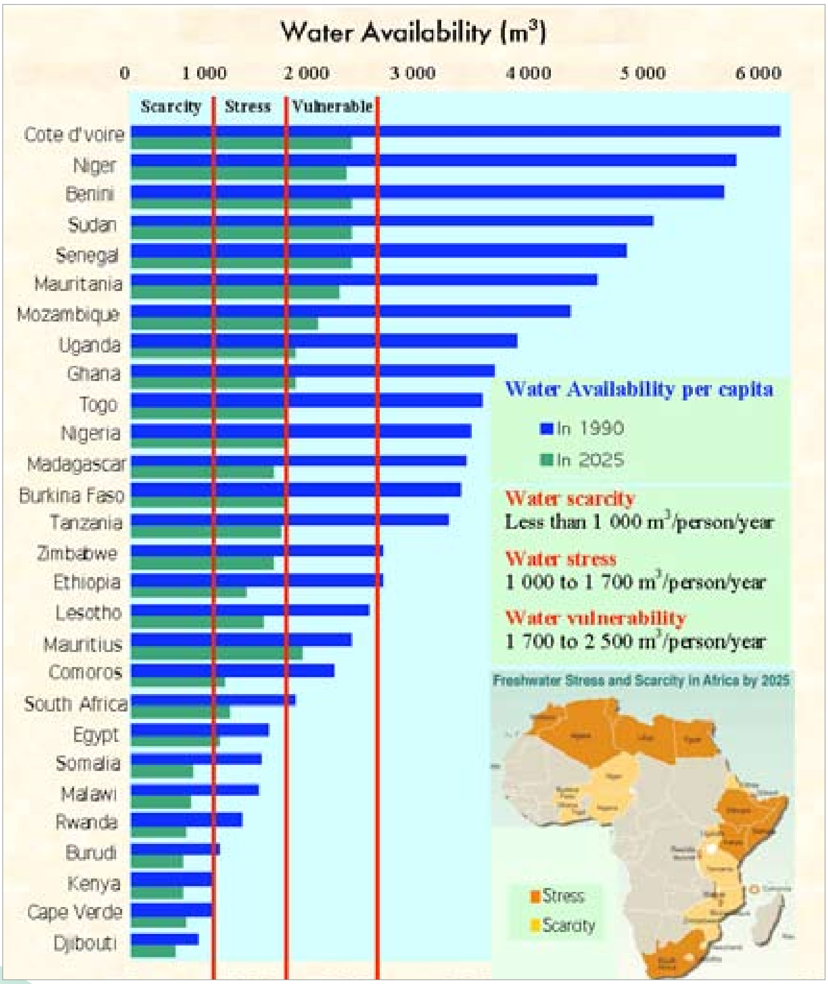
Throughout the world, water resource management will be one of the most important economic and social issues of this century (World Bank 1993). Water allocation, water quality, growing and changing social demands for water, new technologies, water-use efficiency, economic feasibility and benefit-cost measurement are issues of great concern to research institutions and decision-makers at various levels (ESCWA and ICARDA 2003). Water management can be defined as the planned development, distribution, and use of water resources in accordance with predetermined objectives while respecting both the quantity and quality of water resources (ICID 2001)

In Africa, water resources have high temporal and spatial variations. Moreover, Africa has abundant rainfall and relatively low levels of water withdrawals with internal renewable water resources[6] of 70 percent of the total flow (UNECA 2001). The renewable groundwater resources are estimated at 421,000 mm^3 per year (AWDR 2006). However, the withdrawals are rather low in relation to both the rainfall and the internal renewable resources, as shown in Figure 2. The only exception is in northern

5 Water stress is defined as water availability of ≤ 1,700 m^3 per capita per year. Water scarcity is defined as water availability of ≤ 1,000 m^3 per capita per year.

6 The internal renewable water resources is defined as the average annual flows of rivers and groundwater generated from rainfall within the sub-region

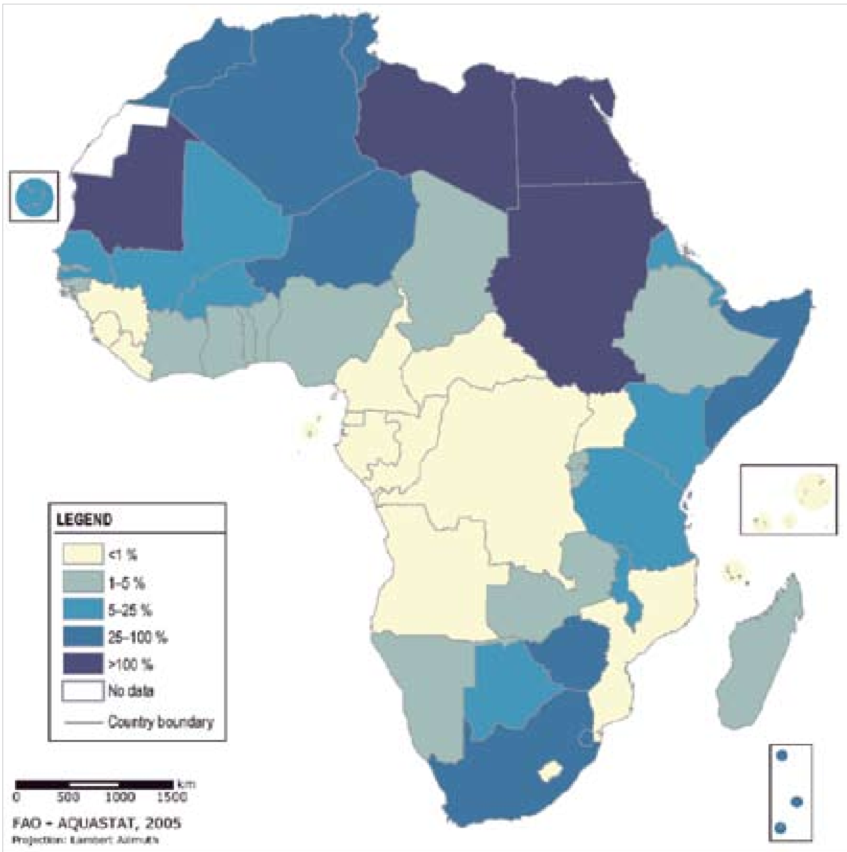
Africa where the withdrawals are about 20 percent of the rainfall and 150 percent of the internal renewal resources (AWDR 2006).



Source: Adapted from UNEP, 1999

Figure 1: Projected freshwater stress and scarcity in Africa by 2025

In SSA, the amount of water withdrawn for agricultural use amounts to about 3 percent of the internal renewable resources,[7] and only 6 percent of agricultural land is under irrigation (World Bank 2006a). This may reflect a low level of development and use of water resources in the continent (AWDR 2006). Annual freshwater withdrawals in East Africa are a small percentage of the total available, ranging from less than 3 percent of the total resources available in Burundi to 12 percent in Rwanda (UNEP 2002).



Source: ftp://ftp.fao.org/agl/aglw/docs/wr29_eng.pdf

Figure 2: Water withdrawals as a percentage of internal renewable water resources in Africa

7 The 3 percent withdrawal only accounts for formal (conventional) irrigation schemes, mainly public irrigation schemes. This figure could rise to 10 percent if informal (e.g. spate irrigation) and private irrigation is included. Green water (rainfed AWM systems) withdrawal is also not accounted for.

However, despite the low utilization of its renewable freshwater resources[8] (WRI *et al.* 2000), water is becoming one of the most critical natural resource issues in Africa, and the continent is one of the two regions in the world facing serious water shortages (Johns Hopkins 1998). Africa's extreme variability of rainfall is reflected in an uneven distribution of surface and groundwater resources, from areas of severe aridity with limited freshwater resources such as the Sahara and Kalahari deserts, to the tropical belt of mid-Africa typified by abundant freshwater resources (UNEP 2008). For instance, while the Sahelian countries have limited supplies of fresh water, most countries in the humid tropical zone have abundant water. The availability of water varies considerably, even within countries, and the situation is further complicated by frequent droughts and inappropriate water management programs. The demand for water is increasing rapidly in most countries due to population growth and economic development (AWDR 2006).

3.1.1.1 Surface water

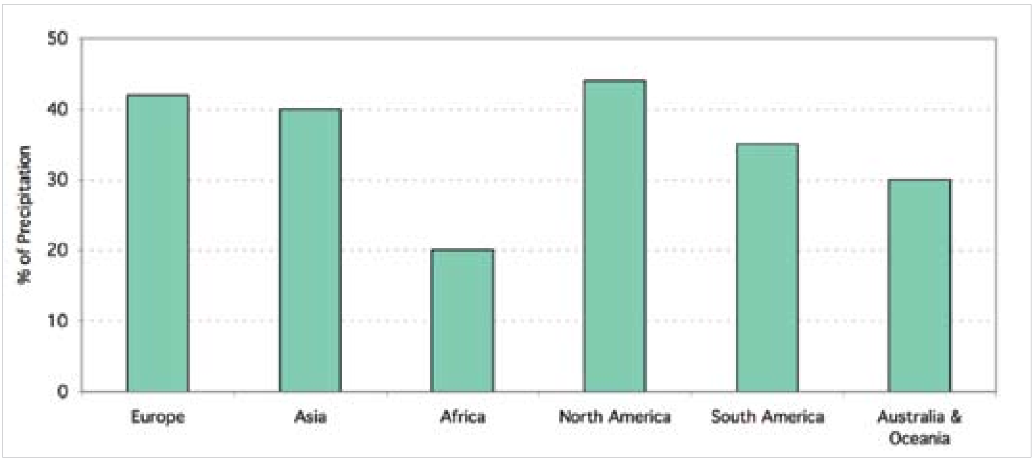
Surface water, especially rivers and lakes, reflect higher fluctuations than groundwater. In recent years, significantly reduced river flows and dam storage have resulted from severe droughts in Africa (Conway and Hulme 1996). The hydrological performance of Africa results in much less run-off yield than in other regions.[9] Figure 3 shows comparative hydrology in world regions, with Africa indicating the lowest run-off yield.

At river basin scale, a change in the hydrographs of large basins (Niger, Lake Chad and Senegal) has been observed (IPCC 2001) as shown in Figure 4, which gives an example of the Niger River at Niamey. Between the mean annual discharge of the humid and drought periods, the percentage of reduction varies from 40 to 60 percent (Olivry *et al.* 1993). The Nile basin has recorded a reduction in run-off of 20 percent between 1972 and 1987 (Conway and Hulme 1993). Moreover, different simulations give conflicting results, varying from 77 percent flow reduction to a 30 percent increase (Smith *et al.* 1996). Conway and Hulme (1996) conclude that "the effects of future climate change on Nile discharge would further increase uncertainties in planning and management". The Zambezi River has the worst scenario, with decreased precipitation by 15 percent, increased potential evaporative losses by 15-

8 This indicates water availability is not the problem, but inadequate financial capacity to exploit the water resources; hence the issue is economic water scarcity, not hydrological water scarcity.

9 In simple terms, this refers to the process of partitioning rainfall into different hydrological components, and in this case the focus is on surface run-off as percentage of total rainfall.

25 percent and diminished run-off by 30-40 percent (IPCC 2001). In addition, run-off simulation under climate change is projected to decrease by 40 percent (de Wit and Stankiewicz 2006).

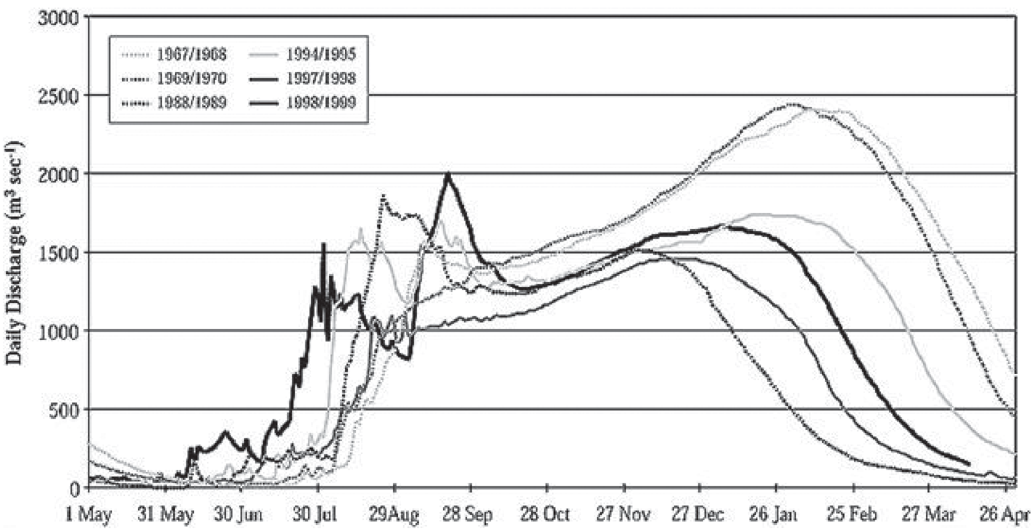


Source: IPCC 2001: http://www.grida.no/climate/ipcc_tar/wg2/fig10-4.htm

Figure 3: Comparative hydrology in world regions – total run-off as percentage of precipitation

Most rivers in Africa traverse semi-arid to arid lands on their way to the coast from the tropics, hence; evaporative losses also are high in comparison to rivers in temperate regions (IPCC 2001). High temperatures will increase evaporative losses; unless they are compensated for by increased rainfall, run-off is likely to be further reduced (IPCC 2001). In addition, most lakes in Africa experience a delicate balance between precipitation and run-off; all of the large lakes show a less than 10 percent run-off-to-precipitation ratio (Smith *et al.* 1998). Water basins like Lake Chad and the Okavango Delta have no outflow because evaporation is equal to or less than inflows (IPCC 2001). In the SASE, the incidence of seasonal flow cessation may be on the increase, as shown by some streams (Ngigi *et al.* 2008, Magadza 2000). Drought periods now translate into critical water shortages for industrial and urban domestic supplies (Magadza, 1996).

Renewable water resources in Africa constitute only about 20 percent of the total rainfall (IPCC 2001). In the Sudano-Sahelian and Southern African regions, the figures are about 6 percent and 9 percent respectively, due to high losses of rainfall (UNECA *et al.* 2000). Arnell (1999) shows that the greatest reduction in run-off by 2050 will be in the southern Africa region, also indicating that, as the water use-to-resource ratio changes, many countries will shift into the high water stress category. Both surface water and groundwater resources are already showing diminishing trends, with a bleak future for agricultural development.



Source: http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg2/384.htm

Figure 4: Decadal changes in hydrograph of the Niger River at Niamey between 1961 and 1999.

3.1.1.2 Groundwater resources

Adelana and MacDonald (2008) stated that "groundwater is one of Africa's most precious natural resources, providing reliable water supplies for many people for drinking water, sanitation, and irrigation. This is crucial, particularly during the dry seasons and in large arid zones. Further development of groundwater resources is fundamental to increasing access to safe water across the continent to meet water coverage targets and reduce poverty. However, groundwater accounts for only about 15 percent of the continent's total renewable water resources". In many parts of the continent, groundwater resources have not yet been fully explored and tapped (AWDR 2006). In these regions, recharge rates are generally very low, and extraction practices are based on mining a very finite supply (Burke and Moench 2000).

Recent studies show that most aquifers in Africa are unsustainably mined (Taylor and Tindimugaya 2008) due to inadequate monitoring systems, technical capacity and financial resources. In Kenya, the Nairobi aquifer has dropped over 15m since the 1960s and the Naivasha aquifers have dropped over 7m, while the Merti and Daadab aquifers in northern Kenya are also at risk (Mogaka *et al*. 2006). Moreover, unsustainable groundwater exploitation has attributed to salt water intrusion in many coastal aquifers.

Effective economic instruments to manage groundwater are underdeveloped for several reasons: the high cost and complexity of assessing groundwater resources, the abstract nature of the true supply, and the near irreversibility of most contamination (Kemper *et al.* 2006). For these reasons, traditional assessment has tended to undervalue local groundwater resources. The issue of scale further complicates the problem. Moreover, political boundaries are rarely aligned with the natural boundaries of an aquifer, creating a further disjoint in the management of resources. Finally, state and national oversight often fail to address the local needs of farmers in governing groundwater use, while local groups often lack a regional perspective on water management (Foster *et al*. 2000).

Approximately 20 percent of cultivated lands under irrigation are fed through groundwater sources, although the use and distribution is highly uneven (FAO 2005). In general, agricultural groundwater schemes are of two types: shallow, small-scale systems that supply water for both crops and livestock; and deep, large-scale irrigation systems (Foster *et al*. 2000). The hydro-geological characteristics of an aquifer limit its use by determining both the susceptibility of groundwater to exploitation and the vulnerability of groundwater to agricultural pollution (Foster *et al.* 2000).

Intensive groundwater use is prevalent in the north and arid regions of Africa, for example, Algeria, Eritrea, Libya and Tunisia, rely almost entirely on groundwater for irrigation (Giordano and Villholth 2007). In addition, the irrigation of vast areas of arable land with groundwater from wells and deep boreholes has become widespread in Chad, Libya, South Africa, Sudan and other countries (Shahin 2002), for example, in Libya, groundwater accounts for 95 percent of freshwater withdrawals, while in many river basins groundwater is a significant source of water for irrigated agriculture.

Information about regional groundwater is scanty and the role groundwater plays in sustaining livelihoods is limited. Appelgren (2004), stated that "the need to expand the knowledge base of regional groundwater and surface water systems is therefore critical to manage water resources, to anticipate and mitigate impacts of droughts and to reduce the risk of over exploiting limited resources. Similarly, the capabilities and scientific strengths of African countries need to be enhanced to address long-term and regional groundwater resource assessment and management, while simultaneously addressing immediate societal needs. In this context, groundwater is closely linked in an overall holistic approach to water resources management, especially surface water and non-conventional water resources".

The effects of climate change on groundwater remain uncertain, and as IPCC (2007) has stated, further research in this regard is needed. Depending on the physical attributes of the aquifer, infiltration will occur at various rates due to climate change. The effect on groundwater is directly linked to the impact of climate change on recharge rates, which can decrease or increase in proportion to decreases or increases in precipitation (Green *et al*. 2007; IPCC 2007).

UNEP (2008) noted that "in a continent already facing water scarcity, phenomena such as climate change and rapid population growth are expected to force local populations to increase their reliance on groundwater resources to meet domestic, agricultural and industrial water demands."

3.1.2 Agricultural water use

As UNEP (2006) stated "the availability of and access to fresh water is an important determinant of patterns of economic growth and social development". World Bank (2006a) reiterated that "in recent years, agricultural water has helped meet rapidly rising food demand, and has contributed to the growth of farm profitability and poverty reduction in many countries". In SSA, where water scarcity is a major challenge to rural development and poverty reduction, however, the story is different. Since water availability is variable in space and time, rural well-being is dependent on its supply, use, disposal, and reuse (ICID 2001). Investment in agriculture requires the assurance of irrigation to overcome the vagaries of the natural availability of water (ICID 2001, IWMI 2005).

Despite the importance of irrigation for economic growth, SSA exploits only a meager proportion of its potential, primarily due to high investment costs and shifting investment priorities of development agencies (Peacock *et al*. 2007). Of the total amount of water withdrawn, 85 percent is used for agriculture, 9 percent for community water supply, and 6 percent for industry (UNECA 2001). At both continental and sub-regional levels, the withdrawals are low in relation to both rainfall and internal renewable resources (AWDR 2006). SSA's water withdrawals for agriculture amount to only 3 percent of its total renewable water resources despite the highly spatial and temporal variability of rainfall and resultant low land productivity and crop failures (UNECA 2001, UNEP 1999).[10]

Table 1 shows water withdrawals as a percentage of available water resources in selected SSA countries. FAO (2005) stated that "nearly 70 percent of Africa's total water withdrawal occurs in the Northern and Sudano-Sahelian regions. Of this total, 86 percent of withdrawals are for agricultural purposes, ranging from 95 percent in the Sudano-Sahelian region to just 56 percent in the Central region". Water for livestock production is also included as part of agricultural water use. The production of animal protein requires significantly more water than the production of plant protein. Although livestock directly use only 2 percent of the total water used in agriculture, water input for livestock production is substantial since water is required for the forage and grain crops they consume (Pimentel and Pimentel 2003).

Furthermore, because 75 percent of Africa's agricultural land lies within regions with a crop moisture index (CMI)[11] of less than 0 and ranging within +1 to -1, irrigation demand increases at an exponential rate (Vörösmarty et al. 2000). The average rate of irrigation development in SSA from 1988 to 2000 was 46,600 ha per year (FAO 2001c). If this rate continues, an additional 1 million ha will be brought under irrigation by 2025[12]. The World Bank estimates that water infrastructure investment in the order of USD 180 billion per year is needed up to 2025 (Faulkner *et al*. 2008). Past experience of irrigation development, especially with large-scale irrigation projects in Africa, calls for caution in making such huge investments. Sustainability and performance of irrigation development projects are compromised by water scarcity and aggravated by climate change.

There is a clear correlation between economic development and per capita investment in water storage, management and utilization. Developed countries have high per capita water resource development compared to developing countries, particularly

10 This figure varies in different literature, and a value of more even than 10 percent has been reported by Hillel (1997).

11 Crop Moisture Index (CMI) is the ratio of precipitation to evapotranspiration.

12 The Africa Water Vision for 2025 target to increase the area of irrigated land by 25 per cent and 100 percent by 2015 and 2025 respectively.

SSA, which has yet to realize its Green Revolution. A 'Blue Revolution' must therefore accompany the Green Revolution in Africa. The major challenge is how SSA can attract investments in AWM and overall water resources management to increase land productivity and economic development.

Table 1: Agricultural water use per country in 2000

Country	Total renewable water resources (km^3)	Water withdrawal for agriculture (km^3)	Water withdrawal (% of renewable water resources)
Burkina Faso	12.5	0.69	5%
Burundi	3.6	0.19	5%
Côte d'Ivoire	81	0.60	1%
Egypt	58.3	53.85	92%
Eritrea	6.3	0.29	5%
Ethiopia	110	2.47	2%
Ghana	53.2	0.25	0%
Kenya	30.2	1.01	3%
Madagascar	337	14.31	4%
Malawi	17.28	0.81	5%
Mali	100	6.87	7%
Niger	33.65	2.08	6%
Nigeria	286.2	5.51	2%
Rwanda	5.2	0.03	1%
Senegal	39.4	1.43	4%
Somalia	13.5	3.28	24%
South Africa	50	11.12	22%
Sudan	64.5	36.07	56%
Tanzania	91	1.85	2%
Tunisia	4.56	2.23	49%
Uganda	66	0.12	0%
Zambia	105.2	1.32	1%
Zimbabwe	20	2.24	11%
SSA	3518	97	3%

Source: http://www.fao.org/ag/agl/aglw/aquastat/water_use/index.stm

3.1.3 Anticipated impacts of climate change on agricultural water resources

Water scarcity will be aggravated by the looming climate change. By 2020, yields from rainfed agriculture could be reduced by as much as 50 percent in some countries (IPCC 2007). This will adversely affect food security and further exacerbate malnutrition and poverty, especially in SSA. The vulnerabilities and anticipated impacts of climate change will be observed at different scales in different countries (IPCC 2001). These heterogeneous and inconsistent data impose serious limitations in constructing scenarios of water resources in response to climate change. Where consistent long-term climatic data are available, they indicate a trend towards reduced precipitation in semi-arid to arid regions (IPCC 2001). Instrumental data and climate model simulations indicate an imminent water crisis in large parts of Africa (IPCC 2007). Climate change will have a major impact on the baseline environmental characteristics and hydrological cycle (World Bank 2009) on which ecosystems and livelihoods are based.

A common feature in rainfall patterns as impacted by climate change is greater variability in cycles (IPCC 2001). In SSA, most areas are characterized by low and erratic rainfall, concentrated in one or two short rainy seasons. This results in high risk of droughts, intra- and off-seasonal dry spells, and frequent food insecurity. Intra-seasonal dry spells occur due to inadequate rainfall during the growing period, while off-seasonal dry spells are due to rainfall cessation before crop maturity. Several studies on water assessment and impact of climate change have been undertaken in Africa (viz Kabat *et al*. 2003, Olomoda 2002, Gyau-Boakye and Tumbulto 2000, Falkenmark 1990 and Gleick 1998). The IPCC (2001) indicates that extreme events, including floods and droughts[13], are becoming increasingly frequent and severe. Even countries that previously did not experience floods, such as Burkina Faso, have recently reported severe flooding, notably in 2007.

The impact of changes in precipitation and enhanced evaporation could have profound effects on some lakes and reservoirs (IPCC 2001). Table 2 shows estimates of ranges of percentage changes in precipitation, potential evaporation and run-off in African river basins as reconstructed from Arnell (1999). This scenario shows diminishing water resources for agriculture. Moreover, under the present climate regime, several lakes and wetlands show a delicate balance between inflow and outflow, such that evaporative increases of 40 percent, for example, could result in much reduced storage and water availability (IPCC 2001).

13 UNDP defines drought as a 50 percent shortfall in rainfall over three months.

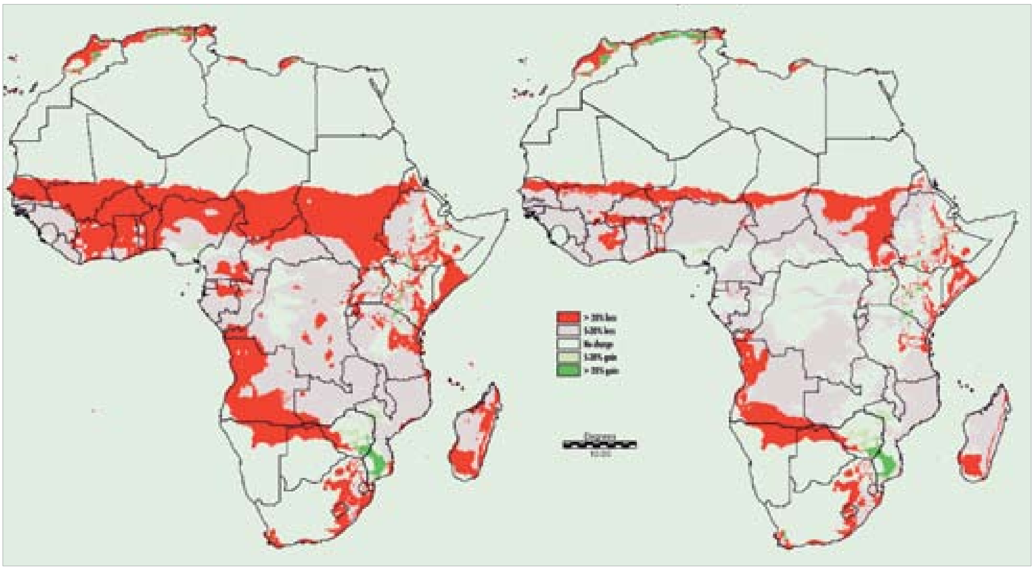
Table 2: Expected ranges of percentage changes in precipitation, potential evaporation and run-off in African river basins, 1951-90

Basin	Change in rainfall (%)	Change in evaporation (%)	Change in run-off (%)
Nile	-10	10	0
Niger	-10	10	10
Volta	-20	4 to 5	-20 to -40
Shebelle	-5 to 18	10 to 15	-10 to 40
Zaire	10	10 to 18	10 to 15
Ogooue	-2 to 20	10	-20 to 25
Rufiji	-10 to 10	20	-10 to 10
Zambezi	-10 to -20	10 to 25	-26 to -40
Ruvuma	-10 to 5	25	-30 to -40
Limpopo	-5 to -15	5 to 20	-25 to -35
Orange	-5 to 5	4 to 10	-10 to 10

Source: IPCC 2001

In most cases, floods and drought cycles alternate, with dire consequences for agricultural production. Estimates suggest that one third of African people live in drought-prone areas and that around 220 million people are annually exposed to drought (UNFCCC 2006). The African Sahel, situated at the southern fringe of the Sahara desert and stretching from the West African coast to the East African highlands, is particularly prone to drought. Droughts have particularly affected the Sahel and other parts of Africa, especially the Horn of Africa and southern Africa, since the late 1960s. Reduced river flows and groundwater recharge related to decreasing rainfall have significant impacts on agricultural production (IWMI 2006). Figure 5 shows the expected changes on the length of growing seasons, and Figure 6 the percentage of failed seasons.

Large basin-scale analyses often give the incorrect impression that many areas of Africa are rich in water reserves, in which case local water problems could be rectified easily through technological solutions that could transfer water from the source to stress areas. Although in theory this may appear feasible, the high costs associated with such projects make them impractical. Political goals such as self-sufficiency in food production and general socio-economic development cannot be achieved under severe water scarcity (Falkenmark 1990). Drought-prone zones of Africa are already water-limited, further increasing their vulnerability (IPCC 2007). Therefore, upgrading rainfed agriculture, mainly through rainwater harvesting and irrigation, is one of the climate change adaptation strategies[15].



Source: Thornton *et al.* 2006, IPCC 2001

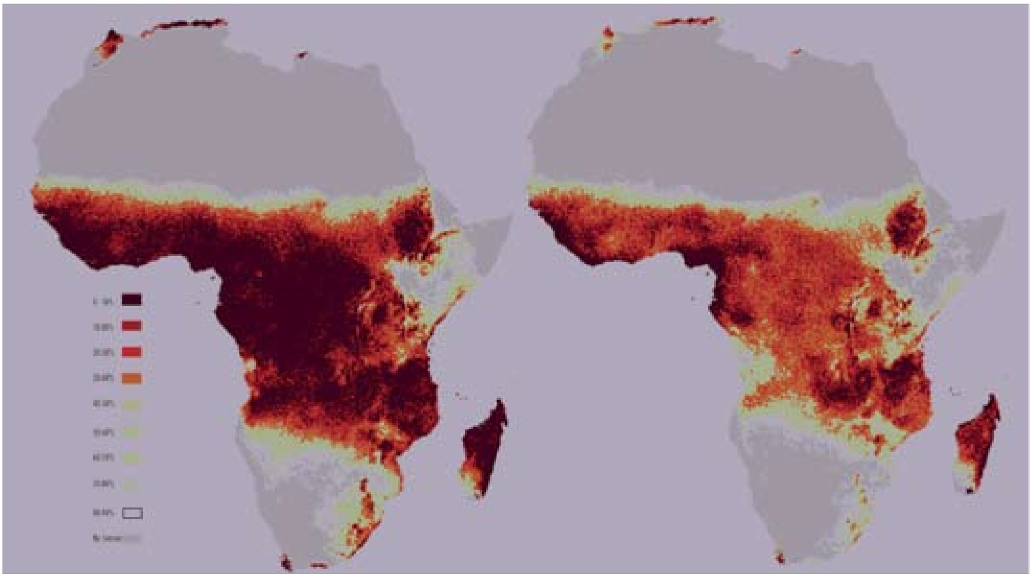
Figure 5: Predicted changes in the length of the growing season from 2000 to 2050[14].

3.1.4 Upgrading rainfed agriculture

The focus on upgrading rainfed agriculture is not misplaced. The International Food Policy Research Institute (IFPRI) stated that Africa is particularly vulnerable because of its limited ability to adapt because of its dependence on rainfed agriculture. The majority of the population of SSA depends on subsistence, rainfed agriculture. In Botswana, for example, 76 percent of the population depends on subsistence agriculture; in Kenya, 85 percent; in Malawi, 90 percent; and in Zimbabwe, 70-80 percent (Rockström 1999).

14 Data taken from downscaled outputs from the EC Centre Hamburg global circulation model (GCM) version 4 for a scenario with rapid economic development (left); and a scenario with slower economic development (right). Dark red represents >20 percent shortening, pink a 5-20 percent shortening, white no change, light green a 5-20 percent lengthening and dark green >20 percent lengthening of the growing season.

15 This reiterates the Africa Water Vision for 2025, which target to increase water productivity of rain-fed agriculture and irrigation by 10 per cent and 60 per cent by 2015 and 2025 respectively (ECA et al. 2000).



Source: Thornton *et al.* 2006, IPCC 2001

Figure 6: Percentage of failed seasons in 2000 and in 2050[16].

The key role of agriculture in Africa's economic life is apparent – the sector accounts for 35 percent of the continent's GDP, 40 percent of its exports and 70 percent of its employment (Kijne 2000). However, due to population pressure, the potential for agricultural development lies in upgrading agriculture in the SASE, which receives an average annual rainfall of 300-600 mm/year, ranging from 200mm/year in the semi-arid zones to 1000mm/year in the dry sub-humid zones.

The length of the growing period ranges from 75 to 120 days in the semi-arid zones and from 120 to 180 days in the dry sub-humid zones. Potential evaporation levels are high, ranging from 5 to 8 mm/day, giving a cumulative evapotranspiration of 600-900 mm/season over the growing period. This explains the persistent water scarcity coupled with low crop yields.

16 These are defined as fewer than 50 growing days with actual to potential evapotranspiration (Ea/Et) greater than 0.5 and more than 20 stress days (Ea/Et less than 0.5) within the period, as predicted from the EC Centre Hamburg GCM version 4 for a scenario of a world with rapid economic development.

The nature and occurrence of rainfall in SSA provides more insight into the food production and water scarcity situations. The problem is aggravated by intra-seasonal and off-seasonal dry spells. Intra-seasonal dry spells occur due to inadequate rainfall during the growing period, while off-seasonal dry spells are due to rainfall cessation before crop maturity. According to Rockström *et al*. (2001), these dry spells can be mitigated by:

- "Maximizing plant water availability by maximizing infiltration of rainfall; minimizing unproductive water losses (evaporation, deep percolation[17] and surface run-off); increasing soil-water holding capacity; and maximizing root depth
- Maximizing plant water uptake capacity by monitoring timeliness of operations, crop management and soil fertility management
- Dry-spell mitigation, using supplemental irrigation and effective conventional irrigation systems"

More investment in rainfed farming systems in SSA is essential to reduce chronic food shortages and poverty and to make progress toward the MDGs (Cooper *et al*. 2006). However, in such systems rainfall variability is the fundamental factor defining production uncertainty. While farmers have learned to cope with current climatic variability, they – as well as many associated potential investors – are risk-averse and over-estimate the impact of rainfall variability on crop and livestock production. As a result, they are reluctant to make such investments when the outcomes are so uncertain from year to year. Climate change will result in even greater rainfall variability in many parts of SSA and can only exacerbate this situation.

3.1.4.1 On-farm water management

On-farm water management (OFWM) can be defined as the manipulation of water within the borders of an individual farm, a farming plot or field (Wolff and Stein 2003) for both rainfed and irrigated agriculture. OFWM generally seeks to optimize soil-water-plant relationships in order to achieve high crop yields. This can be achieved by minimizing inputs and maximizing outputs so as to optimize profits. OFWM covers water resources, irrigation facilities, by-laws and procedures, farmers' institutions and

17 Although deep percolation is an unproductive water loss at field scale, it can contribute to groundwater recharge at a river basin scale, and thus feed other systems downstream.

soil and cropping systems (Wolff and Stein 2003). It encompasses management of water used for plant growth, ie, rainfall and water applied through irrigation.

Water-use efficiency and water productivity are two of the measures of OFWM (Mahoo *et al*. 2007). Water-use efficiency is an indicator commonly used to evaluate the performance of an irrigation system and is defined as the ratio between the amount of water used for an intended purpose (such as crop production) and the total amount of water input within a spatial domain of interest (such as river abstraction). Besides evapotranspiration, water lost off-farm through drainage can also be considered. This water, however, may flow through rivers and be utilized by downstream users, highlighting the importance of often neglected linkages (Perry 1999). The efficiency ratio is determined through proper investment and appropriate water management practices. Under low investment scenarios, irrigation in particular suffers and production decreases. In developing countries, the loss equated with low-investment irrigation development exceeds gains in rainfed production (Rosegrant *et al*. 2002, 2005).

Efficiency is generally associated with a transformation of an input into an output (Hillel 1997). Irrigation efficiency is defined as the amount of water from the main water source that can be effectively supplied to the root zone. It can also be defined as the portion of water stored in the root zone that is transpired by the crop (Wang *et al*. 1996, Hsiao *et al*. 2007). This concept includes both crop water-use efficiency and crop water productivity. The combined application of agronomic and engineering principles results in improving water-use efficiency, defined as the ratio of transpiration (mm) to total water supply (mm) and water productivity, defined as the ratio of yield (kg) to total water supply (mm). These concepts reflect the technical measures of efficiency and thus are not sufficient to assess the economic level of water-use efficiency. The economically efficient amount of water use depends on the relative prices of water and other inputs, the marginal products of inputs, the prices of inputs, and the amounts of other inputs, including rainfall (ESCWA and ICARDA 2003).

The optimum level of applied water for a particular situation is that which produces the maximum profit or crop yield per unit of land or per unit of water, depending on the underlying objective function and the limiting constraint (ESCWA and ICARDA 2003). In this respect, water productivity, defined as the amount of food produced per unit volume of water used, is more relevant. It is essential to specify the hydrological components (evaporation, transpiration, gross inflow, net inflow) considered when calculating water productivity.

Water productivity can be improved by increasing the yield per unit of land area by using a better variety of agronomic practices or by growing the crop during the most suitable period (when water is adequate). Water productivity is also determined by factors other than water management. Thus water productivity, including other determinant factors, is useful in identifying water-saving opportunities of the system under consideration. The terms *water-use efficiency* and *water productivity* should be used complementarily to assess the impact of water management strategies and practices used to produce more crops with less water.

Inadequate water resources make it imperative to evaluate the efficiency of water utilization to arrive at an efficient type of irrigation. ESCWA and ICARDA (2003) stated that "water-use efficiency and productivity differ according to different systems of irrigation, crop mix and environment, and are comprised of different parameters: crop consumptive use (water requirement), an efficient crop mix (the maximum irrigable area for given water resources) and maximum output and value per unit of water."

3.1.4.2 Irrigated agriculture

Smallholder irrigation development is essential to increasing food production, reducing poverty, mitigation against climate change and providing sustainable rural development. But irrigation development in Africa has been hampered by high investment costs (Carruthers et al. 1997) and poor national agricultural policies. Many countries have neither comprehensive irrigation policies nor an appropriate institutional framework. Significantly, the irrigation sector is placed under various ministries in different countries. This poses a significant challenge to irrigation development in SSA, reducing the ability of irrigated agriculture to respond to increasing food demands and climatic uncertainties.

In a study of 314 irrigation projects in a variety of developing nations, Inocencio *et al.* (2007) found that, "in general, irrigation in Africa is considerably more expensive than in other developing countries (USD 14,500/ha compared to USD 6,000/ha for development, and USD 8,200/ha compared to USD 2,300/ha for rehabilitation).[18] However, when categorized as successful or failing systems, irrigation systems in SSA were priced similarly to those of other developing countries (USD 3,600/ha compared to USD 3,800/ha for development, and USD 2,300/ha compared to USD 1,400/ha for rehabilitation)." This analysis, which focused on large- and small-scale public irrigation schemes, implies that these systems can be cost-effective in SSA with proper implementation and maintenance.

18 The high cost of irrigation development can be attributed to a number of factors, but poor governance (leading to corruption) and high cost of foreign technical assistance are prominent.

Growth required in developing additional water supplies, especially for agriculture, varies between 25 percent and 75 percent (Seckler 1998). Despite the low exploitation of irrigation potential as well as poor performance and various environmental issues related to irrigated agriculture, the contribution of irrigation to food security is recognizable and undeniable. For example, the average level of unaccounted-for water is as much as 70 percent in irrigation, compared to about 50 percent in urban areas. This water is lost and is not used for productive uses. Increasing irrigation efficiency would therefore reduce the need to develop additional water supplies for all sectors in 2025 by roughly one half (Seckler and Young 1985). In most countries, however, operators of irrigation systems lack incentives to supply farmers with a timely and reliable delivery of water (Serageldin 1998). Farmers, for their part, generally tend to over-irrigate as a result of their own perceptions of water requirements and their expectations of rainfall and market values (ESCWA and ICARDA 2003). The immense use of water in the agricultural sector can become more sustainable through economic incentives that will provide farmers with incentives to use more efficient methods of water application. In Kenya, the Water Act of 2002 attempts to address this issue.

Irrigation water management (IWM) involves the managed allocation of water and related inputs in irrigated crop production so that economic returns are increased relative to available water (USDA 1997). Conservation and allocation of limited water supplies are central to irrigation management decisions, whether at the field, farm, irrigation district or river basin level (USDA 2006). Appropriate management of irrigation water leads to conservation of water supplies, reduction in negative water quality impacts and improvement of producer net returns. Water savings through improved management of irrigation supplies are essential for meeting future water needs (USDA 1997). Irrigated agriculture affects water quality in several ways, including higher chemical use rates associated with agro-chemicals, increased soil salinity and erosion, accelerated pollutant load with drainage flows, leaching of plant nutrients and greater in-stream pollutant concentrations due to reduced flows.

Farmers may reduce water use by applying less than full crop-consumption requirements (deficit irrigation), shifting to alternative crops or varieties of the same crop that use less water, or adopting more efficient irrigation technologies (USDA 1997). Many irrigators have responded to water scarcity through the use of improved irrigation technologies – often in combination with other water-conserving strategies – and irrigators will likely look to technology as a means of conserving water in the future. Various management practices and irrigation technologies are available to enhance efficiency of applied water in irrigated agriculture. Irrigation improvements often involve upgrades in physical application systems, with improved field application efficiencies and higher yield potential (USDA 1997, 2006).

Improved water management practices may also be required to achieve maximum potential of the physical system (USDA 2006). In some cases, the effectiveness of improved irrigation practices may be enhanced when implemented in combination with other farming practices such as conservation tillage and nutrient management – good land husbandry is a prerequisite for effective irrigated agriculture. Increasing irrigation efficiency would lead to 'saved water', which can either be used to augment crop yield (expand irrigated area), allow more water for downstream users or release water for other uses. In the light of climate change, improving irrigation efficiency is a plausible adaptive strategy.

The off-farm water storage and delivery system may limit improvements in irrigation management at the farm level. Increased water-use efficiency depends on adequate and timely supplies of water to the crops. This requires a flexible surface-water system with sufficient off-farm storage and conveyance capacity and effective control facilities and operating policies (USDA 1997). Otherwise, on-farm water storage systems, which are suitable for smallholder farmers, will ensure high water-use efficiency and are less susceptible to climate change.

Most of the interventions to upgrade rainfed agriculture can be integrated cost-effectively in smallholder farming systems, especially where irrigated agriculture is not feasible. For example, supplemental irrigation – the watering of essentially rainfed crops with small amounts when rainfall fails to provide sufficient moisture – has been proven a drought-proof strategy in most SASE areas (Ngigi *et al.* 2005a, 2005b). ESCWA and ICARDA (2003) found that," in Syria, supplementing just 50 percent of the rainfed crop irrigation requirements reduces the grain yield by only 10-20 percent relative to full irrigation. Using the saved 50 percent to irrigate an equal area gives a much greater return in total production. In comparison to the productivity of water in fully irrigated areas (when the effect of rainfall is negligible), the productivity is higher with SI." In fully irrigated areas with good management, wheat grain yield is about 6 ton/ha using 800 mm of water per season. Thus, the water productivity is about 0.75 kg/m^3, one third of that under SI with similar management (ESCWA and ICARDA 2003). This suggests that water resources may be better allocated to SI when other physical and economic conditions are favorable.

