Water Resources Management within the Climate Change Context in Africa

Salif Diop[1]

1. Introduction

The IPCC has recognized that Africa is among the most vulnerable continents to climate change impacts, partly because of the projected climatic changes, as well as the poverty levels and the paucity of institutional capacity across the continent (Christensen et al., 2007). Illustrative of this is the fact that, according to the ND-Gain index for climate change vulnerability, 8 out of the 10 most vulnerable countries in the world are in Africa, with the top 5 all being African (Notre Dame Global Adaptation Initiative, 2019).

The challenges of properly addressing climate change impacts in Africa is that not only it is adding to the existing pressures of development on limited water resources, but as climate change pressures intensify, they will do so in the face of growing populations and economies, both placing yet-greater stresses on existing water resources. Thus, the challenge of managing water resources in Africa over the coming decades is both a climate change and development challenge (UNEP, 2009). In this regard, the already-vulnerable rural areas contain the people most at risk from climate change impacts. Any action that increases the resilience of these communities will help them respond more effectively to the impacts of climate change, including removing barriers to the integration of climate change adaptation into development planning and decision-making frameworks. With this in mind, this report provides an overview of the current challenges related to water resources management in the context of climate change faced by some of the most vulnerable areas in Africa, including approaches that may help to alleviate the same.

The report conceived for this module provides a cross-cut of the key insights, observations and findings of individual contributions presented in the Springer book on Climate Change and Water Resources for which the Chief Editor is Prof. S. Diop. The report, in this regard, provides a rich compilation of observations, views, case studies and recommendations made by scientists from across the African continent and beyond. It provides therewith an overview of the current knowledge of climate change/water resources interactions, illustrated by a variety of regional, national and local level case-studies, discussions on tools and methodologies, aspects related to governance and institutional setting, as well as specific management approaches. Based on these analyses and findings, this report also presents possible options and actions for improved management of water resources within the context of climate change in Africa.

2. Africa's climate and Climate Change

Large parts of Africa are subject to seasonally variable hydrology and geographically uneven distribution of water resources. This will be compounded by climate change, to

[1] Professor of University Doctoral School on "Water and Environmental », University Cheikh Anta Diop–Dakar; SENEGAL. Member of the Senegalese National Sciences and Technical Academy (ANSTS) ; Member of the African Academy of Sciences (AAS) and Member of The World Academy of Sciences for the Advancement of Sciences in the Developing Countries (TWAS); P.O.Box: 5346 – Dakar-Fann – Dakar; Senegal. E-mail: Salif.diop@anats.sn

which Africa is particularly vulnerable. These risks are furthermore compounded due to the diversity of hydro-climatic zones across the continent, a range of climate risks exists for the different economic sectors including agriculture, manufacturing and mining. A recent study by Distefano and Kelly (2011), modelling the impact of climate change on economic growth, finds that water remains a significant obstacle to growth in both developed and developing countries irrespective of their level of water scarcity at present (Distefano and Kelly, 2017). It concludes that efficiency gains from greater investment in technological enhancements could alleviate the problem. However, the gains are much with demand management approaches such as reducing the use of water intensive goods and services, less wastages, and shifting our water footprints via trades to regions where such opportunities exist and these supply chains are more resilient to the impact of climate changes in these places. Therefore, water security risk mitigation in Africa needs to consider both infrastructure and management responses.

Climate change projections for Africa, like many climate projections, have large margins of uncertainty but there is a clear signal of warming. Therefore, it is important to recognise that macro-scale estimations may have significant variations should they be rescaled to the regional or sub-regional level. Nonetheless, historical data shows a warming trend across the continent since the 1960s. Under a high Representative Concentration Pathway (RCP), warming projections under medium scenarios estimate extensive areas of Africa will exceed 2°C by the last two decades of this century compared to late 20th century. It is likely that land temperatures over Africa will rise faster than the global land average, particularly in the more arid regions, and that the rate of increase in minimum temperatures will exceed that of maximum temperatures (Niang et al., 2014) (Figure 1).This air temperature warming alone has significant implications for agriculture and the agri-business sector, particularly in relation to increased crop water requirements, changes in growing seasons and impacts on water availability generally.

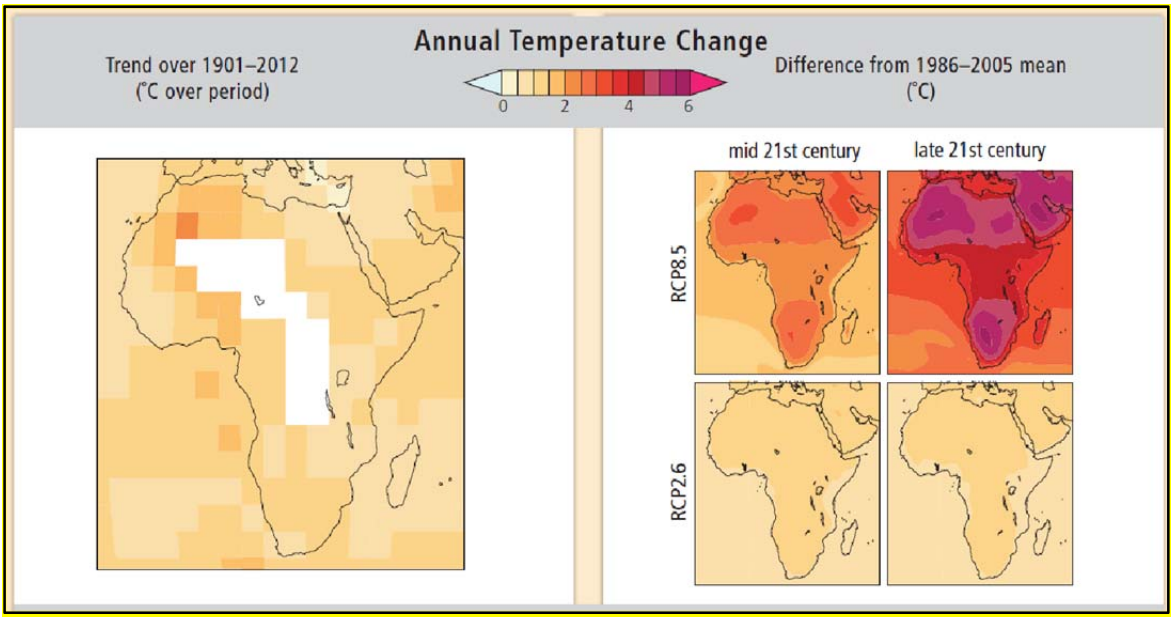

Figure 1. Observed and projected changes in annual average temperature in Africa (Niang et al., 2014)

Understanding the rainfall impacts associated with climate change in Africa is more difficult. Most areas of the African continent do not exhibit changes in mean annual precipitation that exceed the baseline variability in more than 66% of the models in either the mid- or late 21st-

century periods for RCP2.6 (Niang et al., 2014) (Figure 2). The key findings from the report are:

- Very likely decreases in mean annual precipitation over southern Africa and the Mediterranean region of northern Africa in the mid- and late 21st century periods.
- CMIP5 projects likely increases in mean annual precipitation over areas of central and eastern Africa.
- The annual and seasonal drying over the northern African region (including North of Morocco, Algeria, Libya, Egypt, and Tunisia) is a consistent feature in the global and the regional climate change projections for the 21st century under the A1B and A2 scenarios.
- Over the northern basin of Tunisia, climate models under the A1B scenario project a significant decrease in the median and 10th and 90th percentile values of precipitation in winter and spring seasons.
- Furthermore, the projection for East Africa is at variance with the observed rainfall pattern being attributed to East Africa Climate Paradox (Lyon, 2014).

