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United Nations Economic Commission for Africa
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Working Paper 5

Climate Change and Water Resources of Africa: Challenges, Opportunities and Impacts

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CLIMATE CHANGE AND WATER RESOURCES OF AFRICA: CHALLENGES, OPPORTUNITIES AND IMPACTS

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COMMON ACRONYM

AWM:	Agricultural Water Management
ClimDev-Africa:	Climate for Development in Africa
EU:	European Union
IPCC:	Intergovernmental Panel on Climate Change
IWRM:	Integrated Water Resources Management
ISS:	Institute for Security Studies
SSA:	Sub-Saharan Africa
SWC:	Soil and Water Conservation
UNECA:	United Nations Economic Commission for Africa
UNEP:	United Nations Environment Programme

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ABSTRACT

Africa’s water resources, as in many other regions of the world, are facing many challenges including climate change. Climate change is one of the dynamic processes impacting water resources. Other processes such as increase in population, land use, economic development have also major influences. This paper presents the nexus of water resources and climate change in Africa. It uses the existing knowledge from relevant literature as well as the authors’ extensive work on water management in Africa. It looks at major global drivers of change and focuses on water as a decisive natural capital that if managed and used effectively can contribute to economic growth, sustainable development and increased food and energy production in Africa. The paper focuses on the current level of water use by the various sectors and the potential and opportunities for future development. Sensitivity of the water sector to current climate variability and future climate change (i.e. likely additional pressures on water availability, accessibility and demand in Africa as well as increasing difficulty of water resource management) are discussed. Constraints and opportunities for planned adaptation in the water sector and prospects for technological, infrastructural, social, institutional interventions that can improve future water resources management in an era of climate change are highlighted. Interventions that support the development of robust water resource systems that take water infrastructure options with emphasis on water storage are provided through in depth discussion. The typologies of storage interventions taking the continuum of such systems starting from in-situ storage to large scale dams are considered. Comparison of the storage systems considering the inherent benefits and risks, and the additional impacts of climate change and the economic and social benefits are synthesized. Finally, the implications for future development, research, and policy are stressed.

Key words: African water resources, issues and prospects, position to climate change and water, global drivers, interventions focuses

1. **INTRODUCTION**

Today's world is constantly evolving. The precise nature of the future that will actually unfold is inherently uncertain. However, there are a number of global drivers of change and challenges that affect growth and development. Some of the major drivers are climate change, population growth, food crises, energy crises, financial crises, water scarcity, extreme events, dietary change, urbanization, deforestation (resulting in erosion and exhaustion), collapsing biodiversity, e-commerce, and advances in communication. These drivers create challenges and pose threats on the one hand, but also provide some opportunities for accelerated growth, development, and progresses on the other.

Climate change, in combination with other global drivers of change, presents a significant threat to Africa. The continent, which is home to 14% of the world's population, contributes only 3.8% of total Greenhouse Gas (GHG) emissions (just 1.59% from Sub-Saharan African (Spore, 2008)). **Figure 1** illustrates Africa's emission of carbon much less than any other continent, The continent has majority of the world's poor countries and communities, and because of that it will suffer earlier and more than other continents because of its weaker resiliency, weaker adaptive capacity and greater reliance on climate-sensitive sectors like agriculture. Recent modeling indicates that a temperature increase of 2^{o}C could equate to a loss of 4.7% of GNP across the continent (ClimDev-Africa, 2008). Most of this would be due to losses in the agricultural sector. A temperature rise of 2.5-5^{o}C would be even worse resulting 128 million to be hungry and 108 million to be affected by flooding and a sea-level rise of between 15 and 95 cm.

Climate variability is one of the causes of much of the prevailing poverty, food insecurity, and weak economic growth in Africa today. Climate change will even increase hydrology and weather parameters variability causing frequency and intensity, rainfall magnitude and trends to reach to an extreme situation in African regions. The severity and frequency of droughts, floods and storms will increase, leading to more water stress. Changes in agricultural, livestock and fisheries productivity will occur and Africa will face further food insecurity as well as possibly the spread of water-related diseases.

Africa is a continent endowed with abundant natural resources such as land, water, biodiversity, minerals and others. These resources are yet to be significantly developed and hold considerable potential to transform the continent and enhance the overall wellbeing of African people. If properly utilized and managed, these resources could contribute to creating resilient systems of agriculture, improved access to water and energy and modern industrial development.

The crucial role of water in accomplishing socio-economic development is widely recognized (UNECA and Others, 2002). The continent has large rivers, big lakes; vast water lands and limited, but widespread, ground water resources (UNECA and others, 2002). The water resources combined with other natural resources such as vast land resources, and suitable topography, provide high potential for irrigation development and hydropower.

This paper focuses on the nexus of water resources and climate change in Africa. It briefly looks at the continent's water endowment, from the perspective that water is crucial natural capital that if managed and used effectively can contribute to economic growth and increased food and energy access. It also highlights the possible implications and consequences of climate change, with possible adaptation options. It discusses in detail water storage which is widely promoted as both a key factor in water resource and agricultural development and an important contributor to climate change adaptation strategies. The paper emphasizes the challenges and opportunities posed by climate change but does not provide a full account of the climate change-water nexus; topics such as health as related to water borne diseases, sea level rise and coastal waters, etc., although recognized as highly important aspects of climate change, are not discussed.

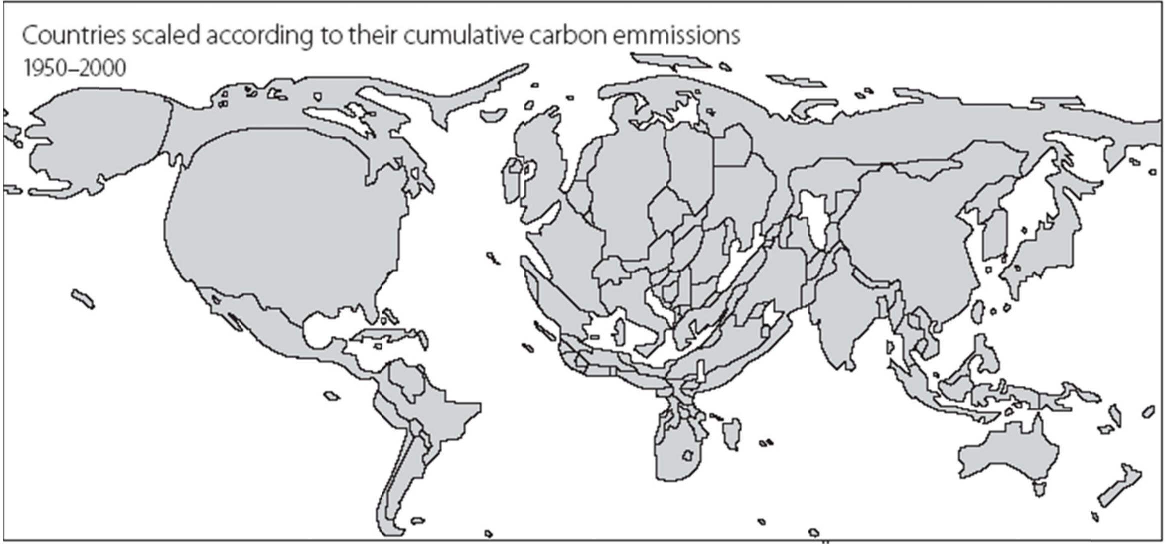


Figure 1: Africa's share of carbon emissions (Source: Climate Change and the Poor. Adapt or die, The Economist, cited by ISS, 2010)

2. AFRICAN WATER RESOURCES AND CLIMATE CHANGE

2.1 The Water Resources Base in Africa

Rainfall in Africa average about 670 mm per year across the continent. However, there is great variation in both time and space (UNECA and others 2002). Of the average of over 20,000 km^3 water falling across the continent, only about 20%, or about 3,931km^3 per year is transformed into surface and groundwater. The difference is returned to the atmosphere through processes of evaporation and transpiration. **Figure 2** shows the continent average rainfall pattern and its distribution. Temporal variability of rainfall is typically 40% around the mean -much higher than in temperate zones. Based on UNECA and others (2002), the highest rainfall occurs in the Island countries (1,700 mm per year), the Central African countries (1,430 mm), and the Gulf of Guinea (1,407 mm). The lowest precipitation occurs in the northern countries where average annual rainfall is only 71.4 mm.

