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Working Paper 9

Agricultural Water Management in the Context Of Climate Change in Africa

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AGRICULTURAL WATER MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE IN AFRICA

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D R A F T

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COMMON ACRONYM

AfDB :	African Development Bank
ASAL:	Arid and Semiarid Lands
AWM:	Agricultural Water Management
CA:	Comprehensive Assessment
CAADP:	Comprehensive Africa Agriculture Development Programme
CBOs:	Community-based Organizations
CPWF:	Challenge Programme on Water for Food
FAO:	Food and Agriculture Organization
IPCC:	Intergovernmental Panel on Climate Change
IFAD:	International Fund for Agricultural Development
IPTRID:	International Programme for Technology and Research in Irrigation and Drainage
NBI:	Nile Basin Initiative
NEPAD:	The New Partnership for Africa's Development
NGOs:	Non-government Organizations
WUAs:	Water User Associations
UNEP:	United Nations Environment Programme
RWH:	Rainwater Harvesting
SADC:	Southern Africa Development Community
SIWI:	Stockholm International Water Institute
SSA:	Sub-Saharan Africa
SSI:	Small Scale Irrigation
WEMA:	Water Efficient Maize for Africa
WAIPRO :	West African Irrigation Project
WOCAT:	World Overview of Conservation Approaches and Technologies

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ABSTRACT

The agricultural systems in Africa are commonly characterized by low-input, drought-prone farming evolved through interaction of a wide range of agro-ecological, cultural, social, political and economical factors. The effect of climate change would be most felt in Africa, where communities, governments and local institutions are not yet well prepared to respond to emerging climate challenges. There has been a wide variety of local climate change adaptation mechanisms in Africa to minimize negative effects, though these adaptation mechanisms are commonly community-specific and didn't expand beyond specific localities. Agricultural water management (AWM) offers a way of facilitating water-centred development to simultaneously reduce poverty, increase food security and adapt to climate variability and change. It focuses on ecosystems rather than commodities; on underlying processes (both biophysical and socio-economical) than simple relationships; and on managing the effects of interactions between various elements of the production systems. It aims to decrease unproductive water losses from a system, as well as increase the adaptive capacity of communities and institutions. The water saved from agriculture could be used for other uses but also balance the water needs between agricultural and environmental services. Adoption of AWM interventions would improve the profitability of smallholder agriculture by increasing crop and livestock yield by factors of up to five-fold, while net returns on investment could double. However, the adoptions of these interventions demand a multi-institutional engagement and collective action of institutions at various levels. The policy and institutional framework of NEPAD/ CAADP recommending sustainable land management and reliable water control systems along with improving soil fertility. Although the national policies in most of Africa didn't have functional policies in AWM, except for scattered statements across different ministries or sectors. The scattering of AWM issues across several sectors had resulted in unavoidable overlapping of policies, duplication of efforts and inefficient use of resources, as well as the lack of clear ownership of AWM issues. Weak institutional capacity at various levels and poor market access are other factors affecting adoption of improved water management for climate change adaptation. Moreover, the regional organizations in Africa need to go beyond prescribing a common initiative to facilitating the ground for coordinated presence of bilateral and multilateral institutions across the board that would improve water resource governance, particularly related to water benefits, leading to efficient and equitable benefit sharing by riparian countries. Based on the past and present achievements, successful AWM examples for increasing agricultural productivity and adaptation to climate change in Africa are discussed herein.

Key Words: Agricultural water management, Water-centred development; climate adaptation, ecosystems focus; Africa

INTRODUCTION

The African agriculture is a mosaic shaped by interaction of a wide range of agro-ecological, cultural, social, political and economical factors though rainfall amounts and distribution, temperature, altitude, resources base, food habits and socio-economic realities may have played the most important role in determining the types of farming systems. The African continent could be roughly divided into five agro-ecologies, with overlapping transitional zones (Dudal, 1980). The humid zone stretches from west to central and eastern Africa with a mean annual rainfall commonly exceeding 1500 mm/year, a temperature ranging between 24 ^{o}C and 28 ^{o}C and a growing period of more than 270 days (Bationo, 2006). This agro-ecology includes the wet central region of the Congo basin, which receives about 37% of all precipitation in Africa (Frenken, 2005). The sub-humid zone covers most of the Central, Western and Southern Africa, with one or two rainy seasons of varying length of growing period ranging from 180 to 269 days. The semi-arid zone covers areas between the sub-humid wooded savannah and the arid zones with rainfall averages from 200 mm to 800 mm/year and a growing period between 75 and 179 days (Bationo, 2006). This zone includes the vast areas of the Sahel and eastern Africa, where pastoral and agro-pastoral production systems are pre-dominant. The Arid zone covers extensive areas with average annual rainfall below 200 mm, where sedentary agriculture is rarely practiced. This zone includes the vast deserts of the Sahara, the Namibian, Kalhari and the Karroo (Dudal, 1980). Moreover, the arid and semiarid lands (ASAL) in Africa in average cover about 41% of the land area, although in some countries the ASAL areas cover about 75% (e.g. Kenya) and in others up to 90 % (e.g. Northern Africa). The Mediterranean zone covers the extreme Northern and Southern Africa, which is one of the most water stressed part of the continent, is already drought prone and about 75% of the region annual renewable water emerging from rivers from other African regions. Figure 1, UNEP (2010) presents the average annual total water balance distribution of Africa, showing where most of the surplus rainfall above evapotranspiration exists.

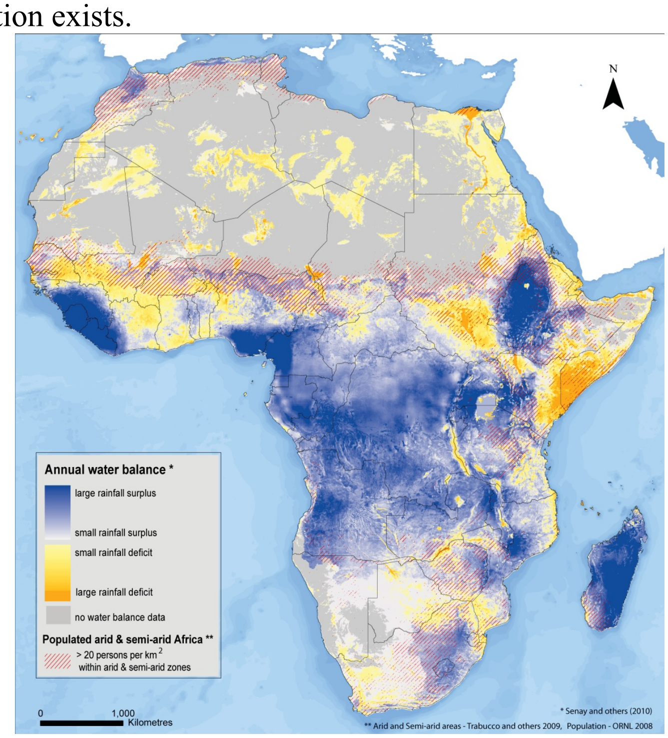

Figure 1. Annual water balance (rainfall minus evapotranspitration) of Africa (UNEP, 2010)

This diversity in agro-ecology is also reflected in the type of agricultural production systems, the respective zones are practicing although the enterprise choices and intensification levels are partly governed by non-climatic factors including investments on irrigation facilities, market access, agricultural policies and institutional arrangements. Moreover, there is a general understanding that the effect of climate variability and climate change in Africa would be most felt in countries with relatively well water endowed regions (about 25% of the continent), where communities, governments and local institutions are not yet well prepared to respond vigorously to emerging climate challenges. The poor and vulnerable populations of Sub-Saharan Africa (SSA) will likely face the greatest risk (IPCC, 2007). Poverty is highly regionalized with SSA as one of the core areas for absolute poverty, sharing with Asia 70% of the world's poor (Namara *et al.,* 2010). With more than 90% of the continent depending on rainfed agriculture (green water), the consequence of climate change on food security and livelihoods could be disasters unless responsive climate change adaption mechanisms are in place at farm, landscape and basin scales. IPCC (2007) indicated that climate change, mainly as a result of human action, is impacting SSA more than any other continents because its economies are largely based on weather-sensitive crop-livestock and agro-pastoral production systems and also due to the low adaptation capacity of SSA countries to climate change and variability. Climate change induced agricultural drought commonly denotes a prolonged period without considerable precipitation or rainfall that would not fulfill crop water requirements, which may cause a reduction in soil water content thereby cause plant water deficit. It is mainly caused by variable supply of rainfall across seasons, poor soil water holding capacity of soils and improper management of water resources (Amede, 2006). In many parts of Africa, farmers and pastoralists have to contend with extreme natural resource challenges and constraints such as poor soil fertility, pests, crop diseases, and a lack of access to inputs and improved seeds. These challenges are usually aggravated by periods of prolonged drought or floods Based on various studies and scenarios, the impact of climate change may include changes in the length of crops growing periods, the onset of rainfall, seasonality, intensity, variability of dry spells, each of which have implications on agricultural productivity and peoples livelihoods. Other impacts include the reduction of land area suitable for rainfed agriculture, increasing of the area of arid and semi-arid land in Africa perhaps about 5-8% (60-90 million hectares) by 2080, disappearance of wheat production from Africa in the same period, and a reduction of yield by up to 50% by 2020 (IPCC AR4-WGII, 2007). Major trade-offs are also forecasted between agriculture and ecosystem services, including trade-offs between increasing food security on the one hand and safeguarding ecosystems on the other hand (de Fraiture *et al.,* 2007; Bossio, 2009).