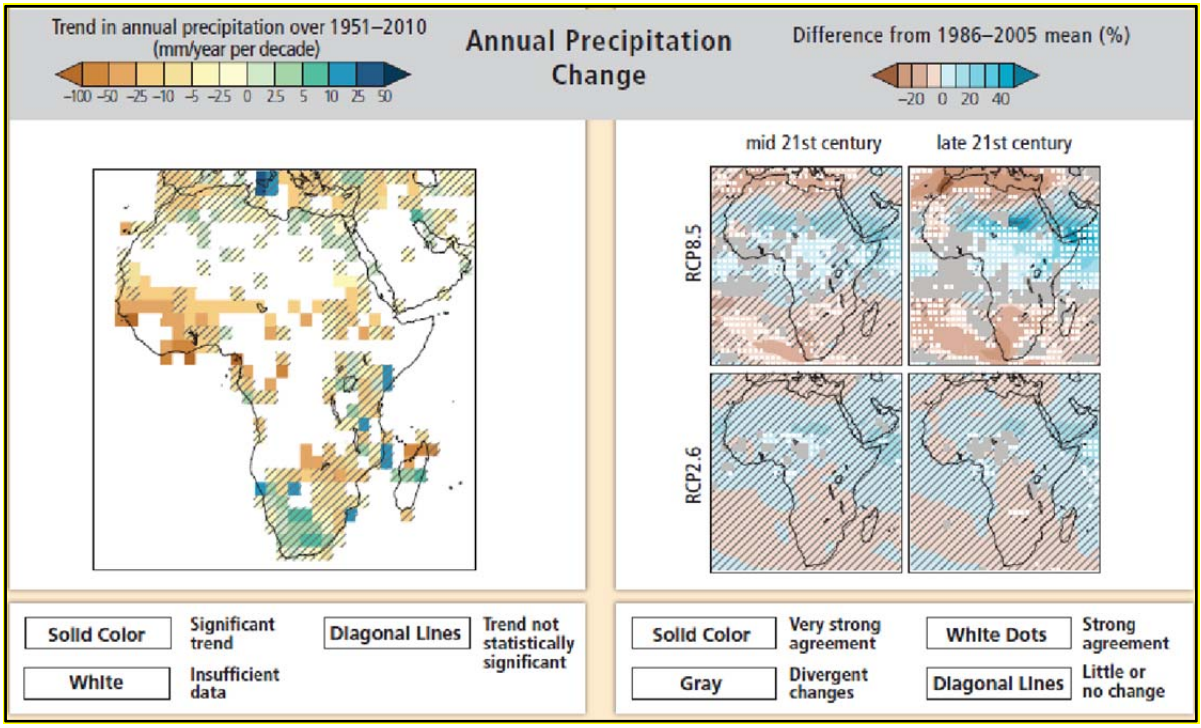

Figure 2. Observed and projected changes in annual average precipitation in Africa (Niang et al., 2014)

Climate projections show a possibility of mix drought in the horn of Africa due to weather anomaly and increased and more intense tropical storm events in the southern Indian Ocean by the end of the century, with significant impacts on agricultural production in countries whose weather patterns are impacted by these systems. Increased extreme events also have implications for decisions about infrastructure, often requiring larger, more engineered solutions that have greater cost and possibly negative environmental implications. Extreme flood, drought and disease events will increase migration pressures on refugee settlements and urban informal areas.

Measurement of changes in rainfall alone is not sufficient to understand the water related impacts of climate change. A further area of impact is changes in streamflow. The amount of rain that is converted into actual streamflow in a river depends on a number of factors, including the nature of the vegetation in the catchment, the level of land degradation, the nature of the soils, slope, and temperature. In South Africa, for example, only around 9% of rainfall ends up as streamflow in rivers. In relation to streamflow, the IPCC predicts that across the continent, streamflow will change from -15% to +5% by 2050. In southern Africa in particular, almost all countries will experience a decrease in streamflow. In other areas there is a lack of certainty, for example, there is no clear understanding of how streamflow in the Nile will be affected. Changes in streamflow are especially pertinent for sectors such as agriculture, manufacturing and mining. This is because streamflow is often translated into blue water that is dammed, piped and then irrigated or treated for domestic consumption or industrial use. The extent of streamflow change is also impacted by development and land use change taking place within a catchment. Therefore, decisions about the nature and extent of agriculture, manufacturing, mining any other land use change will fundamentally change how much water is available for use.

Climate change and green water use in agriculture poses some risks as well as opportunities. Specific risks for rainfed agriculture as a result of climate change include the likely increase in erosion. "In Egypt, climate change could reduce crop production by up to 28% for soybeans, and 11% for rice, by 2050. A 20% reduced crop growing period in semi-arid areas is envisaged by 2050. There may also, however, be positive impacts on agriculture, such as the projected increase in rainfall for some parts of tropical or eastern Africa (Niang et al., 2014). Coastal zones and estuaries are particularly at risk from sea level rise, changes in run-off and changing temperatures. A decrease in rainfall, for example, may significantly change the distance to which salt water penetrates upstream in a river. As a result, coastal agriculture, including palm oil and coconut plantations in Benin and Cote d'Ivoire, may be affected by inundation and soil salinization. In Kenya, a 1m sea level rise could result in US$500 million loss of income from mangoes, cashew nuts and coconuts" (Pegasys, 2011).

The blue water use as a result of growing domestic consumption through urbanisation is also at risk of climate change. A growing body of literature generated since the AR4 suggests that climate change in Africa will have an overall modest effect on future water scarcity relative to other drivers, such as population growth, urbanization, agricultural growth, and land use change (high confidence) (Niang et al., 2014). In Africa increased urbanisation over the next century will also take place through the growth of unplanned settlements. This will place increasing strains on already weak infrastructure and management systems. Particular challenges will arise due to climate change, including poor management of storm water in unplanned settlements, leading to flash flooding, and increased ponding which may act as a vector for water related diseases.