The cost of water is an important factor in the economics of SI. This includes the cost of making the water available for use and the cost of application to the field. For most smallholder farmers, this can be achieved through an on-farm rainwater harvesting and management system, eg, small farm ponds (30-300m^3) for micro-irrigation using low-cost drip irrigation systems. Larger communal rainwater storage structures can also be constructed to provide supplementary irrigation water to a number of smallholder farmers like the micro-dams at the MVP site in northern Ethiopia.

3.1.5 Conflicts over water resources

When water is scarce, conflicts are common. Increasing water scarcity and demand is a recipe for conflict, even among smallholder farmers sharing the same resources. Growing water scarcity, increasing population, degradation of shared freshwater ecosystems, and competing demands for shrinking natural resources have the potential to create bilateral and multilateral conflicts (Gleick 1992). These conflicts lead to social and political instability with negative impacts on socio-economic development. For instance, the ongoing conflict in the Tana Delta in Kenya among pastoralists, environmentalists and a private investor has temporarily stopped a huge irrigated sugarcane project. Many conflicts related to water resources have been documented, both at community and national levels (Ngigi *et al*. 2008, Gichuki 2002).

In addition, gender issues are expected to intensify in some societies where women are traditionally prohibited from owning land or water resources. Use of water for small-scale businesses, especially those run by women, could be at risk where there are competing users. Women and children are the most affected by water-related conflicts, be it over domestic or agricultural water, due to their roles as the main users and managers of water, especially at household levels. For instance, in northern Tanzania, conflicts over water have led to a mass exodus of pastoralists, drastically reducing school attendance.

The evolving trend for water-related conflict and tension across Africa is such that riparian water projects are implemented within country borders to avoid cross-border politics. However, at some point, various externalities – population increase, climate change, limited resources – force a country to expand operations, affecting other downstream users (Wolf 2001). Shared river basins such as the Nile, Niger and Zambezi, already experience tensions over water use. In West Africa, where water withdrawal is expected to increase sixfold by 2025, there is potential for conflict since all 17 countries in that region share at least one of the region's 25 transboundary rivers (Niasse 2005). Recent conflict involved Mauritania with Senegal and Burkina Faso with Ghana. In southern Africa, where climate change is expected to significantly reduce precipitation, risk for conflict over water resources is higher than most other regions (Ashton 2002).

Conflicts over water are not only associated with shared river basins, but also other shared inland basins like Lake Chad and the Okavango Delta. Precise boundaries on Lake Chad have been established between Chad, Nigeria, Cameroon and Niger. IPCC (2007) noted that "sectors of the boundaries that are located in the rivers that drain into the lake have never been determined, and several complications have been caused by flooding and the appearance or submergence of islands." A similar conflict along the Okavango River between Botswana and Namibia led to a military confrontation between the two states. An important factor affecting water resources utilization and management in Africa is the multiplicity of international water basins, characterized by weak international water laws and regional cooperation on water quality and quantity issues (UNECA 2001). Most countries in SSA share at least one international river basin. However, to reduce conflicts over diminishing water resources and to improve river basin water resources management, a number of river basin organizations have been formed. These developments in transboundary water policy and legislation have kept the potential for conflict over water resources relatively at bay.

Moreover, over the last 50 years, 157 treaties have been negotiated and signed, leaving an extensive framework to peacefully navigate future water conflicts (Wolf 2001). These instruments, as well as other organizations, create some optimism that the continent will be able to cope with potential water-related conflicts. Some of these organizations include the Volta Basin Authority, the International Commission for the Congo Oubangui Sangha (CICOS), the Lake Tanganyika Basin Authority and the NBI, all of which facilitate consensus building and support bilateral initiatives (Kameri-Mbote 2007). In addition, the southern African states operate under the Southern African Development Community (SADC) Shared Watercourse Systems Protocol (1995)[19], which is based on recognition of the importance of a coordinated approach to the utilization and preservation of water in the SADC member states.

According to Turton *et al*. (2005), "three key factors that contribute to hydro-political stability are climate change, population dynamics, and socio-economic conditions. A significant shift in any of these factors poses potential conflict over water resources."[20] As the situation worsens, there is need for concerted efforts among various stakeholders to cope with diminishing water supply and escalating demands. This can be enhanced

19 For more information: www.internationalwaterlaw.org/regionaldocs/Revised-SADC-SharedWatercourse-Protocol-2000.pdf; www.africanwater.org/SADCprotocol_Original.PDF; www.africanwater.org/sadcWSCU.htm

20 Besides food and water security, safety of people and property is important, and any intervention proposed should consider reduction of conflicts among different communities/farmers.

through negotiation or cooperation between different sectors, interests or stakeholders. Due to the dynamism of water resources management, diversity and flexibility of actors are needed to cope with anticipated changes and enhance governance. There are no quick fixes – negotiated, proactive strategies that are economically feasible and hence sustainable, should be sought.

Conflicts and tensions can also be minimized by establishing effective water users associations (WUAs) to manage and allocate water equitably. Most effective WUAs adopt a watershed or catchment management approach that encompasses protection/ conservation and water resources management. Current policy reforms in Africa support establishment of WUAs as the basic unit of water resources management, thus decentralizing water resources management. WUAs charge nominal water fees (eg, USD 2/month in Kenya) to sustain their activities, which include operation and maintenance of water supply systems and watershed protection. Formation of a WUA is also a prerequisite for a water permit.

3.2 Adaptation Strategies

Adaptation to climate change and variability necessitates the adjustment of a system to moderate the impacts of climate change, to take advantage of new opportunities, and to cope with the consequences (IPCC 2001). Adaptation involves the action that people take in response to, or in anticipation of, projected or actual changes in climate to reduce adverse impacts or take advantage of the opportunities posed by climate change (Parry *et al.* 2005). In terms of climate change, this latter part of the definition is significant since climate change also presents certain opportunities and advantages in Africa, particularly for increased rainfall in certain areas of the continent (parts of the Democratic Republic of the Congo for example). Thus, it reduces communities' vulnerability or increases their resilience to climate shocks. It also enables ecosystems to coexist with the changing climate, thereby enhancing their capacity for providing the ecosystem services critical for human well-being (Parry *et al.* 2005).

In many cases, adaptation activities are local – district, regional or national – issues rather than international (Paavola and Adger 2005). Because communities possess different vulnerabilities and adaptive capabilities, they tend to be impacted differently, thereby exhibiting different adaptation needs. As a result, adaptation largely consists of uncoordinated action at household, company and organization levels. But it may also involve collective action at the local, national, regional and international levels and cross-scale interaction where these levels meet (Paavola and Adger 2005).

The vulnerabilities of climate change occur at various scales (Adger *et al*. 2005), and hence successful adaptation will depend on actions taken at different levels as outlined by (Paavola and Adger (2005).

*At the national leve*l:

- "Formulation of climate change policy geared toward vulnerable sectors, with emphasis on poverty reduction and food security
- Establishment of an integrated drought monitoring and information system, including an early warning system and farmers' coping mechanisms
- Development of policies and institutions that support adaptation at community levels and encourage private sector participation, allowing for greater dedication of resources to development of adaptive technologies and innovations
- Resource allocation to development of adaptive technologies and innovations to enhance sustainable economic growth"

At the community level:

- "Establishment of appropriate social institutions and arrangements that discourage marginalization of vulnerable population and enhance collective/participatory decision-making process
- Diversification of income sources and livelihood systems that reduce vulnerability and risks, especially for the poor
- Introduction of collective security arrangements such as farmers' cooperatives and community-based organizations (CBOs)
- Provision of knowledge, technology, policy, institutional and financial support (e.g. credit facilities) for the vulnerable communities
- Prioritization of local adaptation measures and provision of feedback to stakeholders"

One of the important characteristics of an adaptation strategy is that it should reflect the needs and aspirations of the society or community it is meant to benefit. Thus, the most effective mechanisms are flexible and relatively independent of scale. Adaptation efforts must be coordinated across sectors and between agencies, which is a challenge in practice. Without proper coordination, disparate actions may diminish overall effectiveness (Adger *et al*. 2005).

Out of this scenario arise the dynamics of cross-sector and cross-scale analysis. Adger *et al*. (2005) defines three key lessons.

a. "Adaptation can amplify existing conflict or disputes between agencies.
b. Choices are made through the choice between expected benefits of action and the costs of inaction, the ultimate choice of action depending on the strength and the will of the implementing authority.
c. Cross-scale linkages in a social construct differ from those of ecological systems and do not necessarily align (boundaries, jurisdiction, etc.)."

Moreover, Adger *et al*. (2005) offers four essential considerations when effectively implementing adaptation mechanisms:

- "There may be uncertainty over how an adaptation option will work even under defined conditions (ie, the level/certainty of the science being implemented must be evaluated and noted).
- The effectiveness of a given option may depend on third-party actors – and in the case of water management, an option may rely on the users' ability to reduce consumption or use water more effectively.
- Effectiveness will likely depend on an unknown set of climate variables and future climate.
- Upstream adaptation may hurt downstream users or lessen their ability to adapt."

Smit and Skinner (2002) argued that effort should be made to build adaptive capacity, which creates the ability of a system to cope with climate-related risks and allows for local assessment and more tailored responses. Thomas *et al*. (2005) differentiates climate responses between simple coping mechanisms (getting by) and adaptation (change in response to changing climatic parameters). This is an important criterion because it helps determine whether a given project or initiative is designed to get over a particularly rough spot, or whether the mechanism is designed with a sustainable long-term impact. The effectiveness of collective action in reducing climate vulnerability is a prerequisite. Thomas *et al*. (2005) found that "projects utilizing local knowledge and based on market principles were most successful."

Capacity building must be an integral component of any climate change adaptation strategy due to existing uncertainty within the climate models, particularly at local and national levels. The capacity of smallholder farmers to adapt to climate change is perhaps the most vital area for development. Burton and van Aalst (2004) argued that, with the exception of capacity building, projects should not be undertaken solely for the purpose of adapting to climate change. Their concern was that these projects may produce certain unintended consequences. Adaptation projects should be based on a solid scientific consensus with flexible implementation methods that consider possible externalities created through the implementation of the project. While geared toward funding priorities, the authors offer useful suggestions for funding in this arena. Routine incorporation of climate risk management into an agency's existing projects will allow for the integration of adaptation strategies to climate change. Furthermore, climate risks must be assessed within other country assistance programs and national development plans.

Huq *et al*. (2003) advanced what is known as the 'no regrets' adaptation strategy: adaptations that "…contribute to equitable and sustainable policies and to the current development decision framework by reducing present-day risk from climate variability and by being relevant to immediate national development priorities." Using the case of Mali, Huq *et al*. (2003) emphasized the importance of incorporating data and information management in an adaptation strategy; "after the drought during the 1970s, a working group was created to disseminate a bulletin with up-to-date information on meteorological conditions, rainfall, water table levels and agricultural impacts." Additional agro-climatic information included forecast tables, planting tips (particularly tied to current climatic conditions) and hydrology reports (Konate and Sokona 2003).

The UNDP climate adaptation program has a fairly well-defined framework that guides both implementation and evaluation of the adaptation programs with respect to climate change. The UNDP Adaptation Policy Framework for Climate Change is based on no-regret options – measures (Box 1) or activities useful even without climate change (UNDP 2003). Low-regret options, on the other hand, require additional outlays to combat negative climate effects. Climate change adaptation strategy is best supported by a set of regulatory and economic instruments designed collectively by stakeholders, without which, it will remain at the level of education and awareness creation (UNDP 2003).

Many governments and development organizations have begun to develop strategies to adapt to the effects of climate change (UNDP 2003). These include a wide variety of approaches, from 'climate-proofing' infrastructure to developing drought-resistant crops. Some adaptation programs also address underlying factors for vulnerability to climate change, such as poverty and ill health. The UNFCCC 7th *ad hoc* working group on long-term cooperative action estimated that USD 86 billion in new funding will be needed by 2016 to help the world's poor cope with the stresses of climate change (UNFCCC 2009). However, contributions to climate adaptation funding mechanisms have so far been relatively small and flowing slowly. In addition, it is unclear what kinds of projects qualify for funding, how the funds will be spent, and how the needs

Box 1: Some types of climate change adaptation measures

- **Sectoral** measures relate to specific adaptations for sectors that could be affected by climate change. In agriculture, for example, reduced rainfall and higher evaporation may call for the extension of irrigation. For infrastructure, sea level rise may necessitate improved coastal protection or relocation of population and economic activities. In most cases, measures will mean a strengthening of existing policies, emphasizing the importance of basing climate change policies on existing coping mechanisms and the necessity of integrating them into national development plans.
- **Multi-sectoral** measures relate to the management of natural resources that span sectors, such as water management or river basin management. The ecosystem approach to climate change adaptation involves the integrated management of land, water and other resources that promote their conservation and sustainable use in an equitable way (Orlando and Klein 2000).
- **Cross-sectoral** measures can span several sectors – an integrated approach is the best road to success.

Source: UNDP (2003)

of women and other vulnerable groups will be addressed. Responsive adaptation strategies should focus on what makes people vulnerable to climate change impacts, or their ability to cope with change without experiencing declines in living standards. Important factors are income level and income inequality, as well as the health and human capacity, including education of a population, in addition to the quality of the natural environment, such as available water and quality of land (Young 2008).

Different communities are affected differently by climate change and variability and, depending on their adaptive capacities, have developed coping strategies. This explains the region-to-region, village-to-village and household-to-household variation in coping strategies. However, as Cooper *et al.* (2006), correctly puzzled, "…farmers cope with climate variability, but can they adapt to climate change?"

The answers to that question are as varied as the agro-climatic zones and expected impacts on peoples' livelihoods due to climate change. Depending on subjective assessment of risks and vulnerability, affected smallholder farmers logically make certain adjustments in their choices of technologies and production systems. Cooper *et al.* (2006) grouped such coping strategies in three categories:

- "*Ex-ante* risk management options such as choosing between risk-tolerant varieties, investment in water management and diversification of farming and other livelihood enterprises prior to the onset of the season

- In-season adjustment of crop and resource management options in response to specific climatic shocks as they evolve
- *Ex-post risk* management options that minimize livelihood impacts of adverse climatic shocks"

However, although many communities have adapted to changes induced by recurrent drought, some of those strategies, such as diversification into off-farm activities, may not be applicable to most smallholder farmers in vulnerable rainfed systems in SSA. New options and innovations are needed to enhance the resilience of agricultural production and reduce vulnerability to climate change and variability. Cooper *et al.* (2006) noted that research investments to enhance tolerance for drought stress, improve water productivity and integrate management of land and water resources have the potential to reduce vulnerability to climate shocks while improving productivity. It is imperative that improving AWM, especially for smallholder farmers in SSA, is one of the key ingredients in any sustainable adaptation strategy. Adoption of integrated watershed management in India (Cooper *et al.* 2006), which has contributed to improved resilience of agricultural production despite the high incidences of drought, attests to this.

The agricultural sector (and by extension, water management) is particularly vulnerable to climatic variability and extreme events. Adaptation in this sector is most likely a reflection of these extreme events rather than the cumulative effects of climate change (Smit and Skinner 2002). The following is a typical package for a national climate change adaptation strategy:

- "*Technological innovations:* improved crop varieties, early warning systems, land and water management, integrated pest management, etc.
- *Government subsidies:* agricultural subsidy among other farmers' support services to cushion famers against the impacts of climate variability
- *Farm production practices:* farm production, land use, land topography, irrigation, and timing of operations
- *Farm financial management:* crop insurance (in case of crop failure related to variations in weather conditions), crop shares and futures, income stabilization programs, and household income (diversification schemes)"

Agricultural intensification (applying more inputs on units of land), agricultural expansion (bringing new units of land under cultivation), livelihood diversification (creating a portfolio of natural resource-based and other livelihood activities), migration (Majule and Mwalyosi 2005) and improved AWM (shifting to high water-use efficient irrigation, adoption of micro-irrigation and rainwater harvesting) (Ngigi 2006) are broad livelihood strategies available for households as adaptive responses. Each of these livelihood strategies has its own logic (Paavola 2004). Box 2 outlines some of the smallholder farmers' adaptation strategies in West Africa.

Intensification and irrigation usually involve greater specialization and investments that, if successful, will result in greater productivity and increased income levels. Improved income levels then provide the sought-after buffer against environmental stress (Paavola 2004). However, investment in upgrading rainfed agriculture is risky, especially in the context of pre-existing environmental risks and water scarcity. On the other hand, expansion seeks to overcome environmental risks with low-input strategies that can increase outputs (Paavola 2004).

Box 2: Some of the adaptation strategies for smallholder farmer in West Africa

- The use of shallow wells and hand-dug wells to supplement the shortfall in water for dry-season irrigation.
- The use of soil moisture improvement techniques such as Zai, semi-moons and mulching, which are practiced in northern Ghana, Burkina Faso and Mali as adaptation strategies. These methods form the subject of research by CPWF, covering both northern Ghana and southern Burkina Faso.
- A more efficient use of water through drip irrigation and the choice of high yielding and high-value crops.
- The use of drought-resistant crop varieties and the improvement of on-farm irrigation efficiency through the use of better water application technologies are all methods that have been tried by smallholder farmers as adaptation methods to climate change in Nigeria, Senegal, Burkina Faso and Ghana.
- Bunds, agroforestry, crop rotation and rainwater harvesting have all been effective adaptation strategies to climate change and variability.
- Agricultural diversification such as the integration of livestock and crops (mixed farming) has also being practiced in some of the countries with good results.
- The alternative use of waste water for irrigation as in peri-urban irrigation schemes is another strategy for adaptation to climate change.
- Migration to wetter regions (from drier to wetter regions), in pursuit of wetter and more fertile lands.
- Engagement in off-farm activities (eg, small-scale gold mining referred to as 'galamsey' in Ghana.

Diversification, in turn, seeks to build up income streams characterized by different risk attributes, thus transforming the opportunity set and its risks. Depending on the impact of livelihood activities on household assets, a distinction can also be made between accumulative, adaptive, coping and survival activities. Accumulative and adaptive activities augment or transform the asset base, while coping and survival activities draw down the assets to maintain the level of consumption (Ellis 2000).

Within the water sector, the majority of adaptation has taken place through capacity building (research, information dissemination, network establishment). In West Africa, various adaptation strategies have been used by smallholder farmers to improve agricultural production in the wake of changing climate.

3.3 Adaptation Initiatives

In SSA, various adaptation initiatives have been implemented to build the capacity to evaluate and manage the risks associated with climate change and variability. Adaptation to climate change is a long-term process that necessitates long-term interventions at local, national and regional levels. A review of some of the current practices to mitigate the impacts of climate change provides insight into the available options that can be considered for adoption, replication and up-scaling by smallholder SSA farmers. This sub-section focuses on pilot projects, research activities, and governance measures undertaken to enhance the capacity of smallholder farmers to adapt to climate change.

3.3.1 Collective action

The role of collective action in facilitating adaptation to climate change and variability cannot be underestimated. For example, Thomas *et al.* (2005) discovered that more than any one specific piece of technology, a community's ability to pool collective resources and facilitate the transfer of knowledge and technology may be the most effective mode to combat climate extremes. However, this decentralized method may also lead to unequal access and distribution of natural resources.

This difficulty is present at any level of authority and cannot be disregarded regardless of how localized the adaptation. The principle of collective action is building a strong, cohesive network to facilitate adaptation through the community and by individuals. This can be done by creating common interest groups (CIGs) such as WUAs and farming associations with common goals and interests transmitted through a structured communications system.

The objective is to share experimentation results, skills and innovations. The underlying aim of an adaptation strategy based on collective action is to empower individuals, especially women, where unequal access should be eliminated and local opportunities created.

Climate change affects farmers collectively, pointing to strategies that call for collective action as a possible solution. It is also easier to build capacity and introduce a new adaptation strategy or technology through an organized group of farmers. Smallholder farmers can be organized into a CIG based on their production systems (eg, using the same water source for irrigation), marketing and credit systems (cooperative societies) and socio-economic activities (women's groups).

Many pilot projects can create collective action through farmers' associations. For example, Thomas *et al*. (2005) found out that "farmers' organizations in Mozambique were able to pool resources and knowledge and learn from trial and error" (Box 3). This was particularly true for farmers moving to either more drought-tolerant crops or going back to indigenous crops such as sorghum and millet. The pilot project showed that 87 percent of households participated in a farmers' association. Of these, 52 percent did so to gain access to information, 45 percent to gain access to extra labor and 68 percent to gain access to more or better land (Thomas *et al*. 2005).

Off-season irrigation is a collective adaptive strategy to boost farmers' rice production in view of increasing unreliability of high floods for on-season rice production. The acquisition of capital equipment is normally a problem unless supported by the government or farmers' cooperatives (USDA 2002). For example, with adequate financial resources, farmers can acquire motorized pumps to lift water from rivers for irrigation in the dry season. By growing vegetables in the dry season, smallholder farmers can increase their earnings and improve their livelihoods. This is practiced in Ghana (Agyare *et al*. 2008), Nigeria, Burkina Faso, Mali and Malawi.

The experience with a collective farmers' initiative to engage in off-season irrigation in Toya MVP (northern Mali) is a good example. Each year, a group of smallholder farmers (15 to 25 households) hire communal 25-hp centrifugal pumps to irrigate up to 25 ha of paddy rice (each pump irrigating about 1.5 ha) (See plate 1). It would be financially impossible for single households to hire or buy the pumps, but collectively, they can afford it. Pumps rent for as much as USD 5 per farmer per irrigation, or USD 200 per irrigation cycle. Most farmer groups pay between USD 1,000-2,000 per pump per season. Most areas are irrigated at least 10 times per crop, and fuel consumption averages 200 liters/ha/crop.[21]

21 To an individual famer, such costs are prohibitive. An IWMI study showed that pumping costs are very high, especially in Niger, hence the lack of sustainability. In Asia, pumping costs are less than USD 150 compared to USD 500 per ha in Africa. This is a serious problem that needs urgent attention.

Box 3: Case study – Mozambican farmers' organizations

- The establishment of formal farming associations, with clear membership structures and responsibilities and democratic leadership, can be a very effective means for transferring expertise and knowledge about successful practices from key individuals to communities. Key individuals are not just extension officers, but may be innovative farmers who have experimented or brought in knowledge gained in other places. These associations are most effective and enduring where high levels of solidarity prevail.
- It is important to develop structures that increase communication at the village level, with strong interactions between formal and informal institutions and between households and individuals (allowing information sharing between entrepreneurs and the village).
- Investment values should encourage learning so smallholders can deal with a broad set of actors and opportunities in the modern market.
- The development of specific adaptation product choices or policy prescriptions (ie, direct adaptation measures) may not be the most useful means of promoting adaptation to climate change – in agriculture or in any sector. As instruments for development, our findings suggest that adaptation policy must be particularly sensitive to this.
- Stakeholders must be involved in the adaptation option and how an adaptation relates to broader decision-making processes. Opportunities for micro-finance and business training, together with infrastructural support, will facilitate livelihood specialization and agricultural commercialization, but can also finance risk-spreading options that include diversification and access to land in a range of ecosystem and catchment contexts. It will also ensure that opportunities remain equitable, especially to young people. Building human capacity at the local level requires a long-term and focused commitment to developing skills.

Source: Thomas *et al.* (2005)

In eastern and southern Africa, many smallholder, community-based irrigation development projects fall under the category of collective action as an adaptation strategy to enhance management of scarce water resources and crop diversification. The MVP in Malawi (Gumulira and Mwandama) and Ethiopia (Koraro) is spearheading collective action approach in smallholder irrigation development initiatives. The performance of smallholder irrigation projects have been evaluated extensively (Mati and Penning de Vries 2005, Blank *et al.* 2002, Herdijk *et al.* 2002, Scheltema 2002, Gichuki 2000, Ngigi 2002, Ragwa *et al.* 1998). However, Mati (2008) stressed the

Plate 1: A common motorized irrigation pump in Toya, Mali.

importance of capacity development to enhance farmers' productivity and performance. Institutional capacity building should be based on how much additional capacity building and knowledge transfer is required for implementation of the adaptation option (USAID 2007).

Improving water management will enhance the role of smallholder irrigation in adapting to decreasing water resources associated with climate change and variability. Moreover, many community-based smallholder irrigation projects have been developed in pastoral areas of the Sahel to cushion the predominant livestock keepers from adverse effects of droughts. In Kenya, World Vision projects in northwestern Kenya are good examples.

Establishment of WUAs to manage common water resource among multiple users is another example of collective action to climate change adaptation. Integration of a sub-catchment's WUA into an umbrella WUA for a river basin has been found to improve water productivity and reduce water conflicts in river basins. The Waseges River (commonly referred to as the Subukia upstream) transcends different communities in the Rift Valley province of Kenya before draining into Lake Bogoria. The river basin regularly experiences water use conflict during the dry season.

To enhance an effective WUA, the basin is sub-divided into three zones. The upper zone (Subukia area) uses water mainly for commerce, the middle zone (Waseges area) is mainly used for livelihood, and in the lower zone (Lake Region), the major use is livelihood and ecological purposes. Water use conflict in Waseges River has been contained through a number of means, including enforcement of Water Act 2002, constant river patrol, sensitization of stakeholders through public meetings and focus group seminars, integrated river basin management through involvement of other stakeholders and the imposition of a total irrigation ban on normal flows. The Weseges model demonstrates how an appropriately constituted WUA can operate effectively and improve water resources management.

3.3.2 Agricultural Water Management

AWM is generally perceived to be a key step in improving low-yielding smallholder farming systems in sub-Saharan Africa (Barron *et al.* 2008). Because of the impact of climate change, AWM is a key adaptation strategy for many smallholder farmers. AWM is defined by IMAWESA[22] as 'all deliberate human actions designed to optimize the availability of water for agricultural purposes.' An integral part of many smallholder farming systems in SSA, AWM includes crop husbandry, soil and water conservation, rainwater harvesting and management (RHM), irrigation and drainage, wetlands management and all aspects of land and water management (Mati 2007). The water from different sources (rainwater, surface, and groundwater) can be used for crop and livestock production (including aquaculture). AWM systems can be classified into several categories:

- Soil and water conservation
- Run-off harvesting and management
- On-farm storage for supplementary irrigation
- Run-off diversion and spreading
  Spate irrigation
- Wetlands farming – valley bottoms or flood recession cultivation (eg, dambos, land drainage interventions)
- Stream diversion for smallholder irrigation, using either gravity or pumps
- Various irrigation technologies (low-head drip, sprinkler, furrow and basin, micro systems)
- Soil management and fertility improvement
- Conservation agriculture (conservation tillage, crop residue management, agroforestry, etc.)

AWM is a continuum that spans from rainfed to irrigated agriculture, and thus there are many options for managing water available to smallholder farmers (Mati 2007).

The success of AWM interventions depends on how well they are integrated into the entire farming system and value chain – from inputs, production and processing to storage and marketing. On-farm water management interventions incorporate a number

22 IMAWESA is a regional knowledge management network supported by the International Fund for Agricultural Development (IFAD), the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Its purpose is to enhance development impacts of public and private investments in smallholder AWM in 23 countries. The IMAWESA secretariat is based at the World Agroforestry Centre (ICRAF). For more information, visit www.asareca.org.imawesa.

of AWM technologies and practices. The 3rd IMAWESA conference in Addis Ababa, Ethiopia (September 15-19, 2008), showed that investment in AWM pays. This was demonstrated by presentations on research findings from 15 IFAD-funded projects and programs in eastern and southern Africa (Mati *et al*. 2008a). The conference was attended by 130 participants from various stakeholder groups (Box 4).

Box 4: Recommendations of the 3rd IMAWESA conference

- Increase investments in AWM through government budgetary support, promotion of private-public partnership, applied/adaptive research, information sharing, and smallholder farmers' capacity building.
- Integrate AWM in the value chain by improving water productivity and land profitability, i.e. reduce production costs and improve marketing infrastructure.
- Strengthen water governance systems through the formulation and implementation of appropriate policy, legal and institutional frameworks that support sustainable AWM.

In SSA, many multilateral and bilateral donor-funded projects incorporate AWM as a primary component in improving agricultural production and rural livelihoods. However, despite the good intention of such projects, their sustainability after donor exit has been found wanting. Nevertheless, a number of projects have been successful. A recent review of experiences with a wide range of micro-AWM technologies in southern Africa by Merry and Sally (2008) found that "these technologies can make major contributions to improving food security, reducing rural poverty and promoting broad-based agricultural growth."

The success can be attributed to adequate capacity building, effective participation of target groups, integration with government and other programs, availability of such support services as extension, credit, inputs and marketing. AWM projects should be holistic, focusing on the value chain from production to marketing process, and implemented in a participatory manner. They should also embrace capacity building and stakeholder involvement, especially by relevant government departments.

The participatory agricultural empowerment project in Tanzania supports sustainable agricultural investments at community and household levels in the form of community and farmer group investment subprojects (URT 2003a). Preparation and implementation of subprojects is undertaken through integrated participatory approaches. Project implementation has reached 32 district council authorities. Communities in these districts have initiated more than 826 community investment subprojects and more than 4,932 farmer group investment subprojects. Over 50 percent of the community investment subprojects are AWM projects that specifically involve rainwater harvesting and smallholder irrigation systems. The success of some IFAD projects in Africa can also be attributed to how well they incorporate and integrate AWM components.

The Improving the Performance of Irrigation in Africa (IPIA) project in Kenya, funded by the French government, attempted to increase the performance of irrigation schemes through relatively low-cost interventions (Blank *et al.* 2007). The aim was to develop irrigation as a profitable enterprise through development and dissemination of appropriate technologies, irrigation capacity building for farmers, support for WUAs and extension staff, production improvement through enhanced water productivity, use of appropriate agronomic practices, improved enterprise profitability and establishment of an interactive database for information sharing among stakeholders. The IPIA project resulted in significant yield increases, particularly in Mwea, Kibirigwi, Naro Moru and Hewani. For example, in Hewani a threefold increase in yield was reported, while yield more than doubled in a Kibirigwi scheme with improved water application. Farmers are open to new markets and realize that cooperation over water allocation is essential for sustainable income improvements (Blank *et al.* 2007). Box 5 lists some of the viable smallholder irrigation systems that can be adopted to transform livelihoods and enhance capacity to adapt to water stress related to climate change.

3.3.2.1 Rainwater harvesting and management

In semi-arid and arid areas where rainfall is low and predicted to decline further, in situ moisture conservation (either through conservation agriculture or construction of rainwater control and management structures) and rainwater storage (in farm ponds, water pans, sand/sub-surface dams, earth dams, tanks, etc.) for supplemental irrigation are gaining prominence. Either through their own experiences or with technical assistance from development agents (especially local NGOs) and development partners, farmers are adopting a variety of innovative RHM technologies to cope with recurrent droughts (Mati *et al.* 2008a and 2008b, Ngigi *et al.* 2008, Malesu *et al.* 2007, Malesu et al. 2006a and 2006b, Oduor and Malesu 2006, Mati 2005, Ngigi 2003, Pandey *et al.* 2003, Duveskog 2001, FAO 1994). For instance, in the Lare division of Nakuru district in Kenya, Blank *et al.* (2007) reported an adoption rate of farm ponds at about 390 percent over a period of six years (1998-2004). In the same area, Malesu *et al.* (2006b) found nine farm ponds per km^2 using satellite imagery, with most households possessing ponds. There has been notable improvement in crop production, diversification, and farmers' incomes.

Box 5: Some viable smallholder irrigation systems in SSA

- Gravity schemes using water diverted from upstream rivers/streams/dams and delivered to cropped area either through open canals or pipes, and applied either by surface irrigation (furrow or basin) or pressurized systems (sprinkler or drip).
- Localized pumping, either from a surface water source (river/stream/lake/dam) or groundwater (borehole/shallow wells/springs), using manual or motorized pumps and various on-farm water application methods.
- Micro-irrigation systems mainly for kitchen gardening using localized water sources (streams/dams), homestead piped water supply, on-farm water storage ponds, and water delivered from a distant source (either manually or by draught animals). The application methods are hand-watering, low-head drip irrigation, pitcher irrigation, etc.
- Spate irrigation – flood diversion and spreading on bunded farm plots planted with various crops, especially cereals, that would otherwise not thrive under normal soil moisture regime.

Another example of high adoption rate is Minjar Shenkora, North Shoa Zone, Amhara Region, Ethiopia, where more than 7,600 farmers have constructed ultra-violet-resistant plastic (geo-membrane) lined farm ponds (40-60 m^3) over a period of five years. This high adoption rate can partly be attributed to government subsidies for the lining material, the most expensive component (Mati *et al*. 2008b). The Mayange MVP in Rwanda has also adopted group-managed 100 - 250m^3 farm ponds fitted with rope and washer pump for vegetable production (see Plate 2). Although the ponds are prone to high evaporation losses (200-300 liters/day), evaporation can be reduced by roofing the farm ponds with simple, inexpensive material. The cost of roofing is compensated by saving more water for production. Ngigi (2008a) found that reduced evaporation losses mean less storage capacity – hence the cost of roofing can be compensated by reducing the size of farm ponds. Water management is enhanced by simple hand pumps, treadle pumps and drip irrigation. Land-use changes, such as the construction of small reservoirs, have been documented to show agricultural intensification, and farm income from irrigated land has

Plate 2: 125m^3 farm pond in Mayange

increased by an average of about 300 percent in Burkina Faso (Gleisberg *et al.* 2008).

While in some tropical areas rainfall is predicted to increase with climate change, the increase is predicted to arise from extreme rainfall events rather than increases in daily rainfall. This will lead to both flooding and water shortages (Turner 2008). Thus RHM strategies must be developed in both tropical and semi-arid areas. This realization is changing intervention strategies for many development partners, especially those working in vulnerable environments. Government policies are also recognizing the role of RHM systems and complementary technologies in their national development plans.

In Burkina Faso, an association of smallholder farmers was mobilized in 1989 on a pilot farm based on the technique of zai pits (Plate 3). Zai are wide pits about 0.6m in diameter and 0.3m depth spaced at about 1m. In each pit, 5-9 plants (sorghum, maize, millet) are grown (Mati 2007).

In Kilifi district of Kenya, the layout is 0.6m x 0.6m – both row and inter-row spacing. The dimensions of 0.6m long x 0.6m wide x 0.6m deep for 5 plants are easy to comprehend, even by illiterate farmers (Diang'a and Ngigi 2009). Manure is usually incorporated into the pits to improve soil fertility.


Plate 3: Layout of zai pits

Zai pits are both a soil moisture conservation measure and a soil fertility improvement technique. They are particularly applicable in degraded soils. Several environmental and human factors cause irreversible soil and land degradation, leading to reduced soil-water holding capacity. However, in situ moisture conservation technologies such as semi-bunds and zai pits retain rainwater and store it for crop production. Excess run-off is collected into a reservoir for other uses.

Farmers use stone contour bunds to reduce the speed of run-off, allowing infiltration into the zai which collect and concentrate the run-off. The larger the planting pits and the wider the spacing, the more water can be harvested from the uncultivated micro-catchment areas between the pits. Despite the high initial labor cost, the zai system has been adopted from the Sahel region of West Africa and is now commonly practiced in eastern and southern Africa as well

(Mati 2007, Ngigi 2003). In West Africa, the zai system, with pits about 10-20 cm diameter and 10-15 cm deep, is a common practice (Bandre and Batta 2002). The holes store rainwater for plant growth, and generally the density is about 10,000-15,000 holes/ha depending on the crop chosen and the spacing between holes. In Niger, zai has been reported to increase biomass yield by 200 percent (Fatondji 2002).

While RHM systems can improve agricultural production and reduce the impact of drought in semi-arid environments, their performance and effectiveness is limited by high water losses, inadequate storage capacity, poor water management, high occurrence of dry spells and drought, farmers' risk aversion and financial constraints to investment in new farming systems. Adoption of RHM systems is affected by high investment costs, the relatively low economic status of farmers, farmers' risk aversion, inadequate design and poor water management (Blank *et al*. 2007). Farmers have identified several problems that affect adoption, including lack of information on proper sizing and other design information and the high infiltration rates experienced with some types of soils.

In economic terms, farm ponds appear to make good economic sense. Farmers are less prone to drought and report increased production throughout the year. In some cases, improved RHM systems have been more beneficial than conventional rainfed systems. In the Laikipia district of Kenya, a benefit-cost analysis of a 50 m^3 pond and low-head drip irrigation system with a total investment cost of USD 650 showed a net increase in income of USD 150 per season. The system had a payback period of about four seasons, or two years (Ngigi *et al*. 2005b). Nevertheless, although promising, RHM systems alone cannot assure sustainable production. The need for improved agronomic practices, such as timely planting to take advantage of expected rainfall, cannot be over-emphasized. The challenge is to convince poor and risk-averse smallholder farmers that they can benefit by improving their agricultural production systems. An integrated approach is a prerequisite for achieving sustainable solutions.

3.3.2.2 Use of wastewater for peri-urban irrigation

In most cities, peri-urban irrigation is a significant part of informal irrigation. In major cities in SSA, the absence of a suitable network of sewers results in pollution of the urban environment, affecting poor people who rely on waste water for peri-urban irrigation. The use of the wastewater contaminates agricultural products that are eventually marketed as gardening products. However, with adequate treatment, urban wastewater, with an acceptable threshold quality, can be used as source water for irrigation (INERA 2008). It is possible to produce various crops of community interest for consumption (vegetable, flowers and fruits), relying on irrigation with recycled wastewater. Use of recycled water reduces pressure on diminishing water resources and minimizes competition with drinking and industrial water in urban areas. Even in the rural areas, reuse of kitchen wastewater for micro-irrigation should be encouraged (eg, the multi-storey 'sack' irrigation used for vegetable production in eastern Africa).

3.3.3 Research programs

Recognizing the importance of agriculture in SSA for food security, agricultural researchers have for several decades been developing and promoting agricultural and pastoral innovations aimed to increase the value and productivity of land, water, labor or capital. Due to changing challenges and new technologies, research will continue to be part of Africa's development arena. The agricultural research agenda in Africa has been driven by a number of factors, *inter alia* donor interest, food insecurity, water crisis, low land and water productivity and, importantly, climate change. Low investments in agricultural research over the last decade, among other reasons, have certainly contributed to the current food crisis in SSA.

In the past, research has often shown great potential on research stations and in farmers' fields, with 'achievable' yields often several hundred percent greater than those obtained by farmers. However, in general terms, adoption has been low. Whilst islands of success continue to provide hope for the future, little scaling up of such successes is reported, and widespread impact is currently not evident. The Consultative Group on International Agricultural Research (CGIAR) centers, local and international universities, international organizations and national agencies have been in the forefront of research and development. The research villages of the MVP have also been carrying out AWM related research and development activities in 10 countries in SSA.

There are many success stories throughout SSA, especially from on-farm research, that future investors in agricultural research and development can borrow from. For instance, on-farm research in semi-arid locations in Kenya (Machakos district) and Burkina Faso (Ouahigouya) during the period 1998-2000 (Barron *et al.* 1999, Fox and Rockström 2000) indicates significant scope for improving water productivity in rainfed agriculture through supplemental irrigation, especially if combined with soil fertility management. Faulkner *et al.* (2008) examined the impact of small reservoir irrigation development in the Upper East Region of Ghana and found that irrigation productivity depends on irrigation methods, water availability and management. Similar positive results are evident from many international journals and research reports. Such research findings provide solid groundwork for mitigating the effects of climate change, even though concrete results have not yet been realized. However, there is renewed interest in research, especially on climate change adaptation in Africa, in a number of international organizations, with the United States Agency for International Development (USAID), the UK's Department for International Development (DFID) and Canada's International Development Research Centre (IDRC) taking the lead.

Research on the local level forms the basis of a community-led solution that is ideal for smallholder farmers. After a participatory diagnosis and analysis of a specific problem, a study on climate change adaptation in Polokwane, South Africa, recommended the construction of a dam and reservoir to augment water supplies (USAID 2007). However, some of the climate change projections suggested that rainfall would decline in the future, limiting the usefulness of a dam. Stakeholders suggested considering other options, such as demand side management, until there is better evidence that future rainfall will be adequate to fill a reservoir. Such research findings show that participatory project planning is a prerequisite for a sustainable adaptation strategy (USAID 2006a). The recommendations of a stakeholder workshop that evaluated the Polokwane case study included simple seven steps for implementing water management adaptations and a water demand management strategy (Box 6).

Box 6: Steps for implementing water management adaptations

- Formulation of appropriate institutional arrangements to identify and coordinate actions between relevant agencies.
- Metering to enhance application of Watergy, a program that promotes efficient water use and energy demand, and uses prepaid water meters to limit demand.
- Adopting block water rates with increasing rates for high-intensity users due to an escalating price structure for high water use.
- Promotion of water-efficient technologies such as adopting building codes that promotes application of energy/water-efficient technologies.
- Reduction of water loss – reducing leakages through reducing pressure in systems.
- Drought risk management – development of drought management plans.
- Enhancement of recycled wastewater use – promoting the use of filtered and recycled sewage (use of gray water) in a non-potable reuses system.

Source: USAID (2006a)

On a continental scale, IDRC and DFID are implementing a comprehensive research and capacity development program on Climate Change Adaptation in Africa CCAA, which aims to improve the capacity of African countries to adapt to climate change in ways that benefit the most vulnerable. Building on existing initiatives and past experience, CCAA works to establish a self-sustained skilled body of expertise in Africa to enhance the ability of African countries to adapt. The program, which is run in Africa by Africans, supports African countries in their efforts to adapt to the impacts of climate change.

A number of CCAA-supported research projects in SSA intend to assess the impacts of climate change and variability on natural ecosystems and livelihood systems and strengthen the adaptation capacity at both local (communities/farmers) and national levels. In addition, these research projects aim to identify sustainable adaptation strategies that can be up-scaled to other regions or countries.

Moreover, the CCAA program and IDRC's Ecohealth program are jointly supporting a research and capacity-building initiative to explore the interconnections between water, health and climate change. Water quantity and quality have serious implications for human health and are extremely climate-sensitive. As climate change is expected to have negative impacts on both, an ecosystem-based understanding of the phenomenon is critical to achieving an effective response. The issue is particularly pressing in the water-stressed regions of West and North Africa.

Notable research activities on AWM for both smallholders and large-scale farmers are being conducted by various CGIAR centers. One comprehensive research component is CPWF, which is led by IWMI and implemented in partnership with other CGIAR centers in three transboundary river basins in Africa: the Limpopo, the Nile and the Volta. CPWF has a number of research projects relevant to climate change adaptation, especially by smallholder farmers (Box 7).

Another research project on AWM Solutions being undertaken by a CGIAR consortium in Africa and South Asia aims to identify promising agricultural water management solutions to unlock the potential of smallholder farming (IWMI 2009). The project started in February 2009 and will continue through December 2011 in Burkina Faso, Ethiopia, Ghana, Tanzania, Zambia, and the two Indian states of Madhya Pradesh and West Bengal. The AWM Solutions project will provide insights into the factors that influence adoption and successful out-scaling of AWM interventions—from the natural resource base to credit and land tenure systems, markets, communication networks, stakeholder interaction and the broader policy environment.

