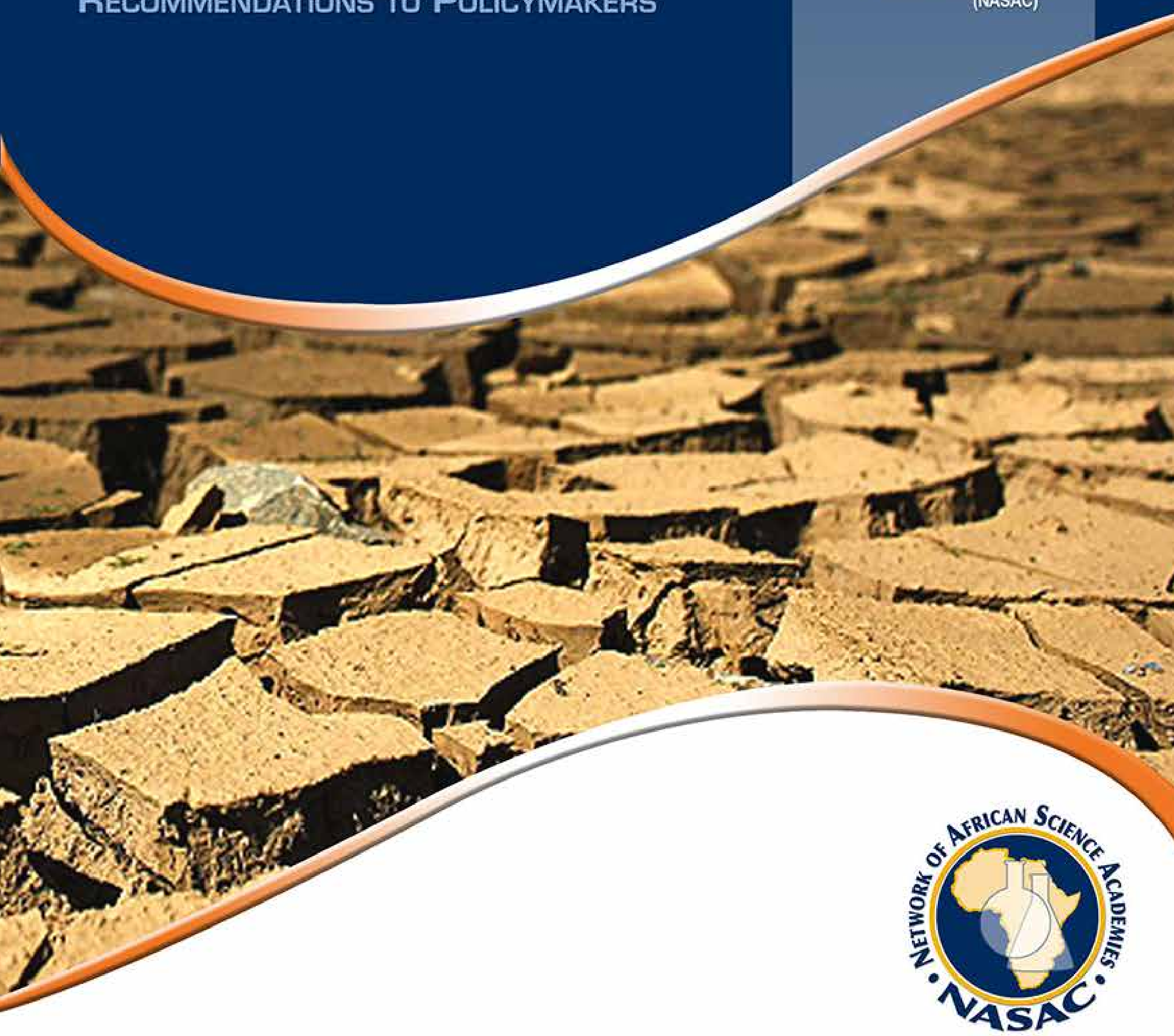
Climate Change Adaptation and Resilience in Africa

Recommendations to Policymakers

by:
NETWORK OF AFRICAN SCIENCE ACADEMIES (NASAC)



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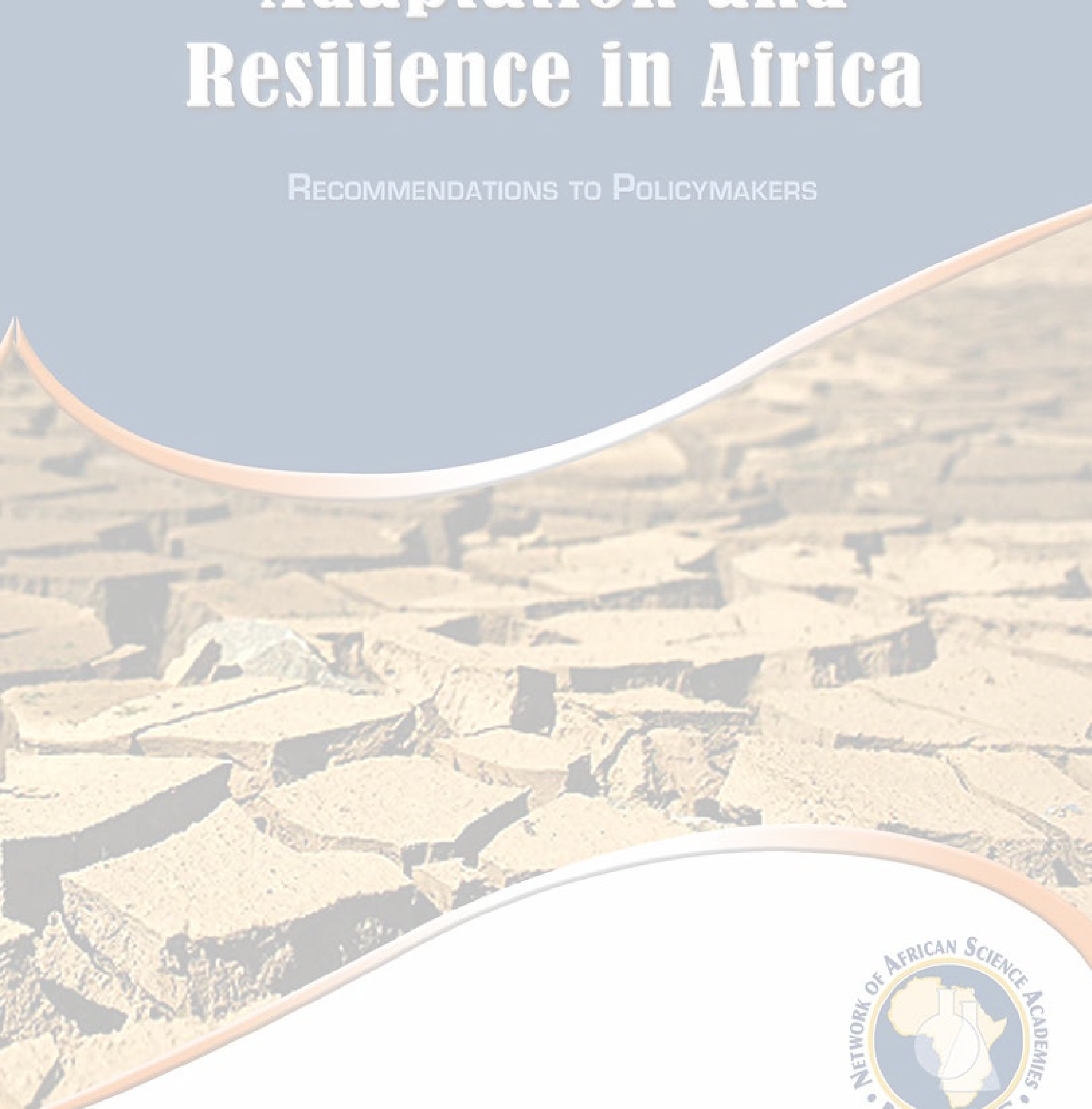

The Network of African Science Academies (NASAC) was established on 13th December 2001 in Nairobi, Kenya, under the auspices of the Inter Academy Panel (IAP), currently known as the InterAcademy Partnership. NASAC is a consortium of merit-based science academies in Africa and aspires to make the "*voice of science*" heard by policy and decision makers within Africa and worldwide. NASAC is dedicated to enhancing the capacity of existing national science academies and champions the cause for creation of new academies where none exist.

This document is an output from the cooperation between NASAC and the German National Academy of Sciences Leopoldina. The Leopoldina is the world's oldest continuously existing academy for medicine and the natural sciences. It was founded in 1652 and has been located in Halle, Germany since 1878. Its more than 1,400 elected members are outstanding scientists from around the world. The Leopoldina was appointed Germany's National Academy of Sciences in July 2008. In this function, one of the Leopoldina's responsibilities is to provide science-based advice to policymakers and to the public. It represents German scientists in international academy circles and maintains links with scientific institutions in European and non-European countries.

The cooperation project between NASAC and the Leopoldina is funded by the German Federal Ministry of Education and Research (*Bundesministerium für Bildung und Forschung,* BMBF). Education and research are a Federal Government policy priority in Germany, based on the firm belief that they are the foundations on which mankind will build this future in a changing world, and that we will only be able to master the challenges of the 21st century through international cooperation in education, research and science. BMBF therefore cooperates with individual states and institutions on many interdisciplinary projects.

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Foreword

Africa remains the most vulnerable continent when considering the impact of climate change, despite being the least emitter of greenhouse gases. The focus of the global community is on COP 21 of December 2015 in France, and, as stated by the hosts, "*The stakes are high: the aim is to reach, for the first time, a universal, legally binding agreement that will enable us to combat climate change effectively and boost the transition towards resilient, low-carbon societies and economies*". They further note that in order to achieve this, the future agreement must focus equally on mitigation – that is, efforts to reduce greenhouse gas emissions in order to limit global warming to below 2°C – **and societies' adaptation to existing climate changes.** The African continent therefore must internally determine its needs and capacities to tackle climate change impacts and adaptation now, and plan for sustainable adaptation to realistic future climate change scenarios.