3. The Challenges of water resources management in the context of climate change in Africa

Climate change in Africa is projected to result in significant changes in the demand for, and availability of, water. The case studies presented in this report show that large parts of Africa are already subject to seasonally-variable hydrology, and geographically uneven distribution of water resources. While pressures on Africa's unique ecosystems, population, and economy continue to grow, this situation will be further compounded by climate change, to which

Africa is particularly vulnerable (Figure 3 and 4). Indeed, climate change is regarded as an additional burden for Africa: while the continent is the least polluting and smallest emitter of greenhouse gases (less than 5% of total worldwide emissions), Africa is projected to be the most impacted continent with drastic consequences on its water resources.

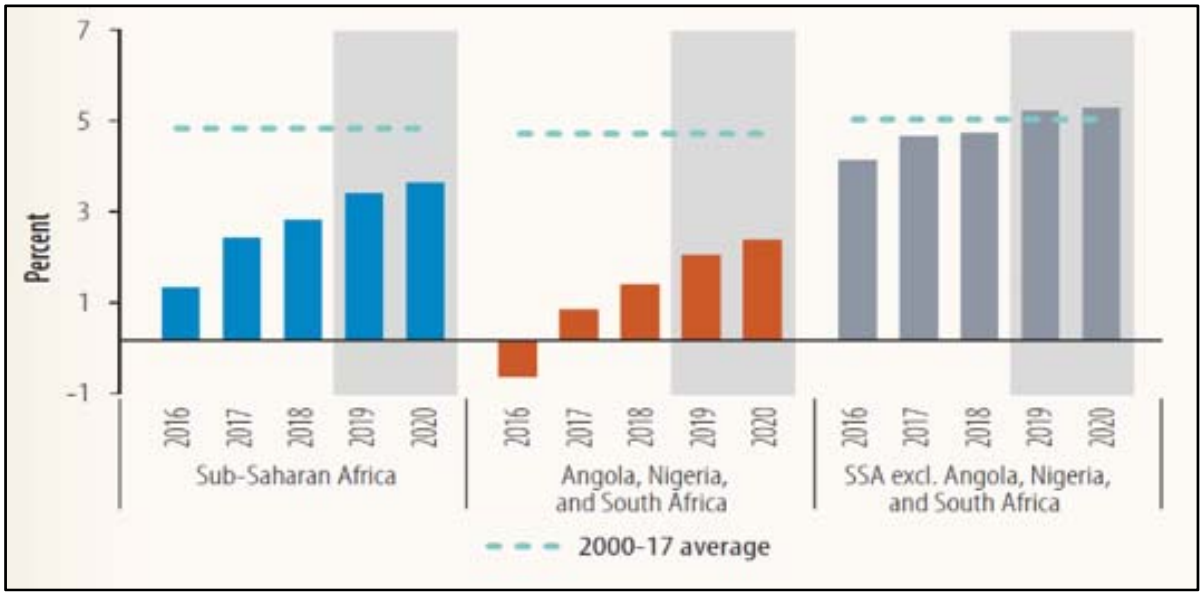

Figure 3. The current and projected average GDP growth in Sub-Saharan Africa. Period 2016-2018 (source: World Bank, 2018)

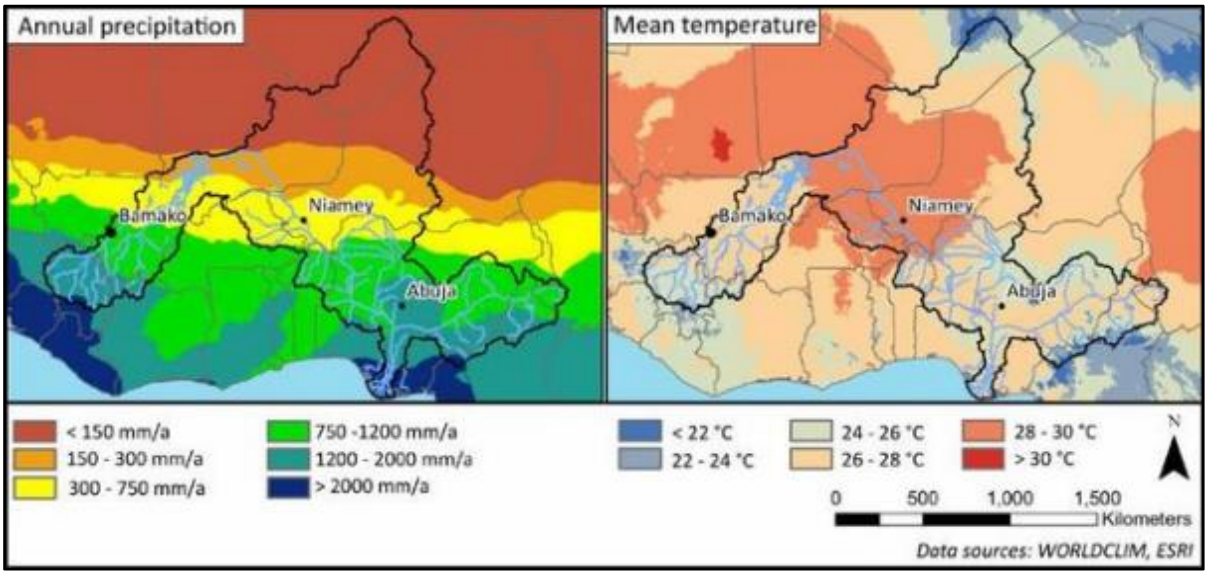

Figure 4. Average annual precipitation and mean temperature in the Niger Basin (source: Aich, 2015)

Although climate change projections for Africa, like many climate projections, have large margins of uncertainty, it is clear that climate change is likely going to bring more frequent and more intense water-related disasters in many parts of Africa, a continent already prone to floods and droughts, with dramatic consequences for critical ecosystem goods and services, and, therefore, its population and its development (Figure 5). While countries like

Mozambique, South Africa, Malawi and Zimbabwe are already experiencing recurrent floods and droughts, projected increases in the frequencies and magnitudes of such events through 2050, coupled with rising populations in the region, suggest a particular vulnerability of weather sensitive sectors, particularly water resources and agricultural production. Because of the difficulty of predicting climate change impacts on water systems with any accuracy at this point in time, the challenge is to ensure a level of flexibility in planning that facilitates adaptation to changing climate conditions over the long term.