According to FAO (2009) recent estimates, the demand for water for farming, industrial and urban needs in Africa will increase about 40 percent by 2030. Climate change is likely to intensify the current challenges of water scarcity and water competition within and between communities and nations, particularly in those countries linked by transboundary aquifers and Rivers. The threat of water scarcity is a real fact, due to expanding agricultural needs, climate variability and inappropriate land use (Amede *et al*., 2009). The spiral of water scarcity commonly reduces crop and livestock productivity, farm incomes, and increases the vulnerability of communities to climatic and market shocks (Amede *et al*., 2006). The negative effects of water scarcity has been aggravated by land degradation, poor water management practices and limited institutional and household capacities to store and efficiently utilize the available water resources at various scales. Moreover, rural poverty thereby weak financial capacity of communities to invest in water and agricultural inputs hindered adoption and dissemination of good water management practices. Community's capacity should be strengthened and technologies that would minimize unproductive water loss and maximize water productivity be disseminated and adopted by local communities. For instance, in the Sahelian region of West Africa climate variability has forced traditional farmers to adapt their farming systems to more water scarce conditions by developing local water management interventions and diversifying their production systems. Recognizing this challenge the 2005 Commission for Africa report, for example, called for a doubling of the region's irrigated area by 2015 (You, 2008).

There has been a wide variety of climate change adaptation mechanisms in Africa to minimize negative effects of climate-change induced drought effects, though these adaptation mechanisms are commonly community-specific and didn't expand beyond specific localities. Kundewicz et al. (2007) differentiated various climate change adaptation mechanisms, and grouped them as 'supply side' adaptation interventions and 'demand side' adaptation interventions. The supply side adaption strategies include exploiting the ground water potential, increasing water storage in reservoirs and dams, desalination of sea water, rainwater harvesting, and water transfer between river basins. The demand-side interventions include improving water productivity of crops and livestock, recycling and use of waste water, saving irrigation water by choosing water efficient crops, improving performance of schemes and reducing water use through adapting 'virtual water' as a cross regional strategy (Allan, 2001). Adaptation could be complicated by the transboundary nature of water resources. Africa's 63 international transboundary river basins cover about 64 per cent of the continent's land area and contain 93 per cent of its total surface water resources (UNEP, 2010). Five river basins in Africa are shared by eight or more countries (Congo, Niger, Nile, Zambezi and Lake Chad) and 30 are shared by more than two countries (Wolf *et al.*, 1999). Moreover, water resource management decisions in Africa are widely taken considering immediate national interest without considering possible future climate change scenarios, while communities vulnerability to future climate change have increased (Ngigi, 2009). The challenges posed by climate change along with increased competition for water resources calls for an integrated water resources management strategy to be implemented in the continent.

Agricultural water management (AWM) is a broad concept which may be understood as all deliberate human actions designed to optimize water utilized by agriculture to produce food, feed, fiber and livestock products in the continuum from rainfed systems to irrigated agriculture using best fit technologies, policies and institutions required to sustainably manage water and land resources. It embraces a whole range of wider practices including *in situ* moisture conservation (e.g. mulching), and ex-situ water management (e.g. dryland farming, rainwater harvesting, supplementary irrigation, full scale irrigation, various techniques of wetland development) (Awlachew *et al*., 2005). AWM offers a way of facilitating water-centred development to simultaneously reduce poverty, increase food security, achieve environmental protection and adapt to climate variability and change. It focuses on ecosystems rather than commodities; on underlying processes (both biophysical and socioeconomical) rather than simple relationships; and on managing the effects of interactions between various elements of the production system (Merrey and Gebreselassie, 2010). The concept includes sustainable use and management of water, land, vegetation, biodiversity and environment through arrays of local institutions, technologies, participatory approaches and consolidated partnerships. The relevance of AWM in increasing agricultural productivity and adaptation to climate change in Africa are significant both in the rainfed and irrigation including agroforestry and livestock systems. The dependency of Agriculture on rainfed system, the rainfall variability, the implications on economy, food security and poverty and related risks in the emerging climate change remains to be the biggest challenge in Africa. Current climate variability, yield gaps, food insecurity and vulnerability in one hand, and in other hand emerging and future climate change effects that worsen these current challenges added with other changing patterns of consumption, growing population, the need for more food etc require serious interventions in AWM and associated agricultural intensification and land use efficiency.

In an attempt to operationalize the concept of AWM the Challenge Programme on Water for Food (CPWF) has developed a strategy called 'Rainwater management' to sustainably manage both green (rainfed) and bleu (surface) water for improving livelihoods and ecosystem services at landscape scales (Amede and Haileslassie, 2011). Rainwater management systems (RWM) is an integrated strategy that enables actors to systematically map, capture, store and efficiently use runoff and surface water emerging from farms and watershed in a sustainable way for both productive and domestic purposes, and ecosystem services. Integrated rainwater management aims to decrease unproductive water losses (runoff, evaporation, conveyance and seepage losses, deep percolation) from a system, as well as improves the water productivity of the respective enterprises to increase returns per unit of water investment. Unlike conventional approaches, it focuses more on the institutions and policies than on the technologies; it capitalizes on rainwater harvesting principles but it also advocates for water storage and water productivity at various scales; in the soils, farms, landscapes, reservoirs and other facilities. RWM is an effective strategy to scope with and manage the consequences of climate change (e.g. floods and drought) by combining water management with land and vegetation management. It renders to satisfy water demands during dry spells and create opportunities for multiple use (domestic uses or for human and animal drinking) as reported by Amede et al. (2011a). It is also about managing soils and landscapes to capture and store water in the rhizosphere, encompassing *in situ* water management strategies through maximizing soil infiltration and improving soil water holding capacity. This strategy is particularly critical for SSA, where unproductive water loss is high and about 70% of the land falls within arid, semi-arid and dry sub-humid zones.

Enhancing and stabilizing crop yield and livestock production of farmers in these crop-livestock systems would encourage farms to invest in rainwater and nutrient management at plot, farm and landscape scales. The choice of a certain agricultural enterprise or management system would also influence water productivity as it affects the quantity and quality of water used to grow crops, forage and pasture. Improved vegetative soil cover, strategic choice of crops and cropping systems and integration of livestock into these systems could reduce unproductive water losses by converting evaporation and runoff into productive transpiration (Amede *et al*., 2009). Rainwater management has multiple components that could be used to improve water storage, water management and water productivity. While acknowledging the presence of wide variety of adaptation strategies in the continent, we are presenting, selected intervention below that are widely tried and validated for minimizing the risk of climate change on local communities and the wider users. These water management interventions may have their own advantages and disadvantages, with their relative benefits hugely vary depending on local circumstances (Kundzewicz *et al.*, 2007).

2. INTERVENTIONS FOR AWM

2.1 Types of Technologies and Their Suites for AWM and Adaptation

The AWM and related technologies may be classified depending on operational objectives as follows (Awulachew *et al*., forthcoming):

- According to functions: Those used for crops, livestock, fisheries, and soil and water conservation
- According to stage of water management: rainfall/runoff capturing, storage, lifting, conveyance and water use/applications
- According to application: supplementary irrigation, full irrigation or drainage
- According to water sources: green water, blue water, rainfall, runoff, ground water, natural or manmade sources
- Spatial scale of management: single farm/field, scheme, watershed and basin scale
- Scale of users: household / community / large scale.
- Ownership: small holders, private, public, commercial and public private partnership

All the above classes of categories are used in describing AWM and the related technologies. While technologies can be specific interventions, we also describe technology suites as combination of technologies that are used in the water quantification and control, conveyance, field application, and drainage and re-use.. In this paper we idealize the AWM technology according to the following chart **(Table 1)**, which may assist to classify scale of application in the agricultural systems, water sources, and combinations of water management interventions.