The principal objective of this advisory booklet is to assess the status and make recommendations that African governments should consider when dealing with climate change and resilience in Africa. Through the cooperation between NASAC and the German National Academy Leopoldina, top African scientists with expertise on this topic agreed to look at the adaptation question using both geographical and sectoral lenses. The consultative process included a joint workshop with the Cameroon Academy of Sciences supported by the Cameroonian Ministry of Environment, Nature Protection and Sustainable Development, the Pan-African Parliamentarians Network on Climate Change and the Pan-African Climate Justice Alliance.

This policymakers' booklet focuses on why climate change adaptation and resilience is crucial for Africa. It further elaborates, through key messages, how climate change impact can be addressed through targeted policy actions and interventions specific to water, agriculture and food security, fisheries, coastal and urban zones, and human health. Adaptation to climate change remains a key concern and priority of all NASAC stakeholders from governments and policymakers to scientists and civil society; regional and international organisations. It is, therefore, our hope that the implementation of the proposed actions will specifically provide Africa's policymakers with a platform to work together to enhance climate change adaptation capacities and thus improving the resilience of people within the continent.

Additionally, it is hoped that governments and the private sector will be stimulated to interact with science academies to enhance climate change adaptation capacities, and to contribute to national policy and decision-making processes.

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List of Acronyms

AU	African Union
CAS	Cameroon Academy of Sciences
CCAFS	Climate Change and Food Security
CC	Climate Change
EAC	East African Community
ENSO	El Nino Southern Oscillation
FAO	Food and Agriculture Organisation
GHG	Greenhouse Gas
ICRAF	International Centre for Research in Agroforestry/World Agroforestry Centre
IEA	International Energy Agency
ITN	Insecticide-treated Nets
IPCC	Intergovernmental Panel on Climate Change
MARA/ARMA	Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique
MDGs	Millennium Development Goals
NASAC	Network of African Science Academies
NEPAD	New Partnership for Africa's Development
NGOs	Non-governmental Organisations
SADC	Southern African Development Community
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SSA	Sub-Saharan Africa
UNEP	United Nations Environmental Programme
WASCAL	West African Science Service Centre on Climate Change and Adapted Land Use
WHO	World Health Organisation
WMO	World Meteorological Organisation

Executive Summary

Africa is a large and highly diverse continent with different people, histories, climates and environments. This booklet intends to offer an integrated expert voice to guide effective policy responses for climate change adaptation, from the national to continental scales.

As a consequence of Africa's diversity, climate change impacts will depend on the peculiar climate, environmental and socio-economic set-up of particular sub-regions. For example, Central, and more so, Eastern Africa are expected to experience major impacts that will be driven by changes in seasonal rainfall and extreme rainfall and drought events, while large parts of Western, Northern and Southern Africa will likely experience significant reductions in overall rainfall amounts, becoming hotter and drier. Warming of fresh and marine waters is impacting on fisheries productivity: warming in freshwaters tends to reduce fisheries production, but in the marine system there may be some short-term benefits. In coastal zones and Small Island Developing States (SIDS), flood risks resulting from sea-level rise and sporadic storm surges will increase. All these changes will have severe attendant impacts on the socio-economic fabric of Africa's nations, including declines in water availability, reduced agricultural production, heightened risk of diseases, and destruction of infrastructure, ecosystem changes and biodiversity loss.

Adaptation to these expected changes is key, if the Africa region is to continue on the path of growth and sustainable development even in light of the projected negative impacts of climate change on the natural and socio-economic fabric of the continent. This particular booklet focuses on providing concise assessments of the effects or impacts of climate change in the water, agriculture and fisheries, and health sectors, as well as coastal/urban zones where a significant proportion of Africa's population dwells, and provides adaptation options that are specific to each of these sectors or zones.

The key messages relating to each of these sectors or zones are presented below. We recognise that implementation of the actions proposed will require significant resources. Current levels of climate finance directed to Sub-Saharan Africa (SSA) are likely to be insufficient to meet the region's need for adaptation finance, estimated by the World Bank as at least USD 18 million per year until 2050. Resource mobilisation efforts at regional level should focus on identification and involvement of regional institutions well positioned to provide financial or technical support or both. African governments must mobilise regional bodies and intergovernmental economic and political groupings to provide financial and technical support to countries and to link with broader capacity-building efforts. Public sector grant-finance will play a crucial role in realising the significant environmental, developmental and social, including gender, co-benefits of climate actions in the region, particularly for adaption measures (Schalatek *et al*., 2012). Chances of success in mobilising resources at global level will be greatly facilitated if African governments are able to demonstrate that climate change adaptation programmes can generate multi-scalar outputs and outcomes that are sustainable and beneficial.

(A) Water

1. Despite uncertainties on the degree of climate change and variability, coupled with the very high sensitivity of water to climate change, access to water will likely become a limiting factor to development in many African regions. It is expected that important seasonal shifts of the hydrological cycle will likely occur in the near future in the continent. Such seasonal shifts will affect all uses of water, including agriculture, food security, and drinking water, hydropower and ecosystems services. Increased variability will render water management more difficult than at present.

2. African countries should consider integration of water quantity and water quality approaches. It is important that these approaches include sediment quantity and quality monitoring, to further understand the societal and economic relevance of water-resource modifications under present and future climate changes. In some regions, the amount of rainfall may not change; it is the pattern of rainfall that will change. Therefore, African governments should implement water catchment technologies including roof and storm water collections for storage in tanks or through managed aquifer recharge.
3. African governments should strengthen research on water resources and upgrade the hydro-climatic monitoring networks in order to better observe, understand, and model the effects of climate change and provide timely and free access of data and information, with particular focus on precipitation processes and their resultant hydrological responses, and help to identify adequate adaptation strategies and to see to their timely implementation.
4. African governments need to put more emphasis on improving understanding of anthropogenic impacts on oceans as climate regulator, including changes in ocean temperatures, already occurring on ocean surface layers and loss of oxygen, salinity, nutrients and sediment loading, with impacts on hypoxia and algal blooms, circulation and acidification impacts.
5. It is essential to improve communication on research results on water issues to local communities, especially in remote areas on the African continent, such that scientific results are made useful for the people living in such areas. Monitoring and research priorities as well as capacity-building at all levels should be fully considered, ranging from the involvement of citizens in scientific water monitoring activities to the dissemination of a basic knowledge about ecosystems and the importance of nature conservation.

(B) Agriculture and Food Security

1. Linkages between research institutions and local farmers should be promoted through agricultural extension services and relevant practitioners. The development of farming organisations offers an entry point for supply of technologies, capacity development and information dissemination, and present opportunities for the collection of data on meteorology, soil and crop processes for research purposes. These could also serve as a basis for joint research-farmer-consumer efforts to develop well-tailored adaptation strategies, which is especially important to foster existing knowledge on production systems and coping mechanisms.
2. Livelihood diversification and development of crop and livestock insurance options should be promoted. This will ensure that there is a safety net if a particular crop fails or there are livestock losses. The diversity of adaptive options is also strongly related to ecosystem services relevant to food-production and resource conservation from other ecosystems, such as forests and wetlands. Vulnerabilities are reduced by increasing the number of food and cash crops options, whether by increased crop diversity or through the purchase of food from those with more successful yields. The development of crop and livestock insurance options for farmers would not only help in the general development of the agricultural sector, but it would also greatly buffer against increased variability and uncertainty under climate change.
3. Although new vulnerabilities emerge with market integration, a shift from purely subsistence practices towards selling of goods can also provide capital reserves for survival during bad seasons, and allow for effective distribution of available food

resources when some crops fail while others do not. In relation to this, the building of infrastructure is needed, such as roads for market integration and/or electrification of farms.

4. Improved weather observation and early-warning systems and ways of effectively communicating this information to farmers are essential to protect agricultural pursuits under a scenario of enhanced weather variability (see Box 7). A number of weather stations across the region have been decommissioned. Their reinstatement should be made a priority for effective early warning of extreme events for climate monitoring over time. Remote sensing is becoming an increasingly useful cost-effective tool for hydrological monitoring. However, capacity development is necessary for its effective use and for effective information dissemination.

(C) Fisheries and Food Security

1. There is need to improve daily and seasonal forecasts in order to build climate resilient fisheries in Africa. Climate change needs to be considered with respect to risks for production systems as well as possible changes in framing conditions (e.g. availability of water resources for irrigation). Policies should encourage and facilitate the technical and institutional framework for information collection and dissemination.
2. There is need for intensive research on improvement and diversification of livelihoods particularly through value addition of goods. This should be coupled with research on climate change adaptation that is case-specific, acknowledging the complexity of production systems and natural environments. Participatory and integrated research approaches are needed to better understand adaptation options, develop solutions, and facilitate effective implementation. Policies should support and encourage research in that direction, and integration with the international research community should be actively sought and an enabling environment provided.
3. There is need to transit to production systems that are more productive, use inputs more efficiently, have less variability and greater stability in their outputs, and are more resilient to risks, shocks and long-term climate variability such as small scale fish farming. This can be supported by, for example, protecting the water resources from pollution, water harnessing by construction of dams, and other such methods as water harvesting techniques and the equitable allocation, pricing, and efficient use of scarce water.
4. Extension services need to be enhanced to better prepare and translate scientific understanding and information to practical guidelines for farmers. Policies should encourage and support extension services, establish quality control and feedback mechanisms.
5. Sustainable fisheries management (e.g. through strict catch quota) helps to increase the natural system's resilience and thus to better buffer against climate change and increased variability. Policies should establish sustainable catch quota and instruments to monitor and enforce them. Alternative use of marine resources (e.g. aquaculture) should be carefully considered with respect to suitability for diversified production strategies and sustainability and resource conservation.

(D) The Coastal and Urban Zones

1. African coastal states and small islands represent areas of rich natural and economic resources, increasing population growth and urbanisation, but are vulnerable to sea level rise and climate change impacts. These areas are already facing several stressors from climate change such as coastal erosion, coastal flooding from storm surges,

ecosystem degradation (including wetlands, mangroves, coral reef, and delta areas), soil salinisation and construction of buildings on wetlands.