Box 7: CPWF research projects in Africa

- **Increased crop water productivity,** which develops interventions (technologies, policies) leading to the improvement of crop water productivity by (1) plant breeding for water-efficient and stress-tolerant crops; (2) water-saving farm practices; (3) management of water supply based on field water requirements; and (4) policies and institutions. With particular reference to the Volta basin, the small reservoirs project is one of several research projects being conducted within the basin with the objective of enhancing the operation of these small reservoirs that provide water for dry-season farming.
- **Integrated basin-level water management systems,** which explore the potential for enhancing agricultural outputs and profitability at the basin scale, and of reducing water use in agriculture by alleviating water constraints to agricultural production.
- **Integrated rainfed farming in the Sahel,** whose aim is to understand the contribution to water and nutrient efficiency in the Volta basin of prototype methods originally designed in Niger for conditions of extreme water scarcity, namely the 'Sahelian Eco-Farm' and the zai method of planting in water-retaining pockets. Responses from farmers in northern Ghana and Burkina Faso have been very positive.
- **African models of transboundary water governance**, which have prepared a database of more than 150 African water treaties, many of which were previously unknown to today's water scientists and policy makers. The underlying project concept is to give Africans access to their knowledge resources. The project has shown the importance of using traditional transboundary practice (between different groups, not necessarily countries) to inform and adapt more recent experience.

Source:www.waterforfood.org

Research addressing future adaptations to climate change tends to be normative, suggesting anticipatory adaptive strategies to be implemented through public policy (IPCC 2001). Generally, (IPCC 2001) based such adaptations on forecasts of expected climate change, and:

- "Focus in response to changes in *long-term mean climate*, though more specific elements of climate change such as reduced precipitation attract attention when sector-specific adaptations like integrated AWM are proposed. Some studies specifically examine potential adaptations to variability and extreme events.
- *Range in scope* from very broad strategies for adaptation (such as enhancing decision maker awareness of climate change and variability) to recommendations of sector specific interventions (such as water resources, coastal resources, agriculture, and forest resources).

- Recognize *regional diversity* since vulnerability to climate change is spatially variable. This is the case in most developing countries due to their greater reliance on susceptible natural systems-based economic activities, mainly agriculture."

A consistent lesson from adaptation research is that climate is not the singular driving force of human affairs that it is sometimes assumed to be – but neither is it a trivial factor (IPCC 2001). Climate is an important resource for human activities and an important hazard. Climate change is a source of significant stress (and perhaps significant opportunities) for societies, yet it has always been and will remain only one factor among many. The consequences of a shift in climate are not calculable from the physical dimensions of the shift alone, but require attention to human dimensions through which they are experienced (Bryant *et al.* 2000).

The significance of climate change for regions depends fundamentally on the ability and likelihood of the inhabitants of those regions to adapt. In most cases they are agro-pastoral smallholders undertaking mixed farming systems in SASE. This means livestock production should be integrated into the development of climate change adaptation strategies in SSA.

Research conducted by the CPWF, as well as the CGIAR's comprehensive assessment of water management in agriculture, suggests that through understanding livestock water productivity, practical opportunities to enhance food security, reduce poverty and foster benefit sharing can be identified. It also suggests that institutions responsible for water resources may benefit from partnering with the livestock sector when developing water resources. This research aims to assist NBI to improve the efficiency of water use and to more equitably share the benefits derived from the Nile's water among its 10 member states (Peden 2008).

On crop adaptation to climate change, IRRI has established the Rice and Climate Change Consortium (RCCC) to assess direct and indirect consequences for rice production, to develop strategies and technologies to adapt rice to changing climate, and to explore crop management practices that reduce greenhouse gas emissions under intensive production (Wassmann *et al.* 2007). The Africa Rice Center (WARDA) has been promoting the New Rice for Africa (NERICA) rice variety in West Africa. This is important because major grains will be extremely vulnerable to climate change in Africa. Because crop selection for farmers is highly climate-sensitive (Niggol *et al.* 2008), more research is necessary to assess how farmers will shift to different crops as a result of climate change. Such a shift will also affect feeding habits and nutrition – hence cultural change may occur.

Addressing problems facing smallholder AWM interventions is a challenging and intricate undertaking because the problems are intertwined (Mati et al. 2008a). The AWM challenges are aggravated by climate change, demographic and land pressure, poor farming practices, inappropriate technology, inadequate or poor extension services, inadequate policies and institutional frameworks, poor marketing infrastructure and so on. These are some of the problems that should be addressed through research. This research should target the needs of smallholder farmers, most of whom are women, and involve them effectively during the research process. Dissemination of research findings should be incorporated into the research process. The research and dissemination capacity of African scholars and institutions should be enhanced. African governments and regional organizations have taken action toward climate change adaptation. The environment initiative of the New Partnership for Africa's Development (NEPAD), for example, prioritizes climate change as one of its 10 programmatic areas (IFAD 2009).

3.3.4 Governance interventions

Many governments in Africa have realized the need for appropriate governance measures to enhance climate change adaptation and mitigation of the negative impacts. Such governance measures are being incorporated in NAPA under the United Nations Framework Convention on Climate Change (UNFCCC). Technical interventions can neither be effective nor sustainable without supportive governance measures concerning legal, policy and institutional issues. Developing appropriate policy and management systems is essential for enhancing the value obtained from freshwater resources. Interventions that should be included are strengthening governance, improving knowledge and information, collecting data, monitoring and evaluation, enhancing human and institutional capacity and developing integrated water resources management (IWRM) systems focusing on watershed as the management unit (UNEP 2008).

Cooperation and partnership, among multiple stakeholders and at multiple levels, from the local to the sub regional to the regional, are at the core of successful interventions. These responses should increase the opportunities to meet urgent needs for potable water, sanitation, irrigation, and hydropower, among others. A critical issue that must be addressed systematically is financing (UNEP 2006). Because no single set of adaptivepolicy recommendations can be universally appropriate, several studies suggest means by which proposed adaptations may be selected and evaluated. At a very basic level, the success of potential adaptations depends on the flexibility or effectiveness of the measures, such as their ability to meet stated objectives given a range of future climate scenarios,and their potential to produce benefits that outweigh costs (Smith and Lenhart 1996).

Planning of climate change adaptation invariably is complicated by multiple policy criteria and interests that may be in conflict (IPCC 2001). For example, the economically most efficient path to implement an adaptation option might not be the most effective or equitable one due to various interests, trade-offs and uncertainty in the decision making process posed by climate change. Given the uncertainties of climate change, it is not surprising that adaptation strategies frequently are described as forms of risk management (Lempert *et al*. 2000). This has led to inadequate or incomprehensive governance structures to address climate change adaptation for smallholder framers in most countries in SSA.

National water policies could encourage water savings in water-scarce areas by providing incentives and effectively enforcing penalties. When upstream managers cannot ensure conveyance efficiency, there may be no incentives for water users to make efficiency gains. In the case of groundwater, this caveat may not apply since the incentive is generally internalized by the users, and in many cases groundwater users show much greater efficiency than those depending on surface resources (ESCWA and ICARDA 2003).

Given the fact that water scarcity will increase, the pricing of water should reflect as closely as possible its long-term marginal cost. As a first step, water charges should be levied to recover operation and maintenance (O&M) costs plus a portion of the investment costs; and as a tool to improve efficient use of the resource (ESCWA and ICARDA 2003). However, pricing should not be counter-productive by undermining crop production. Besides national water policies, the policies of regional organizations such as the Inter-Governmental Authority on Development (IGAD), ECOWAS and SADC focus on enhancing sustainable land management and expanding the area under reliable water control.

Successful policy measures to address water scarcity include the introduction of water pricing (full cost recovery), water pricing[23] through the installation of water meters (providing the possibility to charge a marginal price for water), and relaxing land rent

23 Water pricing, especially in demand management, has been argued as an ineffective policy for improving water use efficiency. Most countries use 'water right' as a form of volumetric water allocation despite the difficulties in establishing water right system (Perry 2003).

control (eg, the Mwea irrigation scheme in Kenya[24]). Water policies should be linked to land and environmental policies and food security (UNCCD 2009). In the past, water policies have focused on the supply management of water resources and have been synonymous with irrigation through investments in irrigation and drainage systems. Good policies should be supported by effective legal and institutional framework. Examples of conflicting and incompatible institutional frameworks are rife in SSA, and their effects have at times been disastrous (Mati *et al.* 2007).

Demand management of water resources has not been explicitly included in water policies (ISESCO 1997) in many countries in SSA, partly because the focus was initially on expanding the supply and partly because, socio-culturally, water was believed to be a free resource. ESCWA and ICARDA (2003) stated that "lack of demand management practices also contributed to a low efficiency of water-use and its consequent waste. In addition, improvements in the availability of water owing to the introduction of advanced technology diverted attention from demand management and reduced emphasis on low-cost alternatives such as improving efficiency, conservation and the reduction of waste through maintenance". However, ongoing water policy reform in many countries in SSA is a positive step toward IWRM. For instance, in Mali, World Bank-supported government reforms in Office du Niger irrigation schemes empowered farmers to pay fully for maintenance of irrigation infrastructure and to take charge of overall scheme management, while a buoyant private sector emerged for milling and marketing rice, credit provision, manufacturing of farm inputs and selling inputs (Aw and Diemer 2005).

According to USAID (2007), "appropriate interventions must incorporate disaster planning response and mitigation into governance systems, engage vulnerable civil society groups in participatory forums to address their vulnerability and to identify adaptations to climate impacts, and examine existing laws and regulations for opportunities to improve governance and resilience to climate variables." Moreover, interventions should mitigate risk of conflict by strengthening institutional capacity to respond to extreme climate events, promote resilience in livelihood strategies, develop early warning response and mitigation programs, support insurance and other safety net programs, and support capacity to manage effects of climate change at local, national and regional levels (USAID 2007).

24 The Mwea irrigation scheme, like many large-scale rice production systems, had operated under a central management structure in which farmers had been passive stakeholders in a scheme meant to benefit them for over 50 years. A 6,000-ha, gravity-fed rice scheme in central Kenya established in 1953, Mwea was, until 1998 when the farmers forcefully took over its management, managed by the National Irrigation Board. The scheme supports over 4,000 families and is currently earmarked for expansion to cover 13,000 ha.

GWA (2006) stated that "appropriate water governance should be designed to ensure effective water resources management that allows for decision making from all stakeholders, including poor women and men. It should provide access to safe and affordable drinking water and basic sanitation for all, while meeting water needs for improved livelihoods. And it should also allow for the development of an enabling environment with supportive policies, legal instruments and fair pricing structures. Currently, there is little evidence to suggest that water management has deliberately and consciously addressed gender concerns".

Effective gender sensitive water management requires that issues such as gender, governance and water management are not viewed as women's issues, but issues of power relations, control and access to resources by disadvantaged groups that may be comprised of women, men or children (Hemmati and Gardiner 2001). Thus, it is important to obtain context specific information about women's and men's different experiences, problems, roles and priorities with respect to water use. Moreover, the importance of the social aspects of water management must be taken into account since women play a central role in managing water for social and health related uses.

Finally, it is important that a conscious effort be made to consult with men and women during the planning process. This can be achieved through the use of gender inclusive participatory tools designed to engage grassroots level women and men. GWA (2006) noted that "it is important that women and marginalized groups have a strong voice to ensure that their views are taken into account. This means promoting the involvement of women and men in consultation and decision making from the community to the highest levels of management".

3.4 Challenges and Constraints

Sub-sections 3.2 and 3.3 discuss a number of feasible adaptation strategies and interventions that should be adopted, replicated and up-scaled to mitigate the effects of climate change and cushion vulnerable smallholder farmers against climate shocks and variability. However, adoption and assimilation in development plans has been slow. This can be attributed to a number of factors that affect or hinder adoption and up-scaling despite the positive results. The primary challenge is to address these factors in such a way as to enhance adaptation capacity.

Some of the main factors are economic resources (poverty and economic status), technology development and dissemination, information and skills, infrastructure, governance structure (legal, policy and institutional), socio-cultural perspectives, gender and equity, environmental and health issues, extension services and incentives, and conflicts among different interest groups (Ngigi 2003, Burton *et al*. 2001).

3.4.1 Economic capacity

Poverty is directly related to vulnerability, and is therefore a rough indicator of the ability to cope and adapt (IPCC 2001). Whether farmers' economic conditions are expressed in terms of economic assets, capital resources or financial means, they are clearly a determinant of adaptive capacity. Adaptation and adoption of new technology costs money, and because poor communities have less diverse and more restricted entitlements, they lack the empowerment to adapt, locking them into a vulnerable situation. It is therefore necessary to provide smallholder farmers with the resources to adopt the new technology. However, it is important to remember that even if their adaptive capacity is increased, the poor will be made poorer by famine, malnutrition and hunger, even without climate change.

In many parts of Africa, according to Lawrence *et al*. (2002) "the poverty index is directly proportional to water availability, especially for farming communities. Even exploitation of water resources for economic gains (irrigation) is hindered by poverty." One means to help vulnerable smallholder farmers is therefore to invest in improving AWM. This investment will increase farmers' productivity and hence their resource base to cope with future climate variability, especially reduced water supply. The World Development Report (WDR) (2008) calls for greater investment in agriculture in developing countries. The report warns that the sector must be placed at the center of the development agenda if the goals of halving extreme poverty and hunger by 2015 are to be realized. There are many examples that favor increased investment to target smallholder farmers (World Bank 2006a), especially interventions that enable them to diversify their rainfed production systems. However, such efforts might be compromised by the escalating costs of agricultural inputs. Fertilizers, for example, are becoming a preserve of the rich because of high prices-a 50kg bag costs as high as USD 70 in Kenya. Unless assisted through a government subsidy plan, such as the case in Malawi, many poor farmers cannot afford the much needed fertilizers to increase crop yields.

3.4.2 Technology

IPCC (2001) stated that "lack of technology has the potential to seriously impede a community's ability to implement adaptation options by limiting the range of possible responses and interventions. Adaptive strategy and capacity is likely to vary, depending on availability and access to technology at various levels and in all sectors. Many of the adaptive strategies for managing climate change directly or indirectly involve technology (eg, protective structures, crop breeding and irrigation, settlement and relocation or redesign, flood management structures, drought proofing). Hence, a community's level of technology and its ability to adapt and modify technologies are important determinants of adaptive capacity". Awareness of and sensitization to the development and utilization of new technologies are also key to strengthening adaptive capacity (Chapman *et al.* 2004).

USDA (1997) noted that "the choice of appropriate irrigation technology is highly site specific, reflecting geographic, technical and market factors. Field characteristics such as field size and shape, field gradient and soil type are perhaps the most important physical considerations in selecting an irrigation system. Other important factors include technology cost; water supply characteristics (cost, quality, reliability, flow rate); crop characteristics (spacing, height); climate (precipitation, temperature, wind velocity); market factors (crop prices, energy cost, labor supply); producer characteristics (farming traditions, management expertise, risk aversion, tenant/owner status, commitment to farming); and regulatory provisions (groundwater pumping restrictions, drainage discharge limits, water transfer provisions)". In many cases, technology choices are limited by inadequate financial resources and knowledge. Technology is costly, so farmers must either make money to use it or receive subsidies or incentives to adopt it.

3.4.3 Technology dissemination

Technology development and dissemination are other concerns associated with low adoption. Slow adaptation in Africa can be attributed to low technology adoption – thus enhanced farmer education would hasten technology dissemination and climate change adaptation (Dinar *et al.* 2008). Besides the importance of extension services in technology dissemination, inadequate funds, technical skills and capacities affect promotion and adoption of appropriate technologies. Any technology seen to disrupt the existing livelihood systems will not be accepted and assimilated easily. For example, introduction of irrigated agriculture in pastoral communities has always been resisted. However, there are success stories that have been attributed to the way the technology was introduced to the community. Capacity building through demonstration, exchange visits, and incorporation of socio cultural aspects is key to any technology transfer package. Technology dissemination or project implementation should embrace participatory and multi-sectoral approaches to ensure effective stakeholder involvement and sustainability.

A number of proven approaches have been tested by development agencies and NGOs such as Participatory Rapid Diagnosis and Action Planning (PRDA) and Farmers Field Schools (FFS). van der Schans and Lemperiere (2006) noted that "PRDA is a method for analyzing constraints to performance and generating interventions for improving performance of an irrigation scheme. The methodology provides a tool to bring farmers and frontline workers together to conduct an assessment of the constraints and plan how to solve them. This is done quickly, inexpensively, and with stakeholder participation. Evidence from the pilot schemes showed that the PRDA methodology assisted the irrigating farmers to identify various problems and to prepare work plans to tackle them".

The FFS approach is used by researchers, extension staff and farmers in participatory testing and demonstration of the effects of integrated technologies and practices (FAO 2008c). Some of these technologies could have been tested by researchers in their research plots, but such experiments are rarely adopted by farmers. Technologies tested against the farmers' indigenous knowledge with full participation of the farmers themselves often lead to improved farm productivity. Another advantage to this method is that it brings the farmers together, usually once a week, enabling extension workers to give advice to a group of farmers with common interests (Duveskog 2001).

Participatory approaches to development are increasingly advocated by development organizations and NGOs. However, putting these methods into practice is difficult, particularly where beneficiaries have to contribute in kind and in cash (Mahoo *et al.* 2003). The proponents of community participation and contribution argue that it enhances ownership and sustainability. Nevertheless, inadequate extension services have been cited as one of the factors affecting up scaling and adoption of appropriate technologies and best practices in SSA.

3.4.4 Information and skills

Information is a powerful tool for enhancing adaptation to climate change and variability. Successful adaptation requires recognition of the necessity to adapt, knowledge about available options, the capacity to assess the options, and the ability to choose and implement the most suitable ones (Lee 2007). In terms of climate change, this can be demonstrated through acquisition and dissemination of information on weather hazards. Once such information becomes more available and understood, it is possible to analyze, discuss, and develop feasible adaptation measures. Building adaptive capacity requires a strong, unifying vision, scientific understanding of the problems, an openness to face challenges, pragmatism in developing solutions, community involvement, and commitment at the highest political level (Holmes 1996).

Inadequately trained personnel can limit a community's or a nation's ability to implement adaptation options (Scheraga and Grambsch 1998).

Therefore, it is important to develop appropriate systems, both at local and national levels, to disseminate weather and climate change information, and to make options and adaptive strategies available for various regions and farming systems. Inadequate information on the usefulness of the measures inhibits adoption of successful adaptation measures (UNEP 2009). Thus it is necessary to create publicity on adaptation measures that have been successfully tested so that others can be made aware of the potential benefits. Effective dissemination strategies must take into consideration all benefits and constraints associated with a technology to ensure that it is attractive at both the individual and the aggregate scale.

3.4.5 Infrastructure

Physical and social infrastructure is an important component in any development program. For smallholder farmers to adapt to climate change, physical infrastructure aspects to be considered are irrigation water supply, water management structures, transport and marketing systems, storage and processing structures and communication. Social infrastructure includes farmers' organizations, WUAs and cooperative societies. Interventions should enhance the farmers' adaptation capacity and ensure sustainable socio-economic development.

Poor infrastructure affects adaptation at both local and national levels. Inadequate infrastructure and associated lack of financial resources restricts the availability of adaptation options, especially for smallholder farmers, whose investment decisions depend on good prices for their produce and expected economic returns.

Equally important are efficient marketing systems (WDR 2008) that encompass good road networks, ready market and storage facilities to avoid post harvest losses, and intermediaries who will ensure the sale of the products on behalf of the farmers. Mati (2008) identified infrastructure and availability of markets as the key drivers for success of smallholder development in Kenya. MVP has also identified infrastructure as a major component towards sustainable rural development and achievement of MDGs.

3.4.6 Land tenure

Land tenure is the system of rights and institutions that govern access to and use of land (Adams 2001). Investment in improved AWM is affected by access to water, which is linked to land tenure (IWMI 2009). Hence secure land tenure is a prerequisite to investments in climate change adaptations related to land and water management. Access to credit for investment or inputs is also linked to land ownership, collateral or security. In the Mubuku irrigation scheme in Uganda, a development partner withdrew due to an insecure land tenure system. The land tenure issue is more pronounced in large scale public irrigation schemes, managed by many smallholder farmers in Africa. The Mwea irrigation scheme in Kenya and Office du Niger irrigation scheme in Mali demonstrate how ensuring farmers' land tenure has increased rice production, improved water management and initiated scheme expansion, which would otherwise not have been possible with central government control of the entire production system.

There are many large irrigation schemes managed by smallholder farmers where the story is different; farmers have no incentive to invest in improved water management, land husbandry or high-yielding varieties because they are 'tenants' of the government or its agencies. Tenant farmers have limited rights to the land and hence inadequate power to influence decisions and policies affecting their plight. Insecure land tenure has also fuelled conflicts among pastoralists and irrigators, especially where irrigation encroaches on pastoral land. This has been the case in many large public irrigation projects like Bura and the proposed Tana Delta in Kenya, and has led to project failure.

3.4.7 Gender issues

Inadequate integration of gender issues compromises the sustainability of many development projects in Africa. Already, there is limited attention to the needs of women in low-income countries, and an even greater lack of women's participation in talks on climate change mitigation and adaptation. Some of the gender issues that affect water management by smallholder farmers, and consequently adaptation to climate change, are:

- Unequal access to land and water resources – most traditional land tenure systems are male-dominated and rarely give equal rights to women, who spend much time working on the land.
- Involvement of women in water resources management systems – such as WUAs – is limited. Gender equity, equality and diversity in the decision-making process are inadequate.
- International protocols that promote gender integration and mainstreaming are rarely down-scaled at national or local levels, and women's representation in most decision-making processes is limited due to poor implementation of gender principles.

- Low economic capacity of women and inadequate access to credit facilities makes women and children highly vulnerable to climate change.
- High illiteracy levels and inadequate access to information and technology increase marginalization of women.

3.4.8 Governance structures

Governance structure refers to the policy, legal and institutional framework that governs socio-economic development in a country or society. (Hope 2009) Poor governance has been cited as a major hindrance to socio-economic development and adaptation to climate change. When the political leadership and management of a country's or community's resources is encumbered by a limited bureaucracy, little attention is paid to the exigencies of including climate change adaptation within the national development agenda. The most notable component of a governance structure is the institution, the effectiveness of which depends on a clear policy framework and supporting legislation.

Kelly and Adger (1999) found that "institutional constraints limit entitlements and access to resources for communities, thereby increasing vulnerability." Weak institutional arrangement is not conducive to addressing climate risks and easing the hardship of the people. Inherent institutional deficiencies, and weaknesses in managerial capacities to cope with the anticipated natural event, affect a country's ability to reduce vulnerability to climate change (Huq *et al.,* 1999). Appropriate changes in economic and policy conditions are required to make agricultural systems more vulnerable to changes in climate (Burton *et al.*, 2001). The inconsistent and unstable agricultural policies have increased the vulnerability of the food production and security in SSA. Thus political and institutional inefficiencies have resulted in resource inequities in southern Africa (Magadza, 2000), and thus compromising the resilience of poor and vulnerable smallholder farmers.

Burton *et al.* (2001) noted that "it is generally believed that established institutions in developed countries not only facilitate management of contemporary climate-related risks but also provide an institutional capacity to help deal with the risks associated with climate change. For example, evolving strategies in the water resource sector based on demand management tools and measures are capable of providing a basis for adaptive response strategies to climate change" and reducing conflict over diminishing water resources. IPCC (2001) stated that "the accumulation of numerous small changes in the present range of water resources management practices and procedures increases the flexibility for adaptation to current climate uncertainty and serves as a precursor to future possible responses with an ill-defined, changing climatic regime". Miller *et al.* (1997) noted that "the time has come for innovative thinking on how water allocation institutions should function to improve capacity to adapt to the impacts of climate change on water supplies." Given the climatic uncertainties and the very different institutional settings in many countries, there is no simple prescription (IPCC 2001).

Sector-based governance structures can be blamed for poor water resources and low adaptation capacity to climate change in SSA. For instance, despite the importance of groundwater, its beneficial use is often constrained by weak social and institutional capacity, and poor legal and policy frameworks. This difficulty may become significant in internationally shared water resources (both surface and groundwater) because of contrasting capacities and institutional frameworks on each side of a border. Attention must therefore be paid to critical elements such as setting up an adequate framework for cooperation, capacity building, participation, raising awareness, investment and appropriate technology (UNESCO 2002).

In general, the African continent has inadequate adaptive strategies to optimize the use of water resources. Where they do exist, there is inadequate governance structure and political will to implement them. South Africa, Zimbabwe and a few countries have begun to develop strategies to optimize use of water resources—for example, water pricing and demand management tools to cope with water scarcity (Inocencio *et al.* 2003). Although construction of storage reservoirs are practical options, demand management—which reduces consumption per unit of product output— has proved increasingly to be a water saving strategy that can allow communities to enter a drought cycle with adequate supplies (IPCC 2001). But there are many other instances where appropriate adaptation strategies are not being effectively implemented. For example, most crop watering technologies by smallholder farmers in SSA are labour intensive and inefficient. Industrial and household water recycling and re use have not been adopted as a water saving strategy in most countries (Hamdy *et al.* 2003).

Due to inadequate governance structures and adaption strategies, most governments resort to water abstraction restrictions and water rationing during drought periods. Water supply shortages are addressed conventionally through the construction of more storage reservoirs (IPCC 2001), which is not the case in SSA. However, as Magadza (1996) noted, "during severe drought periods there is likelihood of failure of water storage facilities, especially where individual reservoirs are dedicated to specific water demand". Therefore, governance reforms in water resources development and management are required to ensure water demands are met, even during prolonged droughts. Currently, even a one season rainfall failure often leads to food insecurity and hunger in most countries, due to inadequate governance structures to deal with climate shocks.

To enhance adaptation and integrated water resources management, both restrictive and incentive measures should be employed. Supportive governance structures are therefore appropriate means of providing extension services, credit facilities, equity in allocation of resources, information dissemination and a good policy environment. IPCC (2001) noted that "it is frequently argued that adaptive capacity is enhanced when social institutions and arrangements governing the allocation of power and access to resources assure that access is equitably distributed". The extent to which nations or communities are entitled to draw on resources greatly influences their adaptive capacity (Kelly and Adger 1999). Scheraga and Grambsch (1998) among others stated that "differentiation in demographic variables such as age, gender, ethnicity, educational attainment and health enhances the ability of community or a nation to cope with risk".

To enhance adaptation and integrated water resources management, both restrictive and incentive measures should be employed. Supportive governance structures are therefore appropriate means of providing extension services, credit facilities, equity in allocation of resources, information dissemination and a good policy environment. IPCC (2001) noted that "it is frequently argued that adaptive capacity is enhanced when social institutions and arrangements governing the allocation of power and access to resources assure that access is equitably distributed". The extent to which nations or communities are entitled to draw on resources greatly influences their adaptive capacity (Kelly and Adger 1999). Scheraga and Grambsch (1998) among others stated that "differentiation in demographic variables such as age, gender, ethnicity, educational attainment and health enhances the ability of community or a nation to cope with risk".

In eastern and southern Africa, the constraints are not in lack of governance structures per se, but in incoherent sectoral policies, legislation and institutional framework. Policies that affect AWM are found under various sectors: water and sanitation, water resources management, agricultural development, rural development, environment and natural resources management (Mati et al. 2007). Poverty reduction and strategy papers (PRSPs) also touch on AWM governance issues. One of the biggest challenges is to harmonize sectoral policies and improve institutional frameworks to enhance their implementation and the enforcement of supportive legislative measures. Many countries in SSA are in the process of formulating and implementing IWRM strategies that will address some of these constraints.

In West Africa, there is no clear policy and institutional framework on adaptation to climate change, especially by smallholder farmers. However, there are intentions of policy scattered around various domains such as land and water resources management, which could have some relevance to adaptation to climate change.

Therefore, unless the existing gaps in related governance issues are addressed, it will be difficult to initiate AWM interventions in countries with such unclear and conflicting ministerial mandates. Moreover, different sectoral policies should be harmonized to reflect how each related sector plans to address climate change. There have been some positive moves to address these incoherencies. For example, a recent shift was the relocation of irrigation from ministry of agriculture to ministry of water in many countries is a positive institutional reform milestone. Ironically on farm water management has remained in ministry of agriculture, hence delinking the software component of AWM.

In some cases, eg, Kenya, even the irrigation and drainage research component is housed under different institution – Kenya Agricultural Research Institute (KARI) is still under the Ministry of Agriculture. However, since many countries in SSA are in the process of formulating and implementing IWRM strategies, some of these discrepancies will be considered. A way forward would be to integrate national and sector policies on socio economic development issues such as poverty alleviation, economic growth, increase agricultural productivity, IWRM, food security, and environmental management. National governance structures should also be harmonized with sub regional adaptation strategies since the impacts of climate change are transboundary.

4. FEASIBLE INTERVENTIONS

The feasible interventions highlighted in this section were gleaned from responses received from various stakeholders and from reviewed information. The interventions, most of which were developed and tested by farmers, government departments and development partners, deal mainly with adaptive strategies to water scarcity in various SSA countries. Several ingenious farmers have developed various coping mechanisms to deal with decreasing rainfall and water scarcity. Moreover, a number of studies have been conducted on adaptive strategies to climate change and variability. These studies provided the basis and criteria used to identify and outline feasible interventions, which we have categorized as water management systems, crop adaptation and insurance, and supporting packages such as information management and capacity building.

4.1 Technical Interventions

4.1.1 Smallholder irrigation development

Small-scale irrigation can be defined as irrigation undertaken by smallholder farmers using levels of technology that they can operate and maintain effectively. In most parts of the world, smallholder irrigators are resource poor, heavily reliant on family labor and weak in bargaining power. However, their contributions to local food security, economic activity, environmentally sound practices and employment is vital to rural communities. IWMI (2009) stated that "research clearly indicates that when farmers are confident of having water and markets for their crops they are willing to invest in inputs, thus reducing or even eliminating the need for government handouts". Box 8 highlights why water is an entry point for boosting agricultural productivity, incomes (IWMI 2009) and adaptation to climate change.

According to Hatibu *et al.* (2002), "the issue of scale in categorizing irrigation schemes is misleading. Many countries categorize irrigation schemes based on the size of irrigated land, but what is large in one region or country may be micro-scale in another. Confusion arises when some agencies measure irrigation schemes by the size of the scheme as a whole and others by the size under a single irrigator/farmer within the scheme." There is a tendency to consider schemes with many irrigators as small-scale – focusing on a single farmer's management unit within a scheme." For this reason, most large centrally-managed schemes (like the 6,000-ha Mwea scheme in Kenya) are referred to as smallholder on the basis of plot size per farmer. Each country has its own system of categorization of existing and proposed smallholder AWM schemes. Table 3 illustrates how the Government of Tanzania manages its irrigation capacity.

Box 8: Water: A key entry point for boosting agricultural productivity and incomes

- Dry spells negatively affect crop yields 2 out of every 3 years in SSA and drought causes complete crop failure in 1 out of every 10 years. Just the right amount of water at the right time significantly reduces these losses
- A reliable water supply is critical for farmers to invest in new crops, high-yielding varieties and other essential inputs.
- Access to water enables farmers to diversify and grow higher-value crops, such as fruits and vegetables.
- Smart investments in water create a wide range of related benefits, especially for women if appropriately targeted.

Source: IWMI (2009)

Table 3: Classification of AWM systems in Tanzania

Type of irrigation	No. of schemes	Developed area (ha)	Potential area (ha)
Existing smallholder schemes	1,189	191,900	670,400
Traditional irrigation	982	122,600	518,700
Existing rainwater harvesting	42	7,900	27,600
Modern irrigation	52	35,900	73,800
Improved traditional irrigation	113	25,500	50,300
Proposed smallholder schemes	239	-	183,900
Proposed rainwater harvesting	163	-	123,100
Proposed modern irrigation	76	-	60,800
Total	**2,856**	**38,3800**	**1,708,600**

Source: URT 2003b

Smallholder irrigation schemes are mainly a common property resource (CPR)[25] faced with various challenges in the use of productive water (Vermillion 1999), especially with recent water reforms in many countries that regard water as an economic good. Samakande *et al.* (2002) pointed out that "the sustainability of a smallholder

25 "Common property is defined as the co-equal ownership of the rights to a bounded resource where community-established rules govern its use. This common property regime is not a free-for-all, but a structured ownership arrangement within which rules are developed and the group size defined, and where incentives are put in place so that co-owners will follow accepted institutional arrangements" (Vermillion 1999).

irrigation scheme depends on its performance, which, in turn, hinges on adherence to CPR concepts. CPR contributes to rural livelihoods through improved household food security, employment and income generation, leading to acquisition of assets". There is a critical need to appreciate and address the complexity of smallholder irrigation schemes. Infrastructure development as a dominant part of an intervention may not succeed alone without comprehensive strategies that consider all activities that comprise the irrigation enterprise. These include markets, finance, inputs, infrastructure, institution building, and crop production information.

Small-scale irrigation system is a farmer-managed water management unit, either serving individual farm households, or a group of farmers, typically comprising between 5 and 50 households (Figure 7). Farmers must be involved in the design process and, importantly, in decisions about boundaries, the layout of canals, the position of outlets and bridges, irrigation water management (irrigation scheduling and water distribution) and maintenance.

Source: Smout and Shaw (1999)

Figure 7: A schematic plan view of a typical smallholder irrigation scheme

According to Smout and Shaw (1999), "small-scale irrigation covers a range of technologies for controlling water from floods, stream-flow, or pumping.

- Flood cropping (spate irrigation)
  - Rising flood cropping (planted before the flood rises)
  - Flood/tide protection cropping (with bunds)
- Stream diversion (gravity supply)
  - Permanent stream diversion and canal supply
  - Storm spate diversion
  - Small reservoirs
- Lift irrigation (pump supply)
- From open water (surface water sources: rivers, lakes, dams, farm ponds, etc.)
- From groundwater sources (boreholes, shallow wells, springs, etc.)"

Smallholder irrigation is most important in rural areas in SSA, especially where farmers' resources are limited and the individual schemes cover relatively small areas. Most smallholder irrigation schemes evolved from traditional irrigation practice with limited external intervention. The practice emerged from knowledge obtained through observation and experimentation, handed down through generational experience and wisdom. Hans *et al.* (1996) pointed out that "traditional irrigation emerged from an understanding of local conditions in response to changing socio-economic, political and ecological conditions".

Traditional irrigation is not just a static and timeless activity, but a dynamic process that varies geographically (Majule and Mwalyosi 2005). Current practices encompass both traditional knowledge and modern techniques, and irrigating communities are capable of assimilating and adapting outside knowledge and experiences to improve their own situation. This is true for most smallholder irrigation schemes in SSA, most of which evolved from traditional irrigation practices. They are either communally owned and managed or individually owned, especially by commercial enterprises that cultivate high-value crops.

Smallholder irrigation schemes have a number of advantages compared with large-scale, mainly public schemes controlled by central governments. They are simple in design and require low investment cost. In addition, they are farmer-managed and have high water-use efficiency and low environmental degradation. In view of increasing water scarcity, it is important to identify the best options for addressing food insecurity as it relates to climate change. Gleick (2003) called for a shift toward a 'sustainable path' away from the large dams and reservoirs of the twentieth century toward decentralized systems that focus on water productivity and poverty reduction by smallholders. Such a shift is supported by many research findings. Similar sentiments were echoed by Hillel (1997), who stated that "to ensure sustainability, irrigation should be developed on small-scale farms operated by individual farmers or groups of farmers".

Mati (2008) pointed out that "investment costs for smallholder irrigation schemes are much lower than large schemes in Kenya, ranging from USD 200 to USD 1,750 per ha, depending on the technology." In Toya, near Timbuktu in Mali, Sanchez *et al*. (2008) found that the cost of developing and maintaining large rice irrigation schemes (such as the 400-ha farm at Daye Hondobomo) is much higher per unit area than for the smallholder schemes that average about 25 ha. In Uganda, a recent project funded by the Japan International Cooperation Agency (JICA) estimated the total cost of small-scale schemes (10-20 ha) to range from USD 2,850 to USD 4,950.

The development cost (equipment and civil works) for a large scheme ranges from USD 3,750 to USD 4,500 per ha[28] compared to USD 450 to USD 540 per ha for the smallholder schemes. Peacock *et al*. (2007) assert that, "at the average cost of USD 6,000 per ha under current productivity levels, new irrigation development will not be economically viable for cereal crops other than rice in most markets." The performance of smallholder irrigation schemes, in terms of improved water management, food security and incomes, is encouraging, with net earnings ranging from USD 200 to USD 1,200 per month for single-crop enterprises (Mati 2008). Moreover, enhancing surface irrigation with rainwater harvesting, for example, has been shown to be profitable for smallholders. Fox *et al*. (2005) found that "the combination of rainwater harvesting and surface irrigation yielded a net profit of USD 151 to USD 626 per ha in Burkina Faso, and USD 109 to USD 477 per ha in Kenya."

Postel (2001) reported that "studies conducted all over the world have found that, when compared to traditional flooding methods, conversion to drip irrigation decreases water use anywhere between 30 and 70 percent, while increasing crop yields from 20 to 90 percent". The gains come from maximizing water use by delivering water at low quantities directly into the root system. Drip irrigation can be easily adapted to diverse settings and is ideal in water scarce regions characterized by poor soils and high labor costs (Kay 2001). While various drip irrigation technologies outperformed surface irrigation both in productivity and in economic returns, adoption has been slow

28 These figures are within the range found by Inocencio *et al*. (2007) for successful irrigation projects in Africa. A major observation is that smallholder irrigation schemes constructed/rehabilitated as part of relatively large-scale investments projects have the lowest costs and highest returns.

due to inadequate technical expertise and access (Namara *et al.* 2007). Moreover, some smallholder farmers view drip irrigation systems as overly complicated and user unfriendly. Besides the cost, drip irrigation requires regular maintenance for problems resulting from emitter clogging or damage by burrowing animals (Kay and Brabben 2000, Kulecko and Weatherhead 2005). Drip irrigation can lead to a shift in cropping systems to more intense cultivation of water intensive crops, which nullifies gains made by increasing water use efficiency.

Most smallholder irrigation schemes in SSA are based on surface irrigation, which involves diverting water from streams/rivers and dams by gravity and pumping, or pumping from groundwater and conveyed by open channel or pipe to the cropped area. The potential for rehabilitating, improving or developing smallholder irrigation schemes in SSA is largely unexploited. In most cases, farmers have already taken up initiatives to start up smallholder irrigation schemes. The MVP Mwandama experience in Malawi (Plate 4) is a good example, where farmers are using temporary diversion structure and plastic lining for the main canal. All that is needed is an extra push to enhance their productivity and sustainability, especially through infrastructure development, irrigation water management and marketing of produce. Both hardware (infrastructure development), and software (capacity building) should be provided to enhance farmers' skills to efficiently manage their schemes. Targeting existing or evolving smallholder schemes has a higher chance of success than starting from scratch because such interventions build on farmers' knowledge and experiences. Working through established governmental agencies or NGOs linked to farmer groups is an added advantage, especially in the production and marketing value chain.

Interventions in smallholder irrigation schemes should also strive to provide technical backstopping, extension services and credit facilities for farmers. Such services can be provided efficiently through organized CIGs (farmer associations or cooperatives),

Plate 4: Emerging smallholder irrigation system in Mwandama MVP in Malawi

which experience has shown are the primary ingredients of successful smallholder irrigation development. Organized farmers' groups are easier to train and link to credit facilities and extension services. Most private service providers are also more comfortable working with organized farmers who can be brought together by a common resource, technology or product.

Appropriate technology is an important component of smallholder irrigation development. Technological factors include water source and supply, water conveyance, water control structures, water application (surface, sprinkler or drip), and farm operations (mechanized or manual). Farmers can be brought together by sharing an irrigation structure (canal or dam), using the same technology (eg, farm ponds with hand or treadle pumps and drip irrigation system), sharing a common market for their produce or drawing on a common source of credit. Such farmers association can be institutionalized to spearhead development and management of smallholder irrigation scheme. Moreover, any intervention in smallholder irrigation should consider the socio-economic status and socio cultural dynamics of the target groups.

Some of the key factors that determine the success of a smallholder irrigation intervention are:

- Choice of technology
- Farmers' participation, skills and capacity
- Water availability
- Type and variety of crops
- Market demands and supply chain
- Provision of back-up services

In SSA, there are many successful smallholder irrigation schemes that we can learn from. On the other hand, there are also many unsuccessful schemes that also provide lessons about what to avoid. The impact made by climate change entails another challenge that must be met to ensure success and sustainability of any investment in smallholder irrigation schemes in the diverse environments of SSA.

Finally, appropriate design, in terms of hydraulic structures, crop water requirements and overall water distribution and management are prerequisites for smallholder irrigation development. With regard to climate change, efficient water delivery (lining canals) and application systems (sprinkler, drip systems) and water-saving practices (deficit irrigation practices) should be considered. Most potential smallholder irrigation schemes have been identified through national master plans, which form the basis for identifying possible projects in which to invest. Each country has its own system of categorization of existing and proposed smallholder AWM schemes. Table 3 illustrates how the Government of Tanzania manages its irrigation capacity.

4.1.2 Micro-irrigation systems

Micro-irrigation systems mainly involve low-head, low-cost drip (LHLCD) irrigation kits for smallholder farmers, mainly for vegetable production. LHLCD kits range from 20-liter bucket kits (Figure 8) to 200-liter drums or mini-tank systems (Figure 9) and operate at 0.5-1.0m water head. Larger systems that can irrigate up to 1,000-2,000 m^2 are also available (Ngigi 2008b). As climate change results in uneven distribution of water, either by scarcity (drought) or excess (flood) in many regions of the world, water is increasingly becoming a scarce resource, even in the humid tropics. Drip irrigation promotes efficient use of water and fertilizers in crop production. Many types of LHLCD irrigation systems are in use in many parts of SSA (Ngigi 2008b, Sijali and Kaburu 2008, Sijali 2001, Chapin 1996), and their costs range from USD 20 to USD 200 (for bucket and drum kits).

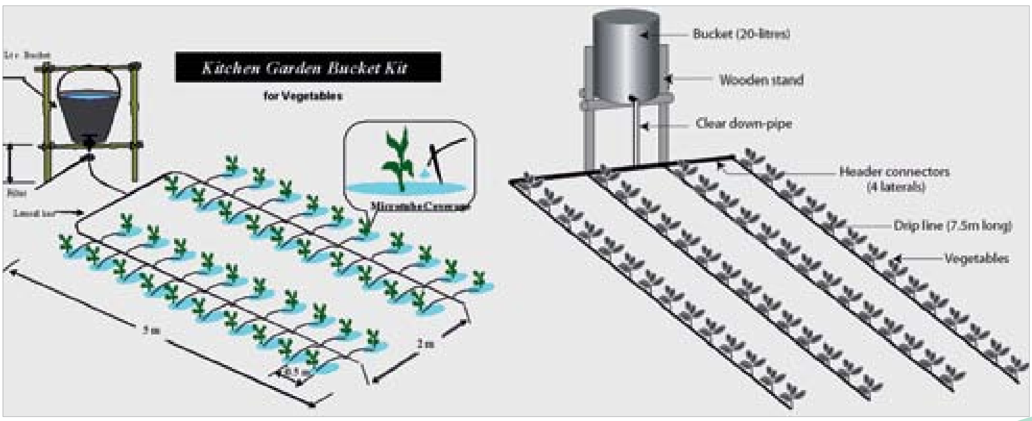


Figure 8: 20-litre bucket kit LHLCD irrigation system

The land area under irrigated agriculture can be increased since a micro-irrigation system uses less volume of water. For example, in Koraro MVP in Tigray (Ethiopia), shifting from surface irrigation to drip irrigation will increase irrigable area by 200 percent – improving irrigation efficiency from 25 to 75 percent. It promotes more efficient use of fertilizers due to reduced nutrient leaching as well as improving yield and quality of vegetables. It also reduces the spread of soil-borne diseases and the risk of groundwater contamination and pollution. The LHLCD irrigation system, in particular, holds promise as a means for increasing water-use efficiency, reducing labor requirements and improving harvests in both quality and quantity. It is best suited for horticultural crops, especially high-value vegetables and fruits.[27] To enhance technological adoption, farmers should be organized into operational CIGs, which should be strengthened and encouraged to join cooperative societies to collectively address both production and marketing challenges in rural business enterprises. In Tiby MVP (Mali), the creation of communal women vegetable gardens is a good example in this direction.