The designation of suits of technologies is to identify the suitable combination of technologies for sustaining the control of water, conveyance and application from the various sources such as rain fall; surface water source of river, lake and wetlands; ground water source of hand dug well, shallow well, deep well, subsurface dams and springs.

Various water management technologies could be combined in a variety of ways ranging from covering one technology such as pits to combination of all categories including ground water well, pump, pipe and drip irrigation for control, lifting, conveyance and field application, respectively. The net impact of agricultural water management interventions on poverty may depend individually or synergistically on the working of these technologies (Namara *et al.*, 2010). In response to the possible effects of climate change and its possible consequences on African agriculture the following sections provide important examples of interventions that could be upscaled to improve access to AWM. Examples and experiences of these technologies and their applications broadly in Africa are presented as below, starting with integrated interventions, beyond the technologies, at watershed scales and scanning through climate smart technologies.

Table 1. AWM Technologies Suites Classifying by Scale of Application (Awulachew et al, forthcoming)

Scale	Water source	Water Control	Water Lifting	Conveyance	Application	Drainage & Reuse
Small-holder farm-level	Rain water	• In situ water • Farm ponds • Rain Column Green Wall • Cistern and underground ponds • Roof water harvesting • Recession agriculture	• Treadle pumps • Water cans	• Drum • Channels • Pipes	• Flooding • Direct application • Drip	• Drainage of water logging • Surface drainage channels • Recharge wells
	Surface water	• Spate and flooding • Diversion • Pumping	• Micro pumps (petrol, diesel) • Motorized pumps	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels • Drainage of water logging
	Ground water	• Spring protection • Hand dug wells • Shallow wells	• Gravity • Treadle pumps • Micro pumps (petrol, diesel) • Hand pumps	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels • Drainage of water logging • Recharge wells
Community or catchment	Rain water	• SWC • Communal ponds • Recession agriculture • Sub-surface dams	• Treadle pumps • Water cans	• Drum • Channels • Pipes	• Flooding • Direct application • Drip	• Drainage of water logging • Surface drainage channels
	Surface water	Spate and flooding Wetland Diversion Pumping Micro dams	Micro pumps (petrol, diesel) Motorized pumps Gravity	Channels Canals Pipes (rigid, flexible)	Flood & Furrow Drip Sprinkler	Surface drainage channels
	Ground water	• Spring protection • Hand dug wells • Shallow wells • Deep wells	• Gravity • Treadle pumps • Micro pumps (petrol, diesel) • Hand pumps • Motorized pumps	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels • Recharge wells and galleries
Sub-basin, Basin	Surface water	• Large dams	• Gravity • Large scale motorized pumps	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels • Drainage re-use

2.2 Integrated watershed management

An integrated watershed management is a strategy to manage natural resources taking into accounts the processes and interactions of naturally occurring biophysical resources, social institutions and human activities within the landscape. Although the hydrology is a key integrator of the landscape, other resources including land, vegetation, animals and social institutions are all an integral part of the watershed. It is also a strategy to address resources management issues that could not be addressed by a single farmer or a community, and to integrate different disciplines (technical, social and institutional) (German *et al.*, 2007) or production objectives (conservation, food security, income generation) for improving livelihoods and ecosystem services. German et al. (2007) identified different forms of integration in a watershed namely a) managing interactions between various landscape units and benefits to diverse landscape level components (trees, water, livestock, crops, soils, land); and b) a multi-disciplinary approach to integrate biophysical, social, market and policy interventions. From the water management perspective, watershed management encompasses strategies that would decrease unproductive water losses (runoff, evaporation, conveyance losses, seepage and deep percolation) from a landscape and increase landscape productivity (increased returns per unit of water, land and labour investments) through adapting integrated and multi-disciplinary approaches and facilitating interaction among various landscape components (Amede and Haileslassie, 2011). Managing water at watershed scale brings an accompanied benefit of managing run-off, controlling soil erosion and improved vegetative cover. For instance, within watershed management interventions there is a strong interaction between physical structures and vegetation management (WOCAT, 2007) that may dictate the amount and quality of water in the landscape that could be used to minimize the effects of climate variability within a locality. Vegetation and vegetation cover has direct relevance to climate change mitigation as it sequesters carbon. Increasing the vegetation cover will result in higher biomass production, higher rates of converting locally unproductive water to economical and productive water use and increased carbon sequestration at all levels, from farm to landscape scales (Amede and Haileslassie, 2011). Better water and nutrient management using watershed approaches could capture more CO_2 from the atmosphere and contribute to mitigating many of the negative effects of climate change and increasing weather variability.

Box 1. Watershed management in Southern Ethiopia. Farmers in Areka, Southern Ethiopia rated soil erosion as one of the major landscape problems, decreasing productivity and increasing vulnerability to climate variability. Despite earlier attempts to curb soil erosion by the government and other development actors, there was little change on the ground until a regional programme called African Highlands Initiative (AHI) arrived in the district. The shortcoming of the earlier approach was that it was seen as imposed initiatives. AHI and Areka research centre, Ethiopia organized consecutive community meetings to create awareness and sought solutions together. Then, soil bund was selected as practical solution for minimizing erosion and reducing removal of seed and fertilizer from the farm lands. Farmers' research groups (FRG), which were established to test interventions, were used to organize farmers and collectively constructed bunds, experimented on fodder crops and established by-laws for sustainable maintenance of the conservation structures. Farmers started to get more crop yield and dry season fodder for their livestock. This was further expanded by grazing management and landscape water management interventions, which has developed overtime as integrated watershed management programme, which is now used a learning site for the district officers and regional governments.

The African continent has vast areas of agricultural land in the highlands, where productivity is constrained by steep slopes, high runoff rates, soil erosion, and loss of nutrients and rainwater. Examples include the highlands of Ethiopia, Madagascar, Rwanda, Burundi, Kenya and Tanzania (Lundgren, 1993). Land degradation in these fragile highlands is commonly aggravated by deforestation and expansion of crop lands to vulnerable hillsides (e.g. the Kabale hillsides in Uganda, Ruwenzori's in Rwanada, and the fragile Ethiopian highlands). Estimates from a national-level study in Ethiopia indicated that the total soil loss due to erosion is about two billion tyr^{-1} (FAO, 1986), which is estimated to cause an annual onsite productivity loss of 2.2% of the national crop yield (Woldeamlak, 2009). FAO (1986) has also reported that soil erosion was causing about 30,000ha of croplands in Ethiopia out of production annually. The highest rate of soil loss occurs from cultivated fields estimated to be on average about 42 $tha^{-1}yr^{-1}$ (Hurni, 1993).

The erosion effects across Ethiopia are expected to decrease due to the very high priority given by the Ethiopian government to land management in the last 15 years using watershed management strategies. Some regions in Ethiopia (e.g. Tigrai) have been achieving a considerable success in managing upper catchments, mainly through the 'SafetyNet' programmes. This is a programme designed to improve the food security of the poor while facilitating the engagement of the local communities in improving natural resources management through food / money for work arrangements. The institutional structures of the programme heavily rely on the existing local arrangements including community representatives / leaders, disaster prevention committees, local byelaws and local governments (Box 1). It also considers assets, income and livelihood criteria for household selection and their ability to physically work. The work includes soil and water conservation structures, planting trees in degraded slopes, protecting landscapes from livestock grazing through 'area enclosure' and creating local institutions to sustainably manage the landscapes. Although the success rates of adoption vary, the benefits of upper catchments protected in the late 1990s in selected sites of the Ethiopian highlands could be seen clearly (Descheemaeker *et al*., 2006). In irrigation schemes where extensive soil conservation was done, erosion and siltation have been considerably reduced - head works and canals continue to serve without the need for frequent maintenance (Amede, 2004). The greatest benefits are found in situations where physical measures were accompanied by innovations that bring short-term benefits in terms of fodder, fuel wood, water and other resources. Introducing and promoting multipurpose legume trees, with feed, fodder and wood values, in farm niches including farm borders, soil bunds and farm strips is becoming an important driver for sustainable watershed management (Amede and Haileslassie, 2011). It increases the vegetation cover, minimize erosion and improve watershed functions. Farmers' groups were found to be effective approaches to identify farm and landscape niches where trees could be integrated in the watershed without competing with other enterprises (Box 1).