2. African governments need to implement adaptation options such as cost effective coastal protection measures, resilient infrastructures and utilities, coastal and marine spatial planning, regulations/legislation and controls for marine pollution and sustainable development.
3. African governments need to promote the existing opportunities and partnership for the private sector engagement in the implementation of adaptation measures in coastal and urban zones.
4. African states with long ocean shorelines should develop blue economy by establishing landing berths, buying fishing ships, training their fisher folks and protecting their territorial oceans from exploitation by others.

(E) Human Health

1. Strengthening national health systems and management for effective prevention and treatment of diseases would significantly improve the responsiveness to (and mitigation of) health hazards associated with climate change in the region. There should be improved approaches to sensitisation and education, data reporting and dissemination which are all critical for effective health management and response.
2. Improving and modernising existing infrastructure associated with sanitation and water resource management, is critical for mitigating the adverse effect of climate change on health in Africa, and should be at the heart of any adaptive options.
3. Medical research into existing and potential diseases due to climate change must be commissioned and/or supported. With the projected population growth in the region, and expected rise of climate change related health challenges, the development of the African pharmacopeia, mixed drug sources and manufacturing industry (given the rich biodiversity of Africa) and health technologies for effective treatments and prevention should be central to any cost-effective and sustainable adaptive option.
4. There is need for innovative approaches, including improved remuneration, towards the training and retention of human resources for health in Africa.
5. Health insurance will be a much needed tool to ensure an improvement in the access to healthcare on the continent. This will serve as a useful adaptation if the health of the people is further challenged by the impacts of climate change.

Science and knowledge are critically important to enable society to understand and respond to threats posed by climate change. There remains significant debate on future climate scenarios, particularly in regional or local contexts. The impacts of a 4°C or 5°C warming remain poorly understood, mainly due to the complexities of positive feedbacks and tipping points. However, forward-thinking policies must take cognizance of worst-case climate scenarios, and the associated possibilities of epidemics, famine, mass migration, and conflicts. They should also draw on prediction models and simulations to inform adaptation and the design of preventive measures and policies. Climate change clearly needs to be integrated into multi-sectorial policies and macro-economic frameworks for these issues to be adequately addressed. The focus must lie on informed, forward-thinking policies that integrate the best understandings of regional risks and vulnerabilities, together with local understandings of the environmental context and cultural needs. This balance is only possible through civic engagement and the active participation of local stakeholders in decision-making processes and policy development.

Introduction 1

The Network of African Science Academies (NASAC), representing independent scientific institutions across the continent, met in Yaounde, Cameroon, to discuss and document expected impacts and formulate policy recommendations in the context of climate change projected for the 21st century. The key themes of concern and recommendations that emerged from these discussions are as follows:

- Africa is particularly sensitive to and facing the consequences of the impacts of climate change due to the level of existing vulnerabilities even though it has little contribution to greenhouse gas (GHG) emissions;
- Projected impacts of climate change will exacerbate existing challenges, affecting the realisation of some of the Sustainable Development Goals (SDGs);
- There is urgent need for appropriate local and regional adaptive actions; and
- There will be severe additional costs if action is not taken now.

Globally, anthropogenic greenhouse gas emissions have increased since the pre-industrial era driven largely by economic and population growth. From 2000 to 2010 emissions were the highest in history (IPCC – AR5, 2014). The survival of many communities in Africa will be dependent on (i) effective greenhouse gas mitigation, particularly in the developed world, and (ii) facilitated adaptation to projected local and regional changes. In their report *Climate Change and Variability in the Sahel Region: Impacts and Adaptation Strategies in the Agricultural Sector,* UNEP and ICRAF (2006) highlight that initial discussions on climate change were overwhelmingly dominated by mitigation concerns, while little consideration was given to adaptation, due to a great extent to the early perception of climate change as a gradual process with impacts only in the medium to long term (i.e. in the next 50 to 100 years). However, increased understanding of impacts of climate change on this continent through the compilation of the Intergovernmental Panel on Climate Change (IPCC) assessment reports, the National Communications of the parties to the United Nations Framework Convention on Climate Change, national and international workshops by experts within Academies of Sciences from seventeen (17) countries on the continent (Figure 1), and direct observations on the ground, have brought adaptation onto the agenda. In particular, it has been noted that there are limits to the effectiveness of adaptation in reducing the risks of climate change impacts, especially if greenhouse gas emissions are not reduced (IPCC AR5, 2014). For Africa to effectively tackle climate change, emphasis on adaptation strategies (*rather than mitigation*) will be paramount.

According to expert consensus, climate change is a reality facing a number of vulnerable societies across the globe. In *Turn Down the Heat: Climate Extremes, Regional Impacts and the Case for Resilience*, a 2013 report by the World Bank, it is highlighted that under a 4°C warming scenario[1], most of the world's population is likely to be affected by impacts occurring simultaneously in multiple sectors. A 4°C world increase in average surface temperatures by the end of the century remains a real risk. The United Nations Environment Programme (UNEP) Emissions Gap Report, released at the Climate Convention Conference in Doha in December 2012, found that present emission trends and pledges are consistent with emission pathways projected to reach warming in the range of 3.5°C to 5°C by 2100 (UNEP, 2012). According to

[1] Defined as a 4°C warming of the global-mean near-surface air temperature relative to pre-industrial levels.

FIGURE 1. *Climate Change Adaptation Workshop of 2013 held in Yaoundé, Cameroon. (A) Members of the international and local organising committee, (B) Participants from seventeen Academies of Sciences in Africa, as well as from Germany and the USA (Photo credit: Samuel Ndonwi Ayonghe)*

the International Energy Agency's *World Energy Outlook 2012* report, based on the IEA current policy scenario and in the absence of further mitigation action, a 4°C warming above pre-industrial levels within this century is a real possibility, with a 40% chance of exceeding 4°C by 2100 and a 10% chance of exceeding 5°C (IEA, 2012).

While adaptation strategies to climate change have now found their way onto the international and national agendas, there is acknowledgement that there are limits to effective adaptation, particularly if GHG emissions are not reduced and warming is not kept below 2°C. Adaptation to even a 2°C warming will be a massive challenge in many regions, and these challenges increase significantly under higher warming scenarios. Despite these grim prospects, climate change simultaneously offers opportunities for learning, for regionally integrated action, and political and economic transformation beyond the status quo. However, these will only be realised through strong policies and measures, appropriate institutions, good governance, behavioural and livelihoods changes, innovation, and investments in infrastructure and new technologies.

Purpose of this Booklet

Africa is a diverse continent that is, in part, characterised by: the linguistic complexity of its different peoples, its varied colonial history and dependence, and different climatic and edaphic environments. Consequently, integration into the world economy, effective adaptation to climate change, and the design of effective trans-boundary policy responses has not been easy. This booklet intends to offer an integrated expert voice to guide the required processes that will enhance effective national, trans-boundary and continent-wide policy responses in adapting to climate change.

Climate Change Risks and Vulnerabilities in Africa

> "*Africa as a whole is one of the most vulnerable continents due to its high exposure and low adaptive capacity*." (Chapter 22, IPCC Working Group 2, 2014).

Africa as a continent faces multiple existing stresses occurring at various scales, including high population growth rates, underemployment, low literacy rates, existing food security challenges, background health issues (including weak health systems), low investment in adaptive technologies, shortages of skills and poor governance. Of significant concern in Africa is the direct reliance of a significant proportion of the population on natural resource, particularly in arable and pastoral agricultural practices, but also through fishing and harvesting of natural vegetation for shelter, fuel, medicines and crafts. Much of agricultural production on the continent currently is rain-fed, and thus making climate variability a key control on food security.

The African context requires particular understanding of differentiated vulnerabilities. It is the poorer communities, and often women and children, who find it more difficult to adapt as they are likely to have fewer economic resources and options. Without capital reserves and insurance, a single extreme weather event can cause devastation of vulnerable communities. For such vulnerable communities (or even for communities with high adaptive capacity but facing extreme stress), effective adaptation might require facilitation, and this is where the role of the policymaker is particularly important. Such facilitated adaptation can take the form of service delivery, provision of aid, education, provision of technologies and other forms of institutional support to sustain communities in times of upheaval. Without the implementation of priority adaptation measures, the increasing exposure to climate related impacts are likely to lead to exponential increases in economic loss and suffering, rising from a backdrop of already significantly crippling economic and social impacts of climate change disasters such as droughts and floods. For example, the floods of 1997–1998 and drought of 1998–2000 cost Kenya an equivalent of 11% and 16% of its Gross Domestic Product (GDP), respectively. Other African governments have incurred similar losses.

Defining Adaptation and Resilience in the Context of Climate Change

The IPCC (2008: 869) defines climate change adaptation as "*adjustments in natural or human systems in response to actual or expected climate change stimuli or their effects, which moderates harm or exploits beneficial opportunities*". Adaptation to climate is not a new phenomenon. Historically, societies repeatedly adapted to climate fluctuations and associated environmental changes through migration, changes in agricultural practices, and modifications to shelter. While African farmers have developed several adaptation options to cope with current climate variability, it is anticipated that such adaptation will not be sufficient for future changes of climate[2] (IPCC, 2007). For example, projected changes for the twenty-first century are expected to result in an increasing frequency of extreme events, including heavy storms interspersed with

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[2] This statement is made with a high (80%) confidence level.

droughts, which will test the survival of many communities across the continent[3].

A forward looking approach to the concept of adaptation requires a focus on 'adaptive capacity'. A high adaptive capacity reduces the vulnerability of communities to environmental change and promotes their resilience or potential to transition with environmental changes. Adaptive capacity is enhanced through anticipation of adverse effects, as this promotes preparedness, which in turn can mitigate damage. In the context of climate change, this requires local research, environmental monitoring, effective information dissemination and institutional mechanisms. Preparedness comprises adjustments in social and economic systems in response to actual or expected climatic stimuli and their effects or impacts. These adjustments in processes, practices and structures can be both protective (i.e., guarding against negative impacts of climate change), or opportunistic (i.e., being prepared to take advantage of any beneficial effects of climate change). Capacity drives action, which in turn can enhance or hinder future capacity to act. For example, protective adaptation might require the selling of productive assets (e.g. cattle or tools), thus limiting the capacity for future adaptation and recovery. As Pelling (2010) highlights, climate change adaptation is a continuous and dynamic process rather than a fixed status. There are thus no 'adaptation solutions', but rather a continuous series of adaptive responses as environments and societies change.