Figure 3 shows the river and lakes basins of Africa. Although the continent appears to have large untapped water potential, it is also the second driest continent on the globe, after Australia, with only 9% of the global renewable fresh water and inhabited by 15% of the world population. The spatial and temporal distribution of water resources in Africa is one of the main challenges and problematic. About 48% of the total water resource is in the central Africa. About 40% of Africa's about a billion population lives in arid, semi arid and dry sub-humid areas, and 60% live in rural area, (with 85% in Sub-Saharan Africa), and mostly depend on rainfed agriculture.

Almost all of the population depend on agriculture which is basically rainfed and highly vulnerable to climate variability and climate change.

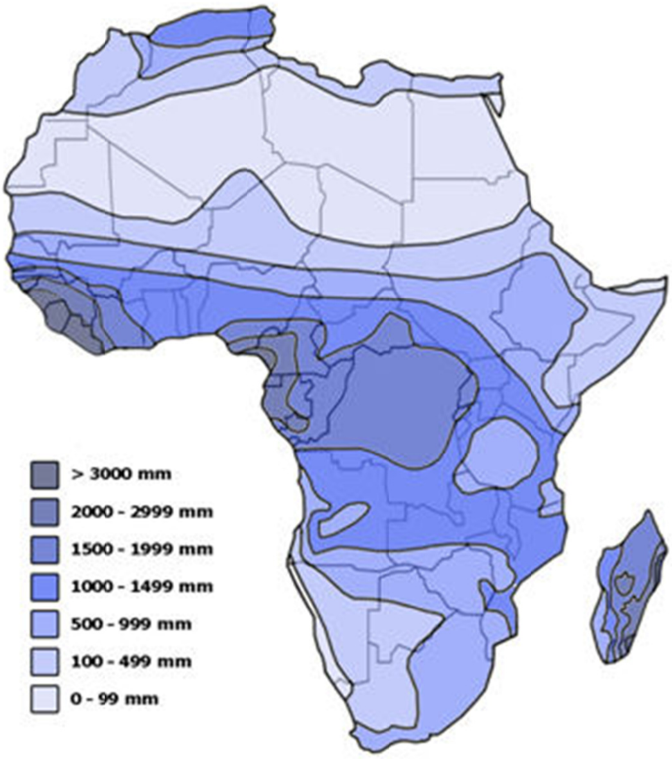
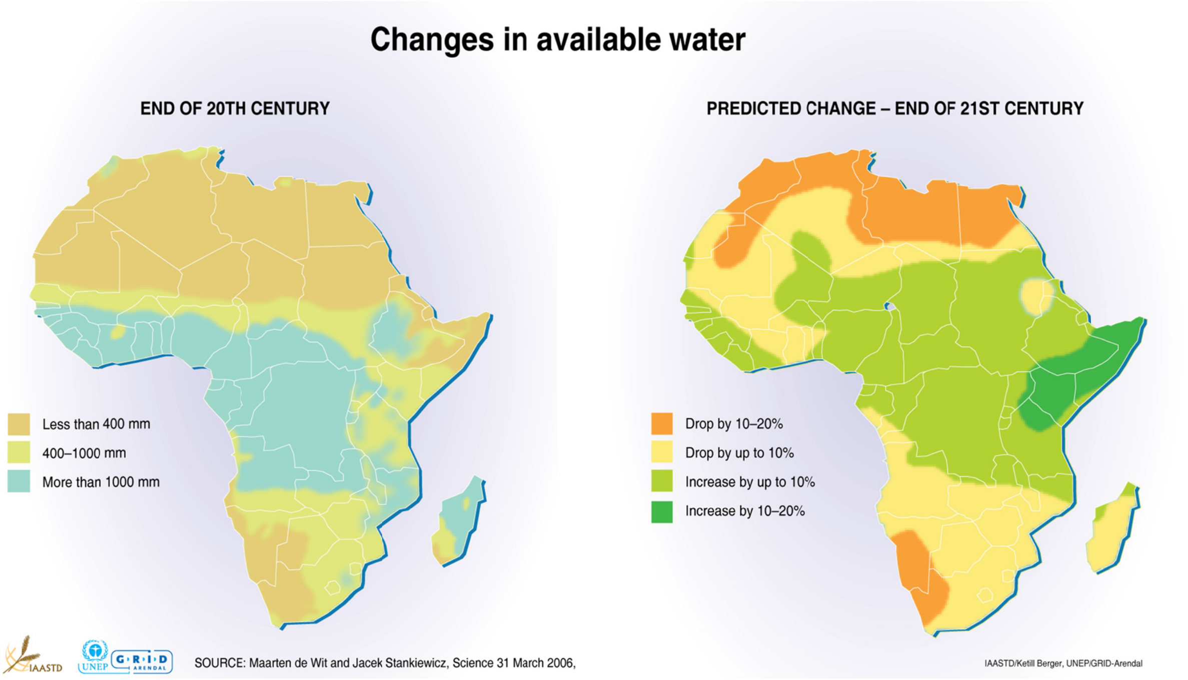


Figure 2. Map depicting the pattern of average rainfall on the African continent. *Source: http://myfundi.co.za/e/Freshwater_resources_in_Africa.*

Figure 3. River basins of Africa (GIS data source).

Water availability and access in different parts of Africa are variable. **Figure 4** represents the change in available water on the African continent. Arid regions of Africa, such as North Africa, are most associated with physical water scarcity, which means there is not enough water available in physical terms, and per capita physical water availability is less than 1,000 m^3 per person per year, which indicates the threshold of scarcity. However, compared to Sub-Saharan Africa, the people in these regions appear to have better water management capacities for their limited resources. In Sub-Saharan Africa, many countries may have good per capita physical water, but the major constraint is access to the water due to poor infrastructure. In these countries the main constraint is inability to finance infrastructure and so they are said to face economic water scarcity.


Changes in available water

END OF 20TH CENTURY

PREDICTED CHANGE – END OF 21ST CENTURY

SOURCE: Maarten de Wit and Jacek Stankiewicz, Science 31 March 2006,

IAASTD/Ketill Berger, UNEP/GRID-Arendal

Figure 4. Changes in available water in Africa: end of 20th and 21st centuries (Source: UNEP cited by De Wit and Stankiewicz, 2006).

2.2 Vulnerability of water resources to the effects of climate change

Africa is already sensitive to climate and weather, which coupled with other multiple stresses, creates varying degrees of climate vulnerability across various parts of the continent (IPCC, 2007). The climate of the continent is controlled by complex maritime and terrestrial interactions that produce a variety of conditions across a range of regions (e.g. from the humid tropics to the hyper-arid Sahara). The climate exerts a significant control on day-to-day economic development across Africa, particularly for agricultural and water-resources sectors, at regional, local and household scales.

There are traditional adaptation and coping mechanisms that if reinforced and adjusted and possibly supported by modern tools and mechanisms (i.e. early warning systems) could make a vital contribution to increasing adaptive capacity. Africa's high vulnerability and susceptibility to the negative impacts of climate change is attributed to its low adaptive capacity and hence inability to quickly respond to any climate induced disturbance. Africa's vulnerability arises from a combination of many factors, including extreme poverty, a high rate of population growth, frequent natural disasters such as droughts and floods, and agricultural systems that depend heavily on rainfall (IPCC, 2007). Africa can design basin wide and continental mechanisms to combat climate change induced water related risks such as flood, drought and desertification if adequate efforts are made to invest in early warning systems and integrated water resources management.