2.3 Rainwater harvesting systems

Lal (2001) reported that the primary limiting factor for crop-yield stabilization in semiarid regions is the amount of water available in the crop rooting zone. Rainfall intensity in SSA could more often be greater than the infiltration rate and the soil water holding capacity, which triggers an overflow of runoff. Moreover, rainfall amount in most Northern African countries is so low that rain and water control and management have very special place in the overall water availability and access. Rainwater harvesting (RWH) is about capturing and storage of seasonal excess runoff diverting it for household and agricultural uses using traditional or improved structures for possible farm, livestock and household use. In SSA where rainfall amount is low and unpredictable, which is also predicted to decline further with impacts of climate change, rainwater storage in farm ponds, water pans, subsurface dams, earth dams are gaining prominence for supplemental irrigation (Ngigi, 2009) and watering livestock. It is also an effective strategy to manage floods, particularly in high rainfall areas. It could be used to satisfy water demands during dry spells and create opportunities for multiple use (domestic uses or for human and animal drinking). The importance and distribution of rainwater harvesting structures in Africa is very well documented (Mati *et al.,* 2008; Malesu *et al.*, 2006). This is particularly critical for Eastern and Southern Africa, where about 70% of the land falls within arid, semi-arid and dry sub-humid zones and periodic excess runoff is available.

RWH has the potential to provide enough water to supplement rainfall and thereby increase crop yield and reduce the risk of crop failure (Oweis *et al.,* 2001) and also provide a supply for livestock. Enhancing and stabilizing crop yield and livestock production for farmers in these crop-livestock systems would encourage farmers to invest in rainwater harvesting and accompanied nutrient management at plot, farm and landscape scales. It has been also strongly promoted as a key strategy to improve water access in drought-prone pastoral and agropastoral systems in Eastern Africa and Sahelian West Africa. Quantitative studies in a drought-prone district in Southern Ethiopia showed that rainwater harvesting improved the adaptation capacity of communities to recurrent drought (Desta, 2010). Using rainwater harvesting, farm households have started to diversify the cropping systems, introducing new vegetables and perennial crops, and increased their household income to invest on their farms as a result of water availability from the water harvesting ponds. Water storage is a key strategy for climate change adaptation in Africa. Site-specific studies showed that adopting water harvesting structures improved irrigation access and impacted a considerable income improvement of households in the Ethiopian highlands (e.g. Chencha in Southern Ethiopia, Abrha Weatsbha in Northern Ethiopia) (Desta, 2010). There are many RWH technologies for which the farmer can survey, layout and construct using own labour at the farm level with minimum training and facilitation. For climate change adaptation, the focus should shift to increasing water storages and supplemental irrigation of crops. This can be achieved by storing water in ponds, pans, tanks and subterranean aquifers, including sand-bed storages. Some of these technologies are described here.

2.3. 1. *In situ* Rainwater Harvesting

Rainwater harvesting includes *insitu* water harvesting methods that would concentrate soil water in the rhizosphere for more efficient use by plants. *In-situ* water harvesting means rainwater is conserved *on the same area* where it falls, whereas water harvesting systems involve a deliberate effort to transfer runoff water from a “catchment” to the desired area or storage structure (Critchley and Siegert,1991). Land and water conservation interventions on sloping lands includes *bench/fanya juu terraces, retention ditches, stone lines, vegetative buffer strips, contour bunds* and all activities that reduce loss of runoff water. They are primarily promoted to reduce soil erosion and to improve rainfall infiltration and conservation in the soil profile (Bossio *et al.*, 2007). The main limitation of these interventions includes high labour demands especially on very steep slopes where proper structural measures are required. Some level of training and site-specific design/layout is also needed. In one example from the Anjenie watershed of Ethiopia (Akalu and adgo, 2010), long-term terracing increased yields of teff, barley and maize significantly. In contrast, cultivation on the steep un-terraced hillsides had negative gross margins. Similarly, Vancampenhout et al. (2005) obtained positive results for the use of stone bunding on the yields of field crops in the Ethiopian highlands associated with increased soil water holding capacity. Fox and Rockstrom (2003) reported that the in-situ RWH had a significant effect on grain yield, and by using this system in Burkina Faso they were able to increase the yield of the sorghum from 715 kg ha^{-1} to 1057 kg ha^{-1}. Micro-basin water harvesting structures (half-moons, eye-brow basins, trenches) are also proven to be effective in improving tree survival and growth in degraded lands. Experiences from Northern Ethiopia showed that these structures improved tree survival and growth significantly compared to non-treated landscapes (Derib *et al*., 2009). The seedlings grown on micro-basins were thicker, taller and more productive than those grown on normal pits, implying the need to integrate tree planting with soil water management.

Some of these interventions are indigenous developed and used by communities in Africa for centuries, including the Konso tribes in Southern Ethiopia and communities in Burkina Faso. Zaï is a traditional practice developed by farmers in Burkina Faso and adapted wider in the Sudano-Sahelian zone for rehabilitating degraded fields which have been eroded and completely crusted, with an infiltration rate too low to sustain vegetation (Roose *et al*., 1999;). Zai pits lead to water and nutrient concentrations around the root zone (Amede *et al*., 2011b). However, Roose and Barthès (2001) from an experiment in the semi-arid Yatenga region of northern Burkina Faso (400- to 600- mm annual rainfall), showed that water harvesting by runoff concentration produced higher benefits together with addition of mineral nutrients. Similarly, in a different agroecology in Eastern Africa, Amede et al. (2011b) reported that Zai pits have significantly increased crop yield (up to 500% for potato) including in high rainfall hillsides, where runoff is very high and water infiltration is low because of slope and soil crust. The benefit was particularly apparent in outfields, where the management and application of farm inputs by farmers is limited. Baron and Rockstrom (2003) also observed that maize yield can be tripled by employing conservation agriculture, which facilitates water infiltration and reduces evaporation. Mati (2010) observed that the productivity and profitability of smallholder agriculture with water management technology increased crop yield levels by factors ranging from 20% to over 500%, while net returns on investment increased by up to ten-folds. Also, it was observed that these gains were linked to poverty reduction, employment creation and environmental conservation.

2.3. 2 Water storage in ponds, pans and underground tanks

Ground level storages offer scope for water harvesting for large areas of SSA. The water is used for drinking, livestock, as well as for supplemental irrigation especially in the dry areas. For instance, there are runoff harvesting from open surfaces and paths, roads, rocks, and storage in structures such as ponds or underground tanks (Guleid, 2002; Nega and Kimeu, 2002; Mati, 2005). Flood flow harvesting from valleys, gullies, ephemeral streams and its storage in ponds, weirs, small dams is also used. Pans and ponds are particularly popular in community scale projects, as they can be made cost-effective using local materials and community labour (Malesu *et al*., 2006). The main difference between ponds and pans is that ponds receive some groundwater contribution, while pans rely solely on surface runoff. Thus, pans which range in size from about 5,000 to 50,000 m^3 (Bake, 1993) are constructed almost anywhere as long as physical and soil properties permit. In areas where seepage is a problem, small storages can be lined with clay grouting, concrete or geo-membrane plastics. Water harvesting with small storage ponds could make major contributions to household incomes and rural poverty reduction (Box 2). For instance, in Ethiopia, water harvesting and storage in small ponds for supplemental irrigation of vegetables and seedlings at Minjar Shenkora obtained average net incomes of US$ 155 per 100 m^2 plot from onion seedlings, while incomes from bulb onions grown in the field provided equivalent of US$1,848 ha^{-1}, adding up to US$ 2,003 ha^{-1}, from onion crop alone (Akalu and adgo, 2010). In other studies, Gezahegn et al. (2006) and Nega and Kimeu (2002) assessed small scale water harvesting technologies in Ethiopia and found that returns on investment were high.