Resilience has been formally defined as "*the magnitude of disturbance that can be tolerated before a social-ecological system moves to a different state controlled by a different set of processes*" (Carpenter *et al*., 2001, 765). The resilience of a system therefore is dependent on its ability to absorb shocks and to adjust in the face of disturbance. Resilience can take the form of social resilience, which includes social networks, social capital, and institutional support, or economic resilience, which includes access to financial assistance (loans/aids), available infrastructure and access to technologies, and livelihood diversification. The development and support of these facets can assist communities in coping during environmental upheavals and in recovering from climate shocks. While adaptation enhances resilience, it can also extend beyond this form of system maintenance to include elements of transition (incremental social changes and the exercise of existing rights) as well as transformation (new rights and claims, and changes in political structures). Environmental crises, for example, provide opportunities for political overhaul (Pelling, 2010).

The extent to which Africa's vulnerability is expected to increase with growing exposure to climate change risks will depend on each country's adaptive capacity and that of its individual inhabitants and/or individual communities or even entire sectors. Adaptive capacity is partially dependent on policies and strategies that respond to local needs and enhance the resilience or transition of vulnerable systems and groups in society. Effective and sustainable adaptation strategies for Africa's future will require the integrated response of multiple stakeholders at multiple scales, from international investments and the regional co-ordination of projects to awareness of local specificities and needs. Without the implementation of priority adaptation measures, the increasing exposure of people and economic assets can lead to exponential increases in economic loss from climate-related risks. Individuals, communities, and policymakers can play vital roles in co-ordinating climate change responses across the continent and promoting access to essential resources and services for survival. The aim of this booklet is to guide these policymakers for what is projected to be a difficult future. In this booklet, we define the challenges from climate changes that Africa faces this century and offer the insights of some experts into opportunities for effective adaptation.

3 This statement is made with a high (80%) confidence level.

Key regional climate change impacts

Africa is subdivided here into six regions (Eastern Africa, Central Africa, Western Africa, Northern Africa, Southern Africa and the Small Island Developing States) for discussion on expected climate changes over the course of the 21st century (Figure 2). These boundaries are of course artificial in the sense that climate change does not obey political boundaries, and local variability within these boundaries can at times be higher than across them. Furthermore, the importance of regional interdependencies and the need for collaborative response can be undermined by a regional analysis. However, for ease of description, these convenient regional subdivisions are used here, but on the explicit understanding that sectoral impacts (e.g. impacts on water access and/or food security) will require trans-boundary policy approaches for effective adaptation to projected impacts. Additionally, coastal flooding due to rise in sea level and storm surges will likely affect a significant number of people by causing unprecedented losses and damages.

FIGURE 2. *Sub-regions of Africa*
(SOURCE: http://www.statemaster.com/encyclopedia/Politics-of-Africa)

Eastern Africa

Research in Eastern Africa has shown that the key socio-economic impacts of climate change will result from changes in patterns of seasonal rainfall and extreme rainfall events and droughts. Although there are particular uncertainties about this region due to conflicting results between global and higher resolution regional models (World Bank, 2013), there is evidence of increasing average rainfall over the northern sector (as intermittent bursts with increased chances of flooding) and declining average rainfall over the southern sector (IPCC, 2007). The projected increases in extreme rainfall events across the region bring heightened risks of floods, landslides, soil erosion, crop damage and the spread of vector- and waterborne diseases (such as malaria and cholera respectively). A decline in the fisheries in some major East African lakes (e.g. Lake Victoria) is also likely (IPCC, 2007) with implications for those who rely on fish for protein and those who sell their catches. Marine catches are projected to increase with a 2°C warming by 2050 off the coast of Tanzania, Kenya and Somalia (Cheung *et al.,* 2010). Previously malaria-free highland areas in Ethiopia, Kenya, Rwanda and Burundi are expected to fall within malaria zones by the 2080s (IPCC, 2007). Potentially beneficial outcomes of expected climate changes include increased grazing area for livestock in the cattle corridor in Uganda with increased rainfall, and opportunities to grow more profitable crops. However, with increased temperatures, greater evaporative losses may offset recharge or run-off (Madzwamuse, 2010).

Central Africa

The Central Africa region is dominated by the Congo basin. With respect to observed long-term temperature changes over the region, the few available station data suggest a statistically significant warming over the region (IPCC, 2007), with an increase in warm extremes (e.g. warmest day increased by about 0.25°C per decade) and a decrease in the occurrence of cold spells (Aguilar *et al.,* 2009). An assessment of several modelling studies confirms that it is unlikely that drastic changes in annual total rainfall will occur in the future over the greater Congo basin region. However, heavy rainfall and dry events are likely to increase substantially in the future. These projected variations in rainfall and temperature will result in substantial changes in the hydrology and increase flood risks in low lying and coastal areas (Figure 3).

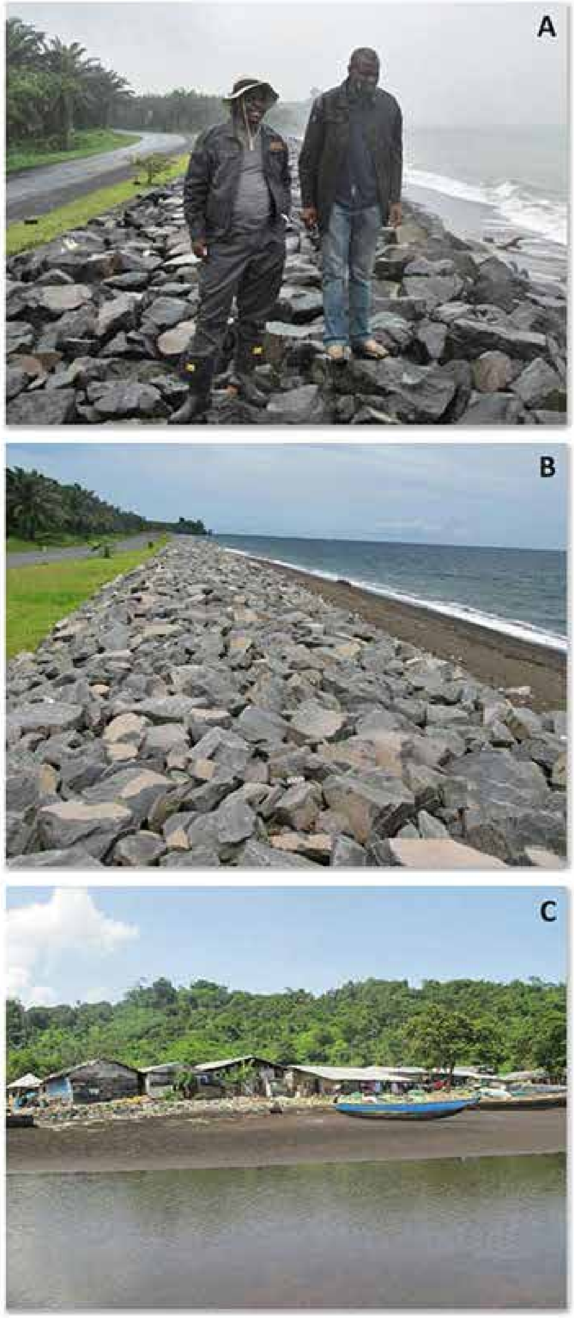


FIGURE 3. *Coastal settlements (A) and road infrastructure (B&C) threatened by storm surges and sea-level rise with an embankment constructed to protect the road at Debunscha, Fako Division, South West Region, Cameroon. (Photo credit: Prof. Samuel Ndonwi Ayonghe)*

Western Africa

The World Bank (2013) highlights that arid areas are expected to expand in the Western African region and the incidence of drought is expected to increase during the course of the 21st century. Much of Western Africa has experienced a significant decrease in rainfall and increase in the number of warm spells since the 1960s (IPCC, 2007). Climate change is expected to cause further declines in viable agriculture with associated socio-economic challenges for a significant proportion of the population in the region that is directly dependent on agriculture. A robust long-term decline in yield of greater than 15% by 2100 is projected for the equatorial fully humid climate zone (which includes the Guinean region of Western Africa, Central Africa, and most parts of Eastern Africa) under a 4°C warming scenario (World Bank, 2013). In certain parts of this region, a decline in rain-fed agriculture could be as high as 50% (Madzwamuse, 2010). The water level of Lake Chad, which is bounded by Cameroon, Chad, Niger and Nigeria is dropping due to decreased rainfall in the catchment area and misuse by anthropogenic agents; this is creating islands that have been contested for by the neighbouring countries. Climate change manifestations will mostly appear through extreme weather and climate events, e.g. droughts and floods, but also on aggravating water stress and water scarcity as well as ecosystems changes and biodiversity losses.

Projected reductions in marine catch potential along the Western African coastline will place further pressures on food security in this region. According to Cheung *et al*. (2010), catch potential in some areas will fall by more than 50% by 2050 relative to 2005 levels with a 2°C warming, while Cheung *et al*. (2011) suggests these reductions may be even higher if one considers changes in ocean acidity and oxygen availability. A distinctive feature of Western Africa is the approximately 15,000 km long coastline. Coastal towns in this region are some of the most developed of Africa's urban areas. Sea-level rise is likely to have a significant impact on these hubs with expected coastal degradation having further impacts on fisheries and tourism (Madzwamuse, 2010). On a more positive note, results from the "Mapping Malaria Risk in Africa" project (MARA/ARMA) indicate that, by 2050 and continuing into 2080, a large part of the western Sahel and much of southern Central Africa is shown to likely become unsuitable for malaria transmission (Thomas *et al.,* 2004).