In recent years, with powerful computers, it has become possible to reproduce for instance the climate variability in Sahel in response to variability of seas surface temperature (Giannini *et al.*, 2008). These simulations provide evidence that it is the oceans that trigger climate variability in the Sahel at interannual to interdecadal time scales (i.e., it is external force to the Sahel itself that shape its characteristic year-to-year and long-term variability). The water sector is strongly sensitive to changes in climate and prolonged climate variability. Climate change will not have uniform impacts on water issues across the continent. In some parts it will aggravate water stress while in others it will reduce water stress. Changes in runoff and hydrology are strongly associated with climate through complex interactions. Due to a lack of information, the interaction between climate change and ground water is not clear, however, there is no doubt that climate change affects water fluxes, including groundwater recharge. Consequently, it is a great concern for Africa as most of the rural water supply is dependent on groundwater.

Major concerns for the water sector in Africa include the limited access to water due to insufficient infrastructure to provide reliable supply of water for drinking, agriculture and other uses combined with limited governance capacity climate change and variability have the potential to impose additional pressures on water availability, accessibility and demand in Africa. Even in the absence of climate change, present population trends and patterns of water use indicate that more African countries will exceed the limits of their "economically usable, land-based water resources before 2025". According to some assessments reported in IPCC-WGII (2007), the total population at risk of increased water stresses across Africa for the full range of SRES scenarios is projected to be 75-250 million and 350-600 million people by the 2020s and 2050s, respectively. Based on various reports and six climate models and SRES scenarios, IPCC-WGII (2007) indicates that there is likely to be an increase in the number of people who could experience water stress by 2055 in Northern and Southern Africa and a reduction of available water in Eastern and Western Africa.

Some studies, made in different parts of Africa, show that with an increase of 1^0C in temperature while keeping the rainfall constant, there would be a reduction of runoff by up to 10%. The possible range of Africa wide climate change impacts on stream flow increases significantly between 2050 and 2100, with a range that includes stream flow decreases of 15% to increases of up to 5% above the 1961-1990 baseline. For 2100, the range is from a decrease of 19% to an increase of 14%. A number of future threats exist in Africa with regards to water and climate change. These include Sea-level rise affecting coastal areas; temperature rises, increased water requirements, imbalances in crop water budgets, decreased water use efficiency and likely reduction of productivity; increased irrigation water demand due to population growth and insecurity of rain fed agriculture; change in soil moisture and runoff; a high degree of uncertainty about the flows in the rivers with potentially significant impacts on hydropower schemes and the generation of electricity.

Assessments of impacts on water resources currently do not fully capture multiple future water uses and water stress and must be approached with caution. Due to uncertainties, there are no clear indications of how the flows will be affected by climate change because of the uncertainty about rainfall patterns across basins and the influence of complex water management and water governance structures. Most climate models still fail to capture the observed magnitude of rainfall change. The difficulties of simulation in Africa are partly attributable to the lack of the required ground field based data, data uncertainties, length, time series scales, and reliability. Most of the projections for Africa are generated using global downscaling models which are unable to quantify specifically and accurately at the local scale. The best mechanism to prepare for climate change is to invest more across Africa to improve water infrastructure in order to enhance the positive roles and mitigate the negative impacts of water. Clearly, more detailed research on water hydrology, drainage, trans-boundary governance; ecosystem functions linked to climate change are required. Focus is needed highly required to improve the water resources data measurement and information network across the African continent.

2.3 Climate Induced-Water Disturbance on Human Development in Africa

Climate change is expected to alter the hydrological cycle, temperature balance and rainfall pattern in the continent (see section 2.2). Water is an essential and central resource in Africa for various sectors. Climate change manifests itself through the medium of water by affecting rainfall, temperature and evaporation. In the uneven distribution of water resources over times and space, the vulnerability of water dependent socioeconomics will increase. Change of water resources in Africa due to the climate, is also expected to damage biodiversity as a consequence of direct and indirect impacts of changes in land use and land cover. For example, decreases in forest cover, linked to climate change may alter run-off and infiltration. A study has shown that 2.3% of the forest reductions in Kenya were associated to the decrease of rainfall because farmers were forced to look for new cropping areas (Mwiturubani, 2010). Indeed, the climate impact on water resources in Africa is producing a dangerous vicious circle, since water scarcity put more pressure on the forest wetland through deforestation, and at the same time the decrease of forest cover also has a negative feedback effect on water resources availability. Changes in the rainfall pattern will affect the human development in Africa by reducing the water for crop and livestock, pasture, soil fertility and moisture content, economic activities and so on. The direct and immediate consequences will be on agriculture with knock affects for food and nutritional insecurity for many Africans.

Agriculture is the mainstay of African economies and the major occupation of most of the African population. Water plays a vital role and strongly connected to agriculture. The livelihoods of pastoralist communities largely depend on livestock. Severe drought directly affects water resources and forage availability for livestock leading to the loss of large numbers of livestock in most pastoral areas. As such, climate threatens human development in terms of security and livelihood, and the economical role of water is its strong relationship to the livestock production process. Any disturbance on water resources supply will be necessarily converted into agriculture with low productivity and recurrent food deficit. Conflicts over water access and use may also arise from the uneven distribution of rainfall between water users; this can significantly compromise the human development in Africa. Failure to address the pressing challenge of water management, the climate change-related disasters will offer no exception to the disturbance of water resources in Africa; it will even increase the continent's dependence on food aid and seriously affect its sustainable development. **Box 1** illustrates some examples of the climate-induced water stress on human development in Sub-Saharan African regions.

Box 1: Illustration cases of climate change disturbance on water resources across Africa:

Tingju and Ringler (2010) analysis focuses on the effects of climate change on hydrology and irrigation in parts of the four riparian countries within the basin: Botswana, Mozambique, South Africa, and Zimbabwe. Their results show that water resources of the Limpopo River Basin are already stressed under today's climate conditions, and the water supply situations are expected to worsen considerably by 2030. In the Gambia, the rainfall has dropped by 30% in the last 30 years; in Mali recurrent drought and occasional Niger River flooding have been observed. Urama and Ozor (2010) have reported that in Nigeria (West Africa), the persistent drought and flooding, off-season rains and dry spells have interrupted the normal growing season in the country; in Cameroon (Central Africa) the droughts have become severe in the last decades, in Kenya (East Africa), 80% of the population has been put at risk since the country is experienced its worst drought in 40 years, and Swaziland (Southern Africa) was severely affected by both drought and torrential rains, the latter ravaged the country in 2000.

In 2009, the worst hits by flood were Burkina Faso, Senegal, Ghana and Niger, nowadays, the Horn of Africa, and Sahel are experienced recurrent drought. Africa's lakes hold about 30 000 cubic kilometers of water, and yield 1,4 million tones of freshwater fish each year, and more than 600 lakes in Africa are declining rapidly owing to the combined impact of climate change and resource overuse (Onuoha, 2010). According to the author, the Lake Chad lost over 50% of its water between 1973 and 2002, meanwhile it is a vital source of fresh water and other resources that sustain human, livestock and wildlife communities in four African states, namely Cameroon, Chad, Niger and Nigeria. It has been pointed out that the three key forces that driving Lake Chad to extinction include resource miss-overuse, population surge and climate change variability. **Figure 5** shows the progressive shrinkage of the Lake Chad over last four decades.

Predicted climate change scenarios impacts for the water sector in Lesotho indicate that it is likely to reach a reduction of more than 60% of the current availability per capita per year by 2062 (Mwangi, 2010). According to the IPCC (2007), the warmer temperatures in East Africa may lead to a 5 to 20% increase in rainfall for December to February (wet months), and a 5 to 10% decrease in rainfall from June to August (dry months).

Boko et al. (2007), in the most recent IPCC report on Africa concluded that the contribution of climate to food insecurity in Africa is still not fully understood, particularly the role of other multiple stresses that enhance the impact of droughts and floods and possible future climate change.