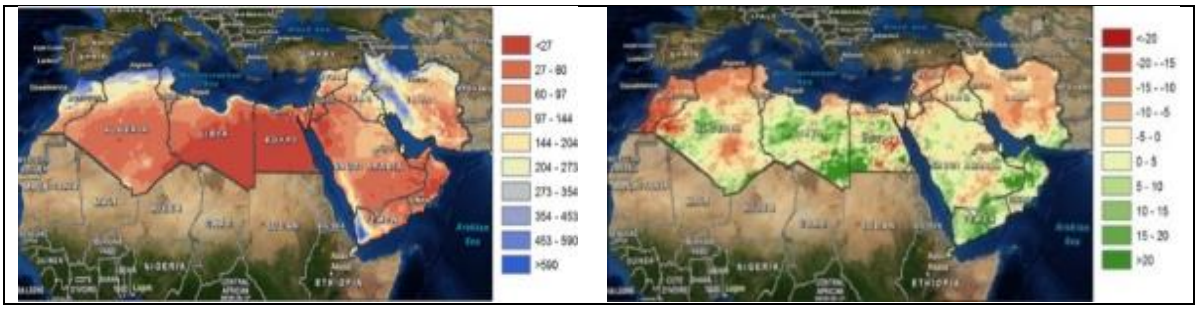

Figure 5. Precipitation projections under climate change.
Left: Precipitation under current climate and right: Precipitation anomaly 2040-2050 [%]
(Terik et al., 2013)

Within the context of water resources management, it should also be recognized that the still rapidly increasing populations in Africa, and their transitional economic developmental needs, will impose growing demands and pressures on the already stressed freshwater resources. To this end, rivers and groundwater resources, but also lakes and reservoirs are readily-usable sources of large volumes of freshwater which, if properly managed, will be an important basis for these populations' health, well-being and continuing economic growth. A related concern is the impact of aging infrastructure in regard to water storage and delivery from these lentic water systems, an issue of obvious importance to both developed and developing countries.

4. Towards improved management of water resources in the context of climate change in Africa

While it is important to address the many weaknesses across the continent that may complicate effective responses to climate change, including limited institutional capacity, poverty levels, paucity of data and limited modelling of climate change impacts at the local scale, it is equally important that immediate action is taken to improve the resilience of communities and societies to climate change impacts. An overview and synthesis of the key approaches is provided below.

4.1 Creating enabling policy and institutional conditions

An important basis for the effectiveness of climate change related freshwater management strategies would be the need to ensure that water management plans are aligned with national development and poverty reduction strategies, and that the enabling conditions for managing the challenges of climate variability are created. Such measures include ensuring that appropriate legislation, including agreements at the transboundary level, are in place, ensuring that the institutional capacity to manage water resources and services effectively exists, including developing sufficient skilled and experienced staff to manage water effectively, ensuring that financial resources to develop, operate and maintain the necessary water

infrastructure to respond to climate change are accessible, and ensuring that appropriate information is available. As human and financial resources are limited in many parts of Africa, it will be important to identify and focus on managing the most vulnerable areas and the most critical issues, rather than attempting to spread limited resources over too large an area or too many issues. It is also critical that transboundary water resource management is practiced within the context of the large number of transboundary basins that are vulnerable to the impacts of climate change (Figure 6).

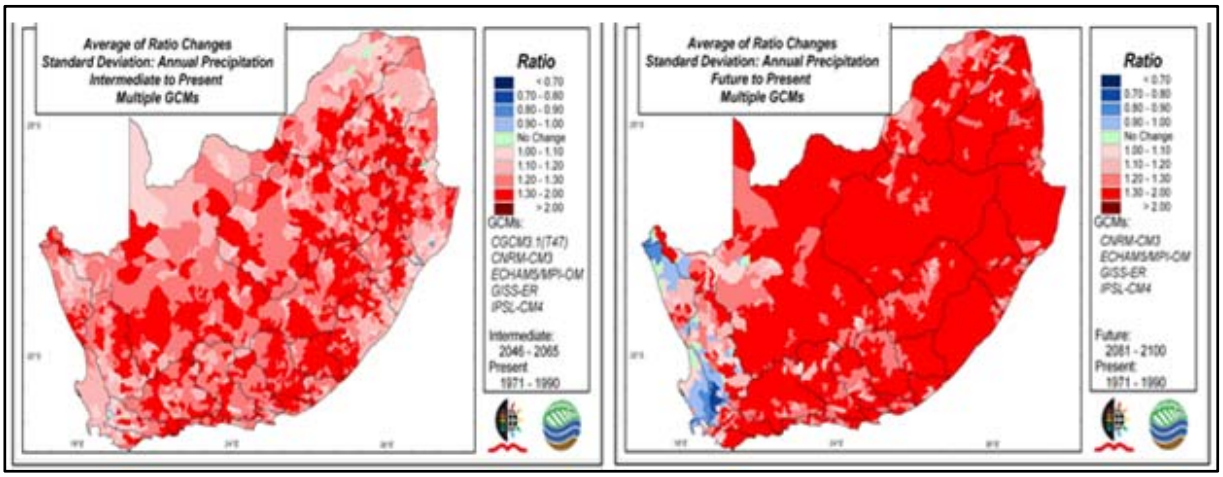

Figure 6. Increase in variability of annual precipitation under projected future climates, derived from multiple GCMs, with variability increasing more into distant future (Schulze, 2011)

Of key importance in managing the water-related impacts of climate change is the need to ensure alignment between national development objectives and water availability. Because of the difficulty of accurately predicting climate change impacts on water management (IPCC, 2014 & 2018), the challenge is to ensure that a sufficiently flexible approach to planning is taken in order to facilitate adaptation to a changing climate over the years. This requires access to relevant and up to date climate change information for the key water-related development planning departments. It will also be critical to integrate local resource development and management plans into macro-planning to ensure their systematic consideration, integration and financing. Given the particular vulnerability of women to climate change impacts, these development and climate change response plans should proactively address the issue of gender, and the protection and support of women, girls and children in particular.

With adaptation as an additional development challenge, substantial increases in financing also are needed to improve rural household land and water management system adaptive capacities and resilience. As the public finance resources in African countries are limited, a range of more alternative financing options is needed, including private sources and public sector funding from developed countries.

4.2 Investing in ecological infrastructure

As a first line of defense, investments in natural infrastructure, for example the protection and rehabilitation of aquifers, lakes and reservoirs and wetlands can contribute significantly to increasing resilience to climate change (Figure 7). Vital ecosystem functions and services are

under great pressure from population growth, energy demands, exploitative land-use practices and other pressures, resulting in deforestation and land degradation. Climate change is just adding to these challenges. Thus, increasing land and water management resilience calls for integrated ecosystem-based approaches, including sustainable land-use management, the designation of water protection areas and the management of natural water storage systems.
At the same time, it is crucial to secure the vital freshwater ecosystem functions through appropriate environmental flow and reserve regulation. The objective of this approach is to secure an appropriate flow of rivers and the reserves of other aquatic ecosystems (in particular groundwater reservoirs and lakes) through appropriate water allocation decisions, regulation of dam operations, etc. Although stakeholders sometimes interpret such approaches as being in direct competition with human development needs, they present in fact an opportunity to maintain the important water-related ecosystem services for the overall benefit of society.