Southern Africa

According to the World Bank (2013), a 40% decrease in precipitation in Southern Africa is expected if global temperatures reach 4°C above pre-industrial levels by the 2080s and there will also be significant decreases in groundwater recharge rates. It is the western parts of Southern Africa that are likely to experience the greatest decreases in rainfall with increased rainfall often as storm events in the eastern regions. Already half of the sub-humid and semi-arid parts of the Southern African region are at a moderate risk of desertification (e.g. Reich *et al*., 2001; Biggs *et al.,* 2004). Projected water shortages are expected to have devastating effects on the agricultural sector, and ultimately on food security. According to the World Bank (2013), even under a 2°C warming scenario, large regional risks to food production will emerge. Various past studies have established a teleconnection between the El Niño Southern Oscillation (ENSO) and rainfall in Southern Africa. Of the 24 El Niño events recorded between 1875 and 1978, 17 corresponded to rainfall decline of at least 10% of the long-term median in the region (Rasmussen, 1987). An increased frequency and intensity of El Niño episodes (as was noted for the 20th century by Cobb *et al*., (2013) could have significant impacts on water availability and agriculture in the region. La Nina events, on the other hand, lead to water logging of soils, leaching of nutrients and increased breeding of agricultural pests in addition to displacement of people, damage to assets and infrastructure and spread of disease in the region (UNEP, 2006). Unprecedented heat extremes also are projected over an increasing percentage of land with implications for human health and livestock losses (World Bank, 2013). In Southern Africa, it is expected that both malaria and schistosomiasis ranges will expand significantly in the next 50 years (Madzwamuse, 2010).

Northern Africa

The Northern African region is projected to be subject to warming above the global average: In a scenario of 2°C global mean warming, temperatures are projected to rise by 3°C by 2100 and in a scenario of 4°C global mean warming, temperatures in Northern Africa could increase by up to 8°C, with slightly lower levels in the Sahel region (World Bank, 2014). Together with projected precipitation declines of 40–60% during the northern hemisphere summer months such high temperatures result in an increased risk of droughts. The northern parts of the region are global hotspots for drought risk, with a 50% increase in days under drought conditions under 4°C global mean warming (Prudhomme *et al*., 2013). Groundwater is a scarce resource in the region, and groundwater levels are already falling due to over-extraction. Projected climatic conditions further aggravate the situation, which is detrimental to the agriculture sector and to food security in the region. Livestock is vulnerable to extreme heat and drought conditions. The length of the growing season for crops is projected to shorten significantly under rising temperatures and declining water availability. However, areas south of 25°N are projected to see increases in precipitation (World Bank, 2014). Salinisation of groundwater resources due to water extraction and projected sea-level rise poses another threat to human health and wellbeing in the region, particularly in deltaic areas (World Bank, 2014). Extreme heat and inadequate access to drinking water compound the health risks as such conditions are associated with diarrheal diseases, heat stress and heat stroke as well as declining labour productivity for people working outdoors (Smith *et al*., 2014).

The Northern Africa region has the highest projected population growth rates across Africa with implications for food and water security in the future (IPCC, 2007). Current trends suggest reduced mixed rain-fed and semi-arid agricultural systems and a shortened growing period on the margins of the Sahel (IPCC, 2007). A major challenge in this region will be to close the rapidly increasing gap between the limited water availability and the escalating demand for water from various economic sectors. Existing conflicts over Nile waters suggest that water basin management and international co-operation is going to become increasingly relevant in this region (IPCC, 2007).

Small Island Developing States

Small Island Developing States (SIDS) are low-lying island nations that are highly vulnerable to climate-related hazards, particularly rising sea levels, increasing frequency and intensity of extreme rainfall events, tropical cyclones, high temperatures, floods and droughts. These impact on their development, and their communities are already facing significant amount of suffering related to an observed increase of 0.85°C in average temperature above pre-industrial levels, yet these islands are the least responsible nations for global warming, producing only 0.02% of the emissions of industrialised nations (Elahee, 2014). SIDS also face a dire need to attain development goals whilst being limited in terms of resources like land availability and, hence, building space (Elahee, 2014). Relying on tourism in many cases, the sustainability of SIDS is necessary to maintain their attractiveness as an exotic destination, not to mention the inherent vulnerability of their ecosystems (Elahee, 2014).

The unique situation of SIDS has been recognised since 1992 at the United Nations Conference on Environment and Development in Rio de Janeiro. Since, a number of national, regional and international initiatives have been undertaken to address the vulnerability of SIDS to climate change. However, the recent report by UNEP (2014) noted that climate change is having significant impacts on the islands, impacts which are unlikely to abate. As a result, SIDS find themselves at the frontline of climate change, and with the appropriate framework, SIDS can turn into incubators for climate responsibility (Betsan, 2014). National regulatory and policy frameworks will be the support needed to enable business and industry to advance sustainable development initiatives needed to support the adaptation of SIDS to climate change impacts.

Assessment of sectoral impacts and adaptation options 3

Access to Water

Importance of the water resource

Water is key for human life, ecosystem services and development. In Africa, it is directly or indirectly used in almost every economic sector including agriculture, manufacturing, trade, mining, tourism and transport. Water is an ecosystem '*good'*, providing drinking water, irrigation and hydropower; an ecosystem '*service'* cycling nutrients and supporting habitats for fish and other aquatic organisms; and also provides '*cultural services*' such as scenic vistas and recreational opportunities. Water connects various sectors through its synergistic inter-linkages with energy, human and livestock health, agriculture, human settlements, aquatic and terrestrial ecosystems. However, water resources are today facing a number of challenges including spatio-temporal variations in quality, quantity and access, low level of investment in their development and poor management practices at different scales. Regional water resources in Africa pose particular management challenges because of competing national interests and limited mechanisms for cooperative action between nations that share major river basins.

Effects of climate changes on water

The sector is particularly sensitive to changes in climate and increased weather variability, with a change in rainfall generally converting to a doubled or even tripled change in runoff (Schulze, 2012). Projections of water availability are limited by the uncertainties associated with low temperature variations. For increasing levels of warming, the model projections generally converge to a decreased annual run-off over significant parts of the continent (Schewe *et al*., 2013).

Decreases of 30–50% in annual run-off are expected in Ghana, Côte d'Ivoire, southern Nigeria, Namibia, east Angola, and western South Africa (all arid zones), as well as over Madagascar and Zambia. With over 80% model consensus, there is a projected increase in annual run-off in East Africa (particularly southern Somalia, Kenya, and southern Ethiopia). Changes in threshold rainfalls (e.g. those producing a hydrograph or those resulting in soil erosion) and increases in the year-to-year variability of rainfall and run-off, render the management of water resources highly challenging (Schulze, 2012). Changes in temperature, rainfall and extreme events will induce significant changes in the different components of the hydrological cycle, and particularly on groundwater recharge which is more sensitive to climate change than surface run-off (Schulze, 2012). Issues of water quality are likely to be exacerbated by higher water temperatures which imply, *inter alia*, higher, eutrophication rates and water purification costs in addition to impacts on aquatic ecosystems. Projections suggest that even in East Africa, where increases in water availability are expected, increased population size would result in a decrease in the per capita water availability.

Water and agriculture

Agriculture is of special concern in climate change impact and adaption assessments as it is the primary source of food and is highly dependent on individual weather events and on overall climatic characteristics. Higher temperatures generally reduce yields of desirable crops while encouraging weed and pest proliferation. Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines. Mitigating climate change impacts through adaptation strategies that preserve natural resources will be a major objective. This will require policies focused on the management of land, water, soil nutrients and genetic resources. Improved management of natural resources should focus on reducing variability in agricultural outputs and increasing resilience to shocks and long-term climate change. Appropriate management of irrigation water leads to conservation of water supplies, reductions in negative water quality impacts and improvements of producer net returns.

Adaptive options

Adaptation measures should be addressed differently by, for example, national water planning departments, regional water planners, bulk water suppliers, water user associations, municipalities, disaster risk managers, rain-fed agriculture, irrigated agriculture, the water related insurance industry, the thermal power industry, the hydro power industry, managers of aquatic ecosystems (e.g. of wetlands, estuaries, environmental flows) and managers of terrestrial ecosystems regarding, for example, biodiversity and land degradation (Schulze, 2012). Adaptation measures should include (but are not limited to) more efficient use of the scarce water resources; enhancement of infrastructural safety (building of flexible flood defence structures); increased water storage in dams; promotion of rainwater harvesting; prevention/reduction of urban water losses; increasing irrigation efficiencies both off-field by reducing canal losses and in-field by promotion of drip irrigation and appropriate water scheduling; rehabilitation of degraded areas to enhance base flows and reduce storm flows; flood surge control along low-lying coastal areas; re-use and recycling of water; development of early warning weather and flood systems; conservation structures on agricultural land; adaptive spatial planning; clearing of alien invasive plants in riparian zones; enhanced reservoir operating rules; heeding indigenous coping mechanisms; remapping flood-lines; the promotion of resilient and sustainable ecosystems by using appropriate approaches such as ecosystem-based management and integrated watershed management, including water demand management; development of drought–tolerant crops; and promotion of agro- forestry practices.

BOX 1:

DRIP IRRIGATION IN THE OMUSATI REGION, NAMIBIA (CCP NAMIBIA, 2013)

The inhabitants of the Omusati Region are largely subsistence farmers, conducting crop and livestock farming. Building on the recommendations of an assessment by Ogongo Agricultural College (University of Namibia), which highlighted the shortcomings of flood furrow irrigation systems, drip irrigation techniques were pioneered in a 300 hectare area in the vicinity of the Olushandja Dam. Drip irrigation is the slow and even application of water to soil and plants using plastic tubes positioned at the plant's root zone. This limits water loss to run off and evaporation, and the leaching of key nutrients is also reduced. There are initial costs in the switch to drip agriculture, including the purchase of drip lines, pipes and pumping facilities, and capacity building is necessary for successful implementation and maintenance. Various benefits to the approach were observed during the course of this project, including increased yields due to targeted delivery of water and nutrients to the plants roots and a reduction in pests by decreases in water-logging. Drip irrigation was also found to be less labour intensive than the flood furrow system. The irrigation systems did not require much maintenance and proved to be highly durable. After the initial intervention, many farmers invested in additional drip lines. Such technologies may assist farmers across Africa, in places where food security is at stake for large proportions of the rural population.

