Economic Commission
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ACPC
African Climate Policy Centre

United Nations Economic Commission for Africa
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Working Paper 4

Climate Change and Water in Africa: Analysis of Knowledge Gaps and Needs

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CLIMATE CHANGE and WATER in AFRICA: ANALYSIS of KNOWLEDGE GAPS and NEEDS

November, 2011

Acknowledgment

This paper is the result of African Climate Policy Center (ACPC) of United Nations Economic Commission for Africa (UNECA) under the Climate for Development in Africa (ClimDev Africa) Programme. The paper is produced with guidance, coordination and contribution of ACPC and contributing authors from various institutions. Contributions to this paper are made by Semu A. Moges; Addis Ababa University (AAU), Seleshi B. Awulachew, UNECA-ACPC; Michael Menker Girma, UNECA-ACPC, Selomon Seyoum Demissie, International Water Management Institute, and Yilma Sileshi is Associate Professor, AAU.

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ACRONYMS AND ABBREVIATIONS

ACCFP	African Climate Change Fellowship Program
ACPC	African Climate Policy Centre
AIACC	Assessment of Impacts and Adaptations to Climate Change
ALCOM	Aquatic Resource Management for Local Community Development Programme
AMMA	African Monsoon Multidisciplinary Analysis
AOGCM	Coupled Atmosphere-Ocean GCM
AUC	Africa Union Commission
BGS	British Geological Survey
CCAA	Climate Change Adaptation in Africa
CCLM	COSMO model in CLimate Mode
CGCM2	Coupled Global Climate Model, version 2
CMIP	Coupled Model Inter comparison Project
CORDEX	COordinated Regional climate Downscaling EXperiment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
GCM	Global Climate Model
GRIB	GRIdded Binary
HadCM3	Hadley Centre Coupled Model, version 3
HadGEM1	Hadley Centre Global Environmental Model, version 1
IPCC	International Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
MM5	Pennsylvania State University / National Centre for Atmospheric Research Mesoscale Model
NetCDF	Network Common Data Form
PCM	Parallel Climate Model
PCMDI	Program for Climate Model Diagnosis and Inter-comparison
PRECIS	Providing Regional Climates for Impact Studies
RBO	River Basin Organizations
REC	Regional Economic Communities
REGCM3	Regional Climate Model, version 3
SDSM	Statistical Down Scaling Model
SRES	Special Report on Emission Scenarios
UCAR	University Cooperation for Atmospheric Research
UNDP	United Nation Development Program
UNECA	United Nations Economic Commission for Africa
UNEP	United Nation Environmental Program
WMO	World Meteorological Organization
WWF	World Wide Fund for Nature

ABSTRACT

The water resource of Africa is increasingly being stressed due to the climate change variability and increased demand over the continent. Africa has suffered the consequences of climate change and climate variability at various periods over the last century, the recurrence of the impacts have shown increasing tendency over the last 40 years. Observational evidences show that many vital water resources of Africa such as Lakes, river and snow covers on the high mountains are showing persistent sign of decreasing.

The future impact of climate on the water resources of Africa remains uncertain and requires high level of scientific interaction and communication to policy makes through better understanding of the impact and developing long term and medium term preparedness strategy (adaptation) which is cost effective and considers the future uncertainty. The scientific knowledge and understanding of climate change science in Africa however requires a fresh look such developing new African GCM model that incorporates the complexities of Atmosphere -Ocean circulation, the local climate drivers and feedbacks, reconstruction and integration of all available data which was not previously used, separate accounting of climatic and non-climatic impacts on the water resources. This requires focused human resources capacity building as well developing regional centre of excellence. In addition, it should be supported by African governments' willingness and commitment to initiatives in this line and to avail financial resources, and available data. It is believed that the challenge of data has compromised the outputs of climate modeling and included additional uncertainty to impact studies, therefore data sharing, lost data recovery and reconstruction activity should form the central core of activities in Africa. ACPC can be used as a think tank wing of AU and facilitate the coordination, advocacy and resources solicitation activities in this regard.