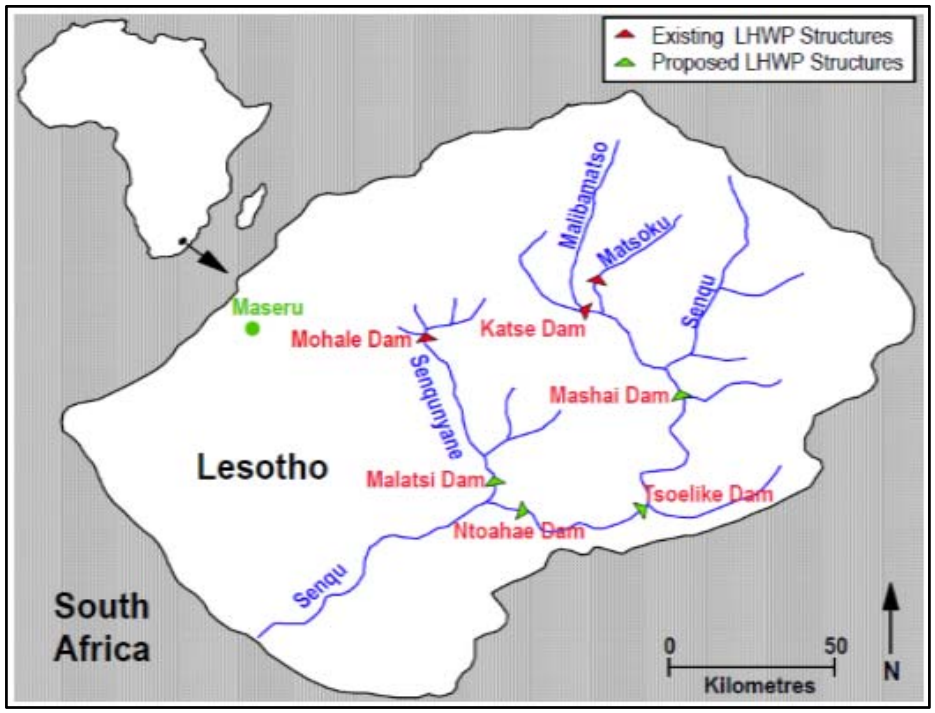

Figure 7. The Lesotho Highlands Water Project (LHW)P showing the water infrastructure (Dube et al., 2014)

4.3 Investing in climate smart infrastructure and technologies

A key approach presented in various case studies is to invest in water management infrastructure and technology. In many areas, climate change is likely to bring increased flood or drought phenomena. A number of management actions are therefore required to improve flood management, including development of early warning systems and rehabilitation of degraded catchments. Also, under flood conditions, water services infrastructures (for water and sanitation) may be damaged, leaving communities vulnerable to poor quality water or lack of drinking water, and lack of functioning sanitation facilities. The flood-proofing of water supply and sanitation infrastructure should therefore be considered in vulnerable areas.
The other side of the coin is that some areas will experience decreased rainfall and increased droughts. In many parts of Africa, water storage is currently insufficient to disconnect economic growth from rainfall. Even if climate change was not a reality, Africa requires increased water storage capacity (both large dams and small storage facilities) in order to overcome the impacts of frequent droughts. With the possibility of climate change extending

the periods of droughts and increasing their intensity, the need to invest in increased water storage becomes all important. In this regard, finding financial resources to develop infrastructure remains a critical challenge, one wherein African governments, the private sector, and international financing agencies all have a role to play.

At the farm level, furthermore, increased investment and access to information about appropriate irrigation technology, including drip irrigation and rainwater harvesting, is required to improve water use and productivity in the face of climate change. In many areas, a shift from rainfed to irrigated agriculture may be necessary to protect rural livelihoods and food security. In the case of groundwater, specific policies, research and development cooperation are required to overcome key obstacles, including the high costs of well construction and limited understanding of groundwater resources that currently restrict development of groundwater for irrigation in many parts of Africa.

Artificial recharge of groundwater sources also presents an important step in the sustainable management of resources in danger of over-exploitation and degradation. This is part of the large number of possible solutions to develop the buffer function of groundwater resources covering the broader process of retaining and intercepting rainfall and runoff, conserving it in the soil or storing it underground as a means of supplementing aquifers during dry periods. However, with increasing impacts of climate change on water resources, it would be an illusion to expect a substantial increase in groundwater recharge in many parts of Africa (Contribution of Working Group II to the Fourth Assessment Report of IPCC, 2008).

Finally, with the likely more frequent and more intense water-related disasters, water systems in many parts of Africa already prone to floods and droughts attributable to climate change, and disaster preparedness, including well-developed early warning systems and post-disaster intervention plans, are a critical part of the resilience of society to the consequences of climate change.

4.4 Improved science and information

The ability to adequately abate and adapt to the effects of climate change on water resources depends on supporting science and information-sharing across vulnerable water basins and aquifers in particular (Figure 8). A critical aspect of improved information is the ability to define the current state, identify emerging trends, and anticipate the possible future path and resulting vulnerabilities and risks. This requires first of all an appropriate monitoring system, which can deliver the necessary information at the appropriate scale. This system should extend beyond simply monitoring climate trends, to also monitoring the status of the resource, to detect emerging trends, and to monitoring related environmental variables and processes related to water and to ecosystem-based climate change adaptation. Commensurate with the critical role of groundwater in regard to climate change adaptation, better knowledge and a coherent region-wide information on groundwater resources, is specifically adamant.