Other types of micro irrigation systems are based on hand watered vegetable gardens and the use of simple manual pumps or small, motorized petrol pumps to lift water from streams or wells. Integration of both manual pumps and drip irrigation can improve water management and reduce labor requirement for micro-irrigation systems. Pitcher (buried porous clay pot) irrigation is according to Abu-Zreig *et al*. (2006), "one of the most efficient traditional irrigation systems in which water seeps out of a buried pitcher due to the pressure head gradient across the wall of the pitcher directly into the root zone of the irrigated crop". In Koraro (Ethiopia) MVP, the technology has been introduced to establish household orchards – planted with oranges, lemons, apples, among other fruits.

Numerous pilot projects have shown the technologies to be both economical and efficient for smallholder farmers. If the viable investment mechanisms are in place and farmers have access to a reliable water source and are able to acquire the technical ability to maintain such practices, the adoption of integrated micro-irrigation systems can lead to greater food security and increased incomes thus buffering smallholder farmers against the adverse effects of climate change.

4.1.3 Greenhouses for smallholder farmers

Climate change affects the growing environment for sensitive horticultural crops, which make it necessary to grow them under greenhouses. Smallholder farmers want to grow high value crops under controlled conditions that assure them quick returns for their investment. Under optimal growing conditions, vegetables and fruits can produce up to

27 Despite these positive attributes the rate of adoption of these systems is very low in SSA due to poor accessibility, inadequate awareness (low technology transfer) and lack of promotion among smallholder farmers. In West Africa, various projects are supported by the World Bank, Israeli's Mashav, MVP and ICRISAT. In eastern and southern Africa more progress has been made in the promotion of micro-irrigation systems.

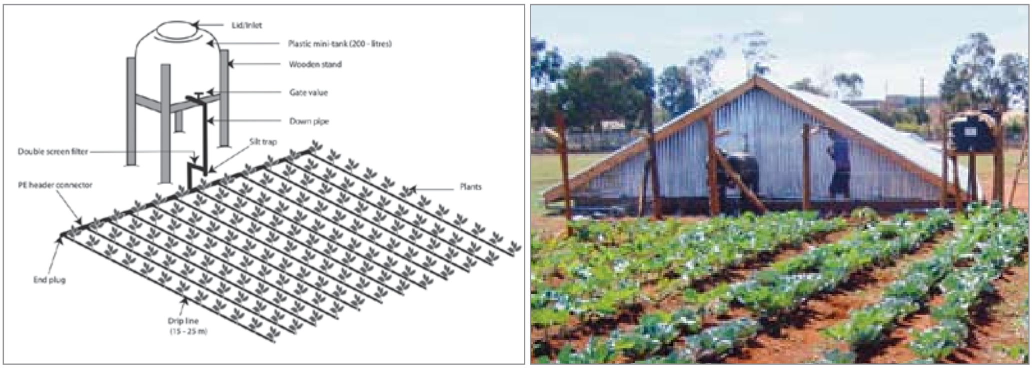


Figure 9: 200-litre mini-tank (drum) LHLCD irrigation system

ten times more than rainfed conditions. This is one of the reasons making greenhouses popular among smallholder farmers. Most smallholder farmers can however, not afford the high investment cost for greenhouses. To address this drawback, farmers are either opting for simple locally constructed structures or taking credit from local banks or micro-finance institutions to acquire the sophisticated technology (see Plate 5).

Plate 5: Smallholder greenhouse for vegetable production

In Kenya, where the technology is being pioneered, there are a number of private companies selling quality plastic sheets and shade nets for smallholder greenhouses ranging from 6m by 12m to 8m by 60m. Construction works for the greenhouses require experienced and technically qualified person. Most smallholder greenhouses incorporate a low-head drip irrigation system using water from different sources. In Kamulu and Kitengela, in the eastern and southern outskirts of Nairobi respectively, hand-dug shallow wells of 10-30m depth are common water sources. Such wells are fitted with submersible pumps, which supply water to drip irrigation supply tank raised about 2m above the ground.

On the sophisticated technology, the Amiran Farmer's Kit (AFK) is a good example, which was created with the aim of allowing small scale farmers afford modern agricultural methods, technologies and inputs of the highest standard[28]. The AFK is a tailor made kit designed to meet the needs of the specific farmer or group of farmers by adapting the components of the Kit to suit the climate, terrain, and agricultural experience of the farmer. It has an integrated greenhouse (120m^2) and outdoor (380m ^{2}) low-head drip irrigation systems, both covering 1/8 acre (≈ 500m^2). Box 9 shows the different AFK components.

Box 9: The Amiran Farmer's Kit (AFK) Components

- **Farmer's Greenhouse:** 8m by15m mini green house tunnel (seeplate5)
- **Drip Irrigation System:** The Family Drip System suitable for an1/8acre
- **Collapsible Water Tank:** 600-litre collapsible water tank
- **Farmer's Sprayer:**16-litre Knapsack Sprayer
- **Gold Medal Seeds:** 2 types of seeds foran1/8acre
- **Fertilizers:** One season worth of required fertilizer
- **Agrochemicals:** One season worth of required Agro Chemicals
- **Health and Safety:** For the safe usage of the chemicals provided
- **Training:** Training offered on the usage of the kit and a certificate awarded upon completion

Source:www.amirankenya.com

To assist smallholder farmers in Kenya access credit to adopt the technology, a partnership between the Equity Bank and Amiran Kenya has been established to finance all or selected components of the AFK. According to the Organic Farmer (2009)[29], the total investment cost of AFK package is about USD 2640, but from 1,000 tomato plants, a farmer can get a gross margin of USD 5330, hence a gross profit of USD 2690. The cost-benefit analysis indicates that AFK package is economically viable for smallholder farmers, since they can repay the loan within one season and make a substantial profit.

28 See, http://www.amirankenya.com

29 See, http://www.organicfarmermagazine.org (The Organic Farmer No. 55, December 2009)

4.1.4 Rainwater harvesting and management

Rainwater harvesting and management is the other end of the AWM continuum and refers to utilization of 'green water' – water that becomes available directly as rain falls and returns to the hydrological cycle in the form of vapor. Conventional irrigation, on the other hand, uses 'blue water', which is diverted from streams and aquifers (Rockström 2001). RHM systems offer a suitable means of agricultural water supply by upgrading rainfed agriculture through in-situ soil moisture conservation and on farm run off storage for supplementary irrigation. They provide water and food security, especially for people living in SASE regions with limited water supply options. Areas with annual rainfall in the range of 300 1200 mm are appropriate for RHM systems. RHM systems can be adopted to upgrade rainfed agriculture in many areas in Africa.

4.1.4.1 In situ RHM systems

In situ RHM refers to rainwater collection, storage and utilization in the soil profile.Some in situ RHM systems are conservation agriculture, terracing, planting/spot pits (referred to by various local names such as zai, tumbukiza, chololo, matengo and ngolo), V-shaped bunds (negarims), majaluba bunds (commonin Tanzania for rice production), contour furrow/bunds, semi circular (demi lunes or half moons) and trapezoidal bunds, trench cultivation, road run off diversion and spate irrigation, among others. Most soil and water management practices developed through research have evolved from indigenous or traditional knowledge of local communities. In addition, some have been developed as a result of integrating both indigenous and local knowledge. These systems can be incorporated in most smallholder rainfed farming systems in SSA, and they are included in many extension service manuals and programs.

Conservation agriculture involves minimum soil disturbance and encompasses land preparation techniques that reduce labor and improve soil fertility and soil and water conservation; these are soil tillage practices that maintain or improve soil structure and increase infiltration and water holding capacity. Conservation agriculture is a premier practice characterized by short hydro-cycles. It is very efficient,with reported crop yield increases ranging from 50 to 150 percent (Ngigi 2003). Water conservation is enhanced through mulching and crop residue retention. It includes zero or minimum tillage, stubble mulch tillage, strip tillage, deep tillage/sub-soiling, ridging, crop rotation and cover crops. The practice can be achieved with simple animal drawn equipment attached to a normal plough frame.

Conservation agriculture is gaining ground in many rainfed farming systems in SSA and has been reported to increase crop yields. Its adoption and promotio requires provision of appropriate equipment and the training of donkeys, oxen or camels. In many countries, draught animal technology (DAT) is already part of traditional farming systems, notably in parts of Ethiopia, Kenya, Tanzania and Zambia. Therefore only training and provision of equipment is required. In Zambia, over 120,000 smallholder farmers practice conservation farming in Lusaka, Southern, Eastern and Central provinces. There are a number of national, regional, and continental organizations promoting conservation agriculture, working under the African Conservation Tillage (ACT) Network, which can spearhead such initiatives.

4.1.4.2 Storage RHM systems

In storage RHM systems, run off is diverted from catchments into either on farm or on stream storage. From storage, water is applied to cropland as full, supplemental or deficit irrigation.On farm storage, which is common for most smallholder farmers, includes 30 300 m^3 farm ponds (either unlined or lined with concrete, plastic or rubble stones (Plate 6), underground tanks (called barkat in Somalia and northeastern Kenya and birkas in Ethiopia) and earth dams/water pans or micro dams (in Ethiopia), and charco dams (in Tanzania).

Rainwater harvesting can offer a partial solution to the issue of climate change. By harvesting rainwater in reservoirs, the dependence on the less reliable sources such as surface water decreases. Even in low rainfall years (200 - 400mm), harvested rainwater can be a crucial supplement to water supply and small scale irrigation. In Burkina Faso, a periodic rainfall of 500 mm/yr created the opportunity to complete the supply of already existing water. In West Africa, a climate change adaptation program entitled "*The construction of infrastructures for water storage*" encouraged

Plate 6: Farm ponds lined with ultra-violet-resistant plastic for micro-irrigation systems

countries to begin massive campaigns of mobilization of surfaces and underground water by the construction of dams and water reserves. Burkina Faso, for example, built more than 1,500 dams during the last three decades. In northern Ghana, small reservoirs have been established for water supply and irrigation. Box 10 shows some of the notable attempts to up scale AWM interventions.

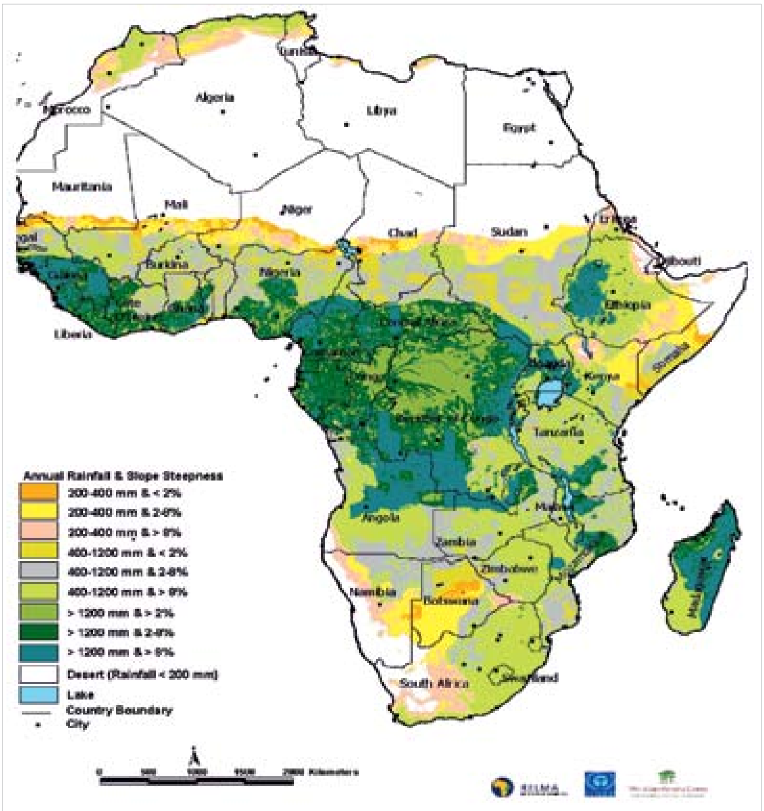
On stream storage includes small earthen dams, sand or subsurface dams, valley dams (common in Uganda and Rwanda) and others. Water from the storage structure is either lifted (using manual or motorized pumps), fetched manually (mainly by women and children) or conveyed by gravity to cropland, where it is applied either manually (hand watering), or by surface (furrows or basins) and pressurized (drip and sprinkler) irrigation technologies. Storage RHM systems thus incorporate both water lifting (hand or treadle pumps) and water application (low head drip irrigation) technologies. Hence a technological package is proving to be the best promotion approach, especially in Ethiopia, Kenya and Rwanda. Moreover, most of the MVP clusters are also adopting similar integrated technology package with promising results. One perceived negative impact is mosquito breeding, which can be controlled by incorporating fish farming–a value addition component.

According to Malesu *et al.* (2006a), "surface run-off in Africa can be harnessed from a wide range of catchments, such as roads, home compounds, hillsides and open pasture lands, and may also include run-off from water courses and gullies that can be stored in small reservoirs such as ponds or water pans." In Figure 10, geographic information system (GIS) technology has been used to map areas where surface run-off interventions in Africa are most suited. This analysis shows that the annual run-off generated in Africa amounts to 5,195 km^3 which, if harnessed, could support the livelihoods of many people. It shows that the highest run-off domains for Africa lie in the medium rainfall and gentle to steep slopes (marked in gray and light green colors on the map). However, inadequate rainwater harvesting has resulted in poor water management: too much water in the rainy season followed by water scarcity in the dry seasons[30]. Investment in storage infrastructure is therefore necessary to harness rainwater and exploit the potential of irrigation in Africa. RHM systems also have the potential to ensure food security in the semi-arid environments of Africa.

30 This is synonymous with the story from Dertu MVP in Garissa (Kenya), in which Dr. Ahmed Mohammed, the Team Leader and Science Coordinator, repeatedly depict the scenario by stating that the people of Dertu "cry for water, and cry from water."

Box 10: Some the notable attempts to up scale feasible AWM interventions

- The MVP, an integrated rural development project, has adopted a number of feasible AWM interventions in its 14 clusters in 10 African countries. Each MVP cluster has developed an integrated 5 year AWM strategy, whose different components are being implemented.
- IFAD, through IMAWESA, has been testing, replicating and up scaling a number of AWM interventions in SSA, which include the upgrading and rehabilitation of smallholder irrigation projects, and rainwater harvesting and management systems.
- GHARP and the Kenya Rainwater Association (KRA) secretariat have been developing, testing, replicating and up scaling integrated RHM systems and complementary technologies in Kenya – rainwater storage, management and utilization for various community uses (domestic, livestock and micro-irrigation). The promotion package also includes improved sanitation and hygiene, low head drip irrigation kits, DAT for de-silting reservoirs, conservation agriculture, apiculture, aquaculture, pasture rehabilitation, fodder production and preservation (manual hay baler), and tree nurseries for environmental conservation. GHARP members have also been replicating some of these interventions and promoting the technology promotion packagein Ethiopia and Uganda.
- SearNet – another regional rainwater network, housed by the World Agroforestry Centre, has also been promoting integrated AWM interventions in eastern and southern Africa. In Rwanda, through collaboration with the Ministry of Agriculture, a pilot project in Bugesera district has been adopted for country wide replication and up scaling
- The World Food Programme (WFP) food for asset/cash for asset initiative in Kenya has adopted AWM interventions in its relief and rehabilitation project. According to the Kenya Programme Review Mission Draft Report (2007), water harvesting based measures are considered a priority to climate proof the most vulnerable – hence a major focus of resilience building measures.The next projectphase (2009 11) will focus on developing RHM based assets as drought preparedness and mitigation measures in the arid and semi arid lands of Kenya.
- A number of country based, agriculture related donor funded projects in SSA have also adopted AWM



Source: Malesu *et al*. 2006a

Figure 10: Surface run-off and flood storage potential in Africa

4.1.5 Energy sources for pumping water

According to WBCSD (2009), "water and energy are inextricably linked – water is used to generate energy; energy is used to provide water. Both water and energy are used to produce crops". Energy supply for irrigation depends on the type of technology. Irrigation of any kind, however, can only be as effective as the source that provides the water. The dominant irrigation technologies in Africa are surface (furrow and basin) and sprinkler systems. In terms of efficiency, water saving means a reduction in energy for supply. Research by FAO (2002) found that, "in most cases, switching from furrow or sprinkler irrigation systems to drip irrigation reduces water consumption by 30-60 percent." Drip irrigation systems, especially low-head systems, use less the energy than surface irrigation by emitting water at or near the root zone – increasing water use efficiency by at least 80 percent) (Ngigi 2008, Smajstrla *et al*. 1991).

In addition, prudent irrigation scheduling can reduce water losses through evapo-transpiration, run-off and seepage, which further reduce energy consumption (Evans *et al.* 1996). Beyond the conveyance system employed to deliver water, consideration should be given to the means by which water is lifted. It is estimated that pumping accounts for 23 percent of on-farm energy consumption (Sloggett 1979). Improvements in water pumping technology could lead to synergistic energy and water efficiencies. As an essential condition, however, the first step is to secure a sustainable and reliable water source. With the onset of climate change, the synergy of water development and renewable energy can then become an effective adaptation, allowing some flexibility to manage climate extremes (IPCC 2007).

Several types of energy sources exist for operating water pumps for irrigation. Zeisemer (2007) noted that "because agricultural energy consumption generally amounts to less than 10 percent of national energy, it is often overlooked, particularly in the context of food security". But because climatic changes alter agricultural practices, maximizing energy use-efficiency may be an essential piece of the adaptation puzzle (WBCSD 2009). There are a variety of ways to achieve on-farm efficiencies in energy consumption and a variety of solutions and opportunities exist at the water-energy nexus. Depending on the size and water sources for irrigation, FAO (2007) categorized the following sources of energy and technologies for pumping water for irrigation.

However, to ensure selection of appropriate pump and good performance, there is a minimum set of conditions to be considered. Akubue (2000) noted that "for a solution to be sustainable it must employ local skills, material resources and local financial resources, while satisfying local preferences and needs and preserving compatibility with local culture and practices". Essential to this is the ability for local farmers or community members to maintain upkeep from both a technical and financial standpoint, which certainly requires a firm commitment from donor agencies (NREL 2003). Furthermore, because irrigation takes place during specific times of the year (when labour is abundant), the economic choice tends to favor the lower-investment pump (often mechanized pumps) (van Campen 2000).

4.1.5.1 Gravity power

Gravity is the most reliable and sustainable source of irrigation energy in rural areas. Most smallholder irrigation schemes are gravity-fed with water being diverted from streams or rivers and conveyed by gravity to cropland. The conveyance canals are normally unlined and have a number of diversion and distributions hydraulic structures. Gravity systems can also be combined with pumping, where water from either groundwater or streams/rivers is pumped to an appropriate head and then conveyed by gravity. Moreover, water application can be by surface (furrows and bunds) or pressurized irrigation technologies (sprinkler and drip). Pumps that use either the flow of water or water head (eg, hydrum) to lift water should also be considered owing to the increasing cost of fuel for pumping in Africa.

4.1.5.2 Electric pump

This pump's applicability for smallholder farmers is limited due to low availability of electricity in rural areas and is therefore only applicable in areas covered by the national grid. However, where small hydro-power projects are feasible, especially on streams/rivers transversing hilly areas (eg, Tungu Kabiri in Chuka district, east of Mount Kenya), an integrated hydropower and water supply can be considered.

4.1.5.3 Petrol/diesel engine-powered pump

For larger-scale applications, a turbine or centrifugal pump is an increasing necessity with price increasing with efficiency (both water and energy use) (Evans et al. 1996). These pumps require a much higher level of technical expertise to maintain. The use of fuel-based generators by smallholder farmers for irrigation during the dry season is common in SSA. For example, the small irrigation program initiated by the Ministry of Agriculture in Burkina Faso has in fact triggered this practice, facilitated through the provision of loans to the farmers to produce more crops. In the West African countries of Mali, Niger and Senegal, use of motorized diesel pumps along the major rivers is a common practice by smallholder farmers, especially for rice production. However, despite the popularity of petrol and diesel pumps, their capital and O&M cost are prohibitive. This problem is compounded by lack of spare parts and support services.

4.1.5.4 Wind-powered pump

Wind power is a renewable, predictable, and clean source of energy. It is CO_2-neutral and is proactive in reducing greenhouse gas emissions. Windmills can be used with submersible water pumps. This technology has been tested in a West Africa pilot project for small irrigation projects in remote areas. In Kenya, wind pumps have been in use in some parts of the country since colonial times, especially for water pumping. The drawback of this system is the availability of wind with sufficient speed to turn/rotate the turbine. Wind speed measurements undertaken by Tumbulto (2005) in Accra, for example, confirmed that the wind speeds are too low to run any wind generators. The maintenance and operation of such technologies will also be high and the know-how not available. However, a number of private companies are already manufacturing wind pumps in SSA, e.g. in Kenya (Thika) and Senegal (Thiès), which also supply pumps to neighboring countries.

4.1.5.5 Solar-powered pump

In Africa, particularly in the Sahel region, sun is the most abundant source of energy, although not often tapped. Few smallholder farmers have access to a public power grid as rural electrification is largely nonexistent in many countries. Solar power can fill this gap. Solar-powered photovoltaic pumps (PVPs) have the potential to promote rural development by simultaneously delivering a reliable water source while reducing dependence on non-renewable energy sources.[31] Perhaps the first consideration in evaluating water pumping systems, beyond the ability to meet the water demand, is cost. The US National Renewable Energy Laboratory (NREL) found that both alternating current and direct current PVPs are more economically efficient for small-scale applications than diesel or gasoline pumping systems. Furthermore, PV/fuel hybrid systems exist that allow a safety net for use during days with excessive cloud cover.

The switch to PVPs generally requires higher initial investments. In life cycle analysis however, PVPs are cost-competitive while providing greater water efficiency and often lower maintenance (van Campen *et al*. 2000). Indeed, with careful planning and proper implementation, PVP systems have proven successful. In the Kalale District of Benin, for example, the Solar Electric Light Fund has implemented a series of micro-irrigation systems using the Africa Market Garden[32] concept. With funding from the World Bank, the project provides between 5,000 and 8,000 gallons of water per day for storage and use during the dry season. In a related study, Omer (2001) found that in Sudan approximately 250 PVPs have been installed at a cost of roughly USD 6000 per pump, fully installed. The study determined that these systems were most effective in supplying drip irrigation systems under fruit production rather than in larger cereal crop production. However, if both the technical and socio-economic factors are accounted for in the implementation of such systems, the PVP technology has advanced to the point where these systems can provide significant advances in sustainable rural development (Short and Thompson 2003). Indeed groundwater can

---

31 However, solar pumps are delicate and their operation and maintenance aspects may be beyond some of the rural communities, as demonstrated by the Ewaso Kidong experience in Kenya. Cases of vandalism (stealing of solar panels) have been reported in West Africa.

32 The concept of the African Market Garden based on low-pressure drip irrigation systems was tested by ICRISAT first on-station and around Niamey, then in several Sahelian countries. For more information, visit www.icrisat.org/WCA/project6.htm.

be used for irrigation with low-cost solar energy, which can be sustainable if a good operating and maintenance system is put in place, especially with private sector participation. Solar pumps are used for groundwater-based irrigation projects in many countries in SSA.

4.1.5.6 Simple manual pumps

Different types of hand pumps (the Afridev rope and washer pump, the Volanta, etc.) are in use in SSA for lifting water from shallow boreholes (up to 60m) and hand-dug shallow wells. Due to low durability of Afridev pumps, more sustainable pumps are under development (eg, Afripump, with a life span of 25 years with minimal maintenance (van Beers 2008). Besides these hand-pumps, the most practical system is the treadle pumps (Kay and Brabben 2000, IPTRID 2000).

The key strength of a treadle pump is that it requires only physical labor rather than external energy inputs. Moreover, these pumps can be produced locally at a relatively low cost ranging from USD 50 to USD 120, and provide as much as an eightfold increase in irrigation capacity on small-scale irrigation schemes (FAO 2001c). Traditional limiting factors of the treadle pump include its applicable scale, limited crop use, and requirements for a water source within six meters of the surface (FAO 2001c). Small-scale irrigation has traditionally been fed through the arduous lift-and-bucket method, which requires high physical input and limited well-depth. The treadle pump was developed to increase both water access and efficiency of supply. The system comes from a basic adaptation of the hand pump with the transfer of power supply to the feet where increased power generation can be supplied (Kay and Brabben 2000). Using low physical input and capital, the treadle pump far outperforms traditional methods by lifting 7m^3 per hour from wells (conventionally up to 7m deep) and surface water. For treadle pumps and micro-irrigation systems, the performance is encouraging.

In many regions, the treadle pump costs less than USD 35 compared with motorized pumps, which often cost over USD 300 and have been shown to increase income by over USD 100 per season for the poorest farmers (Postel 2001). Moreover, Kay and Brabben (2000) reported a sixfold increase in income with increased crop intensity and area irrigated in Zambia. Significant potential exists in the concurrent use of such pumps with micro irrigation systems – there are potentially very large poverty-reduction benefits as proven by KickStart in East Africa. For treadle pumps, the primary issues are access, cost and labor. Accessibility is improving but still remains absent from more remote parts of Africa where cost is not within the farmers' means. Kay and Brabben

(2000) noted that "traditional treadle pumps are also effective only in smaller-scale systems with a water source less than 6m below the ground".

A number of studies have been conducted on the use of treadle pumps (and to a lesser extent drip irrigation) across Africa. In eastern and southern Africa, Kickstart has been distributing two models: the super moneymaker pump (SMP) and the moneymaker hip pump (MHP) [33]. Africa News Network (2008) reported that "retailing at roughly USD 100, the SMP can pump water from a source up to 10m in depth and pressurize water up to 13m, and it can irrigate about 0.75ha using a hose length over 330m. It is used by 62,000 farmers in Kenya, Mali and Tanzania with average profit margins doubling or tripling".

The MHP, which sells for approximately USD 35, is a modified treadle pump which the user operates through a rocking motion (Haskins 2008). It is very light (only 4.5 kg or less than 10 pounds), and can irrigate 0.4 ha. The adoption of MHP is growing fast, and as of September 30, 2009, over 16,000 have been sold (Kinaga, 2008). Treadle pump technology has been promoted by Enterprise Works Worldwide in West Africa as an alternative to the traditional rope-and-bucket irrigation. The pump is necessary to overcome the challenge of uncertain and inadequate rainfall for agricultural production (IWMI 2007). Effective promotion of treadle pumps should adopt an integrated approach to encompass crop protection, soil fertility and marketing (Blank *et al.* 2007).

4.1.6 Integrated AWM

Due to the impacts climate change and variability, promotion and adoption of an integrated approach in SSA is imperative. In most smallholder farming systems in SSA, an integrated AWM intervention that promotes a package of different technologies is more appropriate as it provides the farmers with viable options. Integrated AWM encompasses the promotion of multiple use of water, which caters to actual demands of target communities, rather than sector-based water allocation (van Koppen *et al.* 2006). An integrated AWM intervention will ensure management of water for agricultural production and maximize the returns to the population without compromising the ability of the land and water system to meet the requirements of future generations. van Koppen *et al.* (2006) found that if farmers are given different options, crop production and diversification increase significantly. Smallholder farmers normally have a number

33 Recently, KickStart shifted from local manufacturing to importing the pumps from China. While this is a blow to local industry, the decision was motivated by cost considerations, and the shift has enabled the program to be more sustainable.

of options which, if implemented in a holistic and integrated manner, can yield optimal benefits. Thus integrating different aspects of AWM is a promising intervention that can be practiced throughout SSA.

Many AWM projects in SSA have ensured increased access to water by smallholder farmers and led to improved crop yields and incomes. In general, crop yields have been increased from 1-2 tons/ha to 3-5 tons/ha (Mati *et al*. 2008a). Increased crop yields and incomes encourage smallholder farmers, among other stakeholders, to invest in AWM. Although integrated AWM is meant to improve efficient use of water, this alone will not solve the problem of low yields and agricultural production in SSA. In addition to the correct amount of water, smallholder farmers also need improved seeds and sufficient fertilizer. Other factors related to improved land and crop husbandry, such as pest control and timeliness of operations, has also shown a significant impact on crop yields.

4.2 Crop Varieties and Diversification

In SSA, low crop yields result from degraded lands, inherent low soil fertility, nutrient-depleted soils, unreliable rainfall and inadequate water supply related to climate change and variability. Given that shorter rainy seasons and increasing rainfall variability are predicted, it is prudent to consider specific strategies for climate change adaptation for different farming systems in SSA. There are two fundamental approaches to effective climate change adaptation strategy.

- Selection of high-yielding crop varieties: Shift to cultivating crops that are more tolerant of droughts or shorter rainy seasons, such as switching from maize to sorghum, either as a long term change or as climate prediction information might suggest the likelihood of drier seasons. Select drought-tolerant varieties of crops already in use by farmers. These varieties can be used when forecasts suggests that there is high probability of less precipitation in the coming rainy season.
- Crop diversification: Shift to growing cash crops with existing irrigation technologies which will earn more income and enable farmer to invest in upgrading irrigation systems among other AWM interventions. Crop diversification also includes integration of different variaeties of crops, both food and cash crops.

4.2.1 Crop varieties

Different agronomic adaptation practices are applicable to different farming systems and agro-climatic zones, including drought tolerance for adaptation to climate change.

Many research institutions have developed various crop varieties suitable for specific climatic zones. For instance, new rice varieties with acceptable grain quality and yield and shorter growing duration need to be developed or introduced into rice-growing areas. The adoption of direct seeding pre-germinated seed, either by broadcasting or drum seeding, into flooded paddy fields can reduce the crop cycle by 10-45 days. Farmers need to be linked to leading research institutions to get certified seeds to increase production under changing rainfall regimes. A shift from subsistence to market-oriented enterprise is essential to improve farmer incomes and adaptation capacity.

Some of the CGIAR institutions involved in crop variety development are the International Institute for Tropical Agriculture (IITA), the International Maize and Wheat Improvement Center (CIMMYT), the International Rice Research Institute (IRRI) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The Drought-tolerant Maize for Africa (DTMA) initiative of CIMMYT is supporting the development and dissemination of drought-tolerant maize in SSA. CIMMYT (2008) reported that "the project builds on an established partnership between CIMMYT, IITA, advanced research institutions, private sector seed companies, NGOs, CBOs and 11 national agricultural research institutes. Fifty new maize hybrids and open-pollinated maize varieties have been developed and provided to seed companies and NGOs for dissemination, and several of them have reached farmers' fields. These drought-tolerant maize varieties produce 20-50 percent higher yields than other maize varieties under drought conditions. Farmers choose their crops according to the climate in which they operate". For example, in Sahelian West Africa, farmers prefer drought-tolerant crops such as sorghum and cowpea (Kurukulasuriya and Mendelsohn 2006). Moreover, introduction of improved crop varieties should consider the local community's eating habits, cultural practices, agro-ecological conditions and markets.

Non-food crops such as bio-fuels present opportunities for crop diversification and increased income should also be considered, albeit with caution since they compete with food crops for land, nutrients and water. Bio-fuels produce low greenhouse gas emissions by recycling carbon dioxide extracted from the atmosphere. Besides mitigating the impacts of climate change, bio-fuels have the economic and strategic advantage of replacing fossil fuels (Raswant *et al*. 2008). Due to their high economic returns with minimum investment, bio-fuels are seen by smallholder farmers as a viable alternative to labor-intensive and low-yielding cereals. Plants such as jatropha are becoming popular among smallholder farmers in eastern Africa (eg, Ethiopia) and West Africa (eg, Mali). However, little information on the productivity of bio-fuels in water-stressed conditions is available, and more research is needed.

Other crops such as sugarcane, soybean and maize can also be used as bio-fuels, but the current global food crisis and escalating prices discourage conversion of food crops to bio-fuel.[34] Concern over the diversion of food crops to bio-fuel has placed the issue at the centre of debate concerning future options for bio-fuel (Connor and Hernández 2009). An important consideration, however, is that some bio-fuel crops are drought-resistant and can even be grown on degraded land, hence offering another advantage. The rehabilitation of degraded lands, especially on the vast semi-arid environments of SSA, could be a boon to many smallholder farmers. The combination of modern breeding and transgenic techniques could result in greater achievements in bio-fuel crops than those of the Green Revolution in food crops, and in far less time (Ragauskas *et al*. 2006). There exists some doubt, however, about the long-term negative impact of these crops on soils and human health. Countries such as Burkina Faso are already growing transgenic cotton, vegetables and potatoes, but the jury is still out on this sensitive issue. One advantage of developing transgenic crops is that they can produce in a very short time, and hence cope with low rainfall conditions.

4.2.2 Crop diversification

Crop diversification, which can be defined as increasing the number of crops or the varieties and hybrids of a particular crop, is a potential farm-level response to climatic variability and change (Bradshaw *et al*. 2005). Crop diversification in a subsistence farming system provides an alternative means of income generation for smallholder farmers, the majority of whom are vulnerable to climate change. Because of changing rainfall patterns and water resources depletion, the existing cropping pattern is becoming less productive. Thus crop intensification, through mixed cropping and integration of high-value crops such as horticultural production, is gaining prominence as a climate change adaptation strategy. Riyannsh (2008) noted that "due to shrinking natural resources and ever-increasing demand for food and raw materials, agricultural intensification is the main course of future growth of agriculture". Bindhumadhavan (2005) stated that "it is time to critically redesign alternative cropping patterns based on agro-climatic zones, and to demonstrate them in farmers' fields. Hence the need for crop diversification from:

- Low-value to high-value crops (resulting in a price-risk benefit)
- Low-yielding to high-yielding crops (resulting in a yield-risk benefit)

34 In the African context, six crops seem to have large-scale potential: sugarcane, sweet sorghum, maize and cassava for ethanol; and oil palm and jatropha for bio-diesel (Sielhorst et al. 2008).

- High water-use crops to water-saving crops
- Single cropping to multiple or mixed cropping
- Crop alone to crop with crop-livestock-fish-apiculture
- Subsistence food crop to market-oriented crop
- Raw material production to processing and value addition"

At the individual farm scale, the simplest measure of crop diversity is the total number of different crops per farm. Crop diversification acts to reduce susceptibility to climatic variability such as floods or droughts that might result in crop failure. At the same time, it increases the number of marketable activities such as adding livestock to a cash crop operation or undertaking value-added processing, and hence serves to reduce farmers' risks resulting from weather fluctuations. Additionally, other risk-reducing strategies, such as crop insurance or the securing of off-farm income, may be complimentary.

4.3 Crop Insurance

Farming is often like playing the stock market. Farmers, basing their decisions on a variety of indicators, must choose the best crops in which to invest their time and money. Like certain stocks, some crops are more reliable than others, but even the most stable stocks can crash under specific market conditions. In developing countries, the implications of crop failure are far worse than in the developed world. Responding to this precarious situation, governments and lending facilities have established a number of programs to create insurance or safeguard systems against disasters (index-based insurance) such as droughts or floods against which farmers have little defense. According to IFPRI (2009), "the index-based insurance can serve as a buffer against climate extremes and provide the necessary support system for farmers to navigate an uncertain climatic future and avoid financial ruin."

Crop and livestock insurance is not well developed in SSA because of the reliance of farmers on rainfed agriculture in an unreliable rainfall regime. For example, no company currently provides crop insurance in West Africa. According to the Union des Assurances du Burkina Faso, because risks in Africa are too high and recurrent, it is economically unattractive to commercialize such products as crop insurance. The viability of crop insurance depends heavily on the degree of information, organization and subsidies available to support it. In eastern Africa, it would be more appropriate to strengthen the local social organizations (eg, women's groups and CBOs) and to facilitate linkages with financial services (eg, credit providers). In Ethiopia, a water-based credit service has been initiated, while in Kenya a green water credit [35] is being promoted.

Insurance in the agricultural sector, as in other sectors, is vulnerable to abuse and misappropriation. In crop-yield insurance, traditional schemes cover losses based on a pre-determined average against actual yield from a variety of hazards, often including poor crop management (Skees *et al.* 1999).

Larson *et al*. (1998) stated that "as the notion of crop insurance developed, a variety of other methods were implemented, including buffer mechanisms (stocks and bonds), government investment, and international price stabilization agreements, all of which met with little success". Publicly funded crop insurance has failed for a variety of reasons, notably the inherent difficulty in funding multi-peril insurance – and insurance companies find little incentive to pursue best practices in this regard, knowing that the government will cover most damages in any case (Skees *et al*. 1999).

Skees *et al*. (2006) noted that "additional difficulty arises in assessing risk and determining insurance policies. To establish the basic risk or level of indemnity, a variety of factors must be accounted for, each dependent on the accuracy and objectivity of collection". Risk assessment models are becoming increasingly sophisticated and useful since, they rely on the combination of historical data and knowledge of the physical properties of natural disasters to determine the probability of losses to various structures or crops from hazards at a particular intensity and distribution (Linnerooth-Bayer 2003). Some models are vulnerable to inaccurate or incomplete data sets and to incorrect interpretation of hazard variables. Inherent inaccuracies within these data lead to improper assessment of losses relative to insurance premiums. Moreover, Sachs (2008) noted that "the transaction costs of implementing risk-based policies are traditionally high, resulting in failure to take precautionary measures to safeguard investments".

Over the last 40 years, natural catastrophes have caused a sevenfold increase in economic losses (Dlugolecki 2004). Therefore, to address such risks, an effective insurance system is needed that meets the following criteria:

- Affordable and accessible to all rural people
- Compensation for income losses to protect consumption and debt repayment capacity
- Practical to implement, given potential limits on data availability

35 "Green water credit is a mechanism to pay rural people for specified land and soil management activities that determine all freshwater resources at the source" (Meijerink *et al*. 2007).

- Can be provided by the private sector with little or no government subsidies
- Avoids the problems of moral hazard and adverse selection

As the commodity insurance business has grown and expanded into less developed regions, new indices and schemes have been developed and implemented to combat these growing climatic extremes and encompass these criteria in varying degrees. Rather than measuring individual income or yields, index insurance measures objective variables on a larger scale, such as area yield or weather-related variables (World Bank 2005). When an insurance company assesses the risk of inadequate rainfall over a wide area, for example, it prefers to avoid undertaking in-field assessments to reduce transaction costs. While understandable as a business procedure, this action may not favor affected individual farmer, whose holdings might be quite different from the parameters described in the assessment (Hansen *et al*. 2007). Insurance is sold based on the level of protection that one seeks and buyers in the same region all pay the same premium rate. Once a disaster has struck, all those insured receive the same payout based on the amount of insurance purchased. Sachs (2008) takes this idea further by proposing the idea of bundled services. In this scheme, an agency provides a seasonal loan to a farmers' cooperative to purchase improved seeds and fertilizers, among other inputs. The lending agency protects itself by buying a bond against natural disaster, and farmer's loan repayment is either reduced or cancelled in the event of natural disasters such as drought or floods.

Hess and Syroka (2005) reported on the implementation of weather-based index insurance in Malawi, which aims to develop a weather-risk profile to determine the likelihood of drought, rainfall distribution, and spatial correlation of rainfall across the different regions of the country. For example, the method tied the climatic profile to maize production in the Lilongwe area using regional yield averages as a function of rainfall. Through statistical analysis, the method determined the yield fluctuation per unit of precipitation and thus was able to determine the appropriate payout for losses. In devising contracts, the farmer (or development agency) can purchase an insurance policy based on a specific amount of rainfall, depending on the climatic regime under which the farmer lives. Pricing is then defined from the private insurer's perspective (ie, profit motive) as the expected loss plus a risk margin – likely a percentage of total compensation – for indemnifying the farmer against risk. The final step is to determine the logistical order of executing the contract, taking into consideration the details in administering the contract between local, national and international reinsurers.

Due to farmers' risk averseness, a development agency/partner can purchase bundled services or coordinate premiums through local or national insurance agencies and administer contracts to local farmers. Depending on the specific risk, it is sensible to transact contracts at different levels. Typically, contracts at the farm level are oriented toward removing barriers that keep people in poverty traps. For example, by insuring loans against the large-scale droughts that occur approximately every seven years, a smallholder farmer might be able to purchase quality inputs and be much more productive during the other six years.

Contracts at more macro levels are usually designed to address the complimentary task of famine relief and to prevent people from falling into poverty traps during bad years. Such projects have been designed to allow response to famine to be provided cost effectively along a much quicker timeline than occurs with previous response systems. Larger-scale national transactions have been undertaken by the Government of Ethiopia in partnership with the World Food Programme. In many contexts, it is worthwhile exploring efforts at multiple intervention levels. In Malawi, there has been a number of contracts at different levels, which target different climate risk challenges. In addition to the farm level contracts, there have been meso-level transactions, with banks or contract farming organizations holding contracts to protect their members as well as a national government level contract in partnership with the World Bank. Similarly, MVP, which has transacted a set of contracts at the village level designed to prevent development progress from being destroyed by drought, is exploring index insurance strategies that might help farmers gain access to credit.

A weather-based index can be successful, provided the data forming the index are reliable, ongoing and replete with a continuous record (Hess and Syroka 2005). The challenge is to assure that the index sufficiently encompasses the actual losses for a particular farmer (Skees *et al.* 1999) or farmers' cooperatives. Furthermore, the World Bank (2005) added that "weather-based indices are not appropriate for all growing conditions or all crops because microclimates are highly variable within close proximities, such as hillsides". Much work remains to be done to develop the necessary techniques and practices to address the future challenges in index insurance. Nevertheless, index insurance provides a safety net for farmers and protection against climate shocks.

This insurance provides a sense of security to smallholder farmers and allows them to make investments in on-farm inputs and AWM (eg, irrigation), thus allowing for the opportunity to boost output and build food security. Because insurance prices and policies can be updated, insurance could be an important tool for adaptation. In the short term, it can allow increased accumulation of wealth of smallholder farmers for use in successful financial transitions. By representing climate change in updated insurance pricing, incentives can be made available to manage worthwhile risks while transitioning out of activities that become infeasible as climate change unfolds.

4.4 Information Management

The role of information and knowledge as a component of any climate change adaptation strategy cannot be overemphasized. While economic development is the best means by which to build resilience, climate-informed policy and practice supported by climate information services and data may help to reduce the burden and contribute to the achievement of the MDGs and sustainable development. Climate information is a broad term that includes summary statistics of climatic variables (rainfall, temperature, wind, etc.), historic time-series records, near real-time monitoring, predictive information from daily weather to seasonal to inter-annual time scales and climate change scenarios WMO (2007). It covers a range of spatial scales and can include derived variables related to impacts such as streamflow, water management, crop water satisfaction indices and epidemic disease hazards.

In principle, it is the responsibility of the national meteorological offices to make appropriate observations and to process data to produce the information required by decision makers. But in practice, constraints associated with mandates, priorities and capacities of meteorological offices often oblige potential users to either create their own climate information or get by without it. Reasons for the difficulties in obtaining climate information from the meteorological offices vary. Often it is against government policy to disseminate data freely, for reasons that include a strong push by donors for privatization and institutional cost recovery.