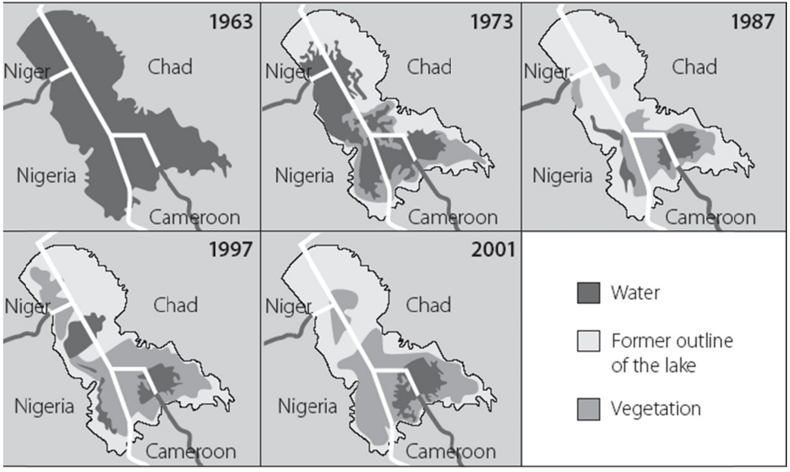


Figure 5. Progressive shrinkage of Lake Chad over the last four decades (Source: UNEP, 2006).

2.4 Africa Position to Water and Climate Change

Climate change and its impact are complex phenomena that require multidisciplinary and comprehensive approaches which must involve policy makers, researchers, practitioners, and the public and private sectors to devise realistic and effective adaptation and mitigation strategies in Africa. Such strategies need to be tailored to the specific biophysical and socio-economic conditions in each country. The anticipated impacts of climate change are bleak for the water sector in Africa with increased frequency of extreme events (i.e. flooding and severe drought) causing the drying up lakes, rivers and ponds.

Serious rational choices need to be considered in the development of clearly defined adaptation strategies to cope with climate change induced impact to water resources in Africa. The way forward clearly requires a holistic approach that combines comprehensive adaptation measures with effective sustainable development, economic growth and water resources management. The continent must strengthen its effective participation in climate negotiations, and also promote integration of climate change and adaptation strategies into the national and sub-regional development policies, programs and activities of member states.

In addition, African countries must reinforce their leadership role in the agendas of climate-water resources related mechanism, and be aware of the need for global mitigation of greenhouse gas emissions to prevent long-term climate change impacts on the African region, scale up investments that provide access to affordable and sustainable cleaner energy, water infrastructure especially for rural communities; to build economic and social resilience, to strengthen their preparedness and adaptive quick response to climate-induced water disaster; and to convert climate and water related challenges into an opportunity for human development and economic growth in the continent.

2.5 Sustainable Development Challenges and Opportunities in Key Sectors

The Africa Water Vision 2025 (UNECA and others 2002) advocates a doubling of the current area under irrigation and developing 25% of hydropower potential. Africa's main challenge is indeed the serious economic water scarcity. Even where water resources are physically available (e.g. in so called water towers like the Ethiopian Highlands), there infrastructure is inadequate to increase water access. The following are the major water sector challenges.

Water supply and sanitation: Africa is yet to develop its water supply infrastructure as the total supplied safe water covers only 64%. **Figure 6** shows the water availability in Africa under stress due to increasing population pressure and climate change. Many countries will shift from water surplus to water scarcity as a result of population changes in combination with climate induced water stress induced effect (UNEP, 2011). According to UNEP (2010), only 26 out of 54 countries are on track to attain the MDG target of halving the population without clean water access. Sanitation is even more challenging and only 5 countries might achieve the targets. The opportunity here is to increase financing, enhance public private partnership, empower women who are disproportionately burdened by the domestic water supply, and target rural population who are most vulnerable through development instead of just assistance during disasters or difficult periods. The major challenges of the water supply utilities under climate change include inadequacy of water storage, inadequate and poorly maintained supply networks, and vulnerability of the supply system to drought and flooding.

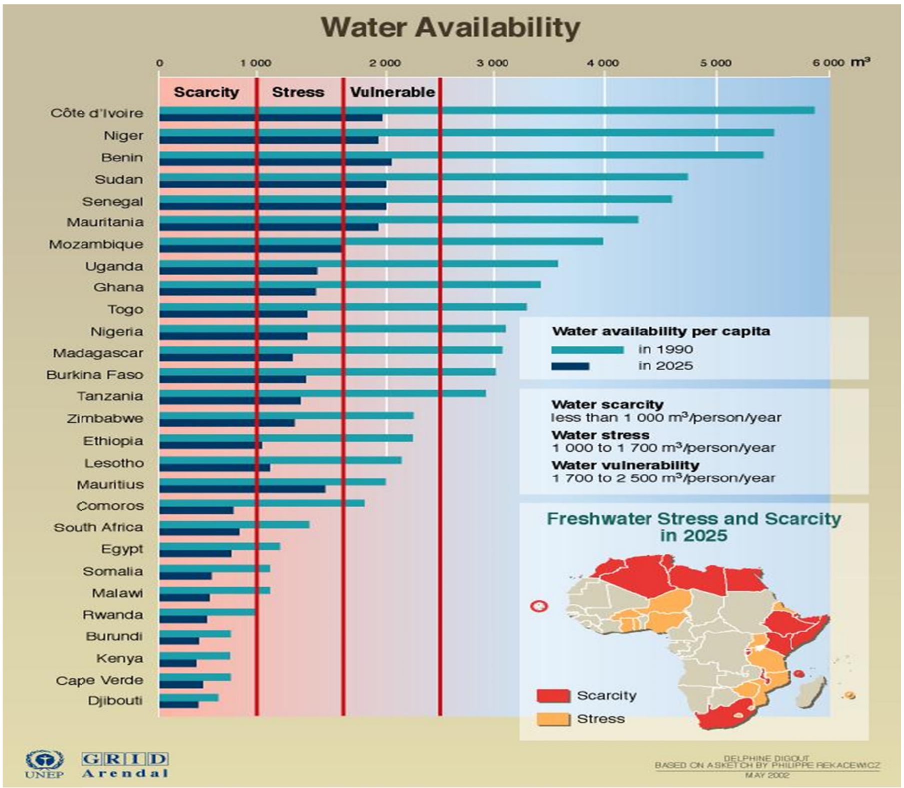


Figure 6. Water availability in Africa under stress due to increasing population pressure and climate change (Source: UNEP, 2011).

Agriculture and irrigation development: Agriculture is the largest user of water in Africa about 85% of the total available water. However, the total water use in Africa is very low about 3.8% of the internally renewable resources. Africa suffers from food insecurity and 30% of the population lives with chronic hunger as a consequence of various factors including low agricultural productivity and inadequate water access for irrigation. Africa has large untapped potential for irrigation, amounting to nearly 40 Million ha. Overall, according to UNEP (2010), a total of 185 million ha of area is under cultivation in Africa, of which only 6 to 7% is irrigated, which is also only 3.8% for SSA. **Figure 7 a**) and **b**) show for example the total irrigated area compared to the global irrigated area..For instance, fifteen SADC countries target, and most likely only 7% irrigation by 2015, and yet only four countries have reached this target, and probably only one country may be added by the target date.