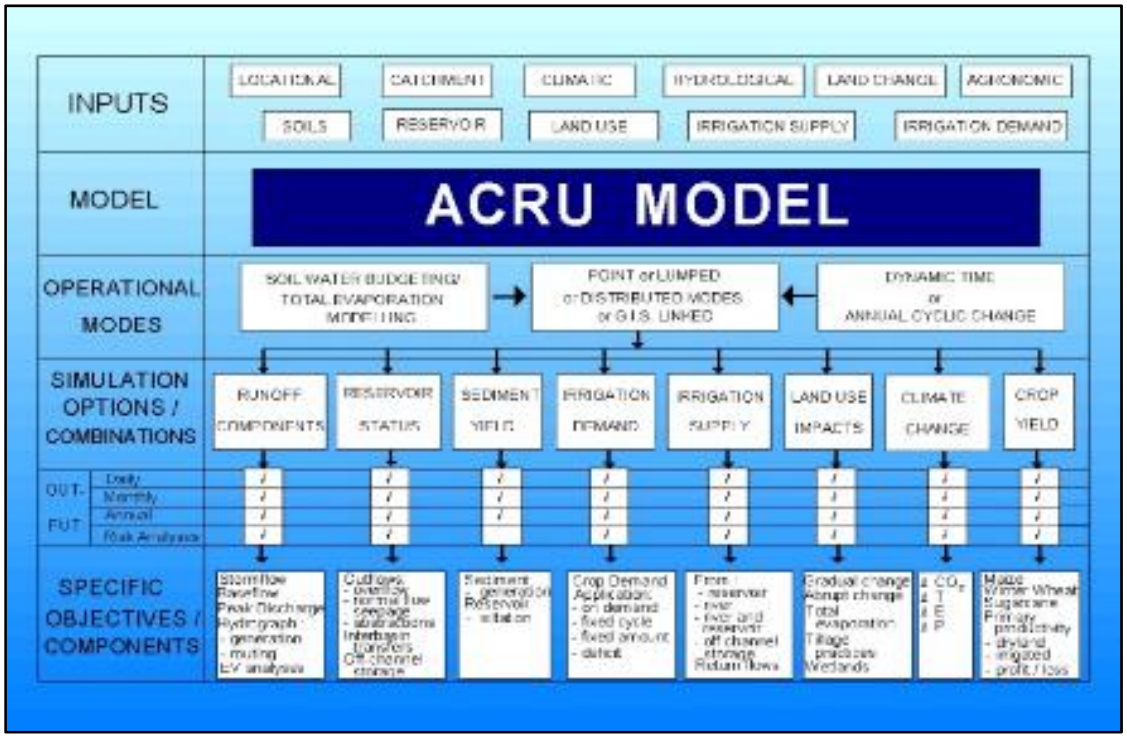

Figure 8. The ACRU agro-hydrological model (concepts and linkages)
(Schulze, 2011 & Koesen, 2012)

Another critical part of an improved information system is development of early-warning systems, particularly for floods. Better forecasting and early warning systems are a prerequisite for adaptation, particularly for predicting and preventing the effects of floods, droughts and tropical cyclones and other extreme events, as well as for practical planning purposes such as indicating planting dates to coincide with the beginning of the rainy season, and predicting whether or not disease outbreaks may occur in areas prone to epidemics. Improved early warning systems and their application will therefore reduce vulnerability to future risks associated with climate variability and change.

Taking into account the limitations of institutional capacity in Africa, a challenge in setting up such monitoring system is the financial and human capacity constraints. It is furthermore critical that protocols are developed that enable the exchange of information across the continent, enhancing the understanding of climate change, and facilitating adaptation to climate change between countries and within countries.

A particular challenge remains the management of transboundary waters in the context of increasing stress, complicated by high levels of political instability and conflict. A key message in this is that there are important lessons that can be learned across the continent about appropriate and indigenous approaches to improved water management and adaptation to climate change; a key part of responding to the coming changes will therefore be the ability to learn from one another, to share information and experiences, and to develop a body of African experience and knowledge about managing the impacts of climate change.

One of the challenges is also the lack of models to predict climate change at the local level. It is critical that the capacity to model climate change is enhanced so that management options can be based on scientifically-sound information. Achieving this goal will require increased

investments in the science of climate change, including understanding its impacts, its trends and its adaptation and remediation methods. Key to this may be the creation of African climate change centres of excellence that would be geared at developing capacity and expertise of Africans to tackle challenges related to climate change, as well as to build local capacity to monitor water quality, collect data and identify good water management approaches, reinforce traditional adaptation mechanisms and provide early warning systems responsive to assisting local communities vis-à-vis frequent climatic hazards and adverse environmental changes.

4.5 Working at different scales

There exists a range of different water allocation systems across Africa, with many parallel formal and customary systems working at different scales. All must be sufficiently flexible to enable water allocation adjustments to address climate variability in the face of national development objectives, while also being sufficiently simple to be effectively implemented and managed within existing capacity constraints.

In transboundary lakes, basins and aquifers, the first level of allocation is between riparian states. In basins facing water stress as a result of climate change, it is particularly important that effective transboundary water allocation systems are put in place, supported by accurate, shared data on the status of the basin. While there are a number of transboundary agreements in place in transboundary basins in Africa, there are also a large number of basins in which no such agreements currently exist. Even where such agreements are in place, some lack effective dispute resolution mechanisms, and many lack effective institutional capacity at the national or transboundary level for effective implementation and optimal sharing of water resources.

The generally-neglected localised groundwater resources also require urgent strengthening of institutional structures at continental and regional scales. Solutions to climate change and related development challenges in many areas will not come only from transboundary co-operation, but also from greater exploitation of regional comparative advantages, thereby considering development opportunities within the context of a region, rather than a country. Climate change in this regard represents a key driver for expanding regional integration across the continent.

Further, regional integration should be seen in a broader context than simply the water sector. Within this context, there is an opportunity for the development of regional public goods, such as transport infrastructure, markets, regional power pools, trade arrangements, and food security responses that can provide substantial benefits in building regional and local resilience to climate change (FAO, 2018).

At the sub-basin or local level, furthermore, a range of water allocation systems operate in Africa, with parallel formal and customary systems in many countries. It is important that these systems are sufficiently flexible to enable adjustments in allocation to manage climate variability and climate change in support of national development objectives. It is also critical that stakeholders are involved in the water resource management process so that there is full support for the approaches to be taken, and so that information exchange between stakeholders and authorities enables quick responses to situations and optimal adaptive responses. However, the key challenge in developing responsive institutions lies in building

the adaptive capacity of such institutions. In fact, an effective response to climate change will not only rely on the ability to accurately predict the changing climate and its water-related impacts, but also on the ability to respond to climate changes, to enable innovation at all levels, and to create flexible and responsive water management systems. In this regard, flexible allocation systems that allow amendments in water use to adjust to short-term climate variability and longer-term climate change are of critical importance (Claussen et al., 2003).

4.6 Decentralized adaptation

Adaptation takes place at a number of levels, ranging from the creation of for example major storage and flood prevention infrastructure, down to the household level, particularly in rural areas (Niang et al., 2014). In this regard, while governments might not be able to extend the necessary services to vulnerable populations to protect them from climate change, the provision of information itself can assist communities and households to prepare themselves for coming changes. The provision of information and training for rural communities is therefore particularly important because of their high levels of vulnerability, and also because they are often left out of the information loop. Information could include alternative crops and climate smart production methods, improved livestock management techniques, local water-resource use and protection, and flood protection and warning systems.