Another reason is inadequate resourcing due to low prioritization in national budgets. While the factors that have led to restrictive data policies may be understandable, the consequences for development have been disastrous. Although countries are encouraged to maintain their observation networks to high standards, technological developments, notably satellites and numerical modeling, are changing the field. Many meteorological offices in Africa have daily access to vast amounts of high quality information from the global network. This includes top quality forecasts, satellite observations and a multitude of ancillary information steadily increasing in abundance.

Information and data management is one of the challenges and constraints affecting climate change adaptation and mitigation in SSA. Different countries have a scattered number of stations that collect different meteorological, and to some extent, hydrological data. Some countries have experts responsible for weather predictions and forecasts providing early warning signals on climate variability. However, data consistency and its availability in usable forms are hindered by inadequate coverage, personnel and modern equipment. A number of national and international research stations also are mandated to collect climatic data such as temperature, rainfall and wind speed for use in research. This information can also be shared with other stakeholders under proper arrangements. Some universities also have been mandated to manage information on the environment and they hold some data on climate. Hydrological data on river levels, daily flows and lake levels are collected by relevant government ministries and used in water resource planning, management and river basin development. A number of transboundary river basins have joint river flow monitoring systems and information-sharing protocols.

Even where long term data exist, filling the data gaps is another challenge that requires greater concentration on community-level participation in observational networks and improving communications to be able to deliver climate services (IRI 2006). Strengthening the observation network is only one side of the coin. If quality control is not embedded in the collection of data, and presented in a format that encourages stakeholders to use the data, the outcomes of such initiatives will be far less than the potential. (IRI 2006) noted that "in order to maximize the development benefits of new investments in nationally and globally relevant observing systems, it is recommended that such investments prioritize the following three initiatives, in the order given:

- "Data rescue, management and dissemination
- Renovation of recently quiet stations such that the archived data from those stations can be used in conjunction with new data
- New stations that combine future benefits (once the station has been running for many years) with immediate benefits such as calibrating satellite data or cross referencing with other data sources (eg, streamflow records)."

4.4.1 Hydro-climatology

The success of any adaptive strategy for optimizing AWM depends entirely on reliable meteorological and hydrological information (Brown and Hansen 2008). In many instances, application of hydrological models on a basin-wide scale is restricted by data availability and consistency. Reliable impact assessments and future predictions depend on robust and updated databases. For example, flood propagation and thus flood warning capability, which are real-time processes, are a function of the density of stations and continuity of measurements. IPCC (2001) reported that "crop yield forecasts can be made spatially more accurate by improving the intensity of climatic measurements".

The density of hydro-meteorological stations in SSA is low and hinders the use of the data for many applications such as modeling and forecasting. Moreover, the non-continuity and inconsistency of the data emanating from these few stations is equally problematic. A wide range of data is necessary to adequately monitor climate and water supply status (eg, precipitation, temperature, streamflow, groundwater and reservoir levels and soil moisture). These data are often unavailable at the density required for accurate assessments. Data quality and the length of recorded data are also critical deficiencies. Wilhite *et al* (2000) noted that "existing networks need to be maintained and expanded, and data reporting needs to be automated wherever possible to ensure timely receipt." This can be achieved by using modern equipment and remote sensing techniques. UNEP (1992) stated that "because accurate data are required to improve climate monitoring and preparedness to cope with droughts and floods, as well as to enhance the early warning system and decision making on sustainable water resources management," financing such data collection is critical. The need for state-of-the-art equipment to replace the obsolete cannot be overemphasized. Capacity building in the use of new equipment, data analysis, storage and sharing to improve upon water resources management is crucial.

Part of this problem is being addressed by the World Hydrological Cycle Observing Systems (WHYCOS) of the World Meteorological Organization (WMO). The WHYCO aims to establish basin-wide water resources information systems worldwide by making up-to-date, quality information easily accessible to all types of users through the internet. The WHYCOS program has specific ongoing projects in several SSA regions and river basins: SADC HYCOS, Niger HYCOS, Volta HYCOS, Chad HYCOS and Congo HYCOS. Senegal HYCOS is about to be started. The HYCOS projects reinforce the technical and institutional capacities of the national hydrological services of the partner countries. They strengthen the hydrological observing networks by using remote measuring technology options and promote the development of national and regional databases. More funding of HYCOS projects is necessary to improve hydro-meteorological data collection.

4.4.2 Climatic variability prediction and forecasting

Harrison and Williams (2008) noted that "climate variability has received less attention than other development issues, in part because it has been considered part of an environmental baseline that is not amenable to management. Yet there is growing recognition that better management of climate risk is both a crucial step toward achieving the MDGs and an opportunity to build some of the resilience needed to adapt to the uncertainties of a changing future climate".

In the past few decades, several things have changed the landscape of climate information products, including three fundamental realizations:

a. The base state of the climate system is changing.
b. Climate variability is, to some extent, predictable.
c. Remote sensing systems can provide valuable climate information.

Accompanying these developments is an increasing awareness of the value of this new information. Climate services now include all aspects of climate, from observations and forecasts to application of the information. But researchers in the field of hydro-climatology need help to better understand the dynamics of climate and its impact on water resources and climate change in SSA. So far, according to IPCC (2007), "climate change prediction and impact assessment using existing global models has been inconsistent and it is unclear as to how some parts of the continent will be affected."

There is great potential in investing in seasonal forecasting and development of tools such as crop models that can be used to make adjustments in management (McCarthy *et al*. 2001). IPCC (2001) noted that "although these models are still experimental, they offer a realistic response to changing climatic patterns. Data must be collected to calibrate and validate these models, and in the longer term governments will need to develop strategic plans based on solid foundations. This area is underdeveloped in almost all of Africa". However, a number of regional climate change monitoring initiatives exist that can provide necessary data for forecasting and preparedness. Examples of these early warning systems are:

- ACMAD, based in Niamey, Niger
- The Center for Agro Hydro Meteorology (AGRHYMET), also based in Niamey
- The Prévisions Saisonnières pour l'Afrique de l'Ouest (PRESAO) in Ouagadougou, Burkina Faso
- Assessment of Impacts and Adaptations to Climate Change
- The SADC Drought Monitoring Centre (currently based in Botswana)
- The IGAD Climate Prediction and Application Centre, based in Kenya
- USAID's Famine Early Warning System Network
- CILSS
- The Program of Inducing Precipitation through Cloud Seeding in the Sahel
- UNDP's Drought Risk and Development Network

Early Warning Systems currently in use include decadal (10-day) rainfall total, the water requirement satisfaction index (WRSI), the Normalized Difference Vegetation Index (NDVI) of the National Oceanic and Atmospheric Administration (NOAA) and other crop- and rangeland-based models (Patt and Winkler 2007). As the face of agriculture changes, early warning systems will have to change to cope with the greater variety of crops, the greater scale at which the information is available and a greater focus on accurately reflecting the needs of small-scale farmers. Monnik (2000) noted that "traditionally, drought early warning systems primarily comprised physical indicators of recent meteorological conditions". Wilhite and Svoboda (2000) added that "effective drought early warning systems must be an integral part of worldwide efforts to improve drought preparedness. Thus timely and reliable data must be the cornerstone of effective drought policies and plans."

One viable option is to build a central information system to disseminate climate-related data that are both accessible and understandable to farmers throughout the continent. This is important since access to accurate and timely climate information can reduce the vulnerability of farmers to climate extremes. Hansen (2002) listed several effective climate forecast requirements:

- "Forecasts must address both perceived and real needs.
- Benefits are contingent upon the options that such information provides and on compatibility with the user's goals and constraints.
- Data must be presented at a relevant scale and time frame.
- Information must reach the appropriate audience in a useable form and with sufficient time to apply it to the decision process.
- Forecast sustainability requires long-term institutional commitment to provide applicable forecasts and subsequent extension support."

Climate forecasts can serve as tools to manage climate risks in a shorter time frame, thus alleviating the burden that a changing climate places on smallholder farmers (Hansen *et al*. 2007). In addition to access, climate forecast information should:

- "Be down-scaled to the local farmers' or community level
- Include information on the timing of variables (eg, the onset of the rainy season or drought)
- Provide the level of confidence in predictions (probability terms)
- Be projectable in terms of agricultural impacts and management implications."

As the accuracy of forecasts improves and communication capabilities expand, the use of climate forecasting will become increasingly effective as a climate adaptation mechanism. Seasonal forecasts may corroborate some of the changes or inclinations that farmers already suspect, but that at present are only a secondary source at best (O'Brien *et al.* 2000). Institutional commitment is essential in building a reliable and accessible network of diverse climatic information. The use of such information by farmers can be further enhanced if innovative measures, such as the use of radio and local languages, are used to disseminate information.

4.4.3 Data collection and management

Wilhite *et al.* (2000) correctly stated "data and information on emerging drought conditions, seasonal forecasts and other products often are not delivered to users in a timely manner". This characteristic significantly limits the usefulness of the data, and hence as Wilhite *et al.* (2000) noted "it is critical that delivery systems be improved and made to be location-specific. Long-term drought forecasts (a season or more in advance) are in most instances unreliable. Drought forecasts often do not provide the specificity of information (eg, the beginning and end of the rainy season, distribution of rainfall within the growing season) needed by farmers and others to be useful for operational decisions". Due to lack of standard monitoring procedures, available data cannot be compared and are inadequate to plan regional action for the sustainable development and use of shared groundwater (UNESCO 2002).

In many countries, the density of meteorological and hydrological stations is insufficient to provide adequate coverage for drought monitoring. Moreover, these data are not widely shared between government agencies. In some countries, the high cost of data acquisition from meteorological services restricts the flow of information for timely assessments and for use in research. To address this problem, a drought preparedness and mitigation plan should be developed. According to Wilhite *et al.* (2000) such a plan should be "integrative, proactive and incorporate the following elements:

- Drought monitoring and early warning systems
- Drought risk and impact assessment
- Institutional arrangements, including mitigation and response actions and programs."

Wilhite *et al.* (2000) further stated that "priority should be given to improving existing observation networks and establishing new meteorological, agricultural and hydrological networks, as well as associated analytical and predictive tools and models. It is critical that an integrated approach to climate monitoring be employed to obtain a comprehensive assessment of the status of climate and water supply. Too often, drought severity is expressed only in terms of precipitation departures from the norm, neglecting information about reservoir and groundwater levels, streamflow, vegetative health and soil moisture"[36].

UNECA (2009) noted that "poor rural people with few choices and little access to resources and whose livelihoods are climate-sensitive are most at risk from climate uncertainty. Hydropower production, irrigation resources, fisheries, pastoralism, post-harvest industries and settlements liable to flooding are all at risk. Currently, climate data is little used in development processes in Africa because of weaknesses in both demand for and supply of pertinent climate services". WMO (2006) stated that "complete, quality-controlled archives of historic daily observations are central to many development applications. They provide the basis for understanding trends, deriving climate statistics of interest and placing current observations into historical context. Climatic time series are particularly important for water resource management. Levees, dams and reservoirs are often engineered on the basis of inadequately short records of flood levels, with dramatic examples of inadequate flood or drought protection".

Since information may be required before network data can be collated and disseminated, satellite data are now widely used for large-scale weather monitoring in near real time. Satellite data is calibrated using available but inconsistency rainfall records, hence the quality is far inferior to what it could be if the observations were adjusted using all locally available gauges. The quality of satellite data is also affected by interference from humidity, temperature and dust. However, rigorous quality checks and blending satellite data with the available rain gauge data would help to overcome these problems. These are some of the challenges being addressed by the Climate for Development in Africa (ClimDev Africa)[37].

- "Strengthened climate observation networks and improved data management
- Improved climate services for a variety of user needs
- Incorporation of climate risk management practices in development planning
- Raised awareness and enhanced political engagement among African decision makers."

The expected outcomes associated with program implementation include improved food security and opportunities for agricultural growth, better protection from malaria and other climate-sensitive diseases, better management of water resources, better management of disaster risks, improved environmental sustainability and more judicious use of energy resources.

36 Means to measure and monitor soil moisture are expensive.

37 See, http://www.wmo.ch/pages/prog/gcos/index.php?name=climdevafrica.

4.5 Capacity Building

Inadequate capacity (technical, financial and institutional) remains one of the significant challenges affecting climate change adaptation in SSA. The foregoing assessment highlights the high vulnerability of Africa to climate change as a result of limited adaptive capacity at the national level. Mutasa (2007) stated that "adaptive capacity was influenced largely by the ability to communicate potential risks to vulnerable communities and the ability to react as a result of perceived risks. For example, the floods of February 2000 in southern Africa that affected Mozambique, South Africa, Botswana and Zimbabwe highlighted huge differences in adaptive capacities between countries". IPCC (2001) added that "the ability to mobilize emergency evacuation was critical in reducing adverse impacts. Although there may be high adaptive capacity locally or nationally, most countries in Africa have low capacity to adapt to abrupt or extreme events". In view of the importance of forecasting to climate change adaptation, support to institutions active in this area to enhance their capacity and operations will go a long way toward improving adaptation.

Wilhite *et al*. (2000) argued that "to improve adaptation, both at national and regional levels, there is need to develop institutional capacity for climate change policy and planning that includes the creation of a task force composed of government agencies with principal responsibility for climate change preparedness, monitoring and assessment, mitigation and response". This task force could also include key stakeholder/citizen groups, NGOs and development partners. Inadequate capacity is clearly reflected in the weak connection between climate indices and impacts. Wilhite *et al*. (2000) noted that "the lack of effective impact assessment methodologies has hindered the activation of mitigation and response programs and reliable assessments of drought-related impacts. Impact assessment methodologies must be improved to help document the magnitude of drought impacts and the benefits of mitigation over response. Significant investment in interdisciplinary research on impact assessment methodologies could result in considerable progress in addressing this problem".

Capacity building should be considered at different levels (for various stakeholders) and on all aspects related to climate change adaptation, with focus on water resources management by smallholder farmers. At the local level, farmers' capacity needs to be enhanced to increase on-farm water-use efficiency and productivity – the 'more crop per drop' principle. However, farmers who have no previous experience with irrigation or who have no experience with producing and marketing high-value crops may not respond readily. The establishment of training and demonstration centers would assist farmers in making the transition from subsistence to commercial producer (Blank *et al*. 2007).

Smallholder farmers are expanding production for the local market and participating in export opportunities. In order to meet quality standards, exporters have established systems and trained smallholders in pest management, pesticide handling and safety, and improved agronomic practices. At the national level, both technical and institutional capacity building is necessary to enhance policy formulation, development and coordination of projects, provision of services to farmers, data collection, analysis and management of monitoring climate change, and impacts of adaptation strategies. At the regional level, capacity building is needed to enhance regional integration of adaptation strategies, address transboundary issues, and improve collaboration and networking, especially in research and information sharing. Any capacity building initiative should incorporate local knowledge, past experiences and existing capacity.

4.5.1 Strengthening local innovation systems

Past experiences have shown that successful interventions in AWM are built on local innovations and knowledge. Innovations are defined as new methods, customs, practices or devices used to perform new tasks or improve existing practices. The Royal Tropical Institute[38] defines "an innovation system as a network of organizations, enterprises and individuals that focuses on bringing new products, new processes and new forms of organization into economic use, together with the institutions and policies that affect their behavior and performance". The concept, which originated from policy debate in the industrialized countries in the 1970s and 1980s, still provides useful insights into strengthening agricultural innovation capacity in developing countries.

Local knowledge, gender diversity and innovations are prerequisites for a successful intervention. It would be useful to get some thinking about harvesting the knowledge that already exists on coping with climate variability, and integrating the robust practices at a larger scale where appropriate. The innovation system concept moves beyond the creation of knowledge and encompasses factors affecting demand for and use of knowledge in novel and useful ways (Arnold and Bell 2001). Sunding and Zilberman (2000) argued that "economic forces, as well as the state of scientific knowledge, affect the forms of innovations generated and adopted in various locations. The analysis of adoption or the impact of risk-reducing innovations may require the incorporation of a risk aversion consideration in the modeling framework, while investigating the economics of a shelf life-enhancing innovation may require a framework that emphasizes inter-seasonal dynamics".

38 See, http://portals.kit.nl/smartsite.shtml?ch=FAB&id=14577&Part=Glossary

For any capacity building to be effective, it should focus on a number of key stakeholders – farmers, CBOs, NGOs, extension agents, the private sector, researchers, etc. – who are directly or indirectly involved in climate change adaptation interventions. Farmers' innovations are key to improving AWM as an adaptive strategy for climate change and variability. Building on local knowledge and traditional systems gives the farmers confidence in adopting and promoting new technologies and practices. Farmers rely on their indigenous knowledge in the production process of both food and cash crops. They are the main implementers and adopters of any external or local interventions that can reduce the impacts of climate change and variability. In addition to accruing benefits from climate change adaptation interventions, farmers are also involved in project monitoring and evaluation to ensure its sustainability.

Consideration of gender diversity and empowerment are prerequisite in famers' capacity building. The role of women in agriculture cannot be overstated – about 70% of agricultural activity in SSA, including water management, is undertaken by women (Young 2008). Any intervention must therefore recognize that women and men adapt differently to new technologies or production systems. Subsequently, both genders need diverse skills to cope with change. The NGOs and extension agents who provide technical support and technology dissemination need to upgrade their skills to help farmers cope with changing environments.

In order to strengthen farmers' capacity to adapt to climate change, it will be necessary to implement adaptation strategies through educating farmers with tested and proven methods. Awareness creation can strengthen farmers' capacity to adapt to climate change and variability through:

- Sensitization of farmers to climate change and inter-linkages with water resources management
- Dissemination of information on adaptation to climate change and its impact on farmers through public seminars, radio broadcasts, cultural events, demonstrations and exchange visits, as well as public awareness materials such as brochures, posters and fliers with clear illustrations in understandable languages

It is worthwhile learning from the World Bank innovation system analytical framework (World Bank 2006b), which focuses on strengthening the broad spectrum of technological activities of farmers, organizations and enterprises, and the mechanisms by which these different agents interact.[38] The framework consists of four main elements:

- Key actors and their roles
- The actors' attitudes and practices
- The effects and characteristics of patterns of interaction
- The enabling environment for innovation.

Box 11 shows the nature and focus of capacity building, which incorporate these elements.

Box 11: Key elements of capacity building

- Strengthening the capacity to innovate throughout the agricultural production and marketing system
- Combinations of technical and institutional innovations throughout the production, marketing, policy research and enterprise domains
- Strengthening communication between actors in rural areas through interactive learning
- New uses of knowledge for social and economic change
- Technology invention, transfer and use of science to create innovations in AWM
- Strengthening interactions between actors, institutional development and change to support interaction, learning and innovation to create an enabling environment

Source: World Bank (2006b)

4.5.2 Enhancing capacity in research and technology development

Word Bank (2006b) noted that "although there is an increasing interest in the innovation system concept as a means of understanding agricultural innovation in developing countries, approaches to applying the concept to interventions are still being explored. As the context of agricultural development has evolved, ideas of what constitutes research capacity have evolved, along with approaches for investing in the capacity to innovate".

This is well demonstrated by the shift in focus by the national agricultural research system (NARS) in SSA. In the 1980s, NARS concept focused development efforts on strengthening research supply by providing infrastructure, capacity, management, and policy support at the national level. In the 1990s, the agricultural knowledge and information system (AKIS) concept recognized that research was not the only means of generating or gaining access to knowledge. Rajalahti (2009) reiterated that "the AKIS concept still focused on research supply but gave much more attention to links between research, education and extension and to identifying farmers' demand for new technologies". However, World Bank (2006b) noted that "more recently, attention has focused on the demand for research and technology and on the development of innovation systems, because strengthened research systems may increase the supply of new knowledge and technology, but they may not necessarily improve the capacity for innovation throughout the agricultural sector".

Researchers also need to upgrade their skills to be able address new challenges effectively and provide science-based interventions to enable farmers to cope with climate change. Advanced research skills in climatic data collection and analysis (ie, integrated climate risk assessment) are also needed to be able to predict different scenarios and provide viable options for farmers to cope with anticipated changes. An adaptive participatory research approach on coping mechanisms and demonstrations of adaptation interventions should also be part of the capacity building package. Research on gender mainstreaming and empowerment will also be paramount to ensure that the roles of men and women are well understood in the implementation of climate change adaptation interventions.

In order to enhance research capacity, SSA researchers should collaborate with their counterparts from developed countries (north-south linkage) and also from other developing (south-south linkage) to enhance technology transfer and information sharing. The establishment of networks of stakeholders in research and the implementation of adaptation interventions among scientists, farmers, NGOs, government agencies and development partners will enhance research, information dissemination and usage of research data. Building capacity to monitor research and climate change adaptation interventions to assess impacts and identify gaps that need additional attention is also important. Enhancing capacity in research and technology development therefore calls for a holistic approach that focuses both on different stakeholders and institutional strengthening of research institutions and extension agencies.

5. POLICY AND INSTITUTIONAL ISSUES

5.1 Policy and Institutional Framework

Africa is endowed with vast water resources, but its unequal distribution and high cost of development are responsible for scarcity in many countries . Despite the endowment, UNEP (2008) noted that "natural phenomena such as erratic rainfall patterns and climate change and variability, as well as human factors such as population growth, competition over water and pollution, increasingly threaten the sustainability of resource use, and hence the livelihoods of poor people". It is widely recognized that a radical change in approach is required to adequately address these threats so that available water resources do not become a constraint but serve as an instrument for accomplishing NEPAD's development agenda[40], Africa Water Vision[41] (UNEP 2006), and the MDGs[42]. The Africa Water Vision for 2025 calls for a new way of thinking about water and a new form of regional cooperation. It aspires to 'An Africa where there is an equitable and sustainable use and management of water resources for poverty alleviation, socio-economic development, regional cooperation and the environment,' and specific targets have been set (UNECA et al. 2000). Achieving this vision requires new approaches to governance and institutions, including the adoption of integrated and participatory approaches, management at the lowest possible level and the mainstreaming of gender issues (UNEP 2008).

There is political good will among African policy makers on how to address the looming water crisis. In the Brazzaville Declaration, AMCOW (2007) recognized "equitable and sustainable management of water as the top development challenge for Africa, affirmed the importance of meeting the MDG targets on water and sanitation in Africa by 2015, and underlined that the African water crisis can only be tackled through strong partnerships among governments, the private sector, civil society and development partners". It further stated that "African countries are committed to mobilizing support to facilitate the preparation and implementation of IWRM plans and stressed the need to improve financing and investment". The Ministerial Declaration of the Second World Water Forum[43] held in The Hague in 2000 on Water Security in the 21st Century drew attention to the problems of managing shared water resources to promote peaceful cooperation and developing synergies between various users.

---

40 See, http://www.nepad.org/home/lang/en

41 See, www.uneca.org/awich/africanwatervision2025.pdf

42 See, http://www.undp.org/mdg/

43 See, http://www.waternunc.com/gb/secWWF.htm

UNESCO (2002) reinstated that "this includes cooperation between adjacent states in the case of shared ground or surface water resources".

However, despite political goodwill, implementation of responsive policies and other governance structures to manage water resources will be affected by climate change and inadequate financial commitment (10 percent of GDP for agricultural development) by both African governments and development partners. Hence the urgent need to include climate change adaptation in poverty reduction strategy papers, economic development agendas, NAPAs and development strategies for the short, medium and long term.

All is not lost as regional economic blocks are taking the lead. In West Africa, ECOWAS established a permanent framework for coordinating and monitoring IWRM, which intends to harmonize and integrate various water policies in the region and to define a water policy framework in order to reconcile social equity, economic development and environmental protection. SADC has also developed a regional policy framework, while other countries in eastern Africa, with support from the Sweden-based Global Water Partnership[44], are also in the process of incorporating IWRM principles into their water policy and institutional frameworks.

However, despite political goodwill, implementation of responsive policies and other governance structures to manage water resources will be affected by climate change and inadequate financial commitment (10 percent of GDP for agricultural development) by both African governments and development partners. Hence the urgent need to include climate change adaptation in poverty reduction strategy papers, economic development agendas, NAPAs and development strategies for the short, medium and long term.

In West Africa, ECOWAS established a permanent framework for coordinating and monitoring IWRM, which intends to harmonize and integrate various water policies in the region and to define a water policy framework in order to reconcile social equity, economic development and environmental protection. SADC has also developed a regional policy framework, while other countries in eastern Africa, with support from the Sweden-based Global Water Partnership[44], are also in the process of incorporating IWRM principles into their water policy and institutional frameworks.

44 Africa's political make-up makes it virtually impossible to place agriculture, water and climate change under a single ministry. Even placing water and irrigation in a single ministry has proven to be a nightmare in some countries (eg, Uganda).

To address the impact of climate change, most African countries have developed NAPAs [45] that articulate a number of issues on adaptation and vulnerability to climate change from the perspectives of different sectors. NAPAs also provide a way forward in terms of implementing different sub-projects on adaptations. In most cases, NAPAs are informed by the aspirations of national development visions, which aim at enhancing economic growth, poverty reduction, good governance, peace and stability and global competiveness. The NAPAs' preparation process involved looking at climate change as a threat mainly to an agrarian population that still depends on subsistence agriculture for its livelihood. Sustainable development strategies, both short- and long-term, must therefore address the impact of climate change on agriculture and other key economic sectors. Some of the AWM-related interventions articulated by a number of NAPAs are:

- Improving community resilience to climate change through the development of sustainable rural livelihoods
- Water efficiency in rainfed and irrigated agriculture to boost production and conserve water in all areas
- Alternative farming systems, rainwater harvesting and wastewater recycling/ reuse
- Developing alternative water storage programs and technologies for communities
- Improving agricultural production under erratic rainfall patterns and changing climatic conditions
- Improving preparedness to cope with droughts and floods
- Improving climate monitoring to enhance early warning capability and decision-making and sustainable utilization of water resources.

According to Mati *et al.* (2007), "most SSA countries have developed national and sectoral policies to address pertinent socio-economic development issues like poverty alleviation, economic growth, agricultural productivity, IWRM, food security and environmental management." Previously, many policies treated water as a social good, but current policy reforms are incorporating IWRM concepts by recognizing water as an economic good (Gumbo and van der Zaag 2001). There are certain barriers in the application of IWRM practice in general or as applied to agriculture. These include demographic pressure and the incompleteness in water management policy, legal and regulatory framework. Despite the positive shift, most policies put

45 See, http://www.afraca.org/

emphasis on drinking water while paying minimal attention to agricultural water, even though it consumes more water. For instance, only a few countries have enacted irrigation development policies.

AWM is a cross-cutting issue among many sectors (eg, 13 sectors in eastern and southern Africa (Mati *et al.* 2007) and its related policies are scattered in those sectors. There is no clear sector coordination, which affects development and implementation of AWM strategies. The scattering of AWM issues across many sectors has led to overlapping of policies, policy gaps, contradictions and duplication of efforts among sectors. For instance, the role of rainfed agriculture in SSA and the policies on 'green water' management have not been given adequate attention (Mati *et al.* 2007). Conflicting institutional mandates have also been affecting policy formulation and implementation, and hence promotion and adoption of AWM, especially among smallholder farmers. This is aggravated by inadequate capacity (human, physical and financial), which makes it difficult to implement AWM projects and programs.

This scenario will have to change because of climate change and variability and their impact on agricultural development. Most analysts in the less-developed countries believe that the urgent need is to identify policies that reduce recurrent vulnerability and increase resilience. Prescriptions for reducing vulnerability include drought-proofing the economy, stimulating economic diversification, adjusting land and water use, providing social support for dependent populations and providing financial instruments that spread the risk of adverse consequences from individual to society over longer periods. For the short term, development strategies should ensure that livelihoods are resilient to a wide range of constraints (Rayner and Malone 1998).

The impacts of AWM-related policies on water use by smallholder farmers are many and have positive and negative effects (Mati *et al.* 2007). The case of the *Office du Niger* in Mali offers a good example on how creating the right conditions, comprehensive macro-economic policy and institutional reform have turned irrigated agriculture into a profitable undertaking, providing sustainable livelihoods for farmers and the entire regional economy (Aw and Diemer 2005). This success illustrates the important contribution irrigation reform can make to poverty reduction, food security and economic growth. Most water management policies and institutional reforms have positive effects on AWM; however, their impacts are constrained by non-supportive land policies and insecure land tenure. Moreover, dominant patrilineal or matrilineal customs impact negatively on gender equity regarding access to land and water, and consequently deter investment in AWM.

Decentralization of AWM, especially through WUAs, empowers farmers and improves water management. WUAs enhance a holistic supply-demand approach to water management (Mati *et al*. 2007). Farmer unions and cooperatives also have a role to play – they negotiate and lobby on behalf of smallholder farmers' interests. The low capacity of smallholder farmers can also be enhanced through WUAs and farmers' unions or cooperatives. Credit to inputs and market accessibility can be enhanced through collective action. WUAs also improve operation and maintenance of irrigation schemes through raised income from water pricing and enhanced access to water by smallholder farmers. The introduction of water use fees makes farmers realize that water has value and thus the need to use it wisely (Mati *et al*. 2007).

At international scene, the UNFCCC 15th Conference of Parties (COP15) in Copenhagen in December 2009 provides an opportunity for shaping policies related to climate change and agriculture. If agriculture is not included, or not well included, in the international climate change negotiations, the resulting policies could threaten poor farming communities in many developing countries (Nelson 2009). The policies could also impede the ability of smallholders to partake in new economic opportunities that might arise from the negotiations. According to Nelson (2009), agriculture must be on the Copenhagen agenda and three avenues must be pursued:

a. "Investments. There must be explicit inclusion of agriculture-related investments, especially as part of a Global Climate Change Fund.
b. Incentives. There must be a deliberate focus on introducing incentives to reduce emissions and support technological change.
c. Information. There must be a solid commitment to establishing comprehensive information and monitoring services in soil and land use management for verification purposes."

5.2 Necessary Governance Reforms

The global policy dialogue informs the national governance reform process. A review of some country-level policies and institutional frameworks revealed a number of critical issues that need to be addressed to enhance climate change adaptation. These include:

- Lack of an integrated approach in addressing climate change adaptation
- Increasing demand for water coupled with climate change is compromising existing national development plans and strategies
- Conflicting sector-based policies dealing with different aspects of water resources

- The irrigation sector has been shifting between different government ministries, especially agriculture and water
- Agriculture, water and climate change are addressed under different ministries [46]
- Different components of AWM are handled by different government ministries in most cases – irrigation under water, rainfed systems under agriculture

- Inadequate coordination of the activities of the various sectors and programs that deal with water resources may affect adaptation to climate change and variability

The following are some of the critical policy and institutional issues that should be addressed to effectively formulate and implement smallholder AWM-related interventions for mitigating the impacts of climate change and variability. Clear policies, implementation strategies and institutional framework are required in many countries. For instance, in Uganda, water for production is still claimed by both the Ministry of Agriculture and the Directorate of Water Development. Unless such institutional issues are settled, it will be challenging to initiate AWM interventions in Uganda and other countries. Thus different sectoral policies should be harmonized to reflect how each related sector plans to address climate change.

A number of countries, notably Kenya and Tanzania, have developed or are in the process of developing irrigation policies; hence the need to incorporate adaptation strategies since any water-related agricultural intervention will be affected by climate change and variability. Moreover, the 3rd IMAWESA conference in Addis Ababa proposed that policy and institutional reforms should strive to:

- Coordinate and harmonize AWM policies across several sectors.
- Optimize water allocation and resolve conflicts among agriculture and other water users (domestic, industry, and environment).
- Embrace participatory management that gives more responsibility to water users.
- Equitably share water resources and improve trans-boundary water management.

46 Africa's political make-up makes it virtually impossible to place agriculture, water and climate change under a single ministry. Even placing water and irrigation in a single ministry has proven to be a nightmare in some countries (eg, Uganda).

- Improve efficiency and sustainability of AWM interventions by building capacity of the farmers, among other stakeholders.
- Promote collective action and build local institutions to manage water and provide services to smallholder farmers to enhance the value chain approach to improve water productivity and farmers' profitability.
- Enhance adaptive and applied research and information sharing to enhance efficient water use, agricultural production and climate change adaptation.
- Establish mechanisms to support rural savings, credit schemes, micro-finance and extension services.
- Promote public-private partnerships and increase investment in AWM and adaptation to climate change.

Merrey and Sally (2008) revealed that "despite the high potential of AWM technologies, serious policy impediments slow down their implementation and scaling up both at national and regional levels. This challenge can be addressed as follows.

- Countries should, in consultation with national and regional stakeholders, adopt consistent, supportive national and sub-regional policies, and designate a lead agency to promote and support AWM technologies.
- Countries should consider limited time 'smart' subsidies to kick-start a process of development as part of a longer-term AWM development strategy.
- Countries should consider designing programs targeting low-cost AWM technologies to specific poverty-stricken groups who may be able to use them to improve their own health and nutrition status even if they have limited access to markets.
- Create larger sub-regional markets for the input side in addition to the output side to achieve economies of scale in the manufacture and provision of AWM technologies.
- Promote AWM as part of longer-term development programs to make a substantial and sustainable contribution.
- Technology providers should offer a menu of technologies and practices and encourage farmers to mix and match, testing and adapting combinations under their own conditions
- Initiate regional networks or programs to create the capacity for enhancing innovation, and to share and disseminate these innovations."

The following policy and institutional reforms adapted from Mati *et al.* (2007) are relevant to this study.

- "The policy formulation and/or reform process should involve all stakeholders since the participatory dialogue will enrich AWM policies and ensure their adoption and implementation.
- Democracy, decentralization and devolution of the decision-making process should be upheld as these principles are associated with positive reforms such as reduced public sector dominance and increased private and community sector investments and participation.
- Specific policies that target AWM are needed and, where such policies exist, they should be harmonized and a national coordination mechanism created for various sub-sectors.
- Governments need to develop, support and strengthen institutional frameworks for effective coordination of agricultural water resources planning, development and management. These institutions need to be empowered with human, physical, technical and financial capacity.
- Farmers should be encouraged to develop and uphold community-based policies and institutional frameworks on AWM, and to review them regularly so as to make them responsive and relevant to changing socio-economic and technological advances and new challenges such as climate change and variability. Existing and new legislation and policies need to be harmonized with community laws and local knowledge to ensure compliance with customary norms.
- Deliberate efforts should be made toward creating awareness on improved AWM amongst stakeholders as well as collaborating and networking between various institutions and development partners implementing AWM projects and programs.
- Farmers should be fully involved in the design, establishment and management of smallholder irrigation schemes through participatory approaches and empowerment processes (technical, managerial and financial) to ensure sustainability of AWM projects and programs. Farmers' involvement should be promoted through effective institutional mechanisms (such as the support of WUAs) for enhancing the role of smallholder farmers in water resources management.
- Governments and development partners should increase support for research activities and in-depth studies on all the aspects of AWM such as wetlands management, RHM, water resources development and management, climate change adaptation strategies, water productivity and policy issues."

Moreover, to address transboundary issues on adaptation to climate change, development of a sub-regional strategy is necessary to enhance the capacity to mobilize resources and share experiences from other regions and between countries. Nevertheless, a regional water strategy should focus on the following objectives

- Foster the development of adaptation guidelines in terms of water management.
- Support the harmonization and integration of water-related policies in the region.
- Encourage development frameworks for water management at national and transboundary basins by reconciling economic development, environmental protection and social equity.
- Develop and implement risk management and mitigation strategies, including early warning systems.
- Promote water governance, investments in the water sector, technology transfer and regional cooperation and integration.

Finally, any successful governance related intervention aimed at assisting smallholder farmers cope and adapt to climate change should also incorporate appropriate support services such as micro-credit (for inputs), extension (technological and management package) and marketing infrastructure (linking farmers to market).

5.3 Farmer Support Services

Farmer support services have been dwindling in most countries in SSA. This was echoed by participants at the African farmers' meeting in Addis Ababa in May 2008, whose final declaration stated that 'Despite the low prices of African agricultural raw products, leading to the impoverishment of the smallholder farmers, the states have harvested much wealth that has not been re-invested in the rural sector.' The main farmer support services are credit services (for inputs), extension services (technology dissemination and information sharing) and marketing infrastructure (roads, communication and storage facilities). These services must be developed to better serve the farming population.

Nevertheless, to enhance the capacity of production by farmers, some governments have put in place mechanisms of credit services to provide loans to the farmers for the purchase of water pumps, chemicals and other products. Also, some private financial institutions, NGOs, local and international organizations are supporting smallholder farmers through the mechanism of micro-credit. For instance, MVP has initiated a phased form of credit (or subsidy) system on agricultural inputs, where the percentage repayment increases from 0 to 100 percent over a period of four years.

This initiative is meant to build farmers' capacity by increasing their financial resources to gradually make them viable to apply for credit from the private sector. In Mali, a credit scheme for purchase of farm machinery and inputs such as seed, fertilizer and fuel could increase the financial return to the farmers. Farmers are obliged to sell their crops at the point of harvest to repay their debts. However, if they were able to store the grain for at least three months, the value of rice would increase from USD 185 to USD 320 per ton. The timing of the repayment period is crucial and determines farmers' profitability. Different credit systems have been tried in many countries with various degrees of success, such as *Kilimo Biashara* and *Kilimo Plus* in Kenya. Credit facilities with low interest rates are very attractive to smallholder farmers.

At the continent level, the African Rural and Agricultural Credit Association (AFRACA)[47], an association of banks and financial institutions, provides financial services for rural development in Africa. It was established in 1977 with support from FAO and is a membership organization open to central banks, commercial banks, government institutions and other institutions involved in rural development in Africa. Currently, its membership comprises 36 financial institutions. Its membership indicates the concern of African bankers to enhance rural development through credit services. Among other objectives related to agricultural credit, AFRACA supports rural financial development through linkage banking programs, which strengthen financial relationships between banks and self-help-groups for savings mobilization and credit delivery. This is aimed at facilitating and mobilizing savings by self-help groups so that they can generate their own collateral and loan guarantees. Currently, the program is being implemented in Burkina Faso, Cameroon, Nigeria, Uganda and Zimbabwe. There are plans to extend the program to other SSA countries.

Although the agricultural banks provide loans to farmers based on agri-business plans, they still require a guarantee or collateral. The best way to help farmers is to develop micro-finance infrastructures supported by governments and development partners who guarantee the loans and support the borrowers until their production and income stabilizes. Indeed, the micro-credit concept, invented by Professor Mohammed Yunus and implemented through his Grameen Bank[48] in Bangladesh, which was created in 1983, may be the best way to help poor smallholder farmers. Based on a similar concept, Crédit Agricole, in partnership with the Grameen Bank, launched a foundation with a EUR 50 million budget called Crédit Agricole Microfinance Foundation[49]. The

47 See, http://www.afraca.org/

48 See, www.grameen-info.org/

49 See, www.grameen-credit-agricole.org/en/index.html

foundation's mission is to develop global initiatives in favor of micro-credit through technical and financial assistance. In 2009, the foundation will launch a fund with a budget of EUR 150 million dedicated to micro-finance. Another upcoming initiative is by MicroLoan Foundation[50] , which is a UK-based microfinance charity providing small loans, business training, and continuing guidance to groups of women in SSA. Another promising micro-finance institution is the Kenya-based Equity Bank[51], which targets small enterprises and smallholder farmers in eastern Africa. In Malawi, Opportunity International Bank is offering agricultural loans to Mwandama MVP, but the 27% interest rate is too high for the poor farmers to get any meaningful profit.

The micro-credit sector is still in a nascent development stage in Africa, hence the need to strengthen it through capacity building and financial support. Indeed, after the first successes, there is a more uncertain step that requires technical and financial support to allow micro-credit institutions to become independent. The geographical adoption of micro-credit is diverse. For instance, in Asia 38 percent of the banking sector is dedicated to micro-credit, while in Africa is only 8.5 percent. However, even this relatively small proportion has generated positive impacts of credit provision in Africa. For example, the turning around of the Office du Niger irrigation scheme in Mali was partly due to provision of short- and medium-term credit to all farmers, administered through village associations (Aw and Diemer 2005). Provision of credit triggered the shift in management from the government to farmers and subsequently led to rice yield increases and improved operation and maintenance.

The micro-credit sector is still in a nascent development stage in Africa, hence the need to strengthen it through capacity building and financial support. Indeed, after the first successes, there is a more uncertain step that requires technical and financial support to allow micro-credit institutions to become independent. The geographical adoption of micro-credit is not the same. For instance, in Asia 38 percent of the banking sector is dedicated to micro-credit. The figure for Africa is only 8.5 percent. However, even this relatively small proportion has generated positive impacts of credit provision in Africa. For example, the turning around of the *Office du Niger* irrigation scheme in Mali was partly due to provision of short- and medium-term credit to all farmers, administered through village associations (Aw and Diemer 2005). Provision of credit triggered the shift in management from the government to farmers and subsequently led to rice yield increases and improved operation and maintenance.

50 See, www.microloanfoundation.org.uk/

51 See, www.equitybank.co.ke/

In addition to the provision of credit, extension services should be incorporated in all aspects of rural development. From regional to national levels, a range of extension services has been available for many years to enhance farmers' capacity to produce and market their crops. Within the public sector, the ministries of agriculture have set up extension services to help the farmers on technical matters, machinery, seed breeding, agricultural practices, water management, and so on. A number of NGOs, development partners and farmer cooperatives also offer extension services to some extent.

In recent years, however, public extension services have been declining due to inadequate financial and human resources and poor infrastructure. The World Bank initiated the Structural Adjustment Program, which, after encouraging voluntary retirement of low level government staff, left many ministries understaffed. Although it was meant to improve delivery of services and cut recurrent expenditure, some services (eg, agricultural extension) were negatively affected. The anticipated private sector takeover of extension services was not successful. A gap therefore exists in the provision of extension services. New initiatives are needed to enhance service delivery to smallholder farmers, especially under climate change adaptation interventions.

Many of the existing extension services in SSA are derivatives of those established during the colonial period with a top-down system of information dissemination. However, since the 1980s, there has been a notable shift towards farmer-based participatory extension services (Green 2006). With new challenges and technological advances, the role of extension services has become more complex. Extension services are now expected not only to provide consultation on agronomic concerns but also on such areas as sustainability, biodiversity and natural resource conservation (Venkatesan and Kampen 1998), as well as climate change.

The transfer of local knowledge between farmers should not be overlooked. An effective extension service is one that can absorb and disseminate indigenous practices along with supplementary technological advances (Berhanu 2008). Peer learning through farmers' exchange visits and on-farm demonstrations have been found to be the most effective modes of technology transfer (Ngigi 2008). Essential to this process is the aligning of agricultural education with the larger national development agenda through targeted sectoral training (Davis *et al.* 2007). Furthermore, extension agents must be sufficiently armed with the capability of providing timely and competent consulting relevant to local needs. Ultimately, extension services provide a means to build adaptive capacity through increased exposure and knowledge transfer to vulnerable smallholder famers. An open and collaborative dialogue between these two entities may indeed create an effective strategy in combating the impacts of climate change.

Another essential farmer support service is marketing. Marketing is the backbone of African farmers at national, regional and international levels. Inadequate marketing infrastructure – mainly transport and communication – and the proliferation of middlemen[52] continue to hinder farmers' realization of benefits from their produce. Climate change can only aggravate the situation, especially in terms of communication (eg, the roads between producing centers and markets) and disrupting cropping patterns. Therefore, local producers should work with governments to put in place effective strategies to promote local products and develop marketing systems. Despite the good quality of African cotton, for instance, inadequate marketing strategies make it less preferable in international markets.