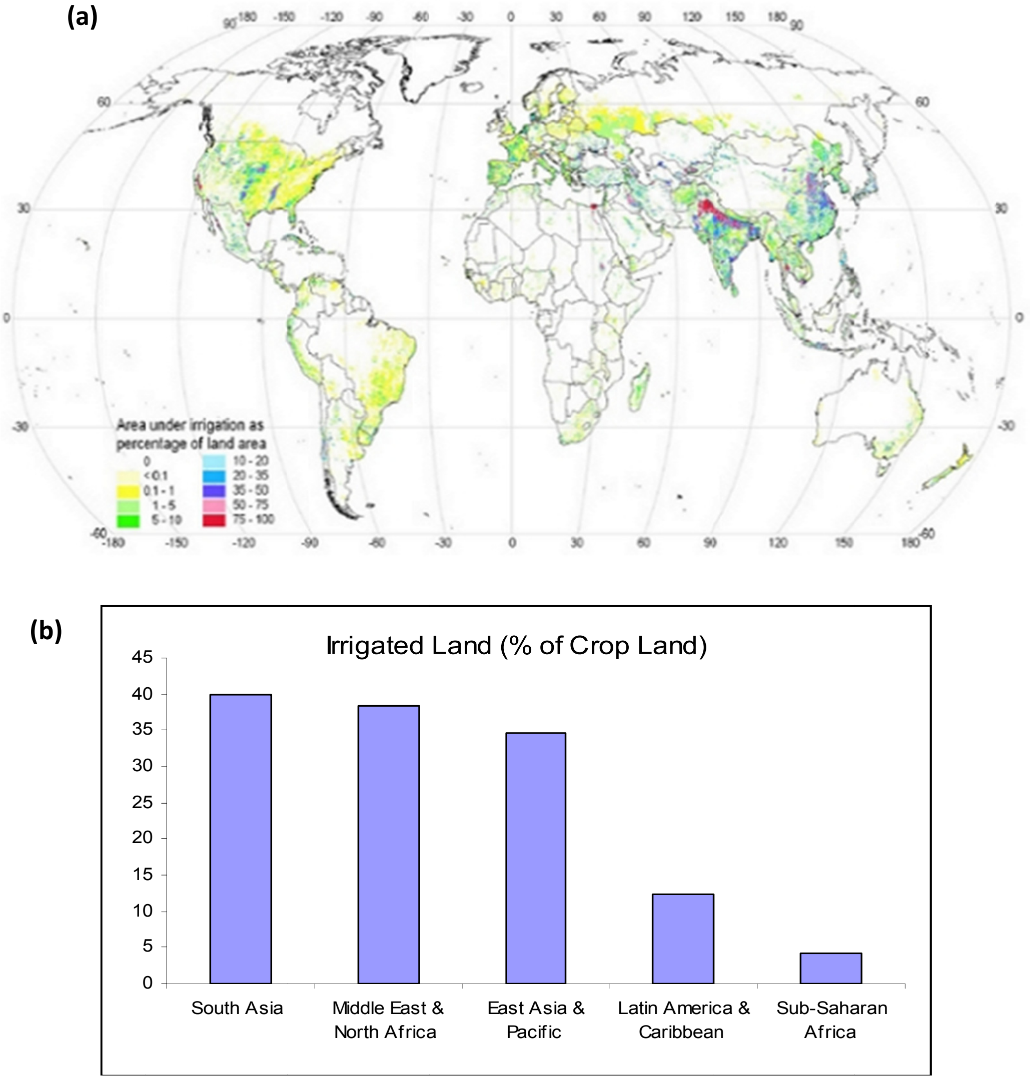


Figure 7. Irrigated land comparisons: a) *Global Map of Irrigation Areas: Percentage of 5-minute grid cell area; b)* SSA has the lowest irrigated area.

Investment in agricultural water can contribute to agricultural growth and reduce poverty directly by a) permitting intensification and diversification thereby increase farm outputs and incomes, b) increasing agricultural wage employment, and c) reducing local food prices and improving real net income. In the climate change context management of water for agriculture: i) reduce risk of failure of agricultural production, ii) reduce agricultural expansion to marginal land through intensification and contribute to mitigation of climate change, and iii) increase productivity of crop planted in a season due to enhanced transpiration or increasing the number of harvest per unit of land, and also per volume of water. Yet SSA water for agriculture remains underdeveloped, providing ample opportunities yet to be realized.

Hydropower development: Compared to what is currently developed, Africa has enormous hydroelectricity potential. Water can play a large role in power generation in many countries. Estimation of the available potential and the developed energy data are variable based on various sources. UNECA and others (2002) estimate the hydropower potential of Africa to be about 1,400 TWh, of which less than 3% is utilized. EU (2007) provides the potential estimate and the utilization level data as 1,750 TWH and 4.9% respectively and the IPCC (2011) energy report puts the 2009 technical potential value at 1,174 TWH (283GW) and utilization at 8.3%. Although different estimates indicate the level of uncertainty, these examples, broadly indicate the very large potential and low level of exploitation. Currently, hydroelectricity supplies 32% of Africa's energy (Kalitsi, 2003), with only 3% contribution to the world's hydropower development. Access to electricity in Africa is very low and 90% of rural populations rely on traditional source of energy (UNEP 2010). This is the lowest in the world. On the other hand there is significant disparity between North Africa and Sub Saharan Africa (SSA), where access in the former is high. The rural energy problem in Africa will continue to be one of the chief causes of underdevelopment and poverty unless it is given the attention it deserves. There is a need both to improve energy access and to link it more closely to the climate agenda. Developing hydropower potential in Africa is crucial as it is a proven technology for development, and in addition is a practicable option for climate change mitigation. Furthermore, it can be developed as a multiple development option for other consumptive and non-consumptive water use and management of extreme events related to droughts and floods.

Growth and Transformation of the Water Sector**:** The water sector in Africa needs a revolution that should based on a sustainable approach with sound management of water resources as well as measures to improve the socio-economic development. Risk reduction and should be given a high priority. Africa can learn from the Asian green revolution, increase food production quantity, and quality, use irrigation as a mechanism for increasing social equity and environmental sustainability. This requires scaling-up and applying the best that is known, since there is significant know-how on water resources sustainable management for building resilience to climate change. In addition, water footprint also has to be explored for good water practice in order to reduce the indirect and direct use of water in the production line of any good and service.

Other challenges**:** In Africa, 63 river basins are transboundary, which poses certain challenges. However, there are also 94 international water agreements in Africa to cooperate and manage shared water resources (Wolf, 1998). Significant opportunities exist to learn from these mechanisms, recognizing water as a binding factor connecting conflicting states. As population grows demand for water increases, and water availability per capita dwindles. Africa's main challenge as it relate to this is to manage the available water to meet demands and available water for all uses rationally. Water quality degradation is a serious challenge in Africa. Expansion of agriculture to marginal land, deforestation, urbanization and urban waste pollution reducing water quality, affect temporal distribution, reduce life span of hydraulic infrastructures due to sedimentation, and affect vital ecosystem functions. However, integrated water resources management interventions, and learning from well designed systems could help to overcome such challenges. Water climate information platform is crucial for Africa, and most importantly for local, regional and continental collaboration specifically when the resources is shared by several nations. Since water resources touch every sector of the economy, therefore, it can be seen as a source of cooperation and development, and subsequently of peace and stability in the African regions.

3. WATER MANAGEMENT INTERVENTIONS FOR ADAPTATION

3.1 Major thrust of interventions in Africa

Adaptive capacity and adaptation related to water resources are considered very important to the African continent (Bates *et al*., 2008). Technological interventions that can contribute to adaptation include: traditional and modern water harvesting techniques, water conservation and storage, improved recycling and re-use of water. The importance of building on traditional knowledge related to water harvesting and use has been highlighted as one of the most important adaptation requirements (Osman-Elasha *et al*., 2006).

The principles of Integrated Water Resources Management (IWRM) are key to effective and efficient management of water resources (both under current and future climate) and need to be enabled through the establishment of appropriate policies and institutional arrangements. Operational responsibility for the allocation and management of water resources should be devolved at the river basin level with policy development being retained at national level (World Bank, 2007). Policy instruments to achieve water management objectives should be structured to offer incentives to enhance innovation in efficient water use and disincentive for practices that result in inefficient and water use (Urama and Ozor, 2010). Within the African context it is also important that IWRM approaches are carefully tailored to the realities of both existing institutional arrangements and livelihood strategies of local people as well as the current low levels of infrastructure development (McCartney *et al*., 2007).

Institutions such as agricultural extension organizations need to sensitize and train farmers on the best practices to adopt in order to minimize water stress. It has been recommended that staff of extension organizations should be re-trained to acquire the necessary skills and knowledge in climate risk management. This would provide them with the knowledge required to apply appropriate interventions and scale up or replicate adaptation interventions that work (Ozor, 2009).