Gender mainstreaming and understanding the particular vulnerabilities of women should also form a key part of climate change adaptation strategies. Women are particularly at risk from climate change and natural disasters, being physically less able to escape from floods, for example because of their need to carry babies or small children. Women in countries with high gender disparities are most vulnerable in this regard. Thus, it is essential that disaster plans are gender-sensitive and address the particular needs of women. Also, it is critical that investments in infrastructure and technology reflect women's priorities and needs, and that women are actively involved in decisions relating to infrastructure development.

Access to groundwater is perhaps the most critical factor enabling both rural and urban, populations to maintain sustainable livelihoods. Groundwater is strategically important for adaptation because it is the key resource for local coping strategies. Because it has remained a poorly understood resource, however, groundwater is still poorly considered in Integrated Water Resource Management (IWRM), and Integrated Lake Basin Management (ILBM) approaches, as well as in more general development planning. This deficiency needs to be addressed strategically through appropriate regional, sub-regional and national policies, through proper integration into IWRM/ILBM processes, structures and institutions, and through its prioritisation in adaptation initiatives.

With the adaptation focus on the local level, attention to local institutions is critically important in designing adaptation projects and policies. Such institutions are necessary enablers of the capacity of households and social groups to deploy specific adaptation practices. Also, a systematic scaling-up of locally-appropriate solutions is key to ensuring area- and region-wide impacts on poverty alleviation, climate change adaptation and economic development.

4.7 Considering the water/energy/food and health nexus

It is important to report that a number of African countries depend on hydropower, even though the hydropower potential of Africa is still hugely underdeveloped. However,

hydropower is under threat in some areas from diminishing stream flows or increased flow variability. As a result, the 'climate change-proofing' of current infrastructure is an important measure to protect the energy supply of many countries and, therefore, to protect economic and social development potential (Figure 9). Such climate change proofing might include, for example, amended operating rules to consider changing rainfall patterns, the raising of dam walls, or changes to environmental flow releases. At the same time, however, new hydropower development should take place with a clear understanding of the potential impacts of climate change in such a manner as to be able to withstand these impacts.

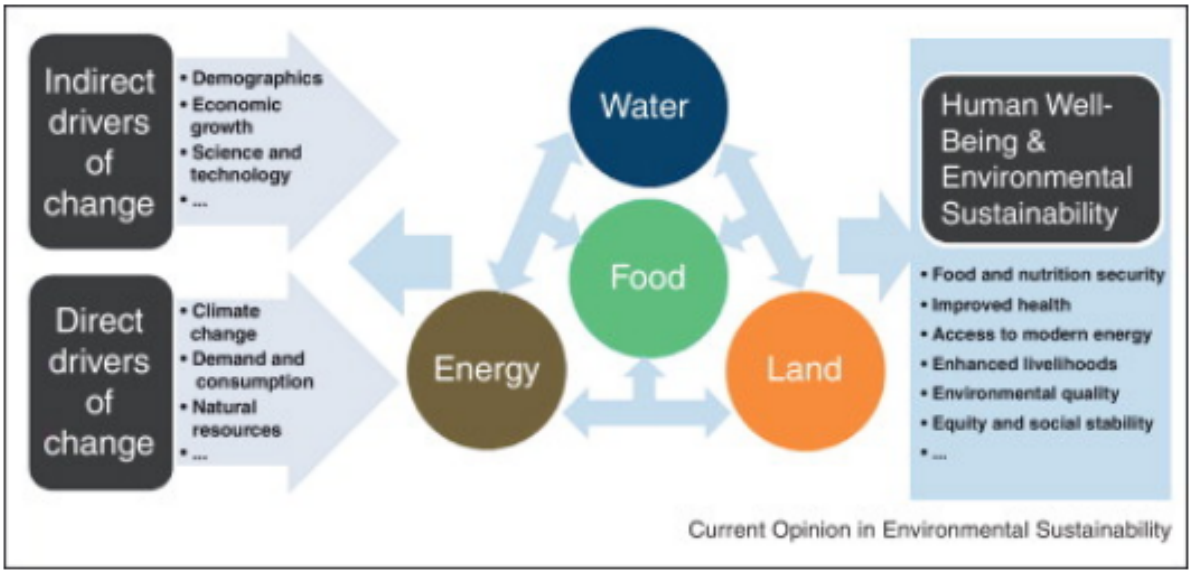

Figure 9. The extended water, energy, food and land nexus presented by (Ringler et al., 2013)

It is therefore important to ensure both water and energy security in an integrated manner, taking into account the likely impacts of climate change. It is particularly important, in the context of the large number of transboundary basins in Africa, for such understanding to exist at both the basin and national level for joint planning across the water-energy-food nexus (Figure 10). Furthermore, and at the core of the 2030 Sustainable Development Goals/SDG's and 2063 African Agenda "The Africa We Want", the water/energy/food/health and ecosystems nexus is increasingly recognized as core to addressing the issue of climate change and securing the wellbeing of the many millions of people in Africa without access to basic services such as water and sanitation, energy, food and health.

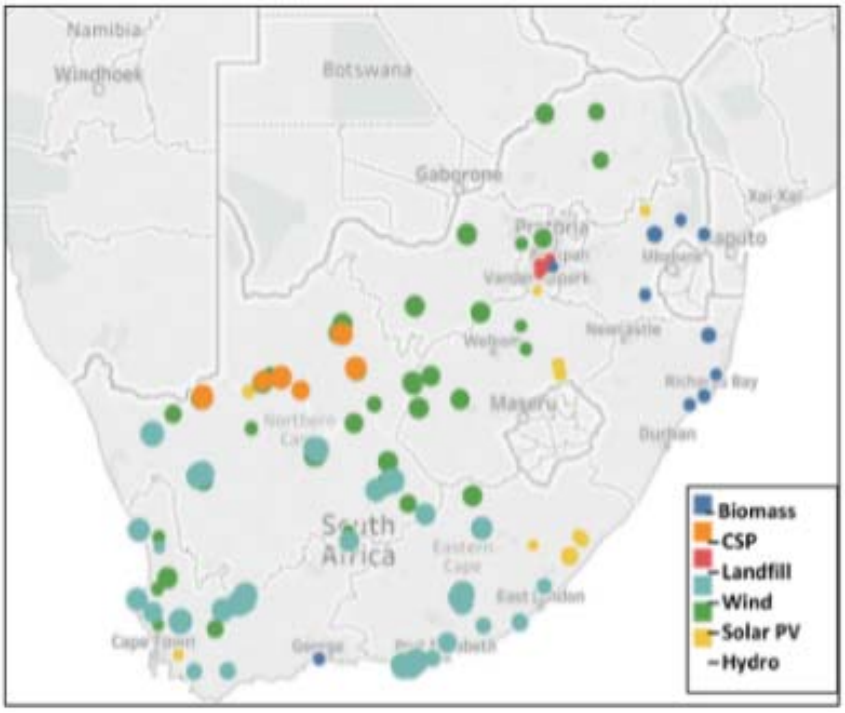

Figure 10. Renewable energy projects in South Africa, as at 2018 (REDIS, 2018)

5. Conclusions

Based on the findings of this report, a number of general conclusions may be drawn. First of all, it is evident that vulnerability to climate change risks and impacts, as well as opportunities for adaptation and mitigation in Africa are shaped by complex interactions between land and water resource characteristics, economic conditions and the often highly-diverse livelihood capitals and strategies of individual households. Thus, effective adaptation planning and implementation in land and water management systems is highly context-specific and therefore demand an appropriate level of knowledge and understanding of local conditions.
Adaptation should therefore be knowledge-based and integrate both scientific and local knowledge. Local knowledge systems on adaptation in many places have evolved from the experiences of generations adapting to changing climate conditions. To be effective, however, the uncertainties about precipitation and water availability, over short- and long-term climate change and its impacts, must be reduced, especially at local levels.