The current food and energy crisis is an opportunity for African smallholder farmers to take advantage of the high prices of imported food products to increase local production. The development of centralized marketing centers through cooperatives is one of the key strategies to promoting marketing of farm produce. A good marketing system should include transport, storage (to reduce post-harvest losses), processing (value adding) and selling. If these pieces of the puzzle are put in place, farmers' losses will be reduced and their profits optimized. Storage facilities will also reduce market saturation and ensure reasonable prices. A good example is the grain bank in Mwandama MVP (Malawi), which has not only ensured food security, but reduced post-harvest losses and allowed farmers to sell their produce at profitable prices. This concept of farmers' grain bank is being adopted in most of the MVP clusters in 10 countries in SSA.

Finally, to reduce the influence of middlemen, contract farming and marketing cooperatives should be encouraged, and farmers should be trained in the best ways to maximize profits. According to Bindhumadhavan (2005), "contract farming is defined as farming of any agricultural produce on the basis of a contract between farmers and a big wholesale buyer or seller. Basically the contract is entered before the farming activity starts because the buyer can then stipulate the condition of the cultivation, use of the grade of the seed, pesticides, insecticides, caring of the crop, grading processing and packaging. Contract farming is beneficial in several ways. It reduces the risk of farmers, ensures a proper price, makes up the market, increases quality consciousness, ensures higher production and reduces distribution cost. Further

52 We do not suggest that farmers should market their own produce. What they need is an appropriate marketing environment that gives them the right to determine the farm-gate prices. Inadequate marketing infrastructure, not middlemen, is what reduces the profit margins. However, middlemen compound the problem by taking advantage of poor marketing infrastructure to exploit the farmers. Middlemen should be dealt with by farmers' cooperatives to reduce their influence on pricing.

it also ensures supply of quality agricultural produces to the industry at right time, at lesser cost and channels direct private investment in agriculture".

A good example of a contracting farming scheme is the outgrowers program of Homegrown, a Kenyan company that produces cut flowers and vegetables for the European market. Homegrown has an out-grower program that works with over 600 outgrowers producing green beans and other crops in 11 regions around the country, including Naro Moru, Thika and Machakos (Blank *et al.* 2007). Crops are produced for several supermarket chains in the United Kingdom that require outgrowers to meet international quality and farm worker safety standards. Farmers are provided spraying equipment and training in safety procedures and are required to rotate crops and fallow bean fields for six months. Farmers are prohibited from spraying during the period prior to harvest, with strict no-spray periods ranging between one and seven or more days, depending on the type of pesticide used. Another example is Mace Foods, a Kenyan exporter, which has sub-contracted Mwitithia Women Self Help Group in Thika to supply it with African Birds Eye chili, an improved capsicum variety and high quality onions (USAID 2006b).

Homegrown has a tracking system that can track shipments back to the individual farmer or at least to the farmer group. Also, farmers are provided with seeds according to what they can produce based on water availability and demand. One of the standards is that the farmers must have a permit for irrigation water. The Homegrown's strategy is to source its crops in various climatic zones so that crops are planted every week and harvested throughout the demand period. Diversifying the supply of produce from different regions minimizes the risk that Homegrown will be unable to provide the UK markets with their expected needs. This is important as water availability (and crop production) varies across regions according to time of year.

However, the effectiveness of contract farming requires a supportive policy environment and regulatory mechanisms to protect the interest of smallholder farmers. Bindhumadhavan (2005) stated that "a legally valid risk sharing mechanism should be formulated to avoid legal wrangle between the producers and contracting firms, which might crop up due to price fluctuations. The risk sharing mechanism should bind both farmers and contracting firms to share the price difference equally so that they do not incur loss during market price fluctuation".

5.4 Stakeholders and Collaborators

Successful implementation of feasible options for AWM related to climate change adaptation depends on how different stakeholders play their roles. There are many stakeholders (national, regional and international organizations) dealing with various elements of climate change adaptation in SSA. The government ministries, especially those dealing with water, agriculture, irrigation agriculture, land, environment and natural resources are charged with various aspects of AWM. In many countries, AWM falls under either the ministry of agriculture or the ministry of water (and irrigation), which provide policy and legislative framework, coordinate related AWM interventions, implement various national programs and projects, regulate activities of other stakeholders, farmers' capacity building, technical backstopping and extension services.

Additionally, various NGOs operate at national or regional levels that are involved community-based interventions aimed at improving the livelihoods of farmers, water and food security, poverty reduction and disaster mitigation, all of which have AWM as core or partial activities. NGO interventions are based on capacity building, technology transfer, research and technology development, extension services, credit provision, community empowerment, policy advocacy and integrated rural development programs. Micro-finance institutions and other private sector counterparts dealing with agricultural credit schemes, supply of agricultural inputs, extension services, crop processing, and marketing should also be brought on board.

Moreover, there are a number of CGIAR centers (IWMI, ICRISAT, IITA, CIMMYT, ILRI, ICRAF and others) working on research, technology transfer, demonstration training/experimentation, farmers' training and follow-up, stakeholders' collaboration and networking in SSA. Other research institutions are NARS and local universities. Bilateral and multinational development partners such as IFAD, DFID, USAID and the Swedish International Development Agency (SIDA), and a number of UN agencies (UNDP, FAO, UNEP and WFP) are also involved in AWM and climate change adaptation interventions. Regional political and economic organizations such as SADC, ECOWAS, ASARECA, NEPAD, IGAD and others are also implementing national and regional initiatives. Annex 3 lists some of the stakeholders.

There is a rich experience in past interventions that new initiatives can build on or learn from to realize the intended objectives. Past experiences show that building synergies among different stakeholders working in the same geographical area and local community is a recipe for success – avoiding the duplication of effort and repetition of mistakes. Working closely with government departments enhances sustainability and reduces dependency among communities since government is seen as a service provider. Unclear and conflicting institutional mandates need to be addressed in some countries because they drastically affect the implementation of good AWM interventions for mitigating or adapting to climate change.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main conclusion of this study paraphrases a statement from the 18 September 2008 issue of The Economist: "The world has a water shortage, not a food shortage", by stating that "SSA has poor AWM, leading to food shortage". Poor AWM is aggravated by climate change, which in turn makes water even scarcer, with negative impacts on vulnerable smallholder farmers. The slogan 'more crop per drop' is becoming more appropriate as countries strive to contend with decreasing water resources. Indeed, if a better understanding of the constraints and opportunities of climatically induced risk is not provided to farmers and other key stakeholders, investment in the rainfed and irrigated agricultural sector in SSA is likely to remain at its current low and inadequate level, resulting in persistent poverty and vulnerability of rural populations. Thus the realization of the much anticipated African Green Revolution is threatened by climate change, which is impacting AWM negatively.

IWMI (2009) stated that "existing AWM technologies, such as drip irrigation and water harvesting, have the potential to double, even quadruple rainfed crop yields in many parts of SSA. But these technologies have been slow to spread because of real and perceived risks as well as lack of practical incentives, knowledge, collaboration among stakeholders and support from government institutions. In addition, reaching the poorest people, especially women, who in many countries make up the majority of farmers, remains a challenge".

In African countries, overall social, environmental and economic vulnerability increases the effects of droughts, floods and other climatic events. UNFCCC (2006) stated that "many factors contribute to and compound the impact of current climatic variability in Africa and negatively affect the continent's ability to cope with climate change. These include poverty, illiteracy, inadequate skills, weak institutions, limited infrastructure, lack of technology and information, low levels of primary education and health care, poor access to resources, low management capabilities and armed conflicts".

In SSA, increasing investment in AWM is one of the promising climate change adaptation strategies for smallholder farmers. AWM can contribute to agricultural growth and reduce poverty, since better management of water will translate into intensification and diversification in developed land, expansion of irrigated areas, increases in food and feed production and environmental conservation. Climate change and variability are rapidly emerging as global problems that affect many sectors. They are serious threats to sustainable development and adversely impact on the environment, human health, food security, economic activities, natural resources, physical infrastructure and energy (IPCC 2007). Climate change will have far-reaching effects on the sustainable development of developing countries, including their ability to attain the MDGs by 2015 (UNDP 2008). However, increased agricultural investments will play a major role in moving towards the achievement of the MDGs in several countries in SSA, in answer the former UN Secretary-General Kofi Annan's call for a uniquely African Green Revolution.

Public sector investment in irrigation development in SSA has been decreasing since at least the 1980s. Many existing schemes have languished without assistance from governments and other sources. However, in many cases, modest investments and technical support can greatly improve the performance of these schemes. Efforts to encourage farmers to diagnose constraints affecting their irrigation schemes, to plan and undertake improvements, to strengthen farmer organizations, to improve water distribution and to market produce have been readily accepted.

It is,evident that rural poverty in Africa is aggravated by climate change and variability. To address the challenge of rural development, investment in sustainable AWM interventions is urgently needed to ensure improved agricultural production, while promoting integrated water resources management and minimizing environmental degradation. AWM interventions include upgrading rainfed agriculture through improved soil and water management and appropriate AWM systems such as rainwater harvesting and conventional irrigation systems. RHM systems, in particular on-farm storage structures (farm ponds, micro-dams and underground tanks), are meant to reduce hydrological risks by bridging soil moisture deficits during intra- and off-season dry spells through supplemental irrigation. Where adequate water is available (eg, permanent rivers/streams, groundwater or large storage reservoirs), small- or large-scale conventional irrigation systems are appropriate.

Most conventional irrigation systems in SSA are based on labor-intensive and inefficient surface irrigation (furrow or basin methods), with irrigation efficiency ranging from 25 to 40 percent. This means that water productivity remains generally low, and returns to public investment are generally disappointing, especially in large-scale irrigation (World Bank 2006a). This underscores the need to adopt advanced and sustainable irrigation technologies such as highly efficient and less labor-intensive water application methods such as improved surface irrigation, sprinkler and drip irrigation systems. The 2008 African Water Week noted that large-scale projects are slower in delivery of outputs and called for promotion, awareness and the uptake of cost-effective, pro-poor AWM technologies and management practices (IISD 2008).

Increasing water supply and management for agriculture are keys to achieving the MDGs and increasing economic growth in SSA. The call for increased investments in AWM in SSA has been echoed by many stakeholders since 2000. For instance, the World Water Council vision for 2025 envisages increasing water supply for agriculture by 15-20 percent from investments in new large and small dams as well as groundwater exploitation (ICID 2001).[53] Besides increasing water supply for agriculture, investments to improve water use efficiency – "*more crop per drop*" – should also be incorporated.

Moreover, the anticipated impacts of climate change on AWM call for urgent attention and more investments. Comparison of cereal yields in SSA (1-2 tons/ha) and Egypt (6-8 tons/ha) further emphasizes the need for increased investments in form of a Marshall Plan to improve land and water productivity while sustaining water resources for other economic and environmental uses. Investment is increasingly focused on rehabilitating and improving the existing systems. Similar sentiments are echoed by World Bank (2006a) by stating that "new solutions are needed, based on new management options and widely available technologies".

Despite the need for increased investment in AWM, caution is necessary to avoid past mistakes that have led to reduction in development support. There is a need to assess past, current and planned water resources management in selected countries in SSA to identify their requirements, build on their experiences, evaluate investment options and integrate mitigation measures against climate change. Feasible options must therefore be identified that may be adapted for different agro-ecological zones in SSA. Various AWM interventions must be identified and the conditions under which they operate optimally evaluated. Due to the site specificity of many feasible interventions, selection should be done in partnership with local communities, irrigation departments and development agents and partners.

Policy, legal and institutional issues must also be considered to give best returns on the investments and ensure sustainability of selected AWM interventions. The focus should be on how each of the countries can achieve its full irrigation potential, and what kind of investments will be required without impacting negatively on the environment and livelihood systems. The focus must be on AWM rather than irrigation alone. As

53 Groundwater accounts for at least 50 percent of the continent's water resources and is less susceptible to climate change than surface water (IISD 2008).

the World Bank (2006) noted, AWM is diverse and has strong links to other sectors and to the broader economy. It is worthwhile noting that AWM has contributed to poverty reduction in irrigated agriculture, but improvements have largely bypassed farmers in rainfed areas. Therefore, interventions for AWM in rainfed agriculture, which comprises the majority of Africa's farming, should also be given priority.

Recent studies indicate that farmers have already adapted to their climates by choosing appropriate crops, livestock and irrigation methods (Kurukulasuriya and Mendelsohn 2006). Farmers with access to seasonal water run-off can improve production with rainwater harvesting technologies. In Ethiopia and Kenya, farmers have shown high adoption rates for farm ponds and other rainwater harvesting technologies. Rainwater harvesting provides an increased level of drought protection and allows more flexibility in market timing for farmers who produce market crops.

To enhance adaptation strategies and adaptive capacity in the water sector, the following key points adopted from IPCC (2007) should be taken into consideration:

- "Water managers have experience in adapting to change. Many techniques exist to assess and implement adaptive options. However, the pervasiveness of climate change may preclude some traditional adaptive strategies, and available adaptations are too frequently not used.
- Adaptation can involve management on the supply side (altering infrastructure or institutional arrangements) and on the demand side (changing demand or reducing risk). Numerous 'no-regret' policies exist that will generate net social benefits regardless of climate change.
- Climate change is just one of numerous pressures faced by water managers. Nowhere are water management decisions taken solely to cope with climate change.
- Estimates of the economic costs of climate change impact on water resources depend strongly on assumptions made about adaptation. Optimal adaptation may be prevented by constraints associated with uncertainty, institutional capacity and equity.
- Extreme events are often catalysts for change in water management. They expose vulnerabilities and raise awareness of climate risks. Climate change affects monitoring indicators of extremes and variability, hence complicating the decision-making process.
- The ability to adapt is affected by institutional capacity, wealth, management philosophy, planning time scale, organizational and legal framework, technology and population mobility.

- Water managers need research and management tools aimed at adapting to uncertainty and change rather than improving climate scenarios.
- Adaptation requires small actions as well as major national approaches. At the management unit level (eg, watersheds), careful management of rainwater through damming will allow agricultural production. There is vast experience in arid regions of Africa such as Namibia, Botswana and North Africa, where brief periods of rain are utilized very efficiently for farming."

Some of the guiding principles – based on Dublin (1992), Agenda 21 and IWRM – for formulating sustainable AWM strategies are poverty eradication, gender mainstreaming, environmental conservation and protection, watershed management, private-public partnerships, community participation and empowerment, MDGs, market-oriented production, improving land and water productivity, decentralization of water resources management, water as an economic and social good, water and environmental governance and adaptation to climate change.

As climate change issues know no administrative or political boundaries, it is prudent to develop a sub regional strategy for climate change adaptation. This will encourage greater attention, collective responsibility and investment in transboundary issues relating to climate change adaptation.

6.2 Recommendations

The study identified and recommended feasible AWM interventions that can be promoted by development agencies to enhance smallholder farmers' strategies for coping with climate change and variability in SSA. The following are some of the promising AWM interventions that should be considered:

1. Smallholder irrigation development includes rehabilitation of existing schemes to improve water use efficiency and productivity. This covers both gravity-fed (most preferable, where applicable, due to low O&M cost), and pumped schemes (from either groundwater or surface water sources (rivers, dams, etc.).
2. Upgrading rainfed agriculture through in situ rainwater harvesting systems – farming practices that retain water in crop land (terraces, contour bunds, ridges, tied ridges, planting pits, conservation agriculture, etc.).
3. Supplementary irrigation systems – farming practices that supply water to crops during critical growth stages. They are appropriate where irrigation water is inadequate for full irrigation or where crops are grown under rainfed conditions and only irrigated during intra-seasonal dry spells or in case of early rainfall cessation.

4. On- or off-farm water storage systems – rainwater harvesting and management systems that allow the farmers to store run-off in ponds (unlined or lined). For communal land or farmers with appropriate sites, large storage structures such as earth dams or water pans can be considered. Water can be supplied to crop land either by gravity or pumping and applied to crops either by surface irrigation (furrow or basin) or pressurized (especially low-head irrigation systems). Other rainwater harvesting structures such as sand dams, sub-surface dams and rock catchment systems fall under this category.
5. Spate irrigation – flood diversion and spreading into crop land is appropriate in areas where flash floods occur, especially in lowlands adjacent to degraded or rocky catchments.
6. Micro-irrigation systems – these include various technologies, among which low-head drip irrigation kits are most appropriate. Low-head drip kits can use many different water sources. They are mainly used for irrigating high-value crops like garden vegetables and orchard fruits, and for green maize production at times.
7. Land drainage, wetlands management and flood recession are appropriate for areas with excess soil moisture, and should therefore be considered where necessary.

Adaptive strategies are needed to promote these AWM interventions, and must include overcoming barriers that hinder adoption by smallholder farmers. They must also provide the focus for replication and up-scaling of best practices in SSA. The identified strategies can be implemented in most SSA countries, since most of them target smallholder farmers who are already experiencing similar problems and constraints to socio-economic development. To ensure adoption, replication, up-scaling and sustainability, the study identified the following prerequisite measures that should be considered to enhance adoption and sustainability of proposed AWM interventions.

1. *Capacity building and awareness creation at different levels (from farmers to policy makers)*
    - Training of middle-level professionals working with different organizations and government – launching a regional training program with local universities.
    - Building capacity of smallholder farmers and extension staff, including NGOs and civil society organizations (CSOs), to adopt and promote integrated AWM interventions.
    - Policy makers – campaign to raise political and public awareness on climate change to influence development and implementation of appropriate and

adaptive policies and strategies focusing on both legislative bodies and district development institutions.

- The need to enhance capabilities and scientific strengths of African countries to address integrated AWM and climate change adaptation, while addressing immediate societal needs. This includes MSc and PhD training on AWM and adaptation to climate change to enhance capacity at local training and research institutions and government departments.
- Enhancing the sharing of expertise and networking among African professionals – establishing exchange programs within SSA (South-South technology exchange).
- Institutional support to regional centers of research and policy advocacy in AWM and adaptation to climate change: one each in eastern, southern, and West and Central Africa to be based at the relevant CGIAR centers or other strong regional organizations (eg, the regional MDG Centres based at Nairobi and Bamako).
- Support for the development and implementation of comprehensive national plans and strategies for adaptation of smallholder agriculture to climate change – these plans should be government-led, multi-stakeholder efforts, the results of which serve to inform national development policies and plans.

2. *Research, technology development and information dissemination*
    - Assessing the potential for sustainable water resources development (both surface and groundwater extraction) at local and national levels.
    - Farmer-based demonstrations/piloting on plot and adaptive research on promising best practices for climate change adaptation in a range of agro-ecological zones and farming systems. The focus should be a district or hydrological unit where a wide range of feasible adaptation interventions, policies and institutional arrangements are piloted. These districts or units serve as models for best practices. Special emphasis is placed on assisting women farmers in adapting to climate change.
    - Analyzing the yield gap, including cost-benefit of alternative irrigation interventions, to ascertain the appropriate systems for bridging yield gaps.
    - Establishing climate change adaptation tools for monitoring early warning systems and adaptive coping strategies. To effectively monitor adaptation strategies and impacts, a stakeholders' coordination forum will be necessary – building synergies and partnerships.
    - Support for applied research and policy dialogue to determine the agronomic and socio-economic potential for adopting AWM interventions, especially

in countries that depend on rainfed agriculture for food security and rural livelihoods.

- Support for applied research and policy dialogue to better understand how best to address the effects of climate change on major transboundary river basins (eg, the Nile, Zambezi, Limpopo and Niger Rivers, which are already experiencing water stress due to climate change.

3. *Appropriate policy and institutional reforms*
   - Support for a professional, public and political awareness campaign that raises the profile of AWM and adaptation to climate change.
   - Support development of comprehensive national investment plans for promoting the adoption of rainwater harvesting and low-cost smallholder irrigation schemes.
   - Reforms that support investments in AWM and partnership among actors/ stakeholders.
   - Reforms that improve water governance and water users' involvement in the decision making process (ie, empowerment of farmers).
   - Mainstreaming gender issues targeting women and vulnerable groups.
   - Strengthening climate communication and information networks to enhance delivery of timely weather information to intended users.

4. *Farmers' support services to promote adoption and adaptation of integrated AWM systems*
   - Establishment of rural service centers to provide technical advice and information on viable AWM options, and other services to farmers.
   - Micro-credit/revolving grants to farmers, especially to women who form the backbone of smallholder farming system in SSA.
   - Crop insurance, where applicable to reduce farmers' risks to crop failure.
   - Contract farming (farmers-private sector partnership).
   - Value addition (processing and storage) and marketing infrastructure.
   - Crop diversification – introduction of high value crops for irrigated lands.

Increased investments in all of the above areas are urgently needed. The aggregate requirements across the continent are much greater than the financial and managerial capacity of a single development partner. The question is how to create maximum impact and leverage through collaboration, and building synergies among different development partners and investors in SSA. To enhance sustainability, a participatory, integrated and multi-sectoral approach is recommended, in which different stakeholders will collaborate and work together to implement different aspects of the proposed interventions – improved AWM. Development partners and investors should target strong collaborative linkages among communities/farmers (CBOs), self-help groups, NGOs/CSOs, the private sector, agricultural research institutions and relevant government departments (eg, ministries of water, agriculture, irrigation). Some potential collaborators are listed in Annex 3.

Programs and projects should target an integrated and multi-sectoral approach – the entire production and market chain (ie, market-oriented production process). Programs/ projects that integrate the needs of smallholder farmers (bottom-up approach), participatory action research, demonstrations, development, training on feasible AWM interventions, information dissemination and networking should be prioritized.

The MVP model is a good learning lesson that can be adopted by development partners and investors. The 14 MVP clusters in 10 countries in SSA have already developed AWM strategies, which should be the basis for funding consideration. The AWM strategies can be converted into smallholder farming business development plans to widen the scope of funding opportunities, and especially to attract social investments in SSA.

Finally, it is clear that opportunities for smallholder farmers to adapt to water shortage induced by climate change are attainable (especially integrated AWM interventions). Addressing climate change adaptation for smallholder farmers is a prerequisite to a sustained Green Revolution in Africa. However, for this to be achieved increased investment, adaptive research and capacity building are needed. This visionary investment requires a pooling of resources and building synergies among various stakeholders.

7.0 REFERENCES

Abu-Zreig MM, Abe Y and Isoda H. 2006. The Auto-regulative Capability of Pitcher Irrigation System. Agricultural Water Management, 85(3): 272-278

Adelena SMA and MacDonald AM (eds). 2008. Applied Groundwater Studies in Africa. IAH (International Associations of Hydrogeologists) Selected Papers on Hydrogeology, Vol. 13, p 518. Taylor & Francis, Oxford, UK

Adger WN, Arnell NW and Tompkins EL. 2005. Successful Adaptation to Climate Change across Scales. Global Environmental Change. 15 (2005): 77-86.

Admas M. 2001. Tenure Security, Livelihoods and Sustainable Land Use in Southern Africa. Paper presented at the Conference on Land Reform and Poverty Alleviation in Southern Africa. Southern African Regional Poverty Network, Human Sciences Research Council, Pretoria.

Agyare WA, Gyasi O, Aduna A, Laube W and Ayariga R. 2008. Potential for Riverine Pump Irrigation for Dry Season Farming in Northern Ghana. Proceedings of International Conference on Global Change and Water Resources in West Africa, The German-African Glowa Projects. 25-28 Aug 2008.

Africa News Network. 2008. African Agriculture: Inventor of Manual Irrigation Pump Wins Prize. Wednesday, April 23, 2008. http://www.africanagricultureblog.com/2008/04/

Akubue A. 2000. Appropriate Technology for Socioeconomic Development in Third World Countries. Technology Studies, 26(1): 33-43

AMCOW. 2007. The Brazzaville Declaration. The 6th Ordinary Session of the African Ministers' Council on Water (AMCOW), May 30-31, 2007. Brazzaville, Republic of Congo. http://www.dwaf.gov.za/dir_ws/2aww/docs/OutcomesandDecisionsofBrazzavillerev4.doc

Appelgren BG (ed). 2004. Managing Shared Aquifer Resources in Africa. Proceedings of the International Workshop held in Tripoli, Libya from June 2-4, 2002. UNESCO, Paris, France, p 238

Aw D and Diemer G. 2005. Making a Large Irrigation Scheme Work: A Case Study from Mali. Directions in Development, World Bank, Washington, D.C.

AWDR (Africa Water Development Report). 2006. Freshwater Resources in Africa. Africa Water Development Report. www.uneca.org/awich/AWDRpercent202006/FreshwaterResourcesinAfrica.pdf

Arnell P. 1999. Climate Change and Global Water Resources: SRES Emissions and Socio-Economic Scenarios. Global Environmental Change, 14: 31-52.

Ashton PJ. 2002. Avoiding Conflicts over Africa's Water Resources. Ambio 31(3): 236-242.

Bandre P and Batta F. 2002. Case Study of SWC in Burkina Faso. In: Slaymaker, T. and R. Blench (eds.). 2002. Rethinking Natural Resources Degradation in Sub-Saharan Africa: Policies to Support Soil Fertility Management, Soil and Water Conservation among Resource-Poor Farmers in Semi-Arid Area. Vol. II - Country Case Studies. pp 1-44.

Barron J, Noel S, Malesu M, Oduor A, Shone G and Rockström J. 2008. AWM in Smallholder Farming Systems: The Value of Soft Components in Mesoscale Interventions. Stockholm Environment Institute (SEI) Project Report, SEI, Stockholm

Barron J, Rockström J and Gichuki F. 1999. Rainwater Management for Dry Spell Mitigation in Semi-arid Kenya. East Africa Agriculture & Forestry 65(1): 57-69.

Berhanu A. 2008. Matching Extension Service with Farmers' Needs: Towards Combining Social and Agro-Ecological Approaches in Ethiopian Extension. Eastern Africa Social Science Research Review Vol. 24(2): 1-25

Blank HG, Ngigi SN and Sijali IV. 2007. Sustainable AWM Systems in Kenya. Paper to be presented at International Commission on Irrigation and Drainage (ICID) conference in Sacramento, California, USA. http://www.icid2007.org/07prog.PDF

Blank HG, Mutero CM and Murray-Rust H (eds). 2002. The Changing Face of Irrigation in Kenya: Opportunities for anticipating change in Eastern and Southern Africa. International Water Management Institute (IWMI), Colombo, Sri Lanka.

Bindhumadhavan PR. 2005. Executive Summary of Round Table Discussion on "Crop Diversification and Water Resource Management: More Crops per Drop". Tamil Nadu State Planning Commission, Chennai, India. www.tn.gov.in/spc/workshop/agri_diversification_wrm.pdf

Boko M, Niang I, Nyong A, Vogel C, Githeko A, Medany M, Osman-Elasha B, Tabo R and Yanda P. 2007. Africa Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change. In: Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.). 2007. Cambridge University Press, Cambridge UK, pp. 433-467.

Bradshaw B, Dolan H and Smit B. 2005. Farm-Level Adaptation to Climatic Variability and Change: Crop Diversification in the Canadian Prairies. Climatic Change 67: 119–141, 2004.

Brown C and Hansen JW. 2008. Agricultural Water Management and Climate Risk. Report to the Bill and Melinda Gates Foundation. IRI Tech. Rep. No. 08-01. International Research Institute for Climate and Society, Palisades, New York, USA. 19 pp. http://iri.columbia.edu/publications/search.php

Burke J and Moench M. 2000. Groundwater and Society: Resources, Tensions and Opportunities. United Nations Department of Economic and Social Affairs. United Nations, New York.

Burton I and van Aalst M. 2004. Look Before You Leap: A Risk Management Approach for Incorporating Climate Change Adaptation into World Bank Operations. Prepared for the Global Climate Change Team, The World Bank, Washington DC.

Burton I, Challenger B, Huq S, Klein RJT and Yohe G. 2001. Adaptation to Climate Change in the Context of Sustainable Development and Equity. IPCC 2001 Report, Chapter 18, pp. 879-906. Cambridge University Press, UK.

Carruthers I, Rosegrant MW and Seckler D. 1997. Irrigation and Food Security in the 21st Century. Irrigation and Drainage Systems 11(2): 83-101

Chapin RD. 1996. The Chapin Bucket Irrigation Kit: Bucket Kits for Vegetable Gardens. Chapin Living Water Foundation. Chapin Watermatics Inc., New York, USA. www.chapinlivingwaters.org

Chapman R, Slaymaker T and Young J. 2004. Livelihoods Approaches to Information and Communication in Support of Rural Poverty Elimination and Food Security: The Literature Update. Overseas Development Institute (ODI). www.fao.org/rdd/doc/SPISSLLiteratureUpdate.pdf

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Koli RK, Kwon WT, Laprise R, Rueda VM, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A and Whetton P. 2007. Regional Climate Projections. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change.

CIMMYT. 2008. Drought-tolerant Maize for Africa: Better Food Security and Livelihoods. Highlights of 2008. The Drought Tolerant Maize for Africa Initiative (DTMA). CIMMYT and IITA. http://dtma.cimmyt.org/

Conway D and Hulme M. 1996. The Impacts of Climate Variability and Future Climate Change in the Nile Basin on Water Resources in Egypt. Water Resources Development, 12(3): 277-296

Conway D and Hulme M. 1993. Recent Fluctuations in Precipitation and Run-off over the Nile Sub-basins and their Impact on main Nile Discharge. Climate Change, Vol. 25(2), 127-151

Connor DJ and Hernández CG. 2009. Crops for Biofuel, Current Status, Prospects and Limitations for Future. In: Bekunda, M., C.A. Palm, C. De Fraiture, P. Leadley, L. Maene, L. Martinelli, J. McNeely, M. Otto, N.H. Ravindranath, R. Victoria, H. Watson and J. Woods. 2009 (forthcoming). Biofuels in Developing Countries. Working Group C

Cooper PJM, Dimes J, Rao KPC, Shapiro B, Shiferaw B and Twomlow S. 2006. Coping Better with Current Climatic Variability in the Rainfed Farming Systems of sub-Saharan Africa: A Dress Rehearsal for Adapting to Future Climate Change. Global Theme on Agro-ecosystems Report No. 27. ICRISAT, Nairobi. 24 pp.

Davis K, Ekboir J, Mekasha W, Ochieng C, Spielman D and Zerfu E. 2007. Strengthening Agricultural Education and Training in Sub-Saharan Africa from an Innovation Systems Perspective. IFPRI Discussion Paper 00736. International Food Policy Research Institute (IFPRI). Washington D.C.

de Wit M and Stankiewicz J. 2006. Changes in Surface Water Supply across Africa with Predicted Climate Change. Science 311: 1917-1921.

Diang'a E and Ngigi SN. 2009. Consultancy report on Review and Appraisal of WFP's Food-For-Asset (FFA) Projects in ASALs of Kenya. WFP, Nairobi, Kenya.

Dinar A, Hassan R, Mendelsohn R and Benhin J. 2008. Climate Change and Agriculture in Africa: Impact Assessment and Adaptation Strategies. Earthscan, London.

Dlugolecki P. 2004. A Changing Climate for Insurance: A Summary Report for Chief Executives and Policymakers. Association of British Insurers. London.

Duveskog D. 2001. Water Harvesting and Soil Moisture Retention: A Study Guide for Farmer Field Schools. Ministry of Agriculture and Farmesa, Sida, Nairobi, Kenya.

Ellis F. 2000. Rural Livelihoods and Diversity in Developing Countries. Oxford University Press, Oxford, UK.

ESCWA and ICARDA. 2003. Enhancing Agricultural Productivity through On-farm Water-use Efficiency: An Empirical Case Study of Wheat Production in Iraq. United Nations, New York. www.escwa.un.org/information/publications/edit/…/sdpd-03-18.pdf

Evans R, Sneed RE and Cassel DK. 1996. Irrigation Scheduling to Improve Water- and Energy-use Efficiencies. North Carolina Cooperative Extension Service, Raleigh, NC. Pub. No. AG 452-4.

Falkenmark M. 2007. Global Warming: Water the Main Mediator. Stockholm Water Front, No. 2, June 2007, pp 6-7. Stockholm International Water Institute (SIWI), Stockholm, Sweden

Falkenmark M. 1990. Global Water Issues Confronting Humanity. Peace Research, Vol. 27, No. 2, 177-190, http://jpr.sagepub.com/cgi/content/abstract/27/2/177

FAO. 2008a. Water and the Rural Poor: Interventions for Improving Livelihoods in sub-Saharan Africa. Food and Agriculture Organization of the United Nations (FAO), Rome.

FAO. 2008b. Climate Change, Water and Food Security. Technical background document from the expert consultation held on February 26-28, 2008. FAO, Rome, Italy. www.fao.org/nr/water/docs/HLC08-FAOWater-E.pdf

FAO. 2008c. Farmer Field Schools on Land and Water Management in Africa. Proceedings of an international workshop in Jinja, Uganda, 24-29 April 2006. FAO/IIRR, Rome, Italy. 99 p. ftp://ftp.fao.org/docrep/fao/011/i0383e/i0383e.pdf

FAO. 2007. Climate Change and Food Security: A Framework for Action. Report by an Interdepartmental Working Group on Climate Change. FAO, Rome, Italy.

FAO. 2005. Irrigation in Africa in Figures. AQUASTAT Survey – 2005. FAO, Rome.

FAO. 2002. Crops and Drops: Making the Best Use of Water for Agriculture. FAO, Rome.

FAO. 2001a. Global Farming Systems Study: Challenges and Priorities to 2030. FAO, Rome, Italy. www.fao.org/Ag/magazine/GFSS-LAC.pdf

FAO. 2001b. Socio Economic and Gender Analysis (SEAGA) Irrigation Sector Guide. FAO, Rome, Italy. www.genderandwater.org/redir/content/…/Chapter_3.7_July2006.pdf

FAO. 2001c. Smallholder Irrigation Technology: Prospects for Sub-Saharan Africa. International Programme for Technology and Research in Irrigation and Drainage (IPTRID), Knowledge Synthesis Report No. 3. FAO, Rome, Italy.

FAO. 1995. Irrigation in Africa in Figures. Water Report No. 7. FAO, Rome, Italy

FAO. 1994. Water Harvesting for Improved Agricultural Production. Proc. FAO Expert Consultation, 21–25 November 1993, Cairo. Water Report No. 3. Rome.

Fatondji D. 2002. Organic Amendment Decomposition, Nutrient Release and Nutrient Uptake by Millet (Pennisetum glaucum (L.) R.Br.). In: A Traditional Land Rehabilitation Technique (Zai) in the Sahel Ecology and Development Series. N0.1, University of Bonn. Germany, 140 pp.

Faulkner JW, Steenhuis T, van De Giesen N, Andreini M and Liebe JR. 2008. Water Use and Productivity of Two Small Reservoir Irrigation Schemes in Ghana's Upper East Region. Irrigation and Drainage 57: 151–163 (2008).

Foster S, Chilton J, Moench M, Cardy F and Schiffler M. 2000. Groundwater in Rural Development: Facing the Challenges of Supply and Resource Sustainability. World Bank Technical Paper No. 463. The World Bank, Washington, D.C.

Fox P, Rockström J and Barron J. 2005. Risk Analysis and Economic Viability of Water Harvesting for Supplemental Irrigation in semi-arid Burkina Faso and Kenya. Agricultural Systems 83: 231–250.

Fox P and Rockström J. 2000. Water Harvesting for Supplemental Irrigation of Cereal Crops to Overcome Intra-seasonal Dry Spells in the Sahel. Physics and Chemistry of the Earth (B) 25(3): 289-296.

Funk C, Dettinger MD, Michealson JC, Verdin JP, Brown ME, Barlow M and Hoell A. 2008. Warming of the Indian Ocean Threatens Eastern and Southern African Food Security but could be Mitigated by Agricultural Development. Sustainability Science 105(32): 11081-11086. www.pnas.org.cgi. doi.10.1073.pnas.07081896105

Gandure S and Alam K. 2006. Climate Change and Smallholder Farmers in Malawi: Understanding Poor People's Experiences in Climate Change Adaptation. A report by Action-Aid, Action-Aid International. www.actionaid.org

GWA. 2006. Resource Guide: Mainstreaming Gender in Water Management. Chapter 3: Guide to Resources on Gender and the Water Sectors (pp 29-33). Gender and Water Alliance (GWA), Dieren, The Netherlands. http://www.genderandwater.org/page/2778

Gleick PH. 2003. Global Freshwater Resources: Soft-path Solutions for the 21st Century. Science 302: 1524-1528.

Gleick PH. 1998. The World's Water. The Biennial Report on Freshwater Resources, 1998-1999. Island Press, Washington, DC, USA, 307 pp.

Gleick PH. 1992. Water and Conflict: Occasional Papers Series on the Project on Environmental Change and Acute Conflict. Security Studies Programme, American Academy of Arts and Sciences, University of Toronto, Toronto, ON, Canada, 62 pp.

Gleisberg K, Le QB and Vlek PLG. 2008. Assessment of the Impact of Small Reservoir on Land Use and Livelihood in Burkina Faso. A paper presented at the International Conference on Global Change and Water Resources in West Africa, Ouagadougou, Burkina Faso, Agust 25-28, 2008.

Gichuki FN. 2002. Water Scarcity and Conflicts: A Case Study of the Upper Ewaso Ng'iro North Basin. In: Blank, H.G., C.M. Mutero and H. Murray-Rust (eds.). 2002. The Changing Face of Irrigation in Kenya: Opportunities for Anticipating Change in Eastern and Southern Africa. International Water Management Institute (IWMI), Colombo, Sri Lanka, pp 113-134.

Gichuki FN. 2000. Community Water Management: The Case of Matanya Small-scale Irrigation Scheme, Laikipia district, Kenya. NRM3 project report.

Giordano M and Villholth KG (eds). 2007. The Agricultural Groundwater Revolution: Opportunities and Threats to Development, IWMI, Colombo, Sri Lanka. p 419

Gumbo B and van der Zaag P. 2001. Principles of Integrated Water Resources Management (IWRM). A paper presented at the Southern Africa Youth Forum, 24-25 September 2001, Harare, Zimbabwe. GWP-Southern Africa. www.uz.ac.zw/engineering/civil/gumbo/gwpyouthforumpaper-09-01.pdf

Green TR, Taniguchi M and Kooi H. 2007. Potential Impacts of Climate Change and Human Activity on Subsurface Water Resources. Vadose Zone, 6: 531-532.

Green E. 2006. Extension Service, Agricultural Development and Smallholder Agricultural Production in Malawi: 1930s to 2000. Stockholm University, Stockholm, Sweden. http://www.ekohist.su.se/dokument/pdf/erikproject.pdf

Gyau-Boakye and Tumbulto J. 2000. The Volta Lake and Declining Rainfall and Streamflows in the Volta River Basin. Environment, Development and Sustainability. Springer, Netherlands.

Hamdy A, Ragab R and Scarascia-Mugnozza E. 2003. Coping with Water Scarcity: Water Saving and Increasing Water Productivity. Irrigation and Drainage, 52(1): 2-20

Hans JK, Fantaw B, Yahanes GM, and Kajela K. 1996. Creating an Inventory of Indigenous SWC Measures in Ethiopia. In: Reiij, C (ed.). Sustaining the soil. Indigenous Soil and Water Conservation in Africa. Earthscan Publication Ltd., London. 139-144.

Hansen J, Baethgen W, Osgood D, Ceccato P and Ngugi R. 2007. Innovations in Climate Risk Management: Protecting and Building Rural Livelihoods in a Variable and Changing Climate. SAT eJournal, 4.1: 1-38.

Hansen JW. 2002. Realizing the Potential Benefits of Climate Prediction to Agriculture: Issues, Approaches, Challenges. Agricultural Systems, 74: 309-330.

Harrison M and Williams JB. 2008. Communicating Seasonal Forecasts. In: Troccoli A, Harrison M, Anderson DLT and Mason SJ. 2008. Seasonal Climate: Forecasting and Managing Risk. NATO Science Series, Vol. 82: 293-31. Springer Netherlands. http://www.springerlink.com/content/p355048258231532/

Haskins S. 2008. Irrigation Pump Boosts Subsistence Farmers' Profits. Engineering News. http://www.engineeringnews.co.za/article/ 2008-10-03

Hatibu N, Mahoo HF and Mzirai OB. 2002. Relevance of Kenyan Irrigation Development to Eastern and Southern Africa. In: Blank, H.G., C.M. Mutero and H. Murray-Rust (eds.). 2002. The Changing Face of Irrigation in Kenya: Opportunities for Anticipating Change in Eastern and Southern Africa. International Water Management Institute (IWMI), Colombo, Sri Lanka, pp 303-329.

Hemmati M and Gardiner R. 2001. Gender and Sustainable Development. Towards Earth Summit 2002 - Social Briefing Paper No. 2. Heinrich Böll Foundation, p 18. http://www.earthsummit2002.org/es/issues/gender/gender-2.rtf

Herdijk A, Diemer G, Kimani J, Mukolwe M and Thairu M (eds). 1990. Evaluation of Small-scale Irrigation Development Projects: Smallholder Irrigation - A Large Challenge. Ministry of Agriculture, Irrigation and Drainage Branch, Nairobi, Kenya/Ministry of Development Cooperation: Netherlands.

Hess U and Syroka J. 2005. Weather-based Insurance in Southern Africa: The Case of Malawi. Agriculture and Rural Development Discussion Paper 13. World Bank. Washington D.C.

Holmes P. 1996: Building Capacity for Environmental Management in Hong Kong. Water Resources Development 12(4): 461-472.

Hope KR. 2009. Capacity Development for God Governance in Developing Societies: Lessons from the Field. Development in Practice, 19: 79-86

Hillel D. 1997. Small-scale Irrigation for Arid Zones: Principles and Options. FAO Development Series 2. FAO, Rome

Hulme M. 2001. Climatic Perspectives on Sahelian Desiccation: 1973-1998. Global Environmental Change, 11: 19-29.

Hulme M, Doherty R, Ngara T, New M and Lister D. 2001. African Climate Change: 1900-2100. Climate Research, 17:145-168.

Hsiao TC, Steduto P and Fereres E. 2007. A Systematic and Quantitative Approach to Improve Water Use Efficiency in Agriculture. Irrigation Science 25 (3): 209-231

Human Impact Report. 2009. Climate Change: The Anatomy of a Silent Crisis. Global Humanitarian Forum, Geneva. http://www.docstoc.com/docs/6783796/

Huq S, Rahman A, Konate M, Sokona Y and Reid H. 2003. Mainstreaming Adaptation to Climate Change in Least Developed Countries (LDCs). The International Institute for Environment and Development, London.

Huq S, Karim Z, Asaduzzaman M, and Mahtab F (eds). 1999: Vulnerability and Adaptation to Climate Change in Bangladesh. J. Kluwer Academic Publishers, Dordrecht, The Netherlands, 147 pp.

ICID. 2001. Strategy for Implementation of ICID's Concerns Emanating from the Sector Vision on "Water for Food and Rural Development". International Commission on Irrigation and Drainage (ICID)

IFAD. 2009. Research and Innovation for Smallholder Farmers in the Context of Climate Change. Discussion paper prepared for the Round Table organized during the Thirty-second session of IFAD's Governing Council, 18 February 2009. http://www.ifad.org/events/gc/32/roundtables/3.pdf

IFPRI. 2009. Food-Security Risks Must Be Comprehensively Addressed. IFPRI 2008-2009 Annual Report Essay. http://www.ifpri.org/publication/

IFPRI. 2008. New Study Identifies Farmers' Options and Obstacles to Adapting to Climate Change. Press Release, November 12, 2008. http://www.ifpri.org/pressrel/2008/20081112.asp

IISD. 2008. A Summary Report of the First African Water Week (AWW-1). AWW-I Bulletin. International Institute for Sustainable Development (IISD). Vol. 13 (1), March 31, 2008. http://www.iisd.ca/africa/water/AWW1/

INERA. 2008. Responsabilsation du producteur en assainissement urbain durable au Sahel: Traitement et valorisation des dechets liquides domestiques en agriculture peri urbaine. Environment and Agricultural Research Institute (INERA)

Inocencio A, Sally H and Merrey DJ. 2003. Innovative Approaches to Agricultural Water Use for Improving Food Security in Sub-Saharan Africa. IWMI Working Paper No. 55. IWMI, Colombo, Sri Lanka

Inocencio A, Kikuchi M, Tonosaki M, Maruyama A, Merrey D, Sally H and de Jong I. 2007. Costs and Performance of Irrigation Projects: A Comparison of sub-Saharan Africa and Other Developing Regions. Research Report No. 109. IWMI, Colombo, Sri Lanka.