Maintaining water inventories, in relation to both water quantity and quality of both surface and groundwater, is a pre-requisite for effective water resources management. This requires the identification of temporal and spatial variations in water supply and water demand in basins, as well the water resource infrastructure available to store and/or convey water to the users (Azim, 2008). Water supply assessments include available water resources from surface water (from canals, drainage reuse, and wastewater reuse), groundwater, and rainfall. Water demand assessments should include agricultural, municipal (drinking and domestic uses), industrial, and other uses such as for navigation, fishing, hydropower generation etc (Urama and Ozor, 2010).

The role of natural ecosystems (e.g. forests and wetlands) in the hydrological cycle and the function they perform also needs to be incorporated into management planning for adaptation. Forests and wetlands play a crucial role in the hydrological cycle by affecting the rates of transpiration, evaporation and influencing how water is routed and stored in a basin (Bruinjnzeel, 1996; Bullock and Acreman, 2003). Increasing recognition of their role in the supply of water for human use has led to the proposition that natural ecosystems should be considered as "natural infrastructure" and much more closely incorporated into decision making processes pertaining to water resources (Emerton and Bos, 2004).

Currently trade-offs and synergies between human "built" water infrastructure and natural ecosystem functions often go unrecognized and, as a result, the benefits accruing from built infrastructure is often sub-optimal. One reason for the failure to consider ecosystem functions is lack of understanding of them and how they translate into services for people. It is not clear which ecosystems perform which functions or how they will be affected by water resources development. For example, whilst it is widely understood that in relation to hydrology, different wetland types provide different regulating functions (e.g. in relation to both flood flows and low flows), there is little quantitative information on the extent to which they do this or the dynamic nature of such functions. If ecosystem functions, and specifically flow regulating functions, are to be considered in water resources planning for adaptation more information and a method to incorporate them into decision-making processes is required (McCartney *et al*., 2011).

3.2 The role of water storage

This section is mainly based on the work done by McCartney and Smakhtin (2010). The inability to predict and manage rainfall, and consequent runoff, variability is a key contributing factor to food insecurity, poverty and low economic development, which is likely to be exacerbated by climate change in many parts of Africa. Under these circumstances, even relatively small volumes of water storage can, by safeguarding domestic supplies and by supporting crops and/or livestock during dry periods, significantly increase agricultural and economic productivity and enhance people's well-being. Consequently, water storage has an important role to play in poverty reduction, sustainable development and adaptation to climate change. However, throughout Africa the climate and socio-economic conditions vary significantly and will be affected by climate change in a myriad of diverse ways. Hence, storage options need to be carefully tailored to suit exact needs.

3.2.1 The water storage continuum

When it comes to storage, current planning focuses to a considerable extent on large dams. However, large dams are just one of a range of possible water storage options. Others include: natural wetlands, enhanced soil moisture, groundwater aquifers, and ponds/small tanks. In fact, water storage can be considered a continuum of surface and subsurface options (**Figure 7; Table 1**). Each has an important role to play and, under the right circumstances, can contribute to food security, poverty reduction and economic development. However, obviously not all storage types are fit for all purposes. Clearly, enhancing soil moisture can benefit agriculture but will not contribute to hydropower production or industrial and domestic supply.

The effectiveness of options varies, but each of them provides a buffer during dry periods. Broadly, the deeper and/or the larger the storage, the more reliable the water supply it can help ensure; and the more 'natural' it is, the less complex and less costly it is to develop, manage and access (**Figure 8**). However, none of these options is a *panacea*. All have strengths and weaknesses which depend, in part, on their inherent characteristics (**Table 2**) but are also affected by site-specific conditions and the way the storage is planned and managed.

For each option, the way the water is accessed and who can access it varies. Some options are highly technical requiring modern tools and methods for construction and operation. Others are technically simpler and some have been around for millennia. Modes of management also vary considerably. In some cases, decision making and responsibility lies directly with communities whilst in others relatively complex institutional arrangements are required. Hence, in any given situation, each type of storage has its own niche in terms of technical feasibility, socioeconomic sustainability and institutional requirements, as well as impact on public health and the environment.

At any given location the impact of different types of storage on poverty can vary significantly with some options being much more effective than others (Hagos *et al.,* 2010). In other words, boreholes may have a greater impact than small reservoirs in some circumstances and *vice-versa* in others. It is not always clear why a particular option is successful sometimes and ineffective others. For example, in Ghana, some small reservoirs have led to diversification and more stable and reliable income for farmers whilst others, constructed nearby under seemingly almost identical conditions, have failed to bring about significant change.

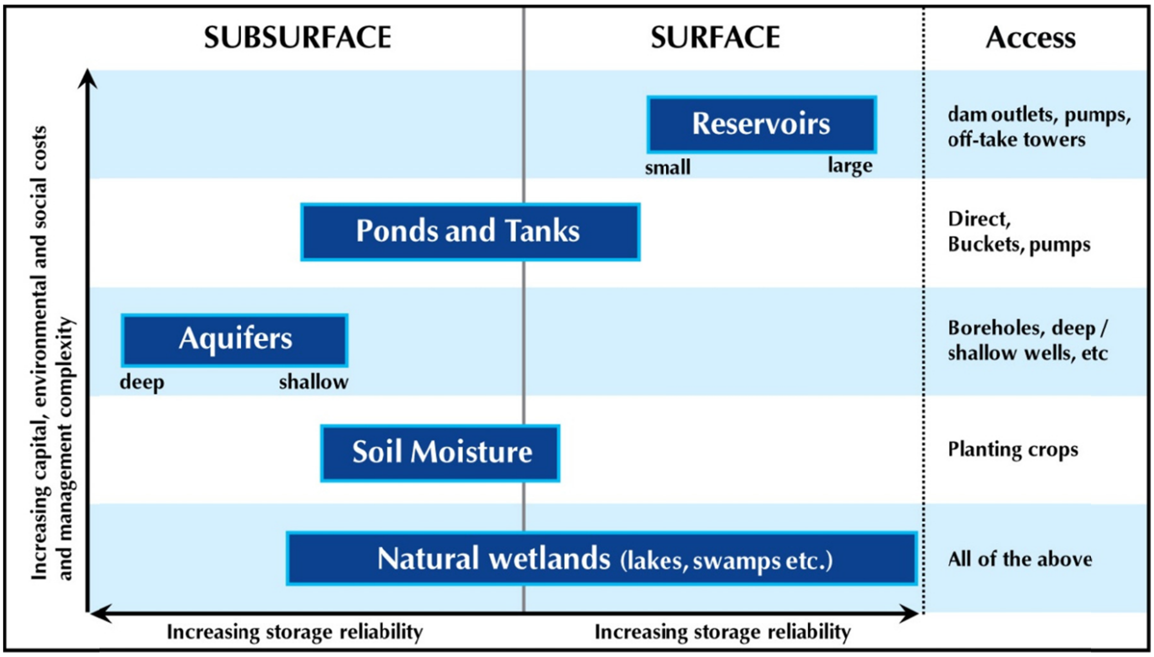


Figure 8: Conceptualization of the physical water storage continuum (McCartney and Smakhtin, 2010).