BOX 2:

WATERSHED MANAGEMENT IN ETHIOPIA

Ethiopia has a history of watershed management initiatives dating back several centuries. The labyrinth of stone walled systems of terracing in Konso constitutes a spectacular example of a living cultural tradition stretching back 21 generations and demonstrates the shared values, social cohesion, and engineering knowledge of its communities on adaptation to water scarcity. In Konso, farmers have gained tangible economic benefits from watershed management in an agro forestry agricultural system. The productivity gains of individual farms are mainly from in-situ rainwater conservation, while farmers in the downstream areas have increased access to irrigation water. Watershed management programmes based on lessons learned from the good practices of Konso have helped farmers in other semi-arid areas of Ethiopia to reduce dependence on rain-fed, low-productivity subsistence agriculture, reverse land degradation and increase the level of water use and local participation in water management.

http://www.christensenfund.org/2012/08/01/ethiopia-konso-people-celebrate-unesco-world-heritage-support/#sthash.5RG41Teg.dpuf.

Key Messages for Water

1. Despite some uncertainties on climate change and variability, access to water will likely become a limiting factor to development in many African regions. Change in rainfall patterns will affect all uses of water, including agriculture, food security, and drinking water, hydropower, and ecosystems services, and increased variability will render water management more difficult than at present.
2. African countries should consider integration of water quantity and water quality approaches, including sediment quantity and quality monitoring, in order to understand the societal and economic relevance of water state modifications under present and future climate change. Even if the amount of rainfall were not to change, it is the pattern of rainfall that will change. Therefore, African governments should implement water catchment technologies including roof and storm water collections and storing it in tanks. Managed aquifer recharge is another option for consideration.
3. African governments should strengthen research on water resources and upgrade the hydro-climatic monitoring networks in order to better observe, understand, and model the effects of climate change and provide timely and free access of data and information, with particular focus on precipitation processes and their resultant hydrological responses, in order to identify adequate adaptation strategies and to see to their timely implementation.
4. There needs to be further research on the oceans as the climate regulator, including changes on ocean temperatures, already occurring on ocean surface layers and loss

of oxygen, salinity, nutrients and sediment loading, with impacts on hypoxia and algal blooms, circulation and acidification impacts.

5. It is essential to improve communication of research results on water issues to local communities, especially in most remote areas in the African continent, in order to make scientific results useful for the peoples living in such areas. Monitoring and research priorities as well as capacity building at all levels should be fully considered, ranging from the involvement of citizens in scientific water monitoring activities to the dissemination of a basic knowledge about ecosystems and the importance of nature conservation.

Agriculture and Food Security

Climate change impacts on agriculture and food security

The IPCC (2014) states that "Climate change will interact with non-climate drivers and stressors to exacerbate vulnerability of agricultural systems… this will have strong adverse effects on food security[4]." Various modelling assessments suggest that by the 2080s, there will be a significant decrease in suitable rain-fed land extent and production potential for cereals across Africa. Even under a 2°C warming, expected decreases in yields will have strong repercussions on food security and may negatively influence economic growth and poverty reduction in the Sub-Saharan region (World Bank, 2012). For Southern Africa below the latitude of 15°S, Thornton *et al.,* (2011) project that rain-fed agriculture will fail once every two years by the 2090s without adaptation. Large parts of the African society are food insecure and projected population growth and changes in dietary habits are likely to amplify the challenge of achieving food security in all parts of the continent.

Crop farming

The agricultural sector is a critical mainstay of local livelihoods across Africa. However, in many parts of Africa, farmers and pastoralists have to contend with natural resource challenges and constraints such as poor soil fertility, pests, crop and livestock diseases, and a lack of access to inputs and improved seeds, which amplify their vulnerability to climate change and variability. Climate change related impacts on crop productivity will decrease the availability of fodder and increase competition for land and water resources between fodder, cereals and other food security crops. Agricultural policies need to focus on the development of agricultural production systems towards sustainable intensification for higher productivity and simultaneous conservation of land and water resources. However, in any development strategy, risks of climate change to adversely affect production systems and/or to alter resource availability (e.g. water supplies for irrigation), need to be accounted for.

The lack of insurance mechanisms in agricultural production is hampering investment in agricultural assets, such as fertilisers and machinery, as variable weather conditions render these investments too risky to be affordable. The development of insurances and micro-insurances for farmers is an urgently needed development in agricultural intensification. Adiku *et al*. (2013), in a study with Climate Change and Food Security (CCAFS) project, demonstrated the feasibility of extending a micro-scale crop insurance product directly to farmers. The farmer-tailored product is for maize and sells at a premium of USD 12 per hectare. In a pilot project at Lawra Upper West Region of Ghana an initial number of 15 farmers and extension workers were trained on crop insurance but as many as 80 farmers had purchased the crop insurance product for the following season.

[4] See Niang *et al*. 2014 in the reference list.

Maize, which is one of the most common crops in Sub-Saharan Africa and the staple crop for many, has been found to have a particularly high sensitivity to temperatures above 30°C during the growing season. Hence for each day that the temperature exceeds 30°C, yields are reduced by one percent compared to optimal, drought-free rain-fed conditions (Lobell *et al.*, 2011). However, not all changes will be negative, as agriculture and the growing seasons in certain areas (for example, parts of the Ethiopian highlands and parts of Mozambique) may lengthen under projected climate changes, due to a combination of increased temperature and rainfall changes. Most populated regions of Central, Western and Southern Africa are expected to be adversely affected. As such, significant adjustments in farming practices will be necessary to promote food security across the continent.

Livestock farming

Livestock production is directly and indirectly affected by climate change. Most direct effects on animal health, wellbeing and production (e.g. growth, reproduction and milk production) are the result of increased ambient temperature and concurrent changes in heat exchanges between the animal and its environment. These lead to decrease in livestock production due to a decrease in feed intake. Heat stress also affects the reproductive performance of livestock and increases their morbidity and mortality. It has, for example, been observed that high incidences of clinical mastitis, an economically devastating disease in dairy cattle, is triggered by hot and humid weather conditions that are a prerequisite for heat stress (Singh *et al.*, 2012; Jingar *et al.*, 2014). Further, greater fly populations that act as transmission agents of the causative mastitis pathogen are favoured by these conditions, which also aggravate infestation of cattle ticks, leading to higher incidences of tick borne diseases (Singh *et al.*, 2012). Diseases such as Rift Valley Fever, associated with flooding due to intense rainfall are also projected to increase due to climate change (FAO, 2013). Some of the most dramatic effects of climate change on animal pests and diseases are likely to be seen among arthropods such as mosquitoes, midges, ticks, fleas and sand flies, and the viruses they carry. With changes in temperatures and humidity levels, the populations of these pests are likely to expand their geographic range and expose livestock as well as humans to diseases, to which they have no natural immunity. Drier conditions under climate change can also create more opportunities for vector-borne diseases: fewer water holes in pastoral areas will increase the interaction between domesticated livestock and wildlife, which could lead to a serious outbreak of malignant catarrhal fever, a highly fatal disease for cattle, since all wild beasts carry the fever virus.

Adaptive options

Given the uncertainties about the specifics of climate change (not about climate change per se), it is impossible to prepare for a specific future situation. As such, farming systems need to be flexible to respond to changes as they come. Central in this respect is the access to alternative production means (e.g. different crops, crop varieties, inputs and machinery). In semi-arid regions, the promotion of water harvesting practices, efficient water usage practices (Box 1), and the use of hybrid seeds, have been demonstrated to improve overall productivity as well as the stability of crop production. Early maturing and drought tolerant or pest tolerant varieties and sequential cropping systems (Box 3) offer opportunities for facilitated adaptation, especially if developed from locally adapted varieties that are suitable for existing soil conditions. This is critical for farming under extreme weather scenarios, particularly in the context of increased flooding, water conservation in soils and potential soil erosion. Soil fertility can be enhanced by the addition of biomass, integrated crop and livestock systems, and control of leaching.

BOX 3:

RESILIENCE AND SEQUENTIAL CROPPING SYSTEMS

Waha et al. (2013) identified traditional sequential cropping systems[5] in seven Sub-Saharan African countries and assessed their sensitivity to climate changes. The authors found that compared to single-cropping systems, multiple-cropping systems reduce the risk of complete crop failure. Multiple cropping, already a common indigenous agricultural practice across the region, is thus a potential adaptation strategy to improve agricultural productivity and food security. However, the authors point out the higher labour intensity of sequential cropping, lack of market access and limited knowledge factor against it. Also, systems selected for high productivity tend to show greater sensitivity to climate change damage. Capacity development and improvement in market access are identified as likely support mechanisms to promote multiple cropping and ultimately facilitate climate change adaptation.

Livestock adaptation strategies comprise a range of options from production adjustments, breeding strategies, market responses, institutional and policy changes, science and technology development, capacity building for livestock keepers and livestock management systems (Calvosa *et al.*, 2010; Taqi *et al.*, 2013). Identification, promotion, and (re)introduction of genetically diverse and locally adapted livestock breeds with resistance to heat stress can increase survival rates (Archer van Garderen, 2001) during times of drought while vaccinations and dipping regimes can promote disease resistance. Infrastructure, including shelter, housing and cooling systems can help to prevent heat stress of livestock. To secure sufficient fodder quantity and quality for livestock, continuously matching of stocking rates with pasture production in combination with rotational grazing of pastures, nutritional modification and mineral treatments are important adaptation strategies to secure livestock health. Maintaining and strengthening disease surveillance systems for monitoring incidence and prevalence of diseases associated with climate change are required. Furthermore, the use of agro-industrial products and by-products (e.g. cotton seed cake) for the feeding of livestock during times of poor pasture can boost their survival rate.