Effective and equitable adaptation actions, furthermore, require that knowledge and information on climate change and adaptation practices in land and water management are shared widely and, in a form, that users can understand. Knowledge and information need to be suitably packaged and appropriately communicated to all decision-makers and actors to scale-up interventions.

In order to address the economic and financial aspects of climate change impacts, it is also important to recognise adaptation as a development challenge that is adding to already substantial poverty and development challenges faced by the continent. Additional and substantial increases in financing are therefore needed to improve the adaptive capacity and resilience of rural households and land/water management systems. To achieve this, a full range of financing options must be utilised, including innovative financing mechanisms, from

both private and governmental sources, from wealthier countries and from those countries that are now major contributors to GHG emissions.

The opportunities in the United Nations Framework Convention on Climate Change (UNFCCC) negotiations covering mitigation and adaptation may be an important conduit in this context. For example, the scope of the Clean Development Mechanism and/or emerging market mechanisms for sustainable development should be expanded to address issues relevant to Africa, such as reforestation, agro-forestry and soil carbon sequestration practices. It is also important that funding for climate change adaptation is substantially scaled up and enhanced. In this regard, the principle of common, but differentiated responsibility as defined under the UNFCCC makes it possible to take into account some form of equity in the fight against climate change. To end with a clear order of magnitude of this challenge, according to a 2012 study by the African Development Bank (AfDB, 2012), adaptation costs in Africa are predicted to be in the order of US$ 20-30 billion per annum over the next 10 to 20 years. To place this in context, at the date of this study, approximately $350m of adaptation funding had been approved for spending in Africa, of which just $130m had been disbursed. Considerable effort will therefore be required to bridge the gap.

"Can Africa really fund its own responses to climate change impacts as unconditional contributions using its domestic resources, irrespective of how marginal this could entail? As Africa is the region bearing the greatest burden of climate change, did Africa over-pledge, and how feasible is it for African countries to internalize their Nationally Determined Contributions (NDCs) in its current form? Is it ethically and morally acceptable to further risk the impoverishment of many more people by deploying scarce national resources for the implementation of NDCs?"
*Nkem, J. (2016) in "Unpacking Africa's enigma with NDCs; September 2016; Science*Policy*Africa; Page 14 and 15"*

References

AfDB, 2012. The Cost of Adaptation to Climate Change in Africa. UNECA, Addis Ababa, 41p.

Aich, V., 2015. Floods in the Niger River Basin in the face of Global Change – Analysis, Attribution and Projections. Doctoral dissertation, Mathematisch-Naturwissenschaftlichen Fakultät, Universität Potsdam.

Bradfield, L., 2014. Seasonal Drought in the Greater Horn of Africa and Its Recent Increase during the March May Long Rains. Journal of Climate.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A., Whetton, 2007. Regional Climate Projections. In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), Climate Change, 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Claussen M., Brovkin V. and Ganopolski A., 2003. Climate change in northern Africa: The past is not the future. Climatic Change 57 (1-2), 99-118.

Distefano T. and Kelly S., 2017. Are we in deep water? Water scarcity and its limits to economic growth. Ecological Economics, *142*, 130–147. https://doi.org/10.1016/J.ECOLECON.2017.06.019

Dube, R., Maphosa, B. and Scott-Goldman, J. 2014. The role of local community institutions in the adaptation of rural and urban communities to the impacts of climate change on water access and use. WRC Report No. 1963/1/14.

FAO, 2018. The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. Rome. Licence: CC BY-NC-SA 3.0 IGO. http://www.fao.org/3/i9540en/I9540EN.pdf

IPCC, 2014. Summary for policymakers. In: Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R. and White L.L. (eds.) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

IPCC, 2018. Summary for Policymakers. In: Masson-Delmotte, V., Zhai, P., Pörtner, H. O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (eds.) Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland, 32 pp http://www.ipcc.ch/pdf/special-reports/sr15/sr15_spm_final.pdf).

Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart, *Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014)

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P., 2014. Africa. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

Nkem, J., 2016. In "Unpacking Africa's enigma with INDCs"; Science*Policy*Africa; Quaterly Newsletter of the African Academy of Sciences; PP 14 and 15; Sept. 2016. Nairobi, Kenya.

Notre Dame Global Adaptation Initiative, 2019. https://gain.nd.edu/our-work/country-index/

Pegasys, Water Footprint and Competitive Advantage in the Nile Basin, (2011). https://studylib.net/doc/8684417/water-footprint-and-competitive-advantage-and-trade-in-th...

REDIS (2018). Location and Contracted Capacities of Renewable Energy Projects in South Africa. Vol. 2018. Deparment of Energy, South Africa.

Ringler, C., Bhaduri, A., and Lawford, R. (2013). The nexus across water, energy, land and food (WELF): potential for improved resource use efficiency? Current Opinion in Environmental Sustainability 5, 617-624.

Schulze, R.E., 2011. A 2011 Perspective on Climate Change and the South African Water Sector. Water Research Commission, Pretoria, RSA, WRC Report 1843/2/11. pp 366.

UNEP, 2009. Kenya. Atlas of Our Changing Environment, United Nations Environmental Programme, Nairobi, Kenya, pp. 1-39.

United Nations ECA, 2019. Economic Report in Africa 2019 ; Fiscal Policy for Financing Sustainable Development in Africa; 169 p. published in March 2019 by United Nations Economic Commission for Africa P.O. Box 3001 Addis Ababa, Ethiopia.

W. Terink, W., W.W. Immerzeel and P. Droogerset, 2013. Climate change projections of precipitation and reference evapotranspiration for the Middle East and Northern Africa until 2050. Intern. J. Clim. (2013). doi:10.1002/joc.3650

World Bank, 2018. Africa's Pulse (English), Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/881211538485130572/Africas-Pulse