In an attempt to assess of the use of AWM technologies and its implications, Awulachew et al (2009) found that access to ponds and shallow wells was strongly associated with lower poverty levels. Another survey of nearly 15,000 household ponds (and a few shallow wells) in the Amhara region, Ethiopia found that only 22% were functional, 70% not functional, and the balance had been destroyed; this was attributed to major technical, social and environmental problems (Wondimkun and Tefera, 2006). One of the major bottlenecks of adoption was targeting. Kassahun (2007) found that targeting is a problem: women-headed and generally poor households were not benefiting from RWH ponds. Moreover, Merrey and Tadelle (2010), after reviewing the wide range of literature in Ethiopia, concluded that low performance of water harvesting structures was related to differences in implementation strategies including top-down quota-driven programmes, failure to identify proper location at farm and landscape scales, failure in design, huge water loss through seepages due to use of inappropriate base materials, open excess surface evaporation and lack of water lifting technologies. In some Africa countries (e.g. Zambia) groundwater has been important for developing more reliable and better quality water supplies for rural communities (Hiscock *et al.*, 2002).

2.4 Small earth dams and weirs

When larger quantities of water are to be stored, bigger dams are more appropriate. This could be in the form of an earthen dam constructed either on-stream or off-stream, where there is a source of large quantities of channel flow (Gould and Nissen-Peterssen, 1999). The volumes of water storage range from thousands to millions of cubic meters. Reservoirs with a water volume less than 5,000 m^3 are usually called ponds. Due to the high costs of construction, earthen dams are usually constructed through donor-funded or Government supported projects. However, there have been cases of smallholder farmers digging earthen dams manually as in Mwingi District of Kenya (Mburu, 2000). Earthen dams can provide adequate water for irrigation projects as well as for livestock watering. Low earthen dams, called "malambo", are common in the Dodoma, Shinyanga and Pwani regions of Tanzania (Hatibu *et al*., 2000). It involves dam construction to collect water from less than 20 km^2 for a steep catchment to 70 km^2 for flat catchment. Some of these are medium-scale reservoirs used for urban or irrigation water supply. Sediment traps and delivery wells may help to improve water quality but, as with water from earthen dams, it is usually not suitable for drinking without being subject to treatment.

2.5 Sand and Sub-Surface dams

The semi arid zones of Africa are subject to flooding during the rainy season, providing an opportunity for rainwater harvesting. Where seasonal rivers carry a lot of sand (sand rivers or "lugga", "wadi", and "khor") the sand formation can be used to store water for use during the dry season (Nissen-Peterssen, 2000). The most convenient way to harvest water in a sand river is by either sand or subsurface dams. Local materials for construction are usually available and the only extra cost is that of cement and labor. It is a cost-effective method for providing water for drinking and also for irrigation. Because the water is stored under the sand, it is protected from significant evaporation losses and is also less liable to contamination. Another advantage of sand river storage is that it normally represents an upgrading of a traditional and, hence, socially acceptable water source. Nissen-Peterssen (2000) distinguished between three types of subsurface dams: (i) sand dam built of masonry, (ii) subsurface dams built of stone masonry, and (iii) subsurface dams built of clay. The construction of river intakes and hand-dug wells with hand pumps in the river bank can further help to improve the quality of water.

Box 2: Water Harvesting for Rice Production in Shinyanga, Tanzania

In Tanzania, farmers make excavated bunded basins, locally known as 'majaluba' which hold rainwater for supplemental irrigation of crops. This system is practiced in the semi-arid areas where rainfall amounts range from 400 to 800 mm per year. About 35 percent of the rice in the country is produced this way under smallholder individual farming Shinyanga, Dodoma, Tabora and the Lake Regions. In many cases, majaluba utilize direct rainfall, but sometimes, farmers combine the system with runoff harvesting from external catchments. Generally, rice yields are higher, attaining 3.43 t ha^{-1} with the use of harvested water for irrigation as compared to 2.17 t ha^{-1} obtained without supplemental irrigation. These systems have increased household incomes by 67 per cent from 430 US\$ ha^{-1} without runoff harvesting to 720 US\$ ha^{-1} with the technology (Kajiru et al, 2010). The main constraint was that with or without runoff harvesting, the majaluba system is predominantly rainfed with water storage in the soil profile (green water). Consequently, climatic uncertainties and prolonged dry spells could adversely affect the system unless it is augumented by other storage infrastructure e.g. ponds.

2.6 Water harvesting and storage in the soil profile

This involves runoff harvesting from land, roads, paved areas and channeling it to specially treated farmlands for storage within the soil profile for crop production. The cropped area may be prepared as planting pits, basins, ditches, bunded basins (majaluba), semi-circular basins (demi-lunes), or simply ploughed land (Hai, 1998; Mati, 2005; Ngigi, 2003). Storing rainwater in the soil profile for crop production is sometimes referred to as "green water" and forms a very important component for agricultural production (Box 2). The design of a run-on facility depends on many factors including catchment area, volume of runoff expected, type of crop, soil depth, and availability of labour (Hatibu and Mahoo, 2000). The source of water could be small areas or "micro-catchments" or larger areas such as external catchments. The latter involves runoff diversion from larger external catchments such as roads, gullies, open fields into micro-basins for crops, ditches or fields (with storage in soil profile) including paddy production where the profile can hold water relatively well (Box 2). The cropped land for these systems is usually prepared in different shapes and designs, such as trapezoidal bunds, semi-circular and contour bunds, planting pits, negarims, T-basins and various types of channeling and conservation of runoff (Critchley et al., 1999; Mati, 2005, Duveskog, 2001).

2.7 Spateflow diversion and utilization

Spate irrigation or floodwater diversions involves techniques in which flood water is used for supplemental irrigation of crops grown in low-lying lands, sometimes far from the source of runoff. Spateflow irrigation has a long history in the Horn of Africa, and still forms the livelihood base for rural communities in the arid parts of Eritrea, Ethiopia, Kenya, Somalia and Sudan (SIWI 2001; Negassi *et al.*, 2000; Critchley *et al.*, 1992). It is also practiced in other dry areas. For instance, in Tanzania, spate irrigation increased rice yield from 1 to 4 t ha^{-1} under RWH systems (majaluba) (Gallet *et al.*, 1996). Spate irrigation is primarily practiced in the dry countries of Tunisia, Morocco and Algeria in the Northen region and Somalia, Sudan and Eritrea in the Sudano-Sahelian region (Frenken, 2005). Although spateflow irrigation has high maintenance requirement, its applicability is valid for large areas of the Sahel and the Horn of Africa, where other conventional irrigation methods may not be feasible. In terms of climate change adaptation, spate irrigation holds promise considering that rainfall events are expected to get ever more erratic with flush floods, which can be harnessed and used wherever possible. For facing climate change adaptation challenges, the spateflow irrigation has to improve the local diversion structures, soil moisture management, field preparations, crop genotype, and land and water tenure.

Box 3. Small scale irrigation in Ethiopia (Amede, 2006)

An impact evaluation of IFAD SSI in four administrative regions of Ethiopia, namely Tigray, Southern regions, Oromia and Amhara, showed that in about 60% of the schemes crop yield under irrigation was higher by at least 35% compared to non-irrigated farms, with benefits being much higher in farms where external inputs (fertilizer, improved seeds and pesticides) were used. With access to irrigation, farmers replaced early maturing varieties by high yielding maize cultivars, shifted towards growing diverse crop, in some sites up to 10 new marketable crops, predominantly vegetables. The real challenge was on how to scale-up the success stories to the 35% non-performing schemes, which calls for protecting schemes from boulders, improving irrigation efficiency, creating local capacity and collective action with local communities to sustainably manage the natural resources.

3. LARGE AND SMALL SCALE IRRIGATION

Despite the presence of large river basins, streams and ground water rich valley bottoms in most part of Africa, irrigated agriculture is still at its rudimentary stage contributing below 10% of the agricultural production in the continent. With increasing population, decreasing farm size and unreliability of rainfall for most of the years, irrigation has been getting emphasis in the policy discussion in Africa. The level of irrigation water withdrawal for agriculture varies from region to region and country to country in Africa. About 60% of the estimated 15.4 million ha under irrigation is lying in the Northern and Sudano-Sahelian region, with Egypt accounts for 54% of the irrigated area in the Northern region (Wichelns, 2006). Frenken (2005) also reported that more than 70% of Africa's irrigation exists in the five major basins, namely the Congo, the Nile, West coast, Niger and Zambezi River. Irrigated agriculture is becoming an increasingly important intervention towards managing climate variability, meeting the demands of food security, employment and poverty reduction. Irrigation along with improved water management practice could provide opportunities to cope with the impacts of increasing climatic variability, enhance productivity per unit of land thereby increasing the annual production volume significantly (Awulachew *et al*., 2005).