Key messages for agriculture and food security

1. Linkages between research institutions and local farmers should be promoted through agricultural extension services and relevant practitioners. The development of farming organisations offers an entry point for supply of technologies, capacity development and information dissemination, and offer opportunities for the collection of data on meteorology, soil and crop successes for research purposes. These organisations could also serve as a basis for joint research-farmer-consumer efforts to develop well-tailored adaptation strategies, which is especially important to foster existing knowledge on production systems and coping mechanisms.
2. An important recommendation in this sector is for livelihood diversification and development of crop and livestock insurance options such that there is a safety net if a particular crop fails or there are livestock losses. The diversity of adaptive options is also strongly related to ecosystem services relevant to food-production and resource conservation from other ecosystems, such as forests and wetlands. Vulnerabilities are limited by increasing the number of food and cash crops options, whether by increased

[5] Sequential cropping systems are defined by Waha *et al.* (2013) as "*a cropping system with two crops grown on the same field in sequence during one growing season without a fallow period*". A specific case is double cropping with the same crop grown twice on the field.

crop diversity or through the purchase of food from those with more successful yields. The development of crop and livestock insurance options for farmers would not only help in the general development of the agricultural sector, but it would also greatly buffer against increased variability and uncertainty under climate change.

3. Although new vulnerabilities emerge with market integration, a shift from purely subsistence practices towards selling of goods can also provide capital reserves for survival during bad seasons, and allow for effective distribution of available food resources when some crops fail. In relation to this, the establishment of infrastructures, such as roads for market integration or electrification of farms is necessary.
4. Finally, improved weather observation and early-warning systems and ways of effectively communicating this information to farmers are essential to protect agricultural pursuits under a scenario of enhanced weather variability (see Box 7). A number of weather stations across the region have been decommissioned. Their reinstatement should be made a priority for effective early warning of extreme events for climate monitoring over time. Remote sensing is becoming an increasingly useful cost-effective tool for hydrological monitoring. However, capacity development is necessary for its effective interpretation and equally for effective information dissemination.

Fisheries and Food Security

Importance of fresh and coastal waters

Africa is endowed with some of the largest freshwater sources and fisheries, several broad and shallow wetlands as well as an extensive coastline (30,497 km) which includes sensitive ecosystems such as estuaries and mangroves. The latter provide various ecosystem services of immense importance such as wood products, coastal stabilisation, nursery grounds for fisheries, rich faunal diversity including crabs, molluscs, and birds, extraction of a large amount of carbon dioxide from the atmosphere owing to their high photosynthetic ability, and release a large part of the fixed carbon into the forest floor in the form of leaf litter. Also, many of these waters host great biological diversity being havens for diverse species of immense ecological and scientific importance with a host of some of the highest endemism particularly of fish. These include lakes Victoria, Tanganyika, Malawi, Nasser, and the Congo, Nile, Niger and Zambezi rivers. Several of the aforementioned aquatic resources provide over 60% of dietary protein in the form of fish and prawns to surrounding communities. They also provide habitats for living organisms, cheap food sources mainly through animals, fish, and plants and regulation of nutrients cycles, potable water for human and livestock use, irrigation water for agriculture, a means of transportation of goods, hydro-electric power; and are a source of revenue from fishing and eco-tourism while their aesthetic value is invaluable. Therefore, these ecosystems contribute significantly to poverty reduction and food security.

Existing challenges

The fisheries sector offers tremendous opportunities to bolster food security in Africa. They are an important source of protein, revenue, and employment for many communities along the African coastline and on the shores of its large lakes. The Food and Agriculture Organisation (FAO) reports that in 2011, the value added by the fisheries sector exceeded USD 24 billion or 1.26 percent of the GDP of all African countries. More still could be gained: Non-African countries harvest about a quarter of marine catches in African waters. If those catches had been made by African States an additional value of USD 3.3 billion would have been generated, compared to USD 0.4 billion that were gained from selling fisheries permits. Less than 5% of fish is produced by aquaculture, compared to 47% globally (Worldfish, 2014). Artisanal marine and inland fisheries provide a third of all catches.

Despite their importance, many African waters are facing challenges and threats in an era of unprecedented usage, policy and management changes and growing evidence shows that these systems are exposed to increasing degradation. Though chief in its impacts on fisheries, it is however, important to note that other factors other than climate change affect fish yields and productivity. These include increasing coastal population, increased demand/uses of renewable water resources, which intensifies competition, conflicts, inequalities and under-development, high variability in water levels and flows, and sea-level rise for coastal waters. Another threat to water resources and fisheries in Africa is dwindling biological diversity due to a number of factors inclusive of overfishing, pollution and eutrophication, and climate change among other factors. The International Union for Conservation of Nature (IUCN) identified 21 species in African waters that are threatened by extinction due to bad land use practices that lead to sedimentation, water pollution, proliferation of invasive alien species, deforestation, mining and habitat loss due to agriculture to mention a few. Furthermore, challenges faced in fisheries include increased pressure on available water resources. This is because of increased human activities including deforestation, soil erosion and domestic and industrial pollution among others. All of these factors have contributed to declining water catchment capacity and more severe flood and drought conditions. Currently, there is underinvestment in fisheries and aquaculture and a lack of infrastructural development in this sector and across the continent. At the same time, there are no credit lines for commercial fisheries and aquaculture development, coupled with lack of information, expertise, training and capacity building initiatives, especially in the rural communities. Most initiatives aim at promoting the trade have mainly focused on low income urban areas and also on training in fish farming without offering any start-up support. In addition, most initiatives that have been undertaken in this sector have limited knowledge regarding the social and political contexts in which to engage people.

All of the commercially caught species monitored by the FAO in the Eastern Atlantic are overexploited, which means that there is no potential for further expansion and a high risk of stock collapse. Some South African species are depleted, while several species recorded for the Indian Ocean are either fully exploited or overexploited. The challenge for African fisheries will be to strengthen the sector to the benefits of African States and to meet growing demand. This needs to be managed carefully and with limits to the natural resource base in mind, in order to avoid the collapse of both systems due to overuse of resources as continues to be observed.

Climate change impacts and challenges

Research has shown that climate variability and change can bear negative impacts on fish production and diversity within the continent, exacerbating the impacts of already existing pressures on the fisheries. Evidence suggests a strong nexus between ecosystems, energy, food production, livelihood, and climate change across the continent (Magadza, 1994; Hulme, 1996; IPCC, 2007). Loss of biodiversity, the shifting of ecological zones and consequent species migration due to habitat reduction and loss, decreased primary productivity as a result of climate changes (warming, flooding and droughts) have been reported across the African region. Droughts in particular, whose frequency has increased across the arid to semi-arid ecological zones of the continent are causing a general trend of reduced rainfall and therefore water stress for plant and animal biomass production, decreased seepage to groundwater stores and reduced river inflows in these regions.

Recent climate warming in several African lakes has led to reduced nutrients and water quality and food resources for planktivorous fish, with consequent negative impacts on human fishery livelihoods. The effect of climate warming can be traced via the food chain with increased temperatures causing higher evaporation rates, lower rainfall and water inflow into rivers and lakes and therefore reduced incoming nutrients. This then leads to reduced primary production and phytoplankton biomass by negatively impacting on the production of palatable phytoplankton (Chlorophytes) and increasing mostly unpalatable, nitrogen-fixing Cyanobacteria, which leads to reduced zooplankton production and a consequent decline in fish stocks, all of which can be associated with elevated water temperatures. However, fishing effort continues to rise and technologies have improved so that in some cases, such as in Lake Tanganyika, landings have increased during the warming period, making it difficult to decipher any impact on fish productivity in response to warming. In Lake Victoria, climate warming has been implicated in the eutrophication of the world's largest freshwater resource fishery. However, increased phosphorus loading is more likely the direct cause, with climate probably playing a smaller role by increasing stability of seasonal stratification and accelerating the onset of de-oxygenation of the deeper waters. Consequences of freshwater resource-warming for the hundreds of endemic cichlid fishes, especially those occurring in littoral areas of the freshwater resource, are speculative.

In Lake Kariba, the commercial fishing industry of the introduced Tanganyika sardine-*Limnothrissamiodon*, commonly known as Kapenta has been hit hard by adverse effects of the lake epilimnion's warming due to rising ambient temperatures leading to over 50% declines in the fish catches. Lake Kariba has exhibited distinct changes in water chemistry and thermal properties, the latter seemingly due to global warming, as the rate of warming in the Zambezi valley has nearly doubled the IPCC global average of 0.2°C per decade. This change in the freshwater resource's thermal properties is reflected as an average increase of 1.9°C of the upper waters and in an upward migration of the thermocline; these changes in thermal properties ostensibly correspond with declines in *Limnothrissa* fish populations. The consequent cascade through a longer trophic chain, due to the dominance of smaller phytoplankton, could potentially affect zooplankton and fish production, and ultimately threatens the viable fishery industries that sustain the livelihoods of riparian communities.

Climate change is a risk to fisheries because warming waters cause species to relocate and ocean acidification threatens to destroy coral reefs – an important habitat and nursery ground for some species. In particular, the coastal zones of Northern and Western Africa, where fish accounts for as much as 50% of the animal protein consumed, are expected to see strong declines in fish availability irrespective of the fishing pressure. Further offshore and in the waters of the Indian Ocean, the effects of warming waters may bring benefits to marine fisheries as potential yields increase. Climate change presents a challenge particularly for artisanal fisheries in Western Africa who will not be able to relocate or fish further offshore, where catches might increase due to warming waters. In coastal regions that have major lagoons or lake systems, changes in freshwater flows and a greater intrusion of salt water into lagoons will affect the species that are the basis of inland fisheries or aquaculture.