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Table 1: Typology of different water storage options (McCartney and Smakhtin, 2010)

Natural wetlands	Lakes, swamps and other wetland types have provided water for agriculture for millennia both directly as sources of surface water and shallow groundwater, and indirectly through soil moisture. Consequently, wetlands span the surface/subsurface interface and provide water in many different ways. As a result of their important role in the provision of water, wetlands are increasingly perceived as "natural infrastructure" (Emerton and Bos 2004).
Soil moisture	Across Africa, the total volumes of water stored within the soil are huge, but at any given locality they are relatively small and quickly depleted through evapotranspiration. Because of this, in recent decades there has been increased interest in various *in situ* rainwater management techniques that enhance infiltration and water retention in the soil profile. Widely referred to as soil and water conservation (SWC) measures, examples vary from place to place but the most promising include deep tillage, reduced tillage, zero tillage and various types of planting basin. The effectiveness of different measures depends a lot on soil characteristics and, particularly, on water holding capacity (Gregory et al. 2000).
Groundwater	Groundwater is water stored beneath the surface of the Earth in aquifers. A major advantage of groundwater is that there is little or no evaporation and total volumes are often much greater than annual recharge. The amount of water that can be abstracted from a well in an aquifer is a function of the characteristics (particularly the permeability) of the rock. Some aquifers will yield only a few liters per day, whilst others can yield as much as several million liters. Methods for increasing groundwater recharge include pumping surface water directly into an aquifer and/or enhancing infiltration by spreading water in infiltration basins.
Ponds and Tanks	Ponds and tanks are cisterns or cavities (covered or uncovered, lined or unlined) built by individuals or communities to store water. They are often linked with rainwater harvesting and store relatively small (but often vitally important) volumes of water. Ponds and tanks fill either by surface runoff or through groundwater and differ from reservoirs by the absence of a dam. A common limitation is that they are usually shallow, with a relatively large surface area, so that often a significant proportion of the water is "lost" through evaporation.
Reservoirs	Reservoirs are water impounded behind small and large dams constructed across streams and rivers. Small dams (often built simply by mounding earth) store relatively small amounts of water (a few hundred to a few thousand cubic meters) and often empty every year. Many small dams do not have outlets and water is simply removed by livestock drinking, pumping and as consequence of spilling and evaporation. They tend to be shallow with relatively large surface areas so that, in common with many ponds/tanks, a significant proportion (sometimes more than 90%) of the water may be lost through evaporation. Large dams (often rock-filled or concrete) store millions, sometimes billions of cubic meters of water. The water may be used for multiple purposes. Sometimes they are also used for flood control. Because they tend to be deeper with a relatively smaller surface area, in comparison to small reservoirs, they often have a higher yield relative to the inflow. Furthermore, some large reservoirs provide storage that is greater than the mean annual runoff and thus provide multi-year carryover of water.

Table 2: Comparison of different water storage options and the possible implications of climate change (McCartney and Smakhtin, 2010)

	Inherent Benefits	Inherent Risks	Possible risks from climate change	Possible social and economic implications
Natural wetlands	• Water storage is provided as an ecosystem service without the need for costly infrastructure	• Excessive utilization of water in, or upstream of, natural wetlands may undermine other ecosystem services	• Reduced rainfall and runoff inputs resulting in desiccation • Higher flood peaks resulting in wetland expansion and flooding of fields/homes • Improved habitat for disease vectors	• Increased failure to provide community/household needs • Loss of water dependent ecosystem services • Increased risk of water borne diseases
Soil moisture	• Generally low cost options that can be implemented by individual farmers and communities	• Where land holdings are extremely small, farmers may be unwilling to use precious land for these interventions. • Limited storage - will not provide water for more than a few days without rain	• Reduced infiltration or water logging/erosion resulting from modified rainfall intensities and durations • Depleted soil moisture arising from higher evaporative demand • Reduced soil quality (including water holding capacity) resulting from modified rainfall and temperature	• Decreased productivity – more frequent crop failures and reduction in yields
Groundwater	• Evaporation losses are low or non-existent. • Multi-year storage that is largely decoupled from seasonal variability	• Detailed geological information is required to locate wells and estimate yields • Depending on geology, may contain high concentrations of toxic chemicals (e.g. arsenic)	• Reduced recharge resulting from modified rainfall intensities • Reduced recharge resulting from land-cover modification and increased soil moisture deficits • Saline intrusion in near-coast aquifers	• Falling water levels make it increasingly costly to access groundwater • Poor water quality make groundwater unsuitable for use
Ponds and Tanks	• Generally relatively low cost options, implementable by communities and NGOs.	• High evaporation losses • Water contamination (e.g. from water flowing in and livestock entering the water) • Risk of siltation • May provide breeding habitat for disease vectors	• Reduced inflow, resulting in longer periods between filling • Higher evaporation, increasing rates of pond/tank depletion • Infrastructure damage caused by larger floods • Improved habitat for disease vectors • Increased risk of eutrophication, salinization and siltation	• Increased failure to provide community/household needs • Increased labor requirements and costs to repair structures • Increased risk of water borne diseases
Reservoirs	• Large volumes of water stored, which can be used for multiple purposes. • The only option that enables production of electricity and can offer protection from floods	• Significant capital investment • Often displacement of large numbers of people • Significant environmental and social impacts arising from changes to river flows • May provide breeding habitat for disease vectors	• Reduced inflow, resulting in longer periods between filling • Higher evaporation, increasing the rate of reservoir depletion • Infrastructure damage caused by larger floods • Improved habitat for disease vectors • Increased risk of eutrophication, salinization and siltation	• Increased failure to meet design specifications (irrigation and hydropower etc.) • Increased costs due to the need to redesign infrastructure (e.g. spillways) • Increased risk of water borne diseases

With the exception of large dams, in most places past storage development has occurred in an *ad-hoc* fashion, largely through local initiatives and with minimal planning. It is generally characterized by the absence of data or poor data management, insufficient communication with local stakeholders and water resource authorities, and lack of any integrated planning (Johnston and McCartney, 2010). In some cases (e.g. where reservoirs are silted, boreholes are dry and ponds have caused severe negative health impacts) it is clear that, despite the best of intentions, the lack of information and planning has resulted in less than optimal investments. For example, of around 4,000 rainwater harvesting ponds constructed in the Amhara region of Ethiopia between 2003 and 2008, the majorities were not functioning by 2009 (AMU, 2009). Failures have been attributed to a range of factors, including: poor site selection, poor design, technical problems (e.g. failure of lining materials leading to seepage), and lack of commitment by communities for maintenance (Eguavoen, 2009).

In many places there is a dearth of information on existing storage, the benefits that they provide and their costs, including the impacts of scaling-up. For example, in both the Volta (West Africa) and the Olifants (South Africa) basins there are many thousands of small reservoirs but the exact numbers, let alone the volumes of water stored, are unknown (Johnston and McCartney 2010; McCartney and Arranz. 2007). This is despite the fact that, though they may increase the reliability of water supplies at the local level, the cumulative effect of large numbers of small reservoirs can have potentially serious implications for downstream reservoirs (Meigh, 1995; Liebe *et al.,* 2009).

Basic scientific knowledge required for planning is also often inadequate. As a result, design failures are common, benefits are frequently suboptimal and, in the worst cases, investments aggravate rather than improve the well-being of local people. For example, the construction of rainwater harvesting ponds and wells in the Tigray region of Ethiopia has considerably increased cases of malaria with not only serious welfare, but also important economic implications (Hagos *et al*., 2006).

3.2.2 The impact of climate change on water storage options

All storage options are potentially vulnerable to the impacts of climate change (**Table 2**). In some situations certain storage options will be rendered completely impracticable whilst the viability of others may be increased. For example, climate change may have significant impacts on soil moisture. Hence, longer dry periods may mean that soil water conservation measures fail to increase and maintain soil moisture sufficiently to prevent crop failure. Groundwater recharge may be reduced if rainfall decreases or its temporal distribution changes in such a way that infiltration declines. Many aquifers near the coast will be at risk from saltwater intrusion as a result of sea level rise. Ponds and tanks may not fill to capacity or the frequency of filling may be reduced so that they are unable to provide sufficient water for irrigation. Changes in river flows may mean that reservoir yields and, hence, assurance of water supplies decline. Storage in ponds, tanks and reservoirs may also be reduced more rapidly as a consequence of increased evaporation and/or greater sediment inflows. Furthermore, both large and small dams as well as ponds and tanks may be at increased risk of both eutrophication and flood damage. Natural wetlands also face a range of climate change related threats arising from changes in hydrological fluxes (i.e., surface water and groundwater flows, evaporation, etc.) as well as increased anthropogenic pressures resulting directly and indirectly from climate change.

In all cases the externalities associated with different storage types are also likely to be affected. For example, malaria transmission in the vicinity of some ponds, tanks and reservoirs may increase as a result of modified rainfall patterns and higher temperatures though the extent to which this occurs is dependent on a large number of complex factors (including the effectiveness of malaria eradication programs), not just the creation of suitable vector habitat (Gething *et al.*, 2010). Impacts of dams on downstream river flows - and the livelihoods of people depending on those flows - may be exacerbated by climate change resulting in the need to release a greater proportion of water stored in reservoirs to maintain riverine environments and ecosystem services. These, and similar factors, will affect both the effectiveness and suitability of different storage options in any specific situation.