Box 4. <u>Small Scale Irrigation Examples Across West African Regions.</u> The small scale irrigation (SSI) contributes to poverty alleviation by enhancing productivity and promoting economic growth and employment (García-Bolanos *et al.,* 2011). Low-cost motorized and treadle pumps have had a big impact in West African agriculture increasing. The example of SSI in Lomé (Togo), Kumasi (Ghana), Niamey (Niger) and Bamako (Mali), appears to be energy efficient, saves labor, adapts well to the yield limitations of low-cost hand-dug wells, and the system is mobile and can reduce irrigation costs per m^3 by 40 percent or more (Van't Hof and Maurice 2002). The data compiled by Danso et al. (2003) in Ghana on individual profits from mixed SSI vegetable production in open-space urban agriculture show that the monthly net income ranges in wide margins between US$10 and more than US$300 per farmer, mostly depending on the size of the farm. In Dakar (Senegal), Faruqui et al. (2004) estimated an average annual gross income of US$620 and a net income of US$365 per farmer generated by SSI production. Zallé (1997) estimated in Bamako (Mali) a monthly net income range of US$10 to 400 dependent on a corresponding increase in farm size and the use of hired labor with the majority of farmers earning on the average, US$40. In Burkina Faso, farmers involved in SSI can obtain 30 to 50% increase in crop yield, and 20-35% increase in farm income (WAIPRO, 2009). The greatest factor influencing farmers' profits is not much the yield obtained but the ability to produce at the right time what is in short demand and sell consistently at above average prices (Cornish and Lawrence, 2001). So, a low cost small scale irrigation strategy is an effective adaptation measure in Africa to climate change pattern.

Irrigation farming is becoming a necessity in the drought-stricken regions of SSA (Amede and Haileslassie, 2011) for the following reasons that it can reduce farmers' vulnerability to annual rainfall variability, increase agricultural production per unit of land, water and labour investments; enable communities to produce high value enterprises in their farms and strengthen collective action for broader land and water management (Boxes 3 and 4). However, the amount of irrigated land in Africa is extremely low except for few North African countries (Figure 2***)***. Moreover, as most of the irrigation schemes in Africa rely mainly on surface

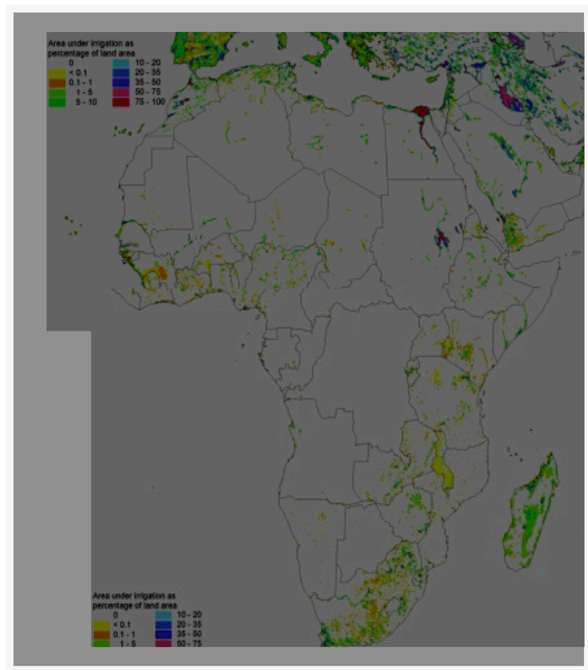

Figure 2. African map of irrigation (Siebert *et al*., 2007)

Box 5. Water-lifting technologies in West Africa. In Nigeria, small water-lifting devices have been introduced, and considerable numbers around 50 000 small pumpsets have already been absorbed accros the country (IPTRID, 2004). This technology has played important part of the economy especially for resource-poor people with the farm sizes small as 0.5 to 1 ha up to 2.5ha elsewhere. Water sources are often shallow groundwater. In Ghana the scale is smaller, and in Mali, there is considerable use of motorized pumpsets, often rented or leased (Arby, 2001). It represents a huge potential for improvements to rural livelihoods. From the farmer's financial viewpoint of Niger, the system is economical viable (IPTRID, 2004).

water, with about 78% of the area, there is a huge ground water potential that could be used for irrigation. Expansion of irrigable land in Africa, particularly at the household level, should explore ground water opportunities. The use of groundwater has also been suggested as an adaptation option to minimize climate change impacts (Kundzewicz *et al.,* 2007). Groundwater access and water lifting are important elements in groundwater based AWM. The main types of water-lifting device relevant for small-scale irrigation, and the framework for consideration of appropriate water-lifting technologies is based on the Supply side (technology-specific) and demand side (place-specific). The main components of the water-lifting system are the technology part (type of power source, type of pump or lifting device, delivery arrangements), the application (static lift, instantaneous discharge), and the condition of the location (soil, farm type and economy). In most cases, small scale irrigation has significantly increased crop yield, improved incomes, and achieve higher agricultural production than non-intervention communities (Amede, 2004; Box 3). Micro-irrigation systems are also promoted to improve water management using low-head, drip irrigation kits for smallholders. Many types of drip irrigation systems are in use in many parts of SSA (Ngigi, 2008). The kits range from 20- liter bucket kits to 200-liter drums or mini-tank systems and operate at 0.5-1.0 m water head. A majority of them target market gardens and vegetable production. This type of irrigation integers the fertigation for achieving high efficient use of water and fertilizers in crop production by bringing them at the right amount and at the right place. In general, irrigation farming is expected to reduce farmers' exposure to climate variability, stabilize crop and livestock yields and improve food security especially in the more remote, disadvantaged and poorer areas. It raises agricultural production and rural incomes, improves crop diversification and promotes market-oriented agriculture (Amede, 2004; Boxes 3 and 4) and enhances the capacity of local communities to demand for better services.

There is a perception that irrigation investments in Africa are much more expensive than elsewhere although the cost of developing schemes varies from location to location within a country and between countries ranging from 2500 USD/ ha to 14500 USD/ha. However, Inocencioeta et al. (2005) showed that the cost was considered high because of the exaggerated costs of some failed irrigation schemes. Some irrigation schemes in Africa failed to give the intended returns not only because of poor design and destruction by unprotected upper catchments, they failed because of lack of the necessary institutional arrangements to manage and to maintain them and absence of incentives measures for farmers to efficiently manage the schemes and use the water efficiently. They have then showed from correctly sampled data that in fact irrigation in Africa is not more expensive than in Asia. In a detailed analysis of the performance of irrigation in Ethiopia done by Awalachew and Ayana (2011), about 87% of the irrigation schemes are operating well but only 47% of the planned beneficiaries have benefited from the implemented irrigation schemes. The major reasons for under performance are related to siltation of main and secondary canals, limited agronomic practices, lack of fund for maintenance and pests and diseases control particularly for high value crops. This calls for the need to design appropriate policies that would create strong local institutional capacity and market incentives to facilitate flow of investment and improve overall scheme productivity. There is also a notion that there should be a policy shifting away from large irrigation projects to small-scale approaches in African irrigation mainly because of the poor performance of many state controlled large irrigation projects.

There is a wide range of technologies adopted in irrigation to bring the water to the crop, e.g. surface irrigation methods like the furrow and small basin methods, low pressure and pressurized systems such as sprinkler and drip and water-lifting technologies/pumps (Box 5) which utilize energy from gravity head, manual pumping, motorized pumps, wind and solar pumps. However, in these systems unproductive water loss is one the major challenges of irrigation farming and a reason for low irrigation efficiency and limited returns from irrigation investments in Africa. The water loss is happening through conveyance, canal seepages, evaporation of surface water, inappropriate scheduling and planning, leakage in heads and storages and consumption of water by weeds and other competitors to crop production. In an attempt to establish the amount of irrigation water losses in small scale irrigation schemes, Derib et al. (2011) reported that the average canal water loss from the main, the secondary and the field canals was 2.58, 1.59 and 0.39 $l\ s^{-1}\ 100\ m^{-1}$, representing 4.5, 4.0 and 26% of the total water flow, respectively. Most of this water was lost through evaporation and canal seepage.

Generally, there are a variety of ways to achieve on-farm efficiencies in irrigated agriculture depending on the size, water sources for irrigation and the sources of energy and technologies for pumping water (FAO, 2007). In addition, the System of Rice intensification (SRI) has been successfully employed in Africa as a method of improving irrigation efficiency and increasing crop yield (Uphoff, 2003; Mati *et al.,* 2011). In order to sustain the adaptation measures to climate change, local farmers or community members should be able to maintain their irrigation infrastructure technically and financially.

4. CROP AND LIVESTOCK WATER PRODUCTIVITY

There is a huge loss of water in various agricultural and non-agricultural systems associated with uncontrolled evaporation, water depletion through runoff, water pollution due to excessive use of chemicals and water contamination by urban and semi-urban activities (Decheemaeker *et al.,* 2011). Water management practices are often poorly adapted leading to low water productivity and failure to the agricultural investments. In order to alleviate water scarcity for agriculture investment, actions should go beyond creating access to irrigation and other water resources by improving water productivity of crop and livestock systems. Water productivity is an important strategy that would enable production of more livestock and crop yield per drop and value from less water, which can reduce future demands for water, limiting ecosystem degradation and reducing the competition for water between multiple uses and users (CA, 2007). Agricultural water productivity considers products and values derived from water use by forests, livestock, fisheries and crops. Molden and Oweis (2007) estimated that if water productivity could be increased by over 40% over the next 25 years, it is possible to reduce additional global diversion of water to agriculture to zero. However, the concept of "more crop per drop" a key concept of high water productivity, was recently criticized for being too narrow and not accommodating the non-crop water outputs with considerable income, livelihood and health implications (Rijsberman, 2006).The water saved from agriculture could balance the water needs between agricultural and environmental services that would enable African communities adapt to climate change. There have been various interventions suggested to improve agricultural water productivity as mentioned earlier.

Improving crop water productivity is producing more grain yield per unit of water used to grow the intended, which could be achieved through genetic manipulation for water use efficiency and/or conversion of water that could have lost the rhizosphere in the form of evaporation and seepage to productive transpiration. Thus, the concept is different from crop water use efficiency, which is estimated based on the proportion of CO_2 fixation and plant transpiration. Most annual crops in SSA have a water productivity below 300 g of grain yield per cubic meter of water while in well managed farms (including within Africa) the crop water productivity could reach as much 2 kg per cubic meter of water (Molden and Oweis, 2007). Low water productivity in these systems is mainly due to the low level of agricultural inputs (fertilizers) and poor agronomic management practices (Amede *et al*., 2011a).

However, agricultural water demand goes beyond crops requirements. One key intervention that would improve agricultural water productivity is integrating livestock into the water agenda, including in the design, planning and implementation of irrigation schemes (Amede *et al.,* 2009). According to Steinfeld et al. (2006), the four mechanisms of how livestock production triggers and aggravates water resource degradation are: 1) to satisfy increasing feed demands; 2) overstock and inadequate watering points; 3) mismanagement of manure and wastewater; and 4) intensification demand which has increased leading to resource mining and soil degradation.

Although water for livestock drinking and servicing might be the most obvious water use in livestock production systems, it constitutes only a minor part of the total water consumption (Peden *et al*., 2009). Recent reports indicate that the major water consumption by livestock is related to the transpiration of water in feed production, which is generally about 50 to 100 times the amount needed for drinking (Peden *et al.,* 2009). Livestock systems depending on grain-based feeds, as is the case in the developed world, are more water intensive than systems relying on crop residues and pasture lands, as is the case in SSA and South Asia. Moreover, strategic allocation of livestock watering points could improve livestock water productivity and increase returns per animal by up to 100%. For instance in the drought-prone areas of Ethiopia, reducing the distance of livestock walking from 12 km to 3 km increased milk gains by 250 lt per lactation period per cow (Descheemaeker *et al*., 2011). Using the Livestock Water framework, Peden et al. (2009) and Amede et al. (2009) identified nine strategies to increase Livestock water productivity, which could be grouped into the natural resources sphere of influence, the animal sphere of influence and the socio-political sphere of influence. These interventions include water management, feed type selection, improving feed quality and quantity, improving feed water productivity, grazing management, increasing animal productivity, improving animal health, supportive institutions, and enabling policies.

Integrating improved forages into various crop-livestock and agropastoral systems is also a key strategy to improve water productivity of systems through using underutilized water that could be depleted through non-productive evaporation and run-off.

Moreover, in most African basins (for instance in the Nile) about 70% of the water is depleted through the grass land pastoral and agropastoral systems (Cook *et al.,* 2009). Grassland management, which encompasses erosion control, controlled grazing, availability of strategic watering points for livestock drinking and different forms of water harvesting structures could be effective adaptation strategies to minimize effects of climate change and variability. Minahi et al. (1993) stated that grasslands are almost as important as forests in the recycling of greenhouse gasses and that soil organic matter under grassland is of the same magnitude as in tree biomass. The carbon storage capacity under grassland could be increased by avoiding overgrazing. Improved grazing management can lead to an increase in soil carbon stocks by an average of 0.35 t C ha^{-1} yr^{-1} but under good climate and soil conditions improved pasture and silvopastoral systems can sequester 1-3 t C $ha^{-1}yr^{-1}$ (FAO, 2009). It is estimated that 5-10 percent of global grazing lands could be placed under C sequestration management by 2020 (FAO, 2009).

5. CLIMATE-PROOF CROP VARIETIES

Drought denotes a prolonged period without considerable precipitation that may cause a considerable reduction in soil water potential thereby cause plant water deficit. In Africa, farmers could experience drought with the following four different occurrences that may happen alone or in combination (Amede, 2006):

a) Unpredictable drought: when the total amount of precipitation is comparable to normal years, but plants are exposed to stress at any stage of growth because of unpredictable and/or uneven rain fall distribution. This is a common phenomenon in the Great Rift Valley of Eastern and Southern Africa. This is where crop varieties with physiological plasticity and water-stress tolerance are needed. This may include crops like sorghum, millets and teff.

b) Full season drought: when the amount of rainfall is much lower than in normal years across the phenological stages, and hence plants did not get enough water to cover the atmospheric demand throughout the growing period. This commonly happened in most Sub-Saharan Africa (e.g. North-Eastern Ethiopia, Sudan and Northern Africa). This is where drought resistant, less water demanding crops fit best, which may include pigeon peas, barley, chickpeas and millets.

c) Terminal drought: when there is enough water for early establishment and growth, but later stages are exposed to soil water deficit. This is typically the case in relay cropped crops of the Rift Valley. For instance, the common practice of relay planting of beans in the maize fields in Eastern Africa commonly exposed bean crops for terminal drought. These are areas where early maturing varieties of maize, wheat, beans and other legumes fit best.

d) Intermittent drought: when there is a predictable short dry spell within a growing season and plants are exposed to drought only at one stage of growth. This is also very common in regions with extended growing period, where agronomic management including adjusting planting dates, mulching, supplementary irrigation and other best practices are more useful than selection of varieties.

Various physiological traits have been associated with drought resistance, and the major drought resistance mechanisms in field crops are classified as drought avoidance (drought resistance with high plant water potential) and drought tolerance (drought resistance with low water potential). To date, however, no traits are known that confer global drought tolerance (Amede, 2006). Moreover, short term responses to water stress at the cellular and sub-cellular level alone may not contribute to yield under conditions of water deficit. Despite the alarming demand for drought- resistant cultivars, breeders in Africa are slow in achieving this goal due to the challenge in identifying traits that reflect true drought resistance. Adoption of crop varieties and forages with increased resistance to heat stress, shock and drought are critical to minimize climate change effects. For example, a private-public partnership, the African Agricultural Technology Foundation, developing Water Efficient Maize for Africa (WEMA), intends to develop maize varieties tolerant to drought and other stress factors. This initiative, though, is not uncontested as it uses biotechnology besides conventional breeding and marker-assisted breeding techniques (www.aatf-africa.org).

Another key strategy to mitigate climate change effects is through improving vegetative cover of African landscapes and increasing the potential of agriculture in Carbon sequestration. However, the landscapes void of vegetation are commonly degraded by erosion and by anthropogenic activities over centuries and may not be able to support good vegetation growth without employing soil and water management practices.

6. POLICIES AND INSTITUTIONAL FRAMEWORKS FOR IMPROVING CLIMATE CHANGE ADAPTATION

Water management is a multi-institutional engagement that calls for collective action of actors at various levels, from local communities to federal ministries and regional authorities. The policy and institutional framework influencing the development of AWM in SSA are well espoused by the New Partnership for Africa's Development (NEPAD), Comprehensive Africa Agriculture Development Programme (CAADP), which recommended among others, "*extending the area under sustainable land management and reliable water control systems, especially small-scale water control, building up soil fertility and moisture holding capacity of agricultural soils and expansion of irrigation"* as one of three "Pillars" (NEPAD, 2003). There are also regional policies such as the Southern Africa Development Community (SADC) Water Policy and Land and Water Management for the Nile Basin Initiative. A review on the nature, functions and gaps of organizations, policies and institutions in three countries in East Africa viz. Ethiopia, Sudan and Uganda indicated that the organizational set up affecting agricultural water management stretches from national level policy/strategy-making ministerial offices to local micro-planning and implementing offices (Amede *et al*., 2009). In most countries, there are national policies that support water development for agriculture, albeit most countries are in the process of reviewing their policies. For instance, in a study of policies, Mati et al. (2007) examined 78 policies from Eritrea, Kenya, Madagascar, Malawi, Mauritius, Rwanda, Sudan, Tanzania and Zimbabwe that were deemed to have implications on AWM in these countries. It found that most countries have developed national and local policies for addressing poverty reduction, achievement of economic growth, attainment of increased agricultural productivity and food security and securing environmental sustainability.

A critical review of the various policies showed that there is no specific policy document that addresses AWM in its broad sense in any of the nine countries. Instead, existing policies had statements on AWM scattered across different ministries or sectors. The scattering of AWM issues across several sectors had resulted in unavoidable overlapping of policies, duplication of efforts and inefficient use of resources, as well as the lack of clear ownership of AWM issues (Mahoo *et al.*, 2007). There is need to support various African countries in their efforts to fast-track their policy reforms and improve their infrastructural and institutional frameworks so as to make them responsive to climate change challenges by adopting suites of AWM technologies as adaptations measures.

Indeed, there is also institutional disconnection between research and development, and lack of institutional arrangements that may recognize the complexity of resources degradation and their implication on food insecurity and climate variability. In the context of climate change, the need is increasingly recognized for integrated, holistic research that may include technological, social, policy and institutional interventions for improving climate change adaptation and carbon sequestration while increasing productivity of water, nutrients and labour for food security and environmental sustainability. A new approach is highly needed, which will place poor men and women farmers at the centre of the climate change research and humanity well-being. This also demands wider interaction and mutual collaboration among key stakeholders at local and higher levels through action research. These positive impacts could be realized if research in water management aligns investments with improving productivity and incomes with managing marginal environments - and are linked with enterprise development. Moreover, policies should be sought at various levels and involved all actors.

At local levels, community institutions within irrigation schemes include traditional water master, modern water user associations (WUAs) and water cooperatives. In some cases, these different organisations exist side by side and play competitive roles. Strengthening water user associations to manage and use water efficiently has been proved to be an important policy strategy to sustainable use irrigation schemes (Amede, 2004). While the current capacity of farmers in most African countries is weak to financially sustain the operation and maintenance of irrigation schemes and other water infrastructure, it is unsustainable to fully rely on funds emerging from governments or development partners (e.g. IFAD, AfDB). This calls for strategies for alternative income sources at local level, including introduction of functional water pricing policies. Water pricing will improve irrigation efficiency, institutional performance at local and regional scales and create the sense of community ownership of water investments within the landscape. While building the local capacity in optimizing irrigation water use and effective distribution, water pricing is a key foundation for enhancing local capacity, improving irrigation efficiency and water productivity of agricultural systems (Molle and Berkoff, 2007). In this modality, beneficiaries pay irrigation charges or fees for accessing irrigation water and related service - based on areas sizes and volumes supplied. The fee could be used for operation and maintenance of the irrigation infrastructure, covering costs of water user associations and modernization of the irrigation facilities. Moreover, the current extension support on irrigation agronomy is far from responding to farmers' needs. One other intervention promoted by some development partners (e.g. IFAD) is the establishment of farmer research groups in SSI scheme to promote farmer-led research on key irrigation constraints including irrigation frequency, pest and disease management, spot application of chemical and fertilizers, management of perishable seeds and related issues. This is best done through the support of the regional agricultural research institutions. The participatory experimentation would give farmers and practitioners opportunities to tryout interventions and develop water, crop and livestock management skills.

At national level, poor market opportunities are commonly identified as disincentives for improving the productivity of irrigation schemes and water harvesting structures (Amede, 2004). Lack of road infrastructure and saturation of markets with similar seasonal agricultural products are two critical marketing constraints. Numerous water investments in SSA regions are not accessible during the rainy season. Intensified cropping requires fertilizer input, while diversification requires new seeds. The inaccessibility to these inputs can possibly impact the farm sustainability. In many cases, farmers are currently entirely dependent on the Government for inputs. For instance in Burkina Faso, the government provides to farmers fertilizers and irrigation equipments contracted under subsidy as part of the small scale irrigation programme. There is also a need to establish strong national and regional water institutions, with multidisciplinary teams that could regularly support and capacitate irrigation and rainwater management experts at Woreda and Kebele levels. However, the current institutional arrangements in the Ministries commonly lack the required manpower and facility to be engaged beyond occasional workshops and management of donor funds.

In general, the major constraints affecting agricultural water management in Africa relate to policy and institutional gaps at local, regional and country levels. At local and regional levels, the major obstacle facing water use and management is weak institutional and administrative capacities to enforce them. The escalating presence of transboundary issues also calls for coordinated monitoring/evaluation of the impact of water policies and institutional arrangement at basin levels. The presence of trans-national initiatives such as the Nile Basin Initiative (NBI) is an encouraging development but in many ways is inadequate to provide full fledged water related policies and strategies. In particular, the initiative has little to no practical link with local governments and communities. The regional bodies need to go beyond prescribing a common initiative to facilitating the ground for coordinated presence of bilateral and multilateral institutions across the board. Similarly, the presence of such initiatives has to cause sufficient influence on transboundary resource governance, particularly related to water benefits, leading to efficient and equitable benefit sharing by all members, mainly with the consent and understanding of those upstream and downstream.

Lack of enabling environment for sustainable use of water resources is another feature common to most African countries. There is an enormous stake in shifting the focus from relief to development, from short-lived and quick-impact objectives to long-term, all encompassing, environmentally sustainable and consciously monitored interventions. Recurring needs in recent years such as in the horn of Africa seemed to have made NGOs and CBOs to lose sight of long-term development objectives. There exists limited coordination role in guiding local organizations towards integrated and climate proof crop-water livestock development. Generally, the existing sectoral policies within the African continent (e.g. food security, irrigation development, watershed management etc…) rarely integrate the broader climate change agenda. Comprehensive and integrated policies that consider climate change-water interaction are desirable to improve the productivity of water and minimizing climate change effects by clearly understanding their interactions and trade-offs. Coordinated treatment of climate change-water management is thus essential as the two are highly interlinked across scales.

7. CONCLUSION AND WAY FORWARD

A number of possible agricultural water management and adaptation options have been discussed in this paper such as developing rainwater storage for surface and underground reservoirs; multiples irrigation schemes with effective technologies and strategies for optimizing water and crop productivities; dryland farming and best agronomics practices, livestock water productivities, and others innovative solutions focusing on the seed genotype improvement, policies and institutional frameworks, etc… Despite the uncertainty about the detail impacts of the climate change on agriculture water resources, many of these above challenges will likely be exacerbate. If the water resource management decisions are taken without considering possible future climate change impacts, then a mal-adaptation may result, as vulnerabilities to future climate change are increased. AWM embraces a whole range of wider practices including *in situ* moisture conservation and ex-situ water management, and offers a way of facilitating water-centred development to simultaneously reduce poverty, increase food security, achieve environmental protection, and adapt to climate variability and change. The potential of using alternative and renewable energy such as wind power, solar will definitely secure the agricultural system in an environment-friendly manner and economically sound. Improving crop, livestock and water productivity is a key strategy in the AWM agenda. Adding to that, crop physiological resistance mechanisms and vegetative cover of African landscapes have a potential role to play in Carbon sequestration. There is huge need to support African fast-track policy reforms, infrastructural and institutional frameworks for scoping with suites AWM technologies adaptations measures. Connect research and development, strengthening institutional arrangements and water user associations at all levels. Finally, a regional coordination for transboundary resource governance within the African continent has to comprehensively integrate the broader climate change issue to water agenda.

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