Adaptive options

Despite these threats and challenges, there are great opportunities to sustainably harness benefits, increase productivity and efficient use of ecosystem goods and services derived from freshwaters and fisheries of the continent through appropriate management and conservation of these resources. For instance, Zimbabwe has more than 12,000 dams and a diversity of rivers, lakes and wetlands, wild fisheries in the country, and like many parts of Africa, currently does not meet the demand for fish protein. Therefore, there is an opportunity to increase natural fish and aquaculture production to meet the high demand. In addition, the management of water resources is critical to economic growth.

One livelihood diversification strategy as an adaptation to climate change in the fisheries sector would be fish farming. To date policy and development practice has paid scant attention to smallholder pond-based fish farming as a form of livelihood. Therefore many African countries do not have a long history of support for aquaculture, and both inland pond-based and sea-based aquaculture, which has grown very slowly if at all. Recent studies have shown that small-scale aquaculture development brings about positive changes and implied benefits, particularly if practised concurrently with and complementary to crop and livestock production. The application of these innovative, science-based yet simple technologies to agricultural production such as small-scale pond fish farming that can be adopted particularly in rural areas and smallholder fishermen can tap into recent innovations that allow small-scale aquaculture in artificial ponds. Targeted and specialised training can lead to enhanced food production and livelihood security. A case in point is the Malawian aquaculture programme where fish farmers opted for *Tilapia rendallii*, a species that grows to market size in only four to six months by feeding on maize bran.

Livelihood diversification and climate smart productive practices include activities such as intensive small-scale fish farming that sustainably increase productivity, and resilience (adaptation), reduce greenhouse gases (mitigation) and enhance achievement of national food security and development goals. Wider livelihood strategies that are not necessarily non-rain dependent such as entrepreneurial value addition of agricultural products are worth considering, including learning from other countries that have come up with models to assist smallholder farmers in livelihood diversification. More specifically, these would be the value addition to fish that can include products such as fish meal and pet food, fillets, canned fish, fish mince.

BOX 4:

COLLABORATIVE FISHERIES MANAGEMENT IN TANZANIA

The Tanga Coastal Zone Conservation and Development Programme (TCZCDP) was formulated in Tanzania in 1994 to enhance the wellbeing of coastal communities by improving fisheries management in light of declining fish catches and the destruction of mangrove communities (McClanahan et al., 2005). A collaborative approach of facilitated management between local authorities and fishing villages was implemented to enhance community development and poverty alleviation. Villages that shared resources formed a delineated Collaborative Management Area (CMA). CMAs were required to identify one or two reefs to be closed to extractive use (although economic pressures saw some of these reopened in 2000 and later replaced by alternatives). Peer pressure appeared to assist with the reduction in illegal activities (e.g. dynamite and poison fishing, beach seining and net dragging) and facilitated local support for closed areas. Collaborative fisheries management resulted in increased fish stocks over time and decreases in erect algae on the local reefs. Stability and diversity of community structure also were maintained during a period of large scale environmental disturbance (the 1998 El Niño event). However, there did not appear to be recovery of sensitive branching or rare coral taxa. Results from this study indicated that large permanently closed areas are required for the latter.

Key messages for fisheries and food security

1. There is need to improve daily and seasonal forecasts in order to build climate resilient fisheries in Africa. Climate change needs to be considered with respect to risks for production systems as well as possible changes in farming conditions (e.g. availability of water resources for irrigation). Policies should encourage and facilitate the technical and institutional framework for collection and dissemination of this information.

2. There is need for intensive research on improvement and diversification of livelihoods particularly in value addition of goods. This should be coupled with research on climate change adaptation that is case-specific, acknowledging the complexity of production systems and natural environments. Participatory and integrated research approaches are needed to better understand adaptation options, develop solutions, and facilitate effective implementation. Policies should support and encourage research in that direction, and integration with the international research community should be actively sought and enabled.
3. There is need to transit to production systems that are more productive, use inputs more efficiently, have less variability and greater stability in their outputs, and are more resilient to risks, shocks and long-term climate variability such as small scale fish farming. This can be supported by, for example, protecting the water resources from pollution, water harnessing by construction of dams, and other such methods as water harvesting techniques and the equitable allocation, pricing, and efficient use of scarce water.
4. Extension services need to be enhanced to better prepare and translate scientific understanding and information to practical guidelines for farmers. Policies should encourage and support extension services, establish quality control and feedback mechanisms.
5. Sustainable fisheries management (e.g. through strict catch quota) helps to increase the natural system's resilience and thus to better buffer against climate change and increased variability. Policies should establish sustainable catch quota and instruments to monitor and enforce them. Alternative use of marine resources (e.g. aquaculture) should be carefully considered with respect to suitability for diversified production strategies and sustainability and resource conservation.

The Coastal and Urban Zones

Socio-economic context and existing challenges

The coastal zone of Eastern Africa, including coastal wetlands, extends from Sudan to South Africa and includes the near-shore islands off the coast of Tanzania and Mozambique and the oceanic islands of Madagascar, the Seychelles, Comoros, Mauritius, and Reunion. The coastal zone of West Africa spans from Mauritania to Namibia and includes the pristine islands of Bijagos Archipelago; the offshore island nations of Cape Verde and São Tomé and Principe; and the remote central Atlantic islands of San Helena and Ascension. A large percentage of Africa's urban population lives in coastal cities and the majority of the industries, economic activities and other assets in most of the countries are located within the coastal zone. It is estimated that in excess of 150 million people live within one metre of high tide level, and 250 million within five metres of high tide, because of this high population densities (and often inadequate urban planning) coastal cities in developing regions are particularly vulnerable to sea-level rise and other impacts of climate change (World Bank, 2012). According to UN-Habitat (2010), Africa has the highest rate of urbanisation of all continents. A common feature that emerged from various regional analyses in the *Turn Down the Heat: Climate Extremes, Regional Impacts and the Case for Resilience* report (World Bank, 2013), was the emergence of clusters of vulnerability in urban areas. Urbanisation rates are high in developing regions; for example, it is projected that up to 56% of Sub-Saharan[6] Africa's population will live in urban areas by 2050 compared to 36% in 2010 (World Bank, 2013).

[6] The report "Turn Down the Heat: Climate Extremes, Regional Impacts and the Case for Resilience" defines Sub-Saharan Africa as the region south of the Sahara from 15° N to 35°S.

Coastal areas are already subject to a number of threats, including erosion, sedimentation, flooding, coral bleaching, ecosystem degradation, soil salinisation, contamination of freshwater reserves and food crops, marine pollution, destruction of wetlands, increased tourism activities and increased infrastructural development. These threats are likely to be enhanced in the face of climate change.

Climate change projections and expected impacts

A recent report by the UN Habitat (2014) noted that coastal cities are particularly vulnerable to the effects of climate change, from rising sea-levels and extreme weather events that threaten fragile physical defences as well as the eco-systems that draw international tourism. For geophysical reasons, the rise in sea level will vary regionally and is projected to be up to 20% higher in the tropics and below average at higher latitudes (IPCC, 2014). Nicholls and Tol (2006), extend the global vulnerability analysis of Hoozemans *et al*. (1993) on the impacts of and responses to sea-level rise with storm surges over the 21st century. They show that Eastern Africa (including small island states and countries with extensive coastal deltas) could experience major land loss.

Dasgupta *et al*. (2009) considered a 10% future intensification of storm surges compared to a 1-in-100-year historical storm surge. They examined the impacts of sea-level rise with these intensified storm surges in developing countries, assessing impacts in terms of land area, population, agriculture, urban extent, major cities, wetlands, and local economies. They found that Sub-Saharan African countries will suffer considerably from the impacts. The study estimated that Mozambique, Madagascar, Nigeria, and Mauritania account for more than half (9,600 km^2) of the total increase in the region's storm surge zones with high level of exposure to extreme floods (Brecht *et al.,* 2012). Indirect impacts, such as socio-economic impacts include uprooting human settlements, dislodging port and navigational facilities, upsetting coastal fishery as well as coast-based tourism. Coastal agriculture (e.g. palm and coconut in Benin and Côte d'Ivoire, palm in Cameroon, and shallot in Ghana) could be at risk of inundation and soil salinisation (IPCC, 2007).

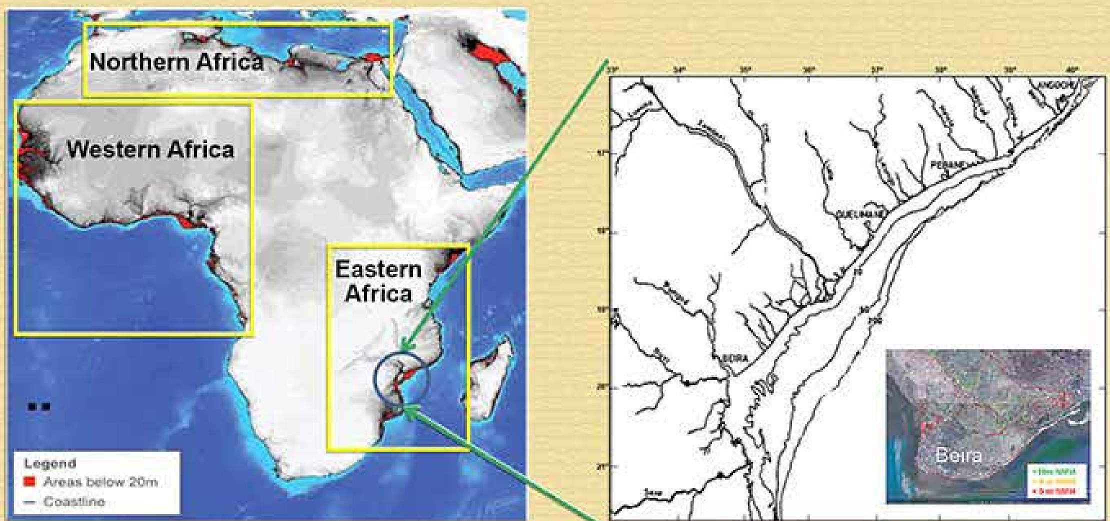
Adaptive options

Housing and infrastructural retreat from the coast offers one opportunity for adaptation. In the case of extreme storm events, however, it is likely that natural protective mechanisms will need to be enhanced by engineering options such as breakwaters. The