3.2.3 Re-thinking water storage

Climate change, in conjunction with population growth, will increase the importance of water storage in many African countries. Appropriate storage will reduce peoples' climate vulnerability by increasing water and food security as well as adaptive capacity (**Figure 9**). However, as noted above, all water storage options are also potentially vulnerable to the impacts of climate change and, as water resources are increasingly utilized and climate variability increases, planning and management will become ever more difficult. In all situations maximizing the benefits and minimizing the costs of water storage options will, as in the past, require consideration of a wide range of complex and inter-related hydrological, social, economic and environmental factors. Thus, future planning needs to be much more integrated across a range of levels and scales, with much greater consideration of the full range of possible options. To date, although there have been many studies of the effects of climate change on hydrological regimes, there has been very little systematic research into the potential impacts of climate change on different water storage options, or how to plan and manage water storage under a changed climate.

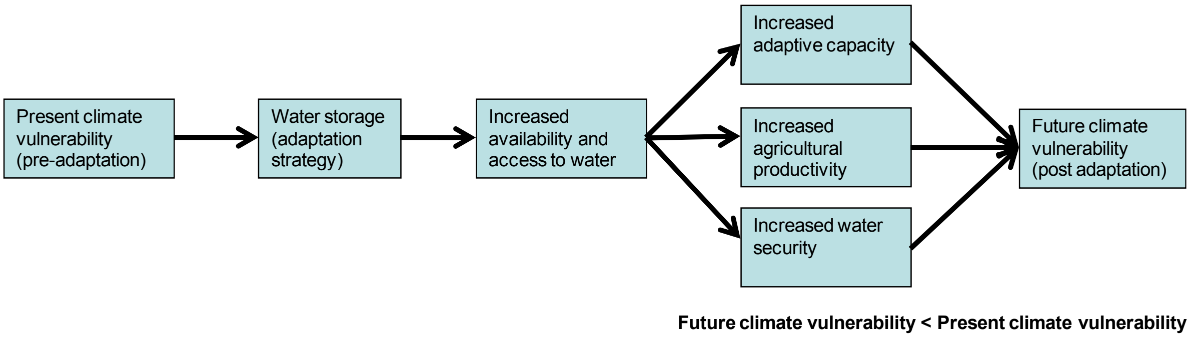

Figure 9: Water storage as an adaptation strategy to reduce climate vulnerability (McCartney and Smakhtin, 2010)

A key to planning water storage is the determination of current and future needs and making appropriate choices from the suite of storage options available. In any given situation this requires understanding both biophysical and socio-economic issues that influence the *need*, *effectiveness* and *suitability* of the different water storage options. In the past, there has generally been little explicit consideration of these issues, even in large dam construction projects. For storage options other than large dams, where planning is generally less formalized, needs are usually regarded as self-evident and alternative options are rarely considered.

The details of climate change are unknown so planning must allow for great uncertainty. Future water storage must be more reliable and resilient and less vulnerable than in the past. All water storage options have strong comparative advantages under specific conditions of time and place. Hence, storage "systems" that combine and build on complementarities of different storage types are likely to be more effective and sustainable than those based on a single option. Combinations of surface and groundwater storage or large and small reservoirs, can dampen mismatches between supply and demand, and are already used successfully in some places (Keller *et al.*, 2000).

The optimal combination of storage options will vary depending on local biophysical and socio-economic circumstances. However, there will rarely be an ideal combination and in most instances trade-offs will need to be considered. Without a greater understanding of which types of storage are best suited for specific agro-ecological and social conditions, and in the absence of much more systematic planning, it is probable that many water storage investments will fail to deliver intended benefits. In some cases they may even worsen the negative impacts of climate change. To avoid inappropriate storage options, future planning needs to be much more evidence-based. To this end, studies are needed to better understand: the social and environmental impacts of different storage options; the implications of scaling up small-scale interventions; and, very importantly, the reasons for the successes and failures of past interventions.

4. SUMMARY AND CONCLUSIONS

Climate change is expected to alter the hydrological cycle, temperature balance and rainfall patterns across Africa. Higher temperatures, altered patterns of precipitation and increased variability will be key physical constraints to the well-being of people in Africa. The combination of climate change and population growth is projected to significantly disturb the current hydrological cycle. As a result, pressure will increase on the water resources across the continent.

If unchecked the negative impacts of climate change on water resources across Africa are likely to translate into food and nutritional deficits, health and economic deterioration, and poverty exacerbation. Changes in climate will result in constraints, but adaptation strategies also provide potential opportunities for socio-economic development across the continent.

In Africa, climate change has the potential to impact negatively on water availability, stability, access, utilization, and demand in most countries. This in turn has the potential to disrupt livelihoods, increase poverty and the marginalization of the poor and escalate inequality. It is a fact that water is an essential and central resource in Africa, because the majority of the population derives their livelihood from cultivation and livestock production dependent on availability of rainfall and water. Experts and scientists all agree that the climate change is a real and present danger to the continent's future well-being. However, currently the capacity to mitigate the problems arising from climate change is for the most part extremely weak. Institutionalized mechanisms for dealing with water resources as an issue of national and continental security are only just being developed.

Many concerns and issues surround water resources are increasingly linked to climate change. Robust action is required to combat climate change and the other drivers of change. To this end the following recommendations are made:

- ✓ Establish continental mechanisms to combat climate change induced water related risks such as flood, drought and desertification;
- ✓ Invest in climate water related risk prevention and management strategies, such as early warning systems; information network and sharing;
- ✓ Protect the vulnerable populations, and enhance the continent adaptive capability to climate change;
- ✓ Consider both traditional and modern knowledge such as water harvesting techniques, water conservation and storage and improved recycling re-use of water;
- ✓ Strengthen capacity building mechanisms for surface and groundwater management, irrigation facilities, water storage reservoir continuum system; and infrastructures for water transportation, effective supply chains for both agriculture and drinking water; secure water availability, sanitation, access and utilization. The best adaptation strategy is to invest more across Africa to improve both small-scale and large-scale water infrastructure.
- ✓ Develop the agriculture and irrigation by intensification and diversification, increasing the wage employment, farm outputs and incomes, optimizing both crop yield and water productivity per unit of land and per volume of water, increase soil moisture content and fertility, promoting effective and low cost irrigation technologies, reducing the water footprint, and agricultural expansion to marginal land;
- ✓ Reinforce the agricultural extension institutions or organizations for assisting, sensitizing, and training farmers on the best adaptation practices,
- ✓ Increase financing, enhance public and private partnership, empower women;
- ✓ Invest in the hydropower schemes and generation of electricity, which means exploring the hydropower potential, technical opportunity, knowledge gap, energy access and mobilizing financial resources in the climate change context;
- ✓ Reinforce water research (i.e. data measurement, water inventories, hydrological fluxes, modelling, assessments of impacts of climate change on water resources at past, current and future in the continent) to fully capture multiple future water uses and water stress;
- ✓ Consolidate at a local, regional, and continental level, an institutional, legal and policy instrument and arrangement for complex shared water management and water governance structures through operational responsibility, dialogue and conjunctives adaptations actions across the continent;
- ✓ Create synergize among ecosystem, biophysical, social, economy, security and policy for a rational, effective, integrated and comprehensive management of water resources. A new paradigm of water resources management in Africa needs to bring all these actors together, and understand their complex functions and inter-relations in the context of climate change and variability i.e. understanding African-climate change-water resources nexus;

- ✓ View climate induced water disturbance not simply as a threat, but also as an opportunity for the development and economic growth;
- ✓ Scale up small-scale interventions; develop systematic methods for evaluating the suitability and effectiveness of different adaptation options, both individually and within larger and small systems;
- ✓ Adopt a common platform and position on African-climate change-water resources related issues at continental and international levels.

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