IPCC. 2007. IPCC 4th Assessment Report - Climate Change 2007. Working Group II on "Impacts, Adaptation and Vulnerability". http://www.ipcc-wg2.org

IPCC. 2001. IPCC 3rd Assessment Report - Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability.http://www.ipcc.ch/ipccreports/index.htm

IPCC. 2000. The Regional Impacts of Climate Change. IPCC Special Report on Climate Change – complete online versions. www.grida.no/Climate/ipcc/regional/019.htm

IRI. 2006. A gap Analysis for the Implementation of the Global Observing System Programme in Africa. International Research Institute for Climate and Society (IRI), Global Climate Observing System (GCOS), Columbia University, New York. www.unfccc.int/files/adaptation/sbsta.../200711_nwp_iri_gco_gap_africa.pdf

IPTRID. 2000. Treadle Pumps for Irrigation in Africa. International Program for Technology and Research in Irrigation and Drainage (IPTRID). FAO, Rome.

ISESCO. 1997. Water Resources Management: Curriculum and Teaching Guide of Special Course Proposed for University Level Studies in Islamic Countries. Islamic Educational, Scientific and Cultural Organization (ISESCO), 1418/1997. http://www.isesco.org.ma/english/publications/water/water.php

IWMI. 2009. The Agricultural Water Management (AWM) Solutions Project: Improved Livelihoods for Smallholder Farmers. A 3 year (2009-2011) project funded by the Bill & Melinda Gates Foundation being undertaken by IWMI, IFPRI, IDE, SEI, FAO and CH2M HILL in Africa and South Asia. http://awm-landscape.iwmi.org/project-overview.aspx

IWMI. 2007. Treadle Pumps Irrigation and Poverty Reduction in Ghana. IWMI Research Report No. 117. IWMI. Colombo, Sri Lanka.

IWMI. 2006. Groundwater Declines: Looking for the Right Solutions. IWMI Water Policy Brief Issue 19. IWMI. Colombo, Sri Lanka.

IWMI. 2005. Reducing Poverty through Investments in Agricultural Water Management. IWMI Working Paper No. 101. IWMI. Colombo, Sri Lanka.

Johns Hopkins (1998). Solutions for a Water-short World. Population Report, Vol. XXVI, No. 1, September 1998. Johns Hopkins Population Information Program, Baltimore, Maryland, United States. http://www.jhuccp.org/popreport/m14sum.stm

Kabat P, Schulze RE, Hellmuth ME and Veraart JA (eds). 2003. Coping with Impacts of Climate Variability and Climate Change in Water Management: A Scoping Paper. DWC-Report no. DWCSSO-01 International Secretariat of the Dialogue on Water and Climate, Wageningen, Netherlands.

Kameri-Mbote P. 2007. Water, Conflict, and Cooperation: Lessons from the Nile River Basin. Navigating Peace.

Kay M. 2001. Smallholder Irrigation Technology: Prospects for sub-Saharan Africa. Knowledge Synthesis Report No. 3. IPTRID, FAO, Rome.

Kay M and Brabben T. 2000. Treadle Pumps for Irrigation in Africa. Knowledge Synthesis Report No. 1. IPTRID, FAO, Rome.

Kelly P and Adger WN. 1999. Assessing Vulnerability to Climate Change and Facilitating Adaptation. Working Paper GEC 99-07, Centre for Social and Economic Research on the Global Environment, University of East Anglia, Norwich, United Kingdom, 32 pp.

Kinaga JW. 2008. Technologies for Efficient Water Use: The Moneymaker Hip Pump. A paper presented at the 3rd IMAWESA Regional Conference on "Agricultural Water Management in Eastern and Southern Africa: Investment in Agricultural Water Management Pays" held in Addis Ababa, Ethiopia. September 15-19, 2008.

Kijne J. 2000. Water for Food for Sub-Saharan Africa. Article prepared for FAO. http://www.fao.org/landandwater/aglw/webpub/watfood.htm

Klein RJT and Tol RSJ. 1997. Adaptation to Climate Change: Options and Technologies. An Overview Paper. Institute for Environmental Studies, Amsterdam, 33 pp.

Konate M and Sokona Y. 2003. Mainstreaming Adaptation to Climate Change in Least Developed Countries (LDCS). Working Paper 3: Mali Country Case

Study. International Institute for Environment and Development (IIED). www.iied.org/pubs/pdfs/10004IIED.pdf

Kulecho IK and Weatherhead EK. 2005. Reasons for Smallholder Farmers Discontinuing with Low-cost Micro-irrigation: A Case Study from Kenya. Irrigation and Drainage Systems 19: 179-188.

Kurukulasuriya P, Mendelsohn R, Hassan R, Benhin J, Deressa T, Diop M, Eid HM, Fosu KY, Gbetibouo G, Jain S, Mahamadou A, Mano R, Kabubo-Mariara J, El-Marsafawy S, Molua E, Ouda S, Ouedraogo M, Séne I, Maddison D, Seo SN and Dinar A. 2006. Will African Agriculture Survive Climate Change? The World Bank Economic Review 20: 367-388

Kurukulasuriya P and Mendelsohn R. 2006. Crop Selection: Adapting to Climate Change in Africa. CEEPA Discussion Paper No. 26, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Larson D, Varngis P and Yabuki N. 1998. Commodity Risk Management and Development. Policy Research Working Paper 1963. Rural Development, Development Research Group. World Bank, Washington DC.

Lawrence P, Meigh J and Sullivan C. 2002. The Water Poverty Index: An International Comparison. Keele Economics Research Papers, KERP, 2002/19. Keele Economics Department. Keele University, Keele, Staffordshire, UK. www.keele.ac.uk/depts/ec/wpapers/kerp0219.pdf

Lee BL. 2007. Information Technology and Decision Support System for On-Farm Applications to cope effectively with Agrometeorological Risks and Uncertainties. In: Sivakumar MVK and RP Motha. 2007. Managing Weather and Climate Risks in Agriculture, Chapter 12: 191-207. http://www.springerlink.com/content/n07834253472x7q4/

Lempert RJ, Schesinger ME, Bankes SC and Andronova NG. 2000. The Impacts of Climate Variability on Near-term Policy Choices and the Value of Information. Climate Change 45(1): 129-161.

Linnerooth-Bayer J. 2003. Insurance-related Actions and Risk Assessment in the Context of the UNFCCC. Background paper for UNFCCC workshops.

Magadza CHD. 2000. Climate Change Impacts and Human Settlements in Africa: Prospects for Adaptation. Environmental Monitoring and Assessment 61(1), 193-205.

Magadza CHD. 1996. Climate Change: Some Likely Multiple Impacts in Southern Africa. In: Downing, T.E. (ed.). 2000. Climate Change and World Food Security. Springer-Verlag, Berlin, Germany, pp. 449-484.

Mahoo HF, Mkoga ZJ, Kasele SS, Igbadun HE, Hatibu N, Rao KPC and Lankaford B. 2007. Productivity of Water in Agriculture: Farmers' Perceptions and Practices. Comprehensive Assessment of Water Management in Agriculture Discussion Paper 5. IWMI, Colombo, Sri Lanka.

Mahoo HF, Rwehumbiza FBR, Demgard-Larsen S, Hatibu N, Kitali A and Kahabi M. 2003. Challenges and Benefits of Participatory Interventions in Rainwater Harvesting: Improvement of Charco Dams in Tanzania. International Symposium on Water, Poverty and Productive uses of Water at the Household Level, 21-23 January 2003, Muldersdrift, South Africa. pp 124-130. www.irc.nl/content/download/8693/132159/file/proceeding_10.pdf

Majule AE and Mwalyosi RBB. 2005. The Role of Traditional Irrigation on Small Scale Production in Rufiji Basin, Southern Highland Tanzania: A case of Iringa Region.. In: Sosovele, H., J. Boesen and F. Maganga (eds.). 2005. Social and Environmental Impacts of Irrigation Farming in Tanzania: Selected Cases. Dar es Salaam University Press.

Malesu MM, Oduor AR and Odhiambo JO (eds). 2007. Green Water Management Handbook: Rainwater Harvesting for Agricultural Production and Ecological Sustainability. Technical Manual No. 8. SearNet Secretariat, RELMA-in-ICRAF, World Agroforestry Centre, Nairobi, Kenya.

Malesu MM, Khaka E, Mati BM, Oduor AR, de Bock T, Nyabenge M and Oduor V. 2006a. Mapping the Potential of Rainwater Harvesting Technologies in Africa: A GIS Overview on Development Domains for the Continent and Nine Selected Countries. Technical Manual No. 7. SearNet Secretariat, RELMA-in-ICRAF, World Agroforestry Centre, Nairobi, Kenya.

Malesu MM, Sang JK, Odhiambo JO, Oduor AR and Nyabenge M. 2006b. Rainwater Harvesting Innovations in Response to Water Scarcity: The Lare Experience. Technical Manual No. 5. SearNet Secretariat, RELMA-in-ICRAF, World Agroforestry Centre, Nairobi, Kenya.

Mati BM, Siame D and Mulinge WM. 2008a. AWM on the Ground: Lessons from Projects and Programs in Eastern and Southern Africa. IMAWESA, SWMnet-ICRISAT, Nairobi.

Mati BM, Mwepa G and Temu R. 2008b. Farmer Initiatives in Managing Water for Agriculture in Eastern and Southern Africa. A Booklet of Farmer Innovations in AWM. IMAWESA, SWMnet-ICRISAT, Nairobi.

Mati BM. 2008. Capacity Development for Smallholder Irrigation in Kenya. Irrigation and Drainage 57: 332-440.

Mati BM. 2007. 100 Ways to Manage Water for Smallholder Agriculture in Eastern and Southern Africa: A Compendium of Technologies and Practices. SWMnet Working Paper 13. IMAWESA, SWMnet-ICRISAT, Nairobi.

Mati BM, Hatibu N, Phiri IMG and Nyanoti JN. 2007. Policies and Institutional Frameworks Impacting on AWM in Eastern and Southern Africa. Synthesis Report of a Rapid Appraisal Covering Nine Countries in ESA. IMAWESA, SWMnet-ICRISAT, Nairobi.

Mati BM. 2005. Overview of Water and Soil Nutrient Management under Smallholder Rainfed Agriculture in East Africa. Working Paper 105, International Water Management Institute (IWMI), Colombo, Sri Lanka. http://www.lk.iwmi.org/pubs/working/WOR105.pdf

Mati BM and Penning de Vries FWT. 2005. Bright Spots on Technology-Driven Change in Smallholder Irrigation. Case Studies from Kenya. In: Bright Spots Demonstrate Community Successes in African Agriculture. Working Paper 102: 27-47, International Water Management Institute. http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR102.pdf

Meijerink G, Muchena F, Njue E, Noel S, Onduru D and Porras I. 2007. Political, Institutional and Financial Framework for Green Water Credits in Kenya. Green Water Credits Report No. 6, ISRIC – World Soil Information, Wagenigen, The Netherlands. www.isric.org/ISRIC/webdocs/docs/gwc_report_6.pdf

Merrey DJ and Sally H. 2008. Micro-AWM Technologies for Food Security in Southern Africa: Part of the Solution or a Red Herring? Water Policy, 10 (2008): 515–530.

Miller KA, Rhodes SL and MacDonnell LJ. 1997: Water Allocation in a Changing Climate: Institutions and Adaptation. Climatic Change, 35: 157-177.

Mogaka H, Gichere S, Davis R and Hirji R. 2006. Climate Variability and Water Resources Degradation in Kenya: Improving Water Resources Development and Management. World Bank Working Paper No. 69. World Bank, Washington D.C.

Monnik K. 2000. Role of Drought Early Warning Systems in South Africa's Evolving Drought Policy. In: Wilhite DA, Sivakumar MKV and Wood DA (Eds.). Early Warning Systems for Drought Preparedness and Drought Management. Proceedings of an Expert Group Meeting in Lisbon, Portugal, 5 - 7 September 2000. WMO, Geneva, Switzerland. http:///www.drought.unl.edu/monitor/EWS/ch5_Monnik.pdf

Mutasa M. 2007. African Environmentalists Discuss Climate Change Adaptation Strategies: The Climate Change Action Africa 2007 Conference (August 28-30, 2007). Southern African News Features (SANF), SANF 07 No 35, July 2007. http://www.sardc.net/Editorial/NewsFeature/07350707.htm

Namara R, Nagar R and Upadhyay B. 2007. Economics, Adoption Determinants and Impacts of Micro-Irrigation Technologies: Empirical Results from India. Irrigation Science, 25(3): 283-297.

Nelson GC. (ed). 2009. Agriculture and Climate Change: An Agenda for Negotiation in Copenhagen. 2020 Focus No. 16. May 2009. http://www.ifpri.org/2020/focus/focus16.asp

Ngigi SN. 2008.Technical Evaluation and Development of Low-Head Drip Irrigation Systems in Kenya. Irrigation and Drainage, 57(2008): 450-462. http://www.interscience.wiley.com

Ngigi SN, H.H.G. Savenije and F.N. Gichuki. 2008. Hydrological Impacts of Flood Storage and Management on Irrigation Water Abstraction in Upper Ewaso Ng'iro River Basin, Kenya. Water Resources Management, 22: 1859-1879. http://www.springerlink.com

Ngigi SN. 2006. Hydrological Impacts of Land Use Changes on Water Resources Management and Socio-Economic Development of Upper Ewaso Ng'iro River Basin in Kenya. Published Ph.D. dissertation, UNESCO-IHE/TUDelft, Netherlands. A.A. Balkema Publishers, The Hague.

Ngigi SN, Savenije HHG, Thome JN, Rockström J and Penning de Vries FWT. 2005a. Agro-Hydrological Evaluation of On-Farm Rainwater Storage Systems for Supplemental Irrigation in Laikipia District, Kenya. AWM, 73(1): 21-41.

Ngigi SN, Savenije HHG, Rockström J and Gachene CK. 2005b. Hydro-Economic Evaluation of Rainwater Harvesting and Management Technologies: Farmers' Investment Options and Risks in Semi-Arid Laikipia District Of Kenya. Physics and Chemistry of the Earth, 30: 772-782.

Ngigi SN. 2003. Rainwater Harvesting for Improved Food Security: Promising Technologies in the Greater Horn of Africa. Greater Horn of Africa Rainwater Partnership (GHARP), Kenya Rainwater Association (KRA), Nairobi, Kenya. 266 pp.

Ngigi SN. 2002. Preliminary Evaluation of Irrigation Development in Kenya. In: Blank, H.G., C.M. Mutero and H. Murray-Rust (eds.). 2002. The Changing Face of Irrigation in Kenya: Opportunities for Anticipating Change in Eastern and

Southern Africa. IWMI, Colombo, Sri Lanka. pp 93-111. http://www.lk.iwmi.org/pubs/Book/Part2.pdf

Niasse M. 2005. Climate-Induced Water Conflict Risks in West Africa: Recognizing and Coping with Increasing Climate Impacts on Shared Watercourses. Presented at the Workshop on Human Security and Climate Change. Asker, Norway.

Niggol S, Robert M, Pradeep K, Ariel D and Rashid H. 2008. Differential Adaptation Strategies to Climate Change in African Cropland by Agro-Ecological Zones.

NREL. 2003. Renewable Energy for Water Pumping Applications in Rural Villages. National Renewable Energy Laboratory (NREL)/SR-500-30361. Golden, CO.

O'Brien KL, Sygna L, Næss L, Kingamkono R and Hochobeb B. 2000. Is Information Enough? User Responses to Seasonal Climate Forecasts in Southern Africa. Report No. 2000-03. CICERO. University of Oslo, Norway.

Oduor AR and Malesu MM (eds). 2006. Managing Water for Food Self-Sufficiency. Proceeding of a Regional Rainwater Harvesting Seminar for Eastern and Southern Africa. Relma Technical No. 32. RELMA-in-ICRAF and World Vision, Nairobi, Kenya.

OECD. 2005. Water and Violent Conflict. Issues Brief. Development Assistance Committee. Organization for Economic Co-Operation and Development (OECD), Paris.

Olivry JC, Briquet JP and Mahe G. 1993. Vers un Apprauvrissment durable des resources en eau de l'Afrique Humide? IAHS Publication No. 216, pp. 67-78.

Olomoda I. 2002. Impact of Climate Change on the River Niger Hydrology. River Symposium 2006, University of Queensland, Australia.

Omer AM. 2001. Solar Water Pumping Clean Water for Sudan Rural Areas. Renewable Energy, 24: 245–258.

Orlando BM and Klein RJT. 2000. Taking an Ecosystem Approach to Climate Change Adaptation in Small Island States. Second Workshop on Climate Change Negotiations, Strategy and Management, Alliance of Small Island States, Apia, Samoa, 31 July - 3 August 2000, 11 pp.

Paavola J. 2004. Livelihoods, Vulnerability and Adaptation to Climate Change in the Morogoro Region, Tanzania. Centre for Social and Economic Research on the Global Environment, University of East Anglia, Norwich. pp 8-12. www.uea.ac.uk/env/cserge/pub/wp/edm/edm_2004_12.pdf

Paavola J and Adger TW. 2005. Analysis of Fair Adaptation to Climate Change. Ecological Economics, 56 (2006): 594-609.

Pandey DN, Gupta AK and Anderson DM. 2003. Rainwater Harvesting as an Adaptation to Climate Change. Current Science, 85(1): 46-59.

Parry J, Hammill A and Drexhage J. 2005. Climate Change and Adaptation. Manitoba, Canada. http://www.iisd.org/

Patt A and Winkler J. 2007. Applying Climate Information in Africa: An Assessment of Current Knowledge. US National Oceanic and Atmospheric Administration (NOAA). www.iiasa.ac.at/Admin/PUB/Documents/XO-07-006.pdf

Peacock T, Ward C and Gambarelli G. 2007. Investment in Agricultural Water for Poverty Reduction and Economic Growth in Sub-Saharan Africa: Synthesis Report. Collaborative Program of African Development Bank, FAO, IFAD, IWMI and World Bank. IWMI, Colombo.

Peden D. 2008. Could 150 Million Thirsty Livestock be Efficient Water Harvesters? Nile Basin Studies Show How. Collective Action News - Updates from Agricultural Research in Africa. Issue No. 4. Alliance for CGIAR Centers. http://www.ilri.org

Perry CJ. 1999. The IWMI Water Resources Paradigm – Definitions and Implications. AWM, 40(1): 45-50.

Perry CJ. 2003. Water Pricing: Some Important Definitions and Assumptions. Occasional Paper No 59 SOAS Water Issues Study Group, School of Oriental and African Studies, University of London, UK. www.soas.ac.uk/research/our_research/projects/waterissues/papers/38402.pdf

Phiri MG, Saka I and Alex R. 2005. The Impact of Changing Environmental Conditions on Vulnerable Communities of the Shire Valley, Southern Malawi. Lilongwe, Malawi.

Pimentel D and Pimentel M. 2003. World Population, Food, Natural Resources, and Survival. World Futures, 59: 145-167

Postel S. 2001. Growing More Food with Less Water. Scientific American 284:2: 46–50.

Ragauskas AJ, Williams CK, Davison BH, Britovsek G, Cairney J, Eckert CA, Frederick WJ, Hallett JP, Leak DJ, Liotta CL, Mielenz JR, Murphy R, Templer R and Tschaplinski T. 2006. The Path Forward for Bio-fuels and Bio-materials. Science, 311: 484-489, DOI: 10.1126/science.1114736.

Ragwa PK, Kamau NR and Mbatia ED. 1998. Irrigation and Drainage Branch Position Paper Presented During the Workshop on "Promotion of Sustainable Smallholder Irrigation Development in Kenya," November 16-20, 1998. Embu, Kenya.

Rajalahti R. 2009. Promoting Agricultural Innovation Systems Approach: The Way Forward. Agriculture and Rural Development Department, the World Bank, Washington, D.C. http://knowledge.cta.int/en/Dossiers

Raleigh C and Urdal H. 2007. Climate Change, Environmental Degradation and Armed Conflict. Political Geography 26 (6): 674-694

Raswant V, Hart N and Romano M. 2008. Biofuel Expansion: Challenges, Risks and Opportunities for Rural Poor People - How the poor can benefit from this emerging opportunity. Paper prepared for the Round Table organized during the Thirty-first session of IFAD's Governing Council, 14 February 2008. IFAD, Rome. www.ifad.org/events/gc/31/roundtable/biofuels.pdf

Rayner S and Malone EL (eds). 1998. Human Choice and Climate Change: The Tools for Policy Analysis. Battelle Press, Columbus, USA. Vol. 3, 429 pp.

Rijsberman FR. 2006. Water Scarcity: Fact or Fiction? AWM, 80: 5–22.

Riyannsh M. 2008. India Agriculture Policy: Vision 2020 [Internet]. Version 2. Knol. 2008 Jul 24. Available from: http://knol.google.com/k/riyannsh-mundraa/india-agriculture-policy-vision-2020/3lr953e1lumvz/2.

Rockström J, Barron JJ and Fox P. 2001. Water Productivity in Rainfed Agriculture: Challenges and Opportunities for Smallholder Farmers in Drought-prone Tropical Agro-systems. Paper presented at an IWMI Workshop. Colombo, Sri Lanka. November 12-14, 2001.

Rockström J. 2001. Green Water Security for the Food Makers of Tomorrow: Windows of Opportunity in Drought-prone Savannahs. Water Science and Technology 43(4): 71-78.

Rockström J. 1999. On-Farm Green Water Estimates as a Tool for Increased Food Production in Water Scarce Regions. Phys. Chem. Earth (B) 24(4): 375-383.

Rosegrant MW, Cai X, Cline SA and Nakagawa N. 2002. The Role of Rainfed in the Future of Global Food Production. EPTD Discussion Paper N0. 90. Environment and Production Technology Division (EPTD), International Food Policy Research Institute (IFPRI), Washington, D.C.

Rosegrant MW, Cai X and Cline SA. 2005. World Water and Food to 2025: Dealing with Scarcity. International Food Policy Research Institute (IFPRI), Washington, D.C.

Sachs JD. 2008. Common Wealth: Economics for a Crowded Planet. The Penguin Press, New York, 386 pp.

Samakande I, Senzanje A and Mjmba M. 2002. Smallholder Irrigation Schemes: A Common Property Resource with Management Challenges. dlcvm.dlib.indiana.edu/archive/00000919/00/samakandei040402.pdf

Sanchez S, Rickman J and Ngigi SN. 2008. Report on a field visit to Toya Millennium Villages Project cluster. 4

Scheltema W. 2002. Smallholder Management of Irrigation in Kenya. In: Blank, H.G., C.M. Mutero and H. Murray-Rust (eds.). 2002. The Changing Face of Irrigation In Kenya: Opportunities for Anticipating Change in Eastern and Southern Africa. IWMI, Colombo, Sri Lanka. Pp. 171-189. http://www.lk.iwmi.org/pubs/Book/Part2.pdf

Scheraga J and Grambsch A. 1998: Risks, Opportunities, and Adaptation to Climate Change. Climate Research 10, 85-95.

Seckler D. 1998. World Water Demand and Supply, 1990 to 2025: Scenarios and Issues. International Water Management Institute, Colombo, Sri Lanka

Seckler D and Young RA. 1985. The Choices of Irrigation Technologies in California. American Journal of Agricultural Economics, 67:2.

Serageldin I. 1998. Water in the Twenty-First Century: A Dialogue. Water Policy 1.

Shahin M. 2002. Hydrology and Water Resources of Africa. Chapter 12: Groundwater Resources of Africa, pp 509-563. Water Science and Technology Library Series, Vol. 41, Kluwer Academic Publishers, The Netherlands, p 659

Short TD and Thompson P. 2003. Breaking the Mould: Solar Water Pumping¬ – The Challenges and the Reality. Solar Energy 75: 1-9.

Sielhorst S, Molenaar JW and Offermans D. 2008. Biofuels in Africa: An Assessment of Risks and Benefits for African Wetlands. Wetlands International. www.wetlands.org

Sijali IV and Kaburu F. 2008. Low-head Drip Irrigation Kits in Kenya. GRID 28, IPTRID Network Magazine.

Sijali IV. 2001. Drip Irrigation: Options for Smallholder Farmers in Eastern And Southern Africa. Technical Handbook No. 24. RELMA, Nairobi.

Skees J, Hazell P and Miranda. 1999. New Approaches to Crop Yield Insurance in Developing Countries. EPTD Discussion Paper No. 55. Environment and

Production Technology Division. International Food Policy Research Institute (IFPRI). Washington D.C.

Skees J, Gober S, Varangis P, Lester R and Kalavakonda V. 2001. Developing Index Insurance in Morocco. Policy Research Working Paper 2577. World Bank. Washington D.C.

Skees J, Goes A, Sullivan C, Carpenter R, Miranda M and Barnett B. 2006. Index Insurance for Weather Risk in Lower-Income Countries. Global AgRisk, developed for USAID. Lexington, NY.

Sloggett G. 1979. Energy and U.S. Agriculture: Irrigation Pumping 1974-1977. Agric. Econ. Report No. 436, USDA, Washington, D.C.

Smajstrla AG, Harrison DS, Haman DZ and Zazueta FS. 1991. Irrigation in Florida. Agr. Eng. Ext. Rpt. 91-12. Fla. Coop. Ext. Svc., IFAS, Univ. of Fla., 32611.

Smit B and Skinner MW. 2002. Adaptation Options in Agriculture to Climate Change: A Typology. Mitigation and Adaptation Strategies for Global Change, 7: 85-114.

Smith JB and Lenhart SS. 1996. Climate Change Adaptation Policy Options. Climate Research, 6(2): 193-201.

Smith JB, Bhatti N, Menzhulin G, Benioff R, Budyko MI, Campos M, Jallow B and Rijsberman F (eds). 1996. Adapting to Climate Change: An International Perspective. Springer-Verlag, New York, 475 pp.

Smout I and Shaw R (eds). 1999. Running Water: Technical Briefs on Health, Water and Sanitation. Brief No. 42: Small-scale Irrigation Design, pp 34-40. WEDC/IT Publications, Southampton, UK, www.lboro.ac.uk/well/resources/technical-briefs/42-small-scale-irrigation-design.pdf

Sunding D and Zilberman D. 2000. The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector. In: Sunding D, Zilberman D, Gardner B and Rausser G. 2001. Handbook of Agricultural Economics, Science, 2001. University of California at Berkeley http://www.are.berkeley.edu/courses/ARE241/fall2005/innovationchptr.pdf

Taylor R and Tindimugaya C (eds). 2008. Proceedings of an International Conference on "Groundwater and Climate in Africa". June 24-28, 2008. Kampala, Uganda

Thomas D, Osbahr H, Twyman C, Adger N and Hewitson B. 2005. Adaptations to Climate Change amongst Natural Resource-Dependant Societies in the

Developing World: Across the Southern African Climate Gradient. Technical Report 35. Tyndall Centre for Climate Change Research.

Thornton PK, Jones PG, Owiyo TM, Kruska RL, Herero M, Kristjanson P, Notenbaert A, Bekele N and Omolo A. 2006. Mapping Climate Vulnerability and Poverty in Africa. Report to the Department for International Development, ILRI, Nairobi, 200 pp.

Tumbulto JW. 2005. A Study of Water Balance of the Pompon Sub-Catchment of the Densu River Basin. Published Ph.D. Thesis, Department of Geology, University of Ghana, Press, Legon, Accra, Ghana.

Turner NC. 2008. Adaptation to Climate Change: Research Needs for Agroforestry Systems for Smallholder Farmers. Report commissioned by the World Agroforestry Centre, Nairobi, Kenya.

Turner NC. 2006. Water Scarcity: Challenges and Opportunities for Crop Science. AWM, Special Issue 80(1-3): 1-3. doi:10.1016/j.agwat.2005.07.002

Turton A, Earle A, Malzbender D and Ashton PJ. 2005. Hydro-political Vulnerability and Resilience along Africa's International Waters. In: Wolf, A.T. (ed.). 2005. Hydropolitical Vulnerability and Resilience along International Waters: Africa, pp 19-67. UNEP, Nairobi. http://www.awiru.co.za/pdf/C_CH2UNEPAfrica.pdf.

UNCCD. 2009. Draft UNCCD Water Policy Advocacy Framework for Securing Water Resources in Water Scarce Ecosystems in the Face of Desertification, Land Degradation and Drought (DLDD) Imperatives. United Nations Convention to Combat Desertification (UNCCD). United Nations, New York, USA

UNDP. 2003. Adaptation Policy Frameworks (APF) for Climate Change: Developing Strategies, Policies and Measures. http://www.undp.org/climatechange/adapt/apf.html

UNDP. 2008. Fighting Climate Change: Human Solidarity in a Divided World. Human Development Report 2007/2008. United Nations Development Program (UNDP), New York, USA. http://hdr.undp.org/en/reports/global/hdr2007-2008/

UNECA. 2009. Summary of the Climate for Development in Africa Programme (ClimDev-Africa). Africa Climate Advisory Bulletin. United Nations Economic Commission for Africa (UNECA). www.uneca.org/eca_programmes/sdd/events/climate/climdev.pdf

UNECA. 2001. Safeguarding Life and Development in Africa – A Vision for Water Resources Management. In: The 21st Century. The Hague, The Netherlands, March 2000, First Edition.

UNECA, AU and AfDB. 2000. The Africa Water Vision for 2025: Equitable and Sustainable Use of Water for Socioeconomic Development. UNECA, African Union (AU) and African Development Bank (AfDB) . Addis Ababa. www.uneca.org/awich/africanwatervision2025.pdf

UNEP. 2009. Climate Information and Capacity Needs for Ecosystem Management under a Changing Climate. White paper prepared for the World Climate Conference – 3 Geneva, Switzerland, 31 August – 4 September 2009. Climate Change Adaptation Unit, UNEP, Nairobi, Kenya. http://www.wcc3.org/wcc3docs/pdf/WS7_WP_needs.doc

UNEP. 2008. Freshwater Resources in Africa: Water, Natural Resource Management and Policy, and Environmental and Resource Management. http://www.eoearth.org/article/ Freshwater _resources_in_Africa

UNEP. 2006. Africa Environment Outlook 2. Chapter 4: Freshwater (Regional Synthesis). UNEP, Nairobi, Kenya. http://www.unep.org/dewa/Africa/publications/AEO-2/content/076.htm

UNEP. 2002. Vital Water Graphics: An Overview of the State of the World's Fresh and Marine Waters. United Nations Environment Programme, Nairobi, Kenya.

UNEP. 1999. Freshwater Stress and Scarcity In Africa By 2025. United Nations Economic Commission for Africa (UNECA), Addis Ababa; Global Environment Outlook (GEO) 2000, UNEO, Earthscan, London, 1999, Population Action International. http://www.unep.org/vitalwater/images/25-waterstress-africaM.jpg/ http://www.unep.org/dewa/assessments/ecosystems/water/vitalwater/21.htm

UNEP. 1992. Protection of the Quality and Supply of Freshwater Resources: Application of Integrated Approaches to the Development, Management and Use of Water Resources. Agenda 21: Chapter 18. http://earthwatch.unep.ch/agenda21/18.php

UNESCO. 2002. Proc. of International Workshop on Managing Shared Aquifer Resources in Africa. June 2-4, 2002, Tripoli, Libya. United Nations Education, Scientific and Cultural Organization (UNESCO). www.unesco.org/water/ihp/events/shared_aquifers_africa.pdf

UNFCCC. 2009. Report on the 7th Ad Hoc Working Group on Long-Term Cooperative Action under the Convention (FCCC/AWGLCA/2009/INF.2), 15 September 2008

UNFCCC. 2008. Physical and Socio-economic Trends in Climate-related Risks and Extreme Events, and their Implications for Sustainable Development. United

Nations Framework Convention on Climate Change (UNFCCC) Technical Paper No. 3 (FCCC/TP/2008/3)

UNFCCC. 2006. Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries. Chapter IV: IV. Regional Impacts of and Vulnerabilities to Climate Change (Africa), pp 18-26. UNFCCC. unfccc.int/resource/docs/publications/impacts.pdf

URT. 2003a. Environmental and Social Framework: Environmental Guidelines for the Participatory Agricultural Development and Empowerment Project (PADEP): Ministry of Agriculture and Food Security, United Republic of Tanzania (URT). www.tanzania.go.tz/pdf/padepe.pdf

URT. 2003b. Initial National Communication under the United Nations Framework Convention on Climate Change (UNFCCC). Vice President's Office, United Republic of Tanzania (URT).

USAID. 2007. Adapting to Climate Variability and Change: A Guidance Manual for Development Planning. USAID, Washington, D.C.

USAID. 2006a. South Africa Pilot Study Report: Climate Change and Water Resource Planning in Polokwane. USAID, Washington, DC.

USAID. 2006b. Crop Diversification and New Technologies Open New Markets for Smallholders. www.kenyaag.org/success/SuccessstoryFelisitus1.pdf

USDA. 2006. Economic Information Bulletin No. 16. Agricultural Resources and Environmental Indicators (AREI 2006 Edition), Chapter 4.6: Irrigation Water Management. Economic Research Service, United States Department of Agriculture (USDA). http://www.econ.ag.gov/epubs/pdf/ah712/index.htm.

USDA. 2002. Agricultural Cooperatives in the 21st Century United States Department of Agriculture, Rural Business–Cooperative Service, Cooperative Information Report 60. www.rurdev.usda.gov/RBS/pub/cir-60.pdf

USDA. 1997. Agricultural Handbook No. 712. AREI (1996-97), Economic Research Service, United States Department of Agriculture (USDA). www.cau.edu.cn/water/cawr/download/usagwue.pdf .

van Beers. 2008. Afripump: A Sustainable Solution for Rural Water Supply. www.handpump.org

van Campen B, Guidi D and Best G. 2000. Solar Photovoltaic for Sustainable Agriculture and Rural Development. Environment and Natural Resources Working Paper No. 2. FAO, Rome.

van der Schans M.L and Lempérière P. 2006. Manual on Participatory Rapid Diagnosis and Action Planning for Irrigated Agricultural Systems (PRDA). FAO, Rome. ftp://ftp.fao.org/agl/iptrid/appia_manual_en.pdf

van Koppen B, Moriarty P and Boelee E. 2006. Multiple-Use Water Services to Advance the Millennium Development Goals. IWMI Research Report 98. IWMI, Colombo, Sri Lanka.

Venkatesan V and Kampen J. 1998. Evolution of Agricultural Services in Sub-Saharan Africa: Trends and Prospects. World Bank Discussion Paper No. 390. World Bank, Washington D.C.

Vermillion DL. 1999. Property Rights and Collective Action in the Devolution of Irrigation System Management. www.capri.cgiar.org/status.asp

Vörösmarty CJ, Green P, Salisbury J and Lammers RB. 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth. Science Vol. 289. (5477): 284 – 288. DOI: 10.1126/science.289.5477.284

Wang Z, Zerihun D and Feyen J. 1996. General Irrigation Efficiency for Field Water Management. Agricultural Water Management 30(2): 123-132

Wassmann R, Butterbach-Bahl K and Dobermann A. 2007. Irrigated Rice Production Systems and Greenhouse Gas Emissions: Crop and Residue Management Trends, Climate Change Impacts and Mitigation Strategies. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 2(4), 14 pp

WBCSD. 2009. Water, Energy and Climate Change: A contribution from the Business Community. Water Project of the World Business Council for Sustainable Development (WBCSD). http://www.wbcsd.org/web/WaterEnergyandClimateChange.pdf

Wilhite DA, MVK Sivakumar and Wood D. 2000. Improving Drought Early Warning Systems in the Context of Drought Preparedness and Mitigation. Drought Network News, Vol. 12, No. 3, Fall 2000. http://digitalcommons.unl.edu/droughtnetnews/104

Wilhite DA and Svoboda MD. 2000. Drought Early Warning Systems in the Context of Drought Preparedness and Mitigation. In: Wilhite DA, Sivakumar MKV and Wood DA (Eds.). Early Warning Systems for Drought Preparedness and Drought Management. Proceedings of an Expert Group Meeting in Lisbon, Portugal, 5 - 7 September 2000. WMO, Geneva, Switzerland, pp 1–21. www.unisdr.org/eng/library/Literature/7819.pdf

Wolf A. 2001. Water, Conflict, and Cooperation. In: Meinzen-Dick RS and Rosegrant MW. (eds.). 2001. Overcoming Water Scarcity and Quality Constraints. http://www.ifpri.org/2020/focus/focus09/focus09_14.htm

Wolff P and Stein TM. 2003. Improving On-Farm Water Management - A Never Ending Challenge. Agriculture and Rural Development in the Tropics and Subtropics, Vol. 104, No. 1, pp. 31-40.

WMO. 2007. Weather, Climate and Water Services for Everyone. World Meteorological Organization (WMO) No. 1024. www.wmo.int/pages/publications/showcase/documents/1024_E.pdf

WMO. 2006. Climate Information for Development Needs an Action Plan For Africa. Report and Implementation Strategy. GCOS 108 (WMO/TD No. 1358). www.wmo.ch/pages/prog/gcos/Publications/gcos-108 (ENGLISH).pdf

World Bank. 2009. Convenient Solutions to an Inconvenient Truth: Ecosystem based Approaches to Climate Change. Environment Department, World Bank, Washington D.C.

World Bank. 2006a. Reengaging in Agricultural Water Management: Challenges and Options. Directions in Development. World Bank, Washington, D.C.

World Bank 2006b. Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Research Systems. Agriculture and Rural Development, The International Bank for Reconstruction and Development, The World Bank, Washington, D.C. http://www.siteresources.worldbank.org/INTARD/.../Enhancing_Ag_Innovation.pdf

World Bank. 2005. Managing Agricultural Production Risk: Innovations in Developing Countries. Agriculture and Rural Development Department. The World Bank. Washington D.C.

World Bank. 1995. Toward Environmentally Sustainable Development In Sub-Saharan Africa. The World Bank. Washington D.C.

World Bank. 1993. Water Resources Management – A World Bank Policy Paper. The World Bank: Washington, D.C. 141 p.

WDR. 2008. Agriculture for Development. Chapter 5: Bringing Agriculture to the Market. World Development Report (WDR), 118-134. The World Bank, Washington, DC. siteresources.worldbank.org/INTWDR2008/.../WDR08_09_ch05.pdf

WRI, UNDP, UNEP and World Bank. 2000. World Resources 2000-2001: People and Ecosystems - The Fraying Web of Life. World Resources Institute (WRI), Washington, D.C.

Young MH. 2008. Global Climate Change: What Does it Mean for the World's Women? Population Action International (PAI) blog. www.populationaction.org/…/global-climate-change-what-doe.html

Ziervogel G, Catwright A, Taas A, Adejuwon J, Zermoglio F, Shale M and Smith B. 2008. Climate Change and Adaptation in African Agriculture. Research Report for Rockefeller Foundation prepared by the Stockholm Environment Institute (SEI). Stockholm, Sweden.