The best assumption from studies so far on climate change is that many regions of Africa will suffer from droughts and floods with greater frequency and intensity. The implication is that we have to plan for the certainty that more extreme events will occur in the future but with uncertain regularity. As 90% of the water resources in Africa are transboundary in nature, it is imperative to underline the importance of regional cooperation in all planning pertaining to climate change.

1. BACKGROUND

1.1 Climate

Africa is characterized by a wide variety of climate systems ranging from humid equatorial, through seasonally-arid tropical, to sub-tropical Mediterranean-type climates. Annual precipitation in Africa is estimated at about 20360 km^3 with a continent wide average of 678mm. The central region of Africa, which covers about 20% of the total area, receives 37% of all precipitation in Africa. In contrast, the northern region which has a similar area receives less than 3% of the total precipitation (Frenken, 2005). Dry regime, rainfall less than 400 mm $year^{-1}$, covers 41% of the continent. The intermediate regime, between 400 and 1000 mm $year^{-1}$, covers 25% of the continent. Mean annual rainfall ranges from less than 1 mm $year^{-1}$ in parts of the Sahara to over 5000 mm $year^{-1}$ in some areas of the tropical rain forest. At a station in the mountains of Cameroon, mean annual rainfall exceeds 10,000 mm $year^{-1}$. As most of Africa lies in tropical and subtropical latitudes, temperatures are high throughout the year and vary more from daytime to nighttime than during the course of the year. The diurnal range is about 10 to 15 °C, except in the deserts.

Rainfall in all but the extra-tropical margins of the continent has been associated with the seasonal excursion of the Inter-Tropical Convergence Zone (ITCZ). The seasonal development of the tropical rain belt over Africa is driven by several features of the general atmospheric circulation, which in turn control the location and character of the ITCZ. According to Conway (2009), the process that drive African climate are several processes that are interrelated in complex and still not yet fully understood ways. The tropical convection and the alternation of the monsoon are local processes that determine the regional and seasonal patterns of temperature and rainfall. The El Niño-Southern Oscillation (ENSO) of the Pacific Ocean is more remote in its origin but strongly influences the year to year rainfall and temperature patterns in Africa.

1.2 Water resources of Africa

The continent has more than 160 lakes that are larger than 25 km^2 (UNEP, 1999) and more than 22 large River basins Figure 1). The total renewable freshwater resources of Africa have been estimated between 4050 and 4590 km^3 $year^{-1}$ (Shiklomanov, 2000; Doll, et al., 2008). About 15 to 51% of the estimated fresh water becomes groundwater (Richard, et al., 2009).

About 75% of the total surface water is concentrated mainly in the 8 river basins of Africa i.e. the Congo, the Niger, the Ogadugne, the Zambezi, the Nile, the Sanga, the Chari-Lagone and the Volta). The basin discharge varies greatly from regions to regions and due to specific characteristics of the rivers, with the highest discharge being in the Congo basin and lowest in the Orange basin in southern Africa. All of the above mentioned river basins have high levels of variability, in particular the rivers of west and southern Africa have coefficient of variations more than 20% (UNEP, 1999).

An estimated 90% of all Africa's surface freshwater resources are located in river basins and lakes that are shared between two or more countries (UNDP, 2006). Among the 60 international river basins of Africa, which covers about 62% of the continent, five are shared by eight or more countries Congo, Niger, Nile, Zambezi and Lake Chad) (Goulden, et al., 2009).

Figure 1 River basins of Africa (ALCOM-WWF, 2003)

Data on the ground water of Africa is scarce. Review of recharge estimation and groundwater resources of Africa by BGS (2010) suggested that it is difficult to estimate the recharge and ground water over much of Africa due to lack of temporal and spatial data. Aquifers with low permeability and with limited storage are believed to occupy about 80% of the African land area (BGS, 2010). Macdonald et al. (2009) identified three broad rainfall recharge zones in Africa: negligible groundwater recharge in zones with less than 200 mm year^{-1} rainfall; about 50 mm year^{-1} recharge in the zones with rainfall range of 200-500 mm year^{-1}; and greater than 50 mm year^{-1} recharge in zones where rainfall exceeds 500 mm year$^{-1.}$ The spatial and temporal distribution and availability of ground water with respect to quantity and recharge mechanism, depth, aquifer extent and vulnerability to non-climatic and climate change is uncertain.

2. CLIMATE VARIABILITY AND CHANGE IN AFRICA

According to IPCC (Boko, et al., 2007) in Africa observed temperatures especially since the 1960s have indicated a greater warming. The warming of Africa in the 20th century has occurred at a rate of about 0.5°C per decade, and the rate of warming increased in the last three decades of the century (Hulme, et al., 2001). Even though these trends seem to be consistent over the continent, the changes are not always uniform. In eastern Africa, decreasing trends in temperature in costal and major inland lakes have been observed.

For precipitation in most parts of Africa either there is decline in annual rainfall or no long-term trend has been noted (Boko, et al., 2007). An increase in inter-annual variability is observed over most of Africa. According to Conway (2011) there was marked drying trend across much of the Sahel from the early 1970s and decadal variability in southern African rainfall linked with the ENSO. However, parts of East Africa showed a mean linear increase in annual rainfall of 10–20% from 1901 to 1995 which is part of a wetting trend seen across most of equatorial Africa. The most significant climatic change that occurred in Africa has been a long-term reduction in rainfall in the semi-arid regions of West Africa and a part of the Sahel (Nicholson, et al., 2001).

In the tropical rainforest regions of Africa, a decrease of precipitation by about 2.4±1.3 percent per decade was observed. This rate was faster in West Africa -4.2 ± 1.2 percent per decade) and in north Congo -3.2 ± 2.2 percent per decade) (Hulme, et al., 2001).

3. CLIMATE CHANGE IMPACT ON WATER RESOURCES OF AFRICA

By 2025, water availability in nine countries, mainly in eastern and southern Africa, is projected to be less than 1,000 m^3 per person per yr. Twelve countries would be limited to 1,000–1,700 m^3 per person per year, and the population at risk of water stress could be up to 460 million people, mainly in western Africa (Bates, et al., 2008). Other estimate presents the proportion of the African population at risk of water stress and scarcity increasing from 47% in 2000 to 65% in 2025 (Ashton, 2002). This could generate conflicts over water, particularly in arid and semiarid regions. These estimates are based only on population growth rates and do not take into account the variation in water resources due to climate change.

Climate change has the potential to impose additional pressures on water availability and water demand in Africa (Bates, et al., 2008). The impact of projected climate change on water resources across the continent is not uniform. An analysis of five climate models CSIRO2, HadCM3, CGCM2, ECHAM and PCM) in conjunction with two different emissions scenarios, Strzepek and McCluskey (2006) showed that almost all countries in southern Africa, except South Africa will probably experience a significant reduction in stream flow. Even for the South Africa, the increases under the high emission scenarios are modest at 10%. Another study by De Wit, et al. (2006) using six GCMs, identified a critical 'unstable' area between Senegal and Sudan, separating the dry Sahara from wet Central Africa and reported a reduction in runoff in Southern Africa. In the Nile Basin, Conway (2005) found that there is no clear indication of how Nile River flow would be affected by climate change, because of uncertainty in projected rainfall patterns in the basin and the influence of complex water management and water governance structures. Another study by Soliman et al. (2009) using ECHAM5 A1B scenario as downscaled by RegCM3 reported future increase in Blue Nile flow at El Diem by about 1.5% annually.

Generally, two features are commonly reported on future African climate change studies. One is the high uncertainty range of modeling attempts, mainly in the precipitation variable. The second issue is the high sensitivity of runoff to changes in the precipitation and evapotranspiration (Elshamy, et al., 2008). These two features pose additional complexity to the fragmented and few scientific communities in Africa. The challenge for the scientific community in Africa and international partners is to meaningfully communicate the impact of climate change on the water resources. Developing a strategy to incorporate the uncertainty in the communication of impact of climate change remains one of the key issues to Africa given the sensitivity nature of runoff.

Other observed or projected effects of climate change and variability on the water resources of Africa include:

- Upper Blue Nile flow is highly sensitivity to change in both precipitation and Evapotranspiration. The flow is magnified 2.9 times as a result of precipitation change decrease or increase) (Elshamy, et al., 2008);
- Lake Tanganyika which provides 25-40% of animal protein intake of the surrounding population is expected to be affected by climate change and fish catches to reduce by 30% (O'Reilly, et al., 2003);
- Lake Chad continues decline in surface area from 23,000 km^2 in 1963 to 304 km^2 in 2001 (FAOWATER, 2009);
- Reductions in snow cover of Mount Kilimanjaro (Buytaert, et al., 2011).
- Sea level rise in Nile delta and around Lagos which will impact the life of millions of people (Dasgupta, et al., 2009; Nicholls, 1995);
- Declining trend of the level of Lake Malawi (Kumambala, 2010) and;
- Declining of stream flow and evidences of flow variability are documented in Southern Africa (Berhanu, et al., 2001) and Western Africa (Ojo, et al., 2003).

Few studies have considered the effects of climate change on groundwater in Africa. Modeling results by Döll & Fiedler (2008), predicted larger percentage decreases in groundwater recharge than in runoff for southwestern Africa. Another study by Cavé et al. (2003) also showed significant reductions in groundwater recharge due to projected reductions in annual rainfall in southern Africa.

From regional perspective, studies have highlighted four major sensitive ecosystems that require regional attention (Ericson, et al., 2006; UNEP, 2010). These regions are i) the key water sources regions of Africa, ii) the coastal regions countries in the west and southern Africa coasts, iii) the semi-desert and iv) the Great Lakes region (Figure 2).

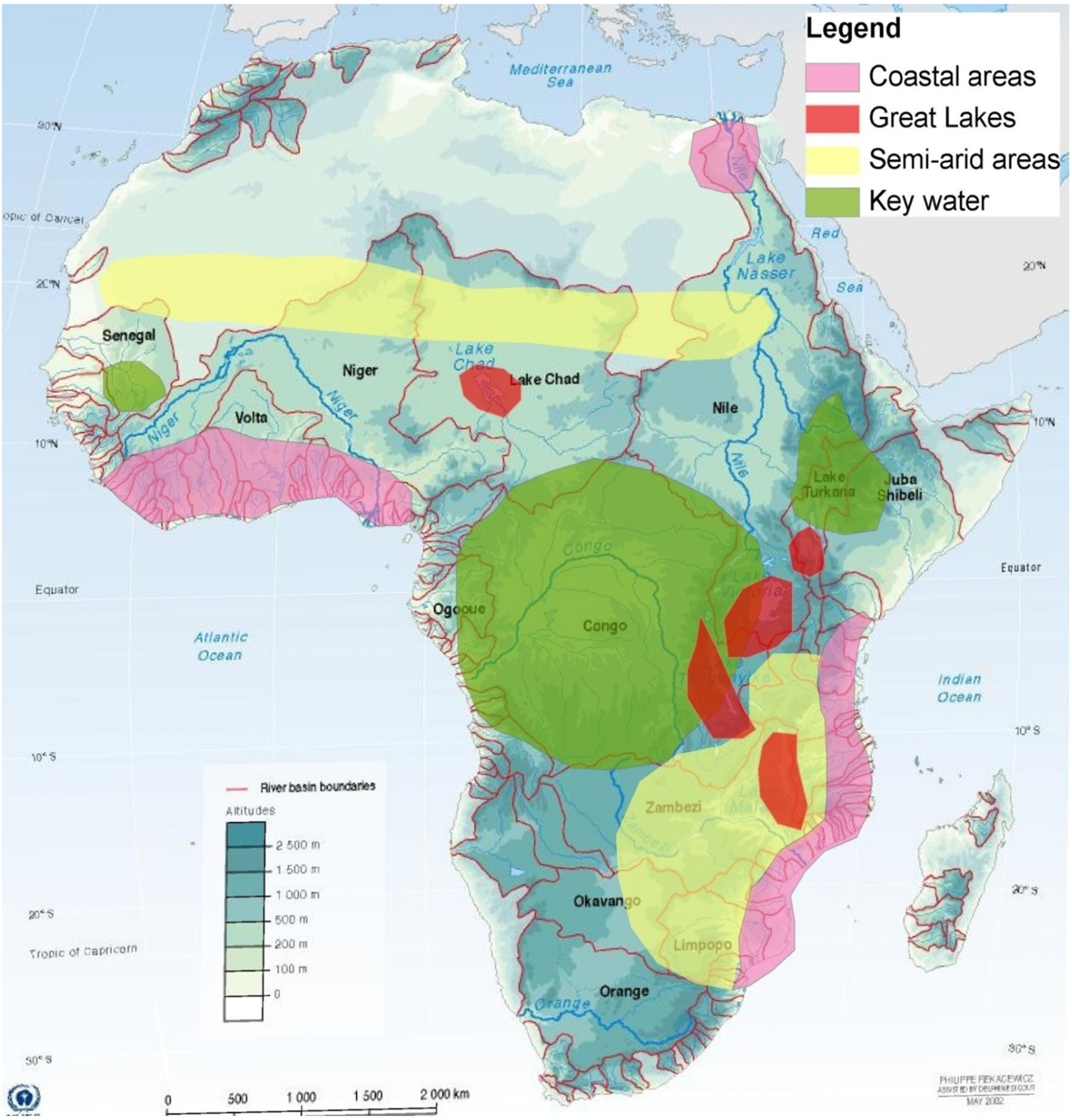

Figure 2: Key sensitive ecosystems of Africa exposed to climate change impacts

Background map: (Aaron, et al., 1998))

Scientific Remark:

According to Conway (2009), *the best assumption is that many regions of Africa will suffer from droughts and floods with greater frequency and intensity. The implication is that we have to plan for the certainty that more extreme events will occur in the future but with uncertain regularity.*

4. KNOWLEDGE GAPS AND NEEDS

4.1 Water sector policies and strategies

In most African water sector policies, climate change impact on the water resources is not explicitly taken in account (ACPC, 2011). Integration of climate change adaptation into water sector policies and planning is required in order to cope with impacts of climate change on water in Africa.

Climate change may affect the river basins of Africa in different ways. Planning at river basin level may provide the opportunity to deal with climate change impacts in coordinated way. Policy options (Smith, et al., 1996) for adaptation of water resources for climate change and/or variability includes:

- Adoption of contingency planning for drought;
- Making marginal changes in construction of infrastructure;
- Use of inter-basin transfers;
- Maintaining options to develop new dam sites;
- Conserving water;
- Allocation of water supplies using market-based systems and;
- Controlling pollution.

As pointed out in the first African Climate Policy Center (ACPC) meeting in April 2011, there is limited policy advice by African climate change initiatives to RBOs, RECs and AU negotiators (ACPC, 2011). The results of climate change research studies on the water resources of Africa should be translated into policies to be used by different water institutes. Uncertainties on climate change projections and water resource modeling should be addressed in order to provide useful information to the development agents.

4.2 Climate change, water resources and development infrastructures

The major research gap in the climate change as related to water in Africa appears to be lack of studies of climate change impact on existing and future water development infrastructures. According to FAO, there are about 1310 storage reservoirs in the continent that are used for different beneficial purposes (AQUASTAT, 2011). Emerging trends show that Africa is geared to develop its huge water resources for boosting energy production and securing food security. How the impact of climate would modify the existing water uses such as hydropower production and irrigation, the operation of reservoirs and navigation locks is not yet explored. The impact of climate change on the water resources infrastructure is not well understood. Whether development of new water infrastructures requires a new guideline that incorporates climate change is not yet explored. Therefore, it is suggested that research should focus at regional as well as national level on the understanding of Climate-Water-Infrastructure operation and development nexuses. In addition, coupling of the water resources development as part of green development mechanism will serve as part of mitigation strategy.

4.3 Communication and knowledge sharing

Communication and knowledge sharing of climate change impact on the water resources at policy makers and field level will have a paramount effect on establishing a policy framework to adapt to climate change impact and on the implementation of proposed adaptation measures. At policy level communication and knowledge sharing can be accomplished through annual forums among water, climate change specialists and environmental ministers.

Initiatives such as AfricaAdapt, which works on knowledge sharing of climate change impact and adaptation, should be strengthened in order to reach a wider audience.

Some of the challenges with communication and knowledge sharing of climate change impact on the water resources are:

1. Few knowledge sharing projects on the impact of climate change on the water resources of Africa;
2. Barriers to access climate change knowledge on the water resources of Africa such as language, infrastructure and technology and;
3. Lack of coordination and collaboration between climate scientists and impact researchers.

4.4 Technologies and practices

Technologies and best practices can help to adapt to the impacts of climate change on the water resources. In order to scale up available technologies and best practices there is a need to assess availability of both surface and ground water resources, synthesize the impact of climate change on the water resources of Africa and available good practices, compile cost of adaptation and investment options for the water sector, promote river basin based flexible water development and create mechanisms to access available technologies and best practices.

4.5 Capacity on climate change modeling and impact studies

Climate change studies are based on GCMs. The coupled atmosphere-ocean GCMs (AOGCMs) combine atmospheric and oceanic GCMs and are basis for model predictions of future climate. In Africa, GCMs are not yet developed. In addition most of the impact studies in Africa are based on regional models developed in Europe and North America. Capacity on climate modeling should be built in Africa in order to incorporate continent wide and regional specific issues pertinent to the climate of Africa in the GCMs and regional models.

Lessons on capacity building from initiatives such as Assessment of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AIACC), the African Monsoon Multidisciplinary Analysis (AMMA), the African Climate Change Fellowship Program (ACCFP), and the program on Climate Change Adaptation in Africa (CCAA) should be synthesized and used for future capacity building of climate change in Africa.

4.6 Climate change modeling and impact studies

4.6.1 Lack of downscaled climate scenarios

Downscaled climate change scenarios are important to study the impact of climate change on water resources in Africa. Even if significant progress has been made since the first generation of global circulation models GCMs in modeling the physical processes of the climate systems, still the resolution of the current GCMs is coarse to be used in impact assessment (i.e. horizontal resolution of about 200km extending 40-80km height in the atmosphere) (Collins, et al., 2008; Roeckner, et al., 2006). To bypass the scale problems statistical and dynamical downscaling techniques are widely used.

In order to describe or quantify the impact of climate change on the water resources, intercomparision studies using statistically and/or regionally downscaled climate scenarios based on data from global circulation models are essential. However data from regional or statistical downscaling is not readily available for Africa to conduct inter-comparison studies and understand the impact of climate change on the water resources. As a result most of the impact studies in Africa used low resolution direct GCM outputs as input to model the impact of climate change (Kim, et al., 2008; Setegn, et al., 2011; Tarekegn, 2006; Hailemariam, 1999; Berhanu, et al., 2001; Ojo, et al., 2003; Elshamy, et al., 2008).

4.6.2 Inconsistent future rainfall scenarios

Projected future rainfall scenarios from GCMs are not usually consistent both in direction and magnitude in Africa (Boko, et al., 2007). Further more recent downscaling studies based on a single GCM and a pair of regional models showed contrasting results with future rainfall scenarios (Girma, 2011). This indicates the low level representation of factors governing the African rainfall in the GCMs and RCMs. The implication of inconsistent future rainfall scenarios is conflicting effects of climate change on the water resources of Africa (Elshamy, et al., 2008; Conway, et al., 1996). In 2009 the world climate research program initiated a COordinated Regional climate Downscaling EXperiment CORDEX) (Girorgil, et al., 2009). One of the main goals is to develop a framework to evaluate and possibly improve regional climate downscaling techniques for use in downscaling global climate projections within the 5th Coupled Model Inter comparison Project (CMIP5). It will employ dynamical and statistical downscaling methods and is expected to sample uncertainties in regional climate change associated with varying GCM simulations, varying greenhouse gas concentration scenarios, natural climate variability and different downscaling methods.

4.6.3 The use of statistical models as black box for downscaling

Downscaling in Tropical Africa is challenging both because there is strong ocean atmosphere coupling and because the relationships between large scale predictors and local variables vary strongly within the annual cycle (Wilby, et al., 2004). As a result, in statistical downscaling, the selection of downscaling domains should be based on the climatology of the area of interest and correlation analysis between large scale and local variables from representative testing climate stations in the study area.

Due to lack of available flexible softwares to carry out domain screening, GCM data processing and/or lack of knowledge of the climatology of the research area, many statistical downscaling studies in Africa used their project area as the only downscaling domain (Abraham, 2006; Abdo, et al., 2009; Yimer, et al., 2009) and used the data as input to statistical downscaling models such as Statistical Down Scaling Model (SDSM) and studied the impact of climate change on the water resources. This leads to wrong conclusion on the impact of climate change on water resources of Africa as the location of the appropriate domain to extract large scale predictor variables might be different.

4.6.4 Availability of global circulation (GCM) model output

Understanding the impact of climate change on water resources in Africa requires water resource modeling, which in turn requires high resolution temporal and spatial data on future projections from GCMs through downscaling. The international panel on climate change (IPCC) and the program for climate model diagnosis and inter-comparison (PCMDI) hosts output of several GCMs in their data distribution portals. Availability and consistency of daily large scale predictors from different modeling groups is very poor. Data availability is further constrained by the seven IPCC's fourth assessment special report on emission scenarios groups (SRES). For example daily large scale variables of the IPCC SRES are missing in the CERA data portal from the Hadley center for climate prediction and research models of HadCM3 and HadGEM1. If we consider the Maxplank model ECHAM5, some of the available large-scale variables are missing when daily time scale is considered.

Furthermore, there is little knowledge about the incorporation of the local as well as regional climate drivers in the Global Circulation Models (GCMs) for future projection of the climate of Africa. Conway (2009) summarized the process that drive African climate are several processes that are interrelated in complex and still not yet fully understood. Hume et al. (2001) also confirms the key limitations to knowledge regarding future African climate have been identified as the mostly poor representation of the climate variability of El Niño in the global climate models, and the absence in these models of any representation of regional changes in land cover and dust and biomass aerosol loadings. This calls for re-thinking and re-shaping of existing GCM models or developing new African GCM models.

4.6.5 Regional downscaling in Africa

Many impact studies in Africa used regional models developed elsewhere for downscaling climatic variables. Some of the commonly used regional models are RegCM3 (Soliman, et al., 2009), CCLM (McCartney, et al., Submitted), REMO (Born, et al., 2008; Paeth, et al., 2005), MM5 and PRECIS

(Providing Regional Climates for Impact Studies) (Tadross, et al., 2005). Even if most of the regional models claimed that they reproduce African climatological patterns, it should be recognized that there are generally limitation in simulating the west African monsoon system, seasonal cycle of temperature and precipitation, inter-annual variability and the small spring) rainfall over East Africa (Paeth, et al., 2011; Hulme, et al., 2001).

One of the principal obstacles in carrying out climate change impact studies by impact researchers in Africa and elsewhere is the data format in which outputs of GCMs and RCMs are available. As most of impact researchers are not climate scientists, they are not capable of using data based on the World Meteorological Organization (WMO) GRIB and the University Cooperation for Atmospheric Research (UCAR) NetCDF formats. Capacity building in using these data formats will increase the number of studies on impact of climate change on water resources and other sectors in Africa.

5 CONCLUSIONS

Africa has suffered the consequences of climate change and climate variability at various periods over the last century, the recurrence of the impacts have shown increasing tendency over the last 40 years.

Observational evidences show that many vital water resources of Africa such as Lakes, river and snow covers on the high mountains are persistently. Though part of the cause may blamed on the highly increasing demand, climate change/variability has shown putting significant pressure on the water resources of Africa as evidenced on lakes and snow covers which have no demand factor on them.

Future of impact of climate on the water resources of Africa remains uncertain and requires high level of scientific interaction and communication to policy makes for better understanding of the impact and to develop long term and medium term preparedness strategy particularly for adaptation which is cost effective and considers the future uncertainty.

The scientific knowledge and understanding of climate change science in Africa requires new African GCM model development that incorporates the complexities of Atmosphere-ocean circulation, the local climate drivers and feedbacks. This requires focused human resources capacity building as well developing regional centre of excellence.

Getting consistent data set with a reasonable accuracy and coverage remains a stumbling block to climate modeling in Africa, it is important to recognize the challenge of data has compromised the outputs of climate modeling and included additional uncertainty to impact studies, therefore data sharing, lost data recovery and reconstruction activity should form the central core of activities for ACPC.

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