Ziesemer J. 2007. Energy Use in Organic Food Systems. Natural Resources Management and Environment Department, FAO, Rome. www.fao.org/docs/eims/upload/233069/energy-use-oa.pdf

ANNEXES

Annex 1: List of Study Interviewees

Name of Interviewee	Organization	Country	Contact Information
Dr Jean Ouédraogo Sibiri, Coordinator, Forest Production Department	Environment and Agricultural Research Institute (INERA)	Burkina Faso	tinsibiri_ouedraogo@yahoo.fr Tel.: (226) 70668186
Dr Bayala Jules, Eco-physiology/ Agroforestry	INERA	Burkina Faso	jules.bayala@coraf.org j_bayala@hotmail.com
Dr Mahamadi Tianda, Microbiologist	INERA	Burkina Faso	
Dr André Bationo, Agroforestry expert	INERA	Burkina Faso	abationo@agra-alliance.org
Dr Badolo Mathieu, General Manager	Institute of Science and Technology	Burkina Faso	iavsmail@gmail.com iavs_ mail@yahoo.fr
Alphonse Ouédraogo, Director, Program of Intensification of the Small Irrigation	Ministry of Agriculture, Hydraulics and Fisheries / Irrigation Development Department	Burkina Faso	cppiv@fasonet.bf Tel: +226 50499941
Ousséni Thanou, Director, Drinking Water Supply	Ministry of Agriculture, Hydraulics and Fisheries / Directorate General of Water Resources	Burkina Faso	ou.tha@gmail.com Tel: +226 50374863
Adama A Diallo, Director	National Meteorological Service	Burkina Faso	meteoburkina@yahoo.fr Tel: +226 50356032/39
Ali Jacques Garané, Head Officer, Meteorology	National Meteorological Service	Burkina Faso	ajgarane@yahoo.fr Tel: +226 76674595
Dr Yasir Mohamed, Senior Researcher	IWMI Regional Office for Eastern Africa	Ethiopia	y.mohamed@cgiar.org
Dr Solomon Abate, Regional Project Coordinator	NBI	Ethiopia	sabate@nilebasin.org
Dr Amare Haileslassie, Research Officer	ILRI	Ethiopia	a.haileslassie@cgiar.org
Tilahun Amede, Research Scientist	ILRI	Ethiopia	t.amemde@cgiar.org
Ephraim A Bogale, Executive Director	Ethiopian Rainwater Harvesting Association	Ethiopia	erha@ethionet.et Tel: +251 911 249426
Dr Boubacr Barry, IWMI/Glowa Volta Project Coordinator	Research on Water Resources and waste water use, IWMI	Ghana	b.barry@cgiar.org Tel: +233 21 784752-4 Fax: +233 21 784752

Name of Interviewee	Organization	Country	Contact Information
Dr Winston El Andah, Coordinator, Volta Basin CPWF, CGIAR	CPWF	Ghana	weiandah@africaonline.com.gh Tel: +233 21 775511/784753-4 Cell: +233 2081 55 948
Dr Konadu Acheampong, Programme Officer	United Nations University / Institute for Natural Resources in Africa	Ghana	Acheampong@inra.unu.edu.gh Tel: +233 21 504323 Cell: +233 24 4717491
Samuel Afram, Cluster Manager	Millennium Village Project, Bonsaso Cluster	Ghana	samuel.afram@undp.org Tel: +233 27 66 41259
Dr Joseph Mensah-Homiah, Science Coordinator	Millennium Village Project, Bonsaso Cluster	Ghana	mensahhomiah@gmail.com Tel: +233 24 46 15777
John Bewuiah, Policy Formulation & Implementation	Ministry of Food and Agriculture	Ghana	Tel: +233 21 668935 Cell: +233 242 01 03 43
JK Antwi, Director, Projects and Operations	Ministry of Food and Agriculture Irrigation Development Authority	Ghana	Tel: +233 21 668 661 / 662 050 Cell: +233 244 859 962
Emmanuel Sackey, Water Engineer	Ministry of Food and Agriculture, Irrigation Development Authority	Ghana	emmasackey@yahoo.com Tel: +233 21 668661 Cell: +233 243 156451
William K. Agyemang-Bonsu National Climate Change Focal Point	Ministry of Environment, Environmental Protection Agency	Ghana	wbonsu@epaghana.org wbonsu@4u.com.gh Tel: +233 21 663451 / 664697
Ben Ampomah, Water Economist	Water Resources Commission	Ghana	Tel.: +233 21 763651 / 765860 / 780231 Fax: +233 21-763649
Dr Patrick Mutuo, Science Coordinator/Team Leader	Millenium Villages Project, Sauri Cluster	Kenya	p.mutuo@cgiar.org Tel: +254 724 817 478
Peter Koinei, Infrastructure/Water Coordinator	Millenium Villages Project, Sauri Cluster	Kenya	p.koinei@cgiar.org Tel: +254 722 819 419
Margaret Wanjiku, Public Sector management Specialist	MDG Centre for Eastern & Southern Africa	Kenya	m.wanjiku@cgia.org Tel: +254 20 722 4494
Ms Sharon Gordon, Environment Specialist	MDG Centre for Eastern & Southern Africa	Kenya	s.gordon@cgiar.org Tel: + 254 20 722 4499
Kolon Idriss, Agriculture / Water Coordinator	Millennium Villages Project, Dertu Cluster	Kenya	idrissahal@yahoo.com Tel: +254 721 256 810
Dr Ahmed Mohamed, Science Coordinator/Team Leader	Millennium Villages Project Dertu Cluster	Kenya	maalimm4@yahoo.com Tel: +254 721 626 499
Duncan Ochieng' Onduu, Country Director	Self Help Development International Kenya	Kenya	kenya@shdi.org Tel: +254 51 221 2291
JE Paturel	Institut de Recherche pour le Développement (IRD)	Mali	paturel@ird.fr

Name of Interviewee	Organization	Country	Contact Information
Nadine Muther	IRD	Mali	Nadine.muther@ird.fr Tel: +223 6187134 Fax: +223 2216444
Alassane Boncana Maiga	Direction National de la Conservation de la Nature	Mali	Tel: +223 6117155
Lassine Diarra	Institut d'Economie Rurale (IER)	Mali	Lassine1945@yahoo.fr Tel: +223 6796178
Dr Boureima Dembele	IER	Mali	
Dr Amadou Boubacar Cisse	IER	Mali	
Daouda Zan Diarra Head, Agrometerology Division	National Meteorological Service	Mali	badiebie@yahoo.fr Tel: +223 2202110
Housseni Amadou Maiga	National Hydraulics Department	Mali	giremali@afribonemali.net Tel: +223 6722848
Abdoul-Salam Savadogo	MDG Centre for West and Central Africa	Mali	abdoul_sav@yahoo.fr Tel: +223 2229130 Fax: +223 2229343
Prof DO Adefolu	Environmental Bureau	Nigeria	Terb2007@yahoo.com
Prof Kparmwang	Institute of Agricultural Research, Soil Science Dept	Nigeria	Abuja - 08035929961
Mr Reverian Harinditwali	RADA	Rwanda	
Mr Theobald Bizimana, Agriculture / Environment Coordinator	MVP, Mayange Cluster	Rwanda	theobiz@yahoo.fr
Malang Diatta, Director, Hydraulic Resources	OMVS	Senegal	malang.diatta@omvs.org
Mahamadou Diakite Hydrologist Expert	OMVS	Senegal	mahamadou.diakite@omvs.org
Mahamadou Sacko, Coordinator, OMVS	OMVS	Senegal	mahamadousacko@hotmail.com
Marième Sow, Coordinator, Enda-pronat program	Ministry of Agriculture	Senegal	mariam@enda.sn
Jörg John, Coordinator, Healthy & Long-lasting Agriculture Program	Ministry of Agriculture	Senegal	pronat@enda.sn
Mrs Guene, In-charge of Program on Climate Change	Environment and Classified Establishments Head Office	Senegal	mactarguene@yahoo.fr Tel: +221 775707809
Dr Assize Touré, Technical Director	Ecological Monitoring Center (CSE)	Senegal	assize@cse.sn
Tinder Sall, Geographer	CSE	Senegal	amadou.sall@cse.sn
Gora Beye, Agronomist	CSE	Senegal	gora.beye@cse.sn
Boubacar Seck, Executive Director	CONGAD	Senegal	congad@orange.sn

Name of Interviewee	Organization	Country	Contact Information
Mamour Ngalane, Economics Consultant in Development	CONGAD	Senegal	mngalane@hotmail.com
Omar Diouf Science Coordinator	MVP, Potou Cluster	Senegal	omar.diouf@undp.org Tel: +221 339870081
Aliou Kandji, Cluster Manager	MVP, Potou Cluster	Senegal	aliou.kandji@undp.org
Mme M Niang Belko, Agronomist, Research Assistant, Eco-physiology	Regional Centre for Study on Drought Adaptation Improvement	Senegal	ceraas@orange.sn agromareme@yahoo.fr Tel: +221 33 9514993/94
Dr Gerson Nyadzi, Science Coordinator/Team Leader	MVP, Mbola Cluster	Tanzania	gerson.nyadzi@undp.org Tel: +255 784 305648
Dr George Sempeho, MVP Advisor	UNDP	Tanzania	george.sempeho@undp.org
John Ogwang, Irrigation Specialist	Ministry of Agriculture, Animal Industry and Fisheries, JICA funded project	Uganda	mbabazi47@yahoo.com Tel: +256 772 613054
Komayombi Bulegeya, Commissioner of Agriculture	Ministry of Agriculture, Animal Industry and Fisheries, Department of Crop Protection	Uganda	kbulegeya@yahoo.com Tel: +256 41 320115 Cell: +256 772 421132
Frank Akena	Ministry of Agriculture, Animal Industry and Fisheries, Department of Crop Protection	Uganda	
Wilson Fred Kyosingira, Principal Hydrologist and Assistant Commissioner	Ministry of Water and Environment, Directorate of Water Development, Water Resources Management Dept	Uganda	kyosingira.wrmd@dwd.co.ug Tel: +256 414 321 342 Cell: +2256 772 441 265
Ms Hamere Wondimu, Senior Program Officer / SVP Coordinator	NBI Secretariat	Uganda	hwondimu@nilebasin.org Tel.: +256 41 321424 Fax: +256 41 320971
Ms Phoebe Luwum Programme Officer	Global Water Partnership, East Africa	Uganda	pluwum@nilebasin.org Tel: +256 722 933598
Jason Oyugi Regional Project Manager	Global Water Partnership, East Africa	Uganda	joyugi@nilebasin.org Tel: +256 414 321424
Ms Gertrude Ngabirano, Regional Programme Manager	Swedish Embassy, SIDA, Lake Victoria Initiative	Uganda	Getrude.ngabirano@foreign.ministry.se Tel: +256 41 340970
Bart Hilhorst, Chief Technical Advisor	FAO Nile Project	Uganda	hilhorst@africaonline.co.ug Tel: +256 41 321391
Dr Tadesse Kibreab, Regional Consultant	FAO Nile Project	Uganda	thkibreab@faonile.org Tel: +256 41 321 391

Name of Interviewee	Organization	Country	Contact Information
Simon E Omoding, Communication Analyst	UNDP	Uganda	Simon.omoding@undp.org Tel: +256 414 233 440/1/2/5
Dr David Siriri, Science Coordinator	MVP, Ruhiira Cluster	Uganda	david.siriri@undp.org Tel: +256 772 443 809
Dr John Okorio, Cluster Manager	MVP, Ruhiira Cluster	Uganda	john.okorio@undp.org Tel.: +256 772 710 125
Robert Ayesiga, Infrastructure / Water Coordinator	MVP, Ruhiira Cluster	Uganda	robert.ayesiga@undp.org
Dr Joseph Mudipe, Agriculture & Environment Coordinator	MVP, Ruhiira Cluster	Uganda	joseph.mudiope@undp.org
Ms Jessica Troni, Regional Technical Advisor, Climate Change Adaptation	UNDP	South Africa	jessica.troni@undp.org Tel: + 27 12 354 80056
Dr Rashid Hassan, Director	University of Pretoria Centre for Environmental Economics and Policy in Africa	South Africa	
Dr Douglas Merrey, Director of Research	Food, Agriculture and Natural Resources Policy Analysis Network	South Africa	djmerrey@fanrpan.org d.merrey@cgiar.org Tel: +27 12 845 9105
Christian Cheron, Acting Director	IWMI	South Africa	c.cheron@cgiar.org
Yogesh Bhatt, Coordinator, Knowledge Management and Outreach	IWMI	South Africa	y.bhatt@cgiar.org

Annex 2: Interviewee Checklist

Background

Some of the information for the study was corrected using open-ended interviews and discussions with selected stakeholders. The purpose of the interviews was to assess how different stakeholders view climate change and its impact on water development, as well as what different stakeholders are doing to mitigate the impacts of climate change. By reviewing various policies that impact on water resources management and climate change mitigation interventions, the interviews helped to identify feasible interventions and strategies with potential for scaling up in other countries or communities.

The following is a checklist of questions and issues discussed during the interviews with various stakeholders.

- Water resources-based indicators for climate change (variations in rainfall, changes in run-off/river flow, variations in groundwater levels, occurrence of droughts and floods)
- Climate change monitoring systems (weather recording stations, river flow measurements, early warning systems, information needs)
- Effects of climate change on agricultural production, food security and livelihood systems in different climatic zones – potential impacts of climate change-driven changes in water resources on society
- Impacts of climate change-induced water resources management on other sectors such as environment and biodiversity conservation
- Water resources management-related conflicts that might occur or are being experienced due to reduced water supply for different uses and users
- Various climate change adaptation measures for smallholder farming systems (irrigation, rainwater harvesting, crop diversification, crop insurance)
- Government policies and institutions that either support or hinder implementation of climate change adaptation measures.
- Socio-cultural factors that affect implementation of adaptation measures (gender issues, traditional beliefs)

Sample Questions

- What climate change-induced water resources related problems have you encountered?
- Does your organization have disaster management strategies that take into account climate change and adaptation?
- What are the major sources of water for irrigation for smallholder famers and how are these affected by climate change?
- What are your activities related to climate change adaptation (soil and water management, food security, information sharing, best practices)?
- What factors have hindered implementation of adaptation to climate change measures and up-scaling of best practices?
- Have you financed any projects on climate change adaptation within the last decade? If yes, specify which projects and in which specified fields.
- What do you think is the best way to prepare for adapting to climate change in the wake of diminishing water resources?
- What are the potential water conflicts (inter-sectoral, inter-state, inter-country, urban vs rural, pastoral vs agricultural, downstream vs upstreamc) related to climate change or changes in water supply?
- Do you know of any institutions working on similar projects that could be considered for partnership and collaboration in future project development and implementation?
- What interventions do you think development partners/agents should focus on in future in terms of improving AWM-related adaptation to climate change in Africa?

Annex 3: Stakeholders in SSA

Organization/ program	Mandate and interventions	Operation Area	Contact Information
The World Bank – Vulnerability and Adaptation to Climate Change - Water and Climate Change Adaptation	The Bank's work on adaptation spans project and analytical work, development of tools for climate data dissemination and mapping as well as screening for climate risk to projects, and pilot insurance programs for protection against weather climate. The World Bank is developing a computer-based tool, ADAPT, that will screen proposed development projects for potential risks posed by climate change and variability. The tool is meant for use by development practitioners, including bank staff, bilateral agencies, the NGO community and client governments.	International, Africa	web.worldbank.org/
United Nations Development Program (UNDP) – Climate change program	UNDP's climate change adaptation program offers the latest information on three GEF funding modalities for Adaptation activities. It explains how the available funds can be accessed. The site also provides links to resources on climate change and adaptation, an overview of UNDP's Adaptation Portfolio including examples of ongoing projects in addition to guidance on preparing proposals.	International, Africa	www.undp.org/gef/adaptation/index.htm
United Nations Environment Programme (UNEP)	UNEP facilitates the development of better local climate data and its use in determining possible impacts of long-term climate change and short-term increased variability; it contributes to improving scientific methods and assessment tools, with a view to advancing the understanding of climate change impacts, vulnerability and adaptation needs; and it supports the improvement of the science and policy communities' ability to undertake adaptation planning and cost effective preventive action, including that linked to disaster prevention efforts.	International, Africa	www.unep.org/themes/climatechange/FocalAreas/Adaptation.asp
Food and Agriculture Organization of the United Nations (FAO)	The FAO leads international efforts to defeat hunger. Serving both developed and developing countries, FAO acts as a neutral forum where all nations meet as equals to negotiate agreements and debate policy. FAO is also a source of knowledge and information. We help developing countries and countries in transition modernize and improve agriculture, forestry and fisheries practices and ensure good nutrition for all	International, Africa	www.fao.org/climatechange/ www.fao.org/nr/water/

Global Environment Facility (GEF)	GEF, which was established in 1991, helps developing countries fund projects and programs that protect the global environment. GEF grants support projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants. The GEF funds projects through three primary funds: • *The Strategic Priority on Adaptation* (SPA) is an ecosystem/focal area focused fund. The goal is to ensure that climate change concerns are incorporated in the management of ecosystems through GEF focal area projects. It will pilot demonstration projects concerned with the management of ecosystems to show how climate change adaptation planning and assessment can be practically integrated into national policy and sustainable development planning. • *The Least Developed Countries Fund* (LDCF) is a development-focused fund. It supports the poorest countries, which are most vulnerable to climate change impacts. The fund provides support to *LDCs* as they prepare *National Adaptation Programs of Action (NAPA)* in which they identify their most urgent adaptation needs. Following their completion, additional funds will be made available to assist LDCs to implement the NAPAs, probably through expedited, medium-sized projects up to US$ 1.5 million. • *The Special Climate Change Fund* is also a development-focused fund concerned primarily with activities, programs and measures in the development sectors most affected by climate change. Areas of support include adaptation in agriculture, water resources management, health, disaster-risk and coastal zone management.	International, Africa	www.gefweb.org/
Food and Agriculture Organization of the United Nations (FAO)	The FAO leads international efforts to defeat hunger. Serving both developed and developing countries, FAO acts as a neutral forum where all nations meet as equals to negotiate agreements and debate policy. FAO is also a source of knowledge and information. We help developing countries and countries in transition modernize and improve agriculture, forestry and fisheries practices and ensure good nutrition for all	International, Africa	www.fao.org/climatechange/ www.fao.org/nr/water/

International Fund for Agricultural Development (IFAD)	IFAD is dedicated to eradicating rural poverty in developing countries. IFAD's goal is to empower poor rural women and men in developing countries to achieve higher incomes and improved food security. IFAD's activities are guided by the Strategic Framework for IFAD 2007-2010: Enabling the rural poor to overcome poverty. Through low-interest loans and grants, IFAD works with governments to develop and finance program and projects that enable rural poor people to overcome poverty themselves. IFAD tackles poverty not only as a lender, but also as an advocate for rural poor people. Its multilateral base provides a natural global platform to discuss important policy issues that influence the lives of rural poor people, as well as to draw attention to the centrality of rural development to meeting the Millennium Development Goals. IFAD focuses on agriculture and rural development and it is one of the largest sources of development financing for agriculture and rural development in many developing countries. It support many national agricultural development programs/projects implemented through governments ministries in SSA. Most of its programs/projects have AWM as a core activity, especially for smallholder farmers.	International, Africa	www.ifad.org/
International Food Policy Research Institute (IFPRI)	IFPRI seeks sustainable solutions for ending hunger and poverty. IFPRI's mission focuses on: • identifying and analyzing alternative international, national, and local policies in support of improved food security and nutrition, emphasizing low-income countries and poor people and the sound management of the natural resource base that supports agriculture; • contributing to capacity strengthening of people and institutions in developing countries that conduct research on food, agriculture, and nutrition policies; and • actively engaging in policy communications, making research results available to all those in a position to apply or use them, and carrying out dialogues with those users to link research and policy action.	International, Africa	www.ifpri.org/themes/climatechange/climatechange.asp

World Meteorological Organization (WMO)	The mission of WMO is to: • Facilitate worldwide cooperation in the establishment of networks of stations for the making of meteorological observations as well as hydrological and other geophysical observations related to meteorology, and to promote the establishment and maintenance of centers charged with the provision of meteorological and related services; • Promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information; • Promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics; • Further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities; • Promote activities in operational hydrology and to further close cooperation between Meteorological and Hydrological Services	International, Africa	www.wmo.ch/
Intergovernmental Panel on Climate Change (IPCC)	The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information about climate change. The IPCC does not conduct any research nor does it monitor climate related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its impacts and options for adaptation and mitigation.	International, Africa	www.ipcc.ch/
Assessments of Impacts and Adaptations to Climate Change – collaborative program of UNEP/ WMO/IPCC	Assessments of Impacts and Adaptations to Climate Change is a global initiative funded by the Global Environment Facility to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries. By funding collaborative research, training and technical support, the initiative aims to enhance the scientific capacity of developing countries to assess climate change vulnerabilities and adaptations, and generate and communicate information useful for adaptation planning and action.	International, Africa	www.wmo.ch/pages/ prog/wcp/wcdmp/ wcdmp_home_en.html

WMO - World Climate Data and Monitoring Programme (WCDMP)	WCDMP is a program of the World Climate Programme that facilitates the effective collection and management of climate data and the monitoring of the global climate system, including the detection and assessment of climate variability and changes.	International, Africa	www.wmo.ch/pages/prog/wcp/wcdmp/wcdmp_home_en.html
WMO - World Climate Applications and Services Programme (WCASP)	WCASP fosters the effective application of climate knowledge and information for the benefit of society and the provision of climate services, eg, prediction of significant climate variations both natural and as a result of human activity.	International, Africa	www.wmo.ch/pages/prog/wcp/wcasp/wcasp_home_en.html
WMO - Climate Information and Prediction Services (CLIPS)	The CLIPS project is an implementation arm of WCASP around the globe. It strives to take advantage of current data bases, increasing climate knowledge and improving prediction capabilities to limit the negative impacts of climate variability and to enhance planning activities based on the developing capacity of climate science	International, Africa	www.wmo.ch/pages/prog/wcp/wcasp/wcasp_home_en.html
WMO - Agricultural Meteorology Program (AGMP)	The purpose of the AGMP is to support food and agricultural production and activities. The Programme assists WMO Members in provision of meteorological and related services to the agricultural community to help develop sustainable and economically viable agricultural systems, improve production and quality, reduce losses and risks, decrease costs, increase efficiency in the use of water, labour and energy, conserve natural resources and decrease pollution by agricultural chemicals or other agents that contribute to the degradation of the environment.	International, Africa	www.wmo.ch/pages/prog/wcp/agm/agmp_en.html
World Resources Institute (WRI): - Climate and Adaptation - Climate Analysis Indicators Tool (CAIT)	• The adaptation to climate change database brings together 135 examples of adaptation projects, policies, and other initiatives from the developing world. • CAIT is an information and analysis tool on global climate change developed by the WRI. CAIT provides a comprehensive and comparable database of greenhouse gas emissions data (including all major sources and sinks) and other climate-relevant indicators. CAIT can be used to analyze a wide range of climate-related data questions and to help support future policy decisions.	International, Africa	projects.wri.org/adaptation-database cait.wri.org/

The Rockefeller Foundation (RF) Climate Change Resilience	The RF Climate Change Initiative seeks to catalyze attention, funding, and action in building climate change resilience for poor and vulnerable people globally by: • creating robust action models of climate change resilience for poor and vulnerable people; • funding, promoting, and disseminating those models; and • increasing pressure on funders, practitioners, and policy-makers to support increased funding and action for climate change resilience for poor and vulnerable people	Africa	www.rockfound.org/initiatives/climate/climate_change.shtml
African Development Bank (AfDB)	The Bank's mission is to promote economic and social development through loans, equity investments and technical assistance. The Bank's strategy to address climate change is to integrate the management of current climate variability and extremes with adaptation to climate change: a climate risk management and adaptation (CRMA) approach.	Africa	Head office in Tunis, Tunisia www.afdb.org
New Partnership for Africa's Development (NEPAD) / Comprehensive Africa Agriculture Development Programme (CAADP)	NEPAD is a vision and strategic framework for Africa's renewal designed to address the current challenges facing the African continent. CAADP, in partnership with FAO, is designed to address challenges facing agricultural development in Africa. The CAADP initiative offers an integrated framework of development priorities that comprises five pillars: • expansion of area under sustainable land management and reliable water control systems; • improvement of rural infrastructure and trade-related capacities for better market access; • enhancement of food supply and reduction of hunger (including emphasis on emergencies and disasters that require food and agricultural responses); • development of agricultural research, technology dissemination and adoption to sustain long-term productivity growth; and • sustainable development of livestock, fisheries and forestry resources .	Africa	Ambassador Olukorede Willoughby Acting Executive Head: NEPAD Secretariat, Johannesburg, South Africa Tel: +27 11 313 3840 olukoredew@nepad.org www.nepad.org

Alliance for Green Revolution in Africa (AGRA)	AGRA is a dynamic, African-led partnership working across the African continent to help millions of small-scale farmers and their families lift themselves out of poverty and hunger. AGRA programs develop practical solutions to significantly boost farm productivity and incomes for the poor while safeguarding the environment. AGRA advocates for policies that support its work across all key aspects of the African agricultural value chain—from seeds, soil health, and water to markets and agricultural education.	Africa	Maintains Offices Nairobi, Kenya, and Accra, Ghana www.agra-alliance.org
International Council for Local Environmental Initiatives (ICLEI) - Local Governments for Sustainability	ICLEI is an international association of local governments and national and regional local government organizations that have made a commitment to sustainable development. ICLEI provides technical consulting, training, and information services to build capacity, share knowledge, and support local government in the implementation of sustainable development at the local level.	International, Africa	Africa Secretariat Cape Town, South Africa Tel: +27 21 487 2070 iclei-africa@iclei.org www.iclei.org
Climate Change Adaptation in Africa (CCAA) – a joint program of IDRC and DFID	CCAA research and capacity development program aims to improve the capacity of African people and organizations to adapt to climate change in ways that benefit the most vulnerable. The program was launched in 2006 and is jointly funded by IDRC and DFID. It is hosted and managed by IDRC from headquarters in Ottawa and three regional offices in Africa. Building on existing initiatives and past experience, the CCAA program works to establish a self-sustained skilled body of expertise in Africa to enhance the ability of African countries to adapt.	Africa	http://www.idrc.ca/ccaa
USAID - Adapting to Climate Variability and Change	Active in more than 40 developing and transition countries, the program integrates climate change into the broad range of USAID's development assistance activities. Through training, tools, and other means of capacity building, USAID helps developing and transition countries address climate-related concerns as a part of their development goals.	International, Africa	www.usaid.gov/our_work/environment/climate/ www.usaid.gov/our_work/environment/climate/policies_prog/vulnerability.html

Organization for Economic Cooperation and Development (OECD) – Sustainable Development	OECD countries bear a special responsibility in achieving sustainable development worldwide. OECD activities are overseen by the Annual Meeting of Sustainable Development Experts, who reviews special projects as well as progress in mainstreaming sustainable development concepts into the overall work of the OECD. Most OECD activities relate to sustainable development, from climate change analysis to development co-operation to corporate social responsibility.	International, Africa	www.oecd.org/
International Water Management Institute (IWMI)	IWMI targets water and land management challenges faced by poor communities in the developing world/or in developing countries and through this contributes towards the achievement of the MDGs of reducing poverty, hunger and maintaining a sustainable environment. The research agenda is organized around four priority themes: • Basin Water Management; • Land, Water and Livelihoods; • Agriculture, Water and Cities; and • Water Management and Environment. Cross cutting activities in all themes include, assessment of land and water productivity and their relationship to poverty, identification of interventions that improve productivity as well as access to and sustainability of natural resources, assessment of the impacts of interventions on productivity, livelihoods, health and environmental sustainability. Research on Water Resources and waste water use:	International, Africa	www.iwmi.cgiar.org/ www.iwmi.cgiar.org/ Offices/Africa
	• Research on water resources assessment, • Utilization of shallow groundwater • Improving peri-urban irrigation with waste water to ensure safety marketed vegetables West Africa	West Africa	Dr Boubacr Barry IWMI/Glowa Volta Tel : +233 21 7847 52-4 b.barry@cgiar.org www.iwmi.org

Comprehensive Assessment of Water Management in Agriculture – a program of the CGIAR	The Comprehensive Assessment of Water Management in Agriculture critically evaluates the benefits, costs, and impacts of the past 50 years of water development, the water management challenges communities are facing today, and solutions people have developed. The results will enable better investment and management decisions in water and agriculture in the near future and over the next 50 years. The assessment is produced by a broad partnership of practitioners, researchers and policy makers.	International, Africa	www.iwmi.cgiar.org/Assessment/
Challenge Program on Water and Food (CPWF)	• CPWF is an international, multi-institutional research initiative with a strong emphasis on north-south & south-south partnerships. Its goal is to increase the productivity of water used for agriculture, leaving more water for other users and the environment. • The multiple-use water service project is part of the Challenge Program on Water and Food, which conducts scientific action research to validate this statement about water-innovation. The project works through so-called learning alliances in 5 river basins around the world to develop locally specific innovations and build capacity for scaling up. The project objectives are: - To produce more crop per drop of water - Research in the Volta basin and other international river basins Rain water harvesting and nutrient use efficiency - Crop Variety development for drought conditions - Reservoir studies to enhance dry season irrigation.	International, Africa	Dr Winston Andah Volta Basin Coordinator, CPWF, CGIAR Tel: +233 21 775511/784753-4 weiandah@africaonline.com.gh www.waterforfood.org www.musproject.net
The International Research Institute for Climate and Society – Columbia University, New York	The institute's mission is to enhance society's ability to understand, anticipate and manage climate risk, in order to improve human welfare. IRI experience has led us to a comprehensive approach to climate-sensitive problems, with aims to: • Help deliver and improve climate science that responds to the demands of decision makers in different economic sectors. • Develop, explore and evaluate climate risk management strategies. • Strengthen development through the integration of climate risk management. • Capture and manage knowledge, train and share information in support of managing climate related risks.	International, Africa	portal.iri.columbia.edu

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	ICRISAT is a nonprofit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. Together with other CGIAR centers is involved in a number of climate change adaptation projects eg, development of drought resistant crop varieties, and land and water management (Global Theme on Agro-ecosystems Development). ICRISAT serves as a catalyst, facilitator and enabler on the areas: • Development of improved watersheds in Asia and sharing of lessons learned with Soil and Water Management Networks in sub-Saharan Africa; • Examining the agricultural implications of current climate variability and potential adaptation to climate change research; • The Oasis Consortium linking global efforts for research at desert margins thus acting as a principal research. • Promote African Market Garden drip irrigation technology for crop diversification in SSA - installing low-head drip irrigation systems in West Africa. • The Sahelian Eco-Farm is an integrated dryland tree-crop livestock system for millet-based production systems.	Semi-arid tropics of SSA	www.icrisat.org
Co-operative Program on Water and Climate	The program builds bridges between water managers and the climate community, from the local up to the global level. Through increasing awareness of the issues and of potential solutions we seek to set in motion social and political processes that will lead to the adoption of coping strategies and best practices.	International, Africa	www.waterandclimate.org
Adaptation Learning Mechanism	This project will draw from experiences on the ground, featuring tools and practical guidance to meet the needs of developing countries. Seeking to provide stakeholders with a common platform for sharing and learning, the project will also complement the wide range of adaptation knowledge networks and initiatives already underway.	International, Africa	www.adaptationlearning.net/

The Stockholm Environment Institute (SEI) - Water Resources and Sanitation Program	The research programs aim to clarify the requirements, strategies and policies for a transition to sustainability. These goals are linked to the principles advocated in Agenda 21 and the Conventions such as Climate Change, Ozone Layer Protection and Biological Diversity. The institute has been engaged in major environment and development issues for a quarter of a century. The institute's Oxford Centre focuses on adaptive resource management, particularly related to climatic risks, with expertise in water, food security and livelihoods. Our mission is to support organizational change to achieve sustainable development, through research, risk communication, decision support, training and participatory approaches. Oxford activities fall into five broad categories: climate change impacts and adaptation; vulnerability assessment; adaptation strategies for climate outlooks; climate risk and insurance; and climate policy research.	International, Africa	www.sei.se/index.php
The Global Water Partnership	The Global Water Partnership is a working partnership among all those involved in water management: government agencies, public institutions, private companies, professional organizations, multilateral development agencies and others committed to the Dublin-Rio principles. They are committed to support countries in the sustainable management of their water resources. Global Water Information Network (GLOBWINET) is one of the Associated Programs of thje partnership in the context of IWRM. GLOBWINET aims to provide an information platform for integrated water resources management. It is an internet-accessible database of water-administration related information around the globe that can be fed and administrated in a decentralized fashion.	International, Africa	www.gwpforum.org/ www.globwinet.org/
SADC-HYCOS	SADC-HYCOS is a regional component of the WMO program aimed at contributing to regional social-economic development through the provision of management tools necessary for sustainable and cost effective water resources development, management and environmental protection.		sadchycos.dwaf.gov.za

SADC - Food, Agriculture and Natural Resources	SADC's mission is to achieve development and economic growth, alleviate poverty, enhance the standard and quality of life of the people of Southern Africa and support the socially disadvantaged through regional integration while promoting and maximizing productive employment and utilization of resources of the Region to achieve sustainable utilization of natural resources and effective protection of the environment.	Southern Africa	Leefa Martin SADC Secretariat, Gaborone, Botswana Tel: +267 395 1863 www.sadc.int/ www.sadc.int/fanr
IGAD - IGAD Conflict Early Warning and Response Mechanism - IGAD Climate Prediction and Application Centre	The IGAD mission is to assist and complement the efforts of the Member States to achieve, through increased cooperation: • Food Security and environmental protection • Promotion and maintenance of peace and security and humanitarian affairs, and, • Economic cooperation and integration. Climate change IGAD-related initiatives: • The Early Warning and Response Mechanism's mandate is to receive and share information concerning potentially violent conflicts as well as their outbreak and escalation in the IGAD region. • The Climate Prediction and Application Centre's mission is provision of timely climate early warning information and supporting specific sector applications to enable the region cope with various risks associated with extreme climate variability and change for poverty alleviation, environment management and sustainable development of the member countries.	IGAD region – 7 countries (Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda as well as Burundi, Rwanda and Tanzania)	IGAD Secretariat, Djibouti Tel.: +253 354 050 igad@igad.org www.igad.org/ www.cewarn.org/ www.icpac.net/
IMAWESA of ASARECA	IMAWESA is a regional knowledge management network supported by IFAD and implemented by ASARECA and ICRISAT, whose goal is to enable poor producers in eastern, central and southern Africa increase their incomes through improved management of agricultural water. IMAWESA's purpose is to enhance the development impacts of public and private investments in smallholder AWM in the region.	23 countries in eastern, central & southern Africa	Prof Bancy Mati IMAWESA Project Manager Tel.: +254 20 7224110 b.mati@cgiar.org imawesa@cgiar.org www.asareca.org/imawesa
Southern and Eastern Africa Rainwater Network (SearNet)	A regional network of National Rainwater Associations in southern and eastern Africa, involved in promotion of RHM systems and technologies for improving water supply and sanitation.	Southern and Eastern Africa	Mr. Maimbo Malesu, SearNet Coordinator m.malesu@cgiar.org World Agroforestry Center, ICRAF www.searnet.org

MDG Centre - East & Southern Africa - West & Central Africa	Through the MVP, the MDG Centres are involved in: • Intensification of food crop production by smallholders: improved access to inputs (seed, fertilizer, water) • Shifts in crop and variety selection towards greater drought and high temperature tolerance and improved pest and disease resistance (CGIAR, AGRA) • Improved production systems to conserve soil moisture; • Grain storage investments to improve quality and quantity of carryover stocks and enable access to regional surpluses; • Enterprise diversification towards higher value products and off-farm employment; • AWM – smallholder irrigation, rainwater harvesting and better land & water management; • Weather forecasting and timely advice to farmers; • Weather-related insurance.	SSA: Ethiopia, Ghana, Malawi, Mali, Nigeria, Kenya, Rwanda, Senegal, Tanzania, Uganda	Dr Belay Begashaw Director, MDG Center – ESA Tel.: +254 20 7224129 b.begashaw@cgiar.org www.mdgcentre.org Dr. Amadou Niang Director, MDG Center - WCA Tel : +223 222 9130 a.niang@cgiar.org
MVP of the Earth Institute at Columbia University (New York), Millennium Promise and UNDP	• MVP offers a bold, innovative science & technology based model for helping rural African communities lift themselves out of extreme poverty. • The Millennium Villages are proving that by fighting poverty at the village level through community-led development, rural Africa can achieve the MDGs—global targets for reducing extreme poverty and hunger by half and improving education, health, gender equality and environmental sustainability—by 2015, and escape the extreme poverty that traps hundreds of millions of people throughout the continent. • Integrated and multi-sectoral rural development focusing on all aspects of improving livelihoods	SSA: Ethiopia, Ghana, Kenya, Malawi, Mali, Nigeria, Rwanda, Senegal, Tanzania, Uganda	Dr Pedro Sanchez, Director p.sachez@ei.columbia.edu www.millenniumvillages.org
GHARP: Some of the active members are: • Ethiopia Rainwater Harvesting Association • Kenya Rainwater Association (KRA) • Uganda Rainwater Association	GHARP is a regional network of National Rainwater Associations in the Greater Horn of Africa involved in: • Promotion of RHM systems and complementary technologies for improving water supply and sanitation, health and nutrition, food security, enterprises creation, environmental management and sustainable livelihoods. • Integrated AWM strategies, especially for water stress communities in semi-arid environment	Greater Horn of Africa (Ethiopia, Kenya, Tanzania, Somalia and Uganda)	Ms Susan W. Kungu GHARP/KRA Secretariat, Nairobi, Kenya gharp@wananchi.com www.gharainwater.org

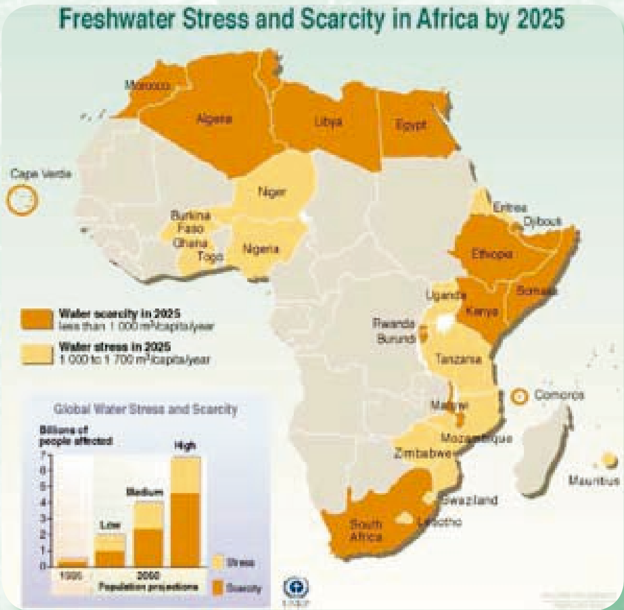
Institute of Science and Technology (IST):	IST works in collaboration with the Universities of Niamey, Canada and Ouagadougou and research on geography/conflict resolution/ renewable energy, policy change/ governance: • Climate insurance, • Climate change risk management in urban areas · • Food safety and - climate change	Burkina Faso, Niger and Canada	Dr Badolo Mathieu, General Manager iavsmail@gmail.com, iavs_mail@yahoo.fr
Permanent Interstate Committee for Drought Control in the Sahel (CILSS)	Its mission is to be involved in the research of food security and to combat the effects of drought and desertification for better ecological stability	Sahel	CILSS Secretariat in Ouagadougou Tel.: +226 5037 4125/265 cilss@cilss.bf; CILSS@ fasonet.bf www.cilssnet.org; www. cilss.bf/
Senegal River Development Organization (OMVS)	Mandated to promote and coordinate studies and implement development projects in water resources of Senegal River Basin: • Implementation of a regional Action plan for the improvement of irrigated agriculture within the Senegal River basin. • Implementation of a warning / communication system the Senegal River basin: program of mitigation and monitoring of the impacts of climate change on the environment	Guinea, Mali, Mauritania and Senegal	Malang DIATTA, Director, Management of the Hydraulic Resources Office malang.diatta@omvs.org omvs-soe.org
International Institute for Water and Environmental Engineering	• Specialized Centre for Water and Environmental Engineering within the framework of the African Institute of Science and Technology, a great project supported by the Nelson Mandela • Training water technicians and Engineers	West and Central Africa	www.2ie-edu.org
Environment and Agricultural Research Institute (INERA)	Mandated to carry out research on: farming systems and adaptation to climate change, the management of natural resources, irrigation and soil management through: • Soil and water Conservation • Impact of climate change on agro-forestry • Waste water treatment and reuse in urban areas	Burkina Faso	Ouédraogo Sibiri Jean, Coordinator of the Forest Production Department, Tel: +226 70668186 tinsibiri_ouedraogo@ yahoo.fr
Council of NGOs for Development Support (CONGAD)	• Intensification of the institutional, organizational and technical capacities of the CONGAD and its members; • Capitalization and sharing of the experiences of NGOs to make their actions visible; • Promotion of political, economic, social and cultural dialogue to influence the national, African and international public policies	Senegal	Boubacar Seck, Executive Director congad@orange.sn

Self Help Africa (SHA) Kenya	• Vision: Flourishing rural communities with access to basic needs and means to sustainable livelihoods. • Mission: To facilitate rural communities to realize sustainable development through bottom-up approaches in partnerships with relevant stakeholders. • Goal: Establishment of self-sustaining communities in food security and social-economic development. • Strategies: - Promote integrated AWM strategies to improve livelihoods of rural communities in drought stricken areas. - Promote the utilization of appropriate crop production technologies. - Identify and promote drought tolerant crop varieties. - Build the capacity of farmers through training in different agricultural enterprises. - Provision of clean water through the existing community opportunities. - Promote soil and water conservation technologies. - Facilitate formation of farmer associations as structures to help farmers to market their produce and undertake other activities. - Facilitate farmers to initiate viable agri-based income generating activities. - Train groups in financial management and credit operations. - Facilitate availability and access to credit for farmers.	Kenya	Mr Duncan O. Onduu Country Director, Country Office, Catholic Diocese of Nakuru Plaza – 2nd floor Stadium Road off Kenyatta Avenue PO Box. 2248 – 20100, Nakuru, Kenya Tel: +254 51 2212291 Fax: +254 51 2212304 duncan.ochieng@selfhelpafrica.net Kenya@sha.org www.selfhelp.ie
Ecological Monitoring Center (CSE)	The main activities of the center are environmental monitoring, environmental economics, coordination of environment baseline studies in Senegal: • The collection and storage natural resources planning and management • Capacity building of development agencies • Project conceptualisation and implementation and fund-raising • Support the development of the private sector by training and partnership • Facilitate technology transfer by training	Senegal	Dr Assize Toure, Technical Director assize@cse.sn
United Nations University / Institute for Natural Resources in Africa	Capacity building in African universities for developing, adapting and disseminating technologies for food security, environmental conservation and efficient use of natural resources	African countries	Dr Konadu Acheampong acheampong@inra.unu.edu.gh www.inra.unu.edu Tel: +233 21504323

Regional Centre for Study on Drought Adaptation Improvement	Basic research, research methodology and strategy, adaptive research, research development, replication & production through: • Improving drought adaptation through research and training • Soil management conservation	Western Africa and Central Africa South America	Mme Marème Niang Belko, Agronomist, Tel: +221 33 9514993/94 ceraas@orange.sn www.ceraas.org
Soil Science Department, Institute of Agricultural Research, Nigeria	• Crop variety selection • Soil management for improved fertility • Irrigation from small dams but shallow wells for small gardens	Nigeria	Prof Kparmwang Abuja - 08035929961
Water Resources Commission	• Mandated to coordinate the development and use of water resources in the country • Management of water including water conservation, water use rights management, sensitization of population on trends in water quality and quantity changes	Ghana	Ben Ampomah, Water Economist, WRC, Ghana Tel: 233 21 763651/765860/ 780231
Environmental Bureau Limited	• Farmers guide on crop-climate relations, transfer of adoption experiences • Most suitable crops for different ecological zones (onset of rains and length of rainy season) • Small dams and rain fed irrigation assistance	Nigeria	Prof DO Adefolu Terb2007@yahoo.com
Institut d'Economie Rurale (IER)	• Conceptualization and implementation of research activities and research studies for agricultural development • Use of appropriate technology for increased production and improvement in rural productivity • Dissemination of research results.	Mali	Lassine Diarra Tel : +223 6796178 Lassine1945@yahoo.fr
Ministries of agriculture (and related sub-sectors)	• Agricultural development in each country • AWM (especially rainfed agriculture – rainwater harvesting for crop production and irrigation water management • Agricultural extension services including soil and water conservation, land husbandry, crop protection • Integrated management of soil fertility and crops • Agricultural marketing • Conduct research on related issues such as land and water management, AWM, crop varieties, etc.	All countries (each country has its relevant department)	Ministry headquarters in each country

Ministries of water (and related sub-sectors, eg, irrigation)	• Mandated to carry out water resources, monitoring, planning, development and management • Integrated water resources management • Sectoral water allocation – water for production • Promotion of small scale irrigation to meet the needs of smallholder farmers / implementation of climate change adaptation measures • Rehabilitation and extension of small-, medium- and large-scale irrigation schemes • Water policy and legislation	All countries (each country has its relevant department)	Ministry headquarters in each country
Ministries of environment (and related sub-sectors)	• Conservation of environment and natural resources (including water resources) • Watershed protection and conservation • Ensuring environmental flows of rivers are sustained • Enforcing water quality control – pollution control • National Environment Management Authority / Environmental Protection Agency – enforcement of environmental conservation measures • Clean development mechanism • Environmental education and training • Vulnerability and mitigation assessment	All countries (each country has its relevant department)	Ministry headquarters in each country
National meteorological services (meteorological departments)	The main activities related to climate change are essentially survey, data collection & analysis, weather forecast and prediction, and assistance to vulnerable sectors such as agriculture and water resources through: • Participation in agro-pastoral monitoring campaigns • Information on rainfall for water resources monitoring in various river basins; • Drought monitoring and forecasting • Participation in disaster prevention activities through the monitoring of hydro-meteorological phenomena • NAPA's focal point	All countries (each country has its relevant department)	National meteorological departments

As many countries in sub-Saharan Africa contemplate how to address water crisis, smallholder farmers who are majority of rural communities, continue to be the most affected due to limited options to adapt to climate change induced water scarcity and variability. The expected water stress and scarcity scenario by 2025 shown clearly below indicates a gloomy picture. The study revealed that all is not lost, and there exist adaptive strategies that can help smallholder farmers to shift from subsistence to commercial agriculture. Despite diminishing water resources, a Green Revolution is still possible in Africa, but increased investment in agricultural water management and support to smallholder farming systems is a prerequisite. It is time for development partners to take action and support a sustainable Green Revolution in Africa.



The MDG Centre

EAST & SOUTHERN AFRICA

United Nations Avenue
P.O. Box 30677-00100, Nairobi, Kenya
Tel.: +254-20-7224411
Fax: +254-20-7224490
Website: www.mdgcentre.org
www.earth.columbia.edu

ISBN 978-92-9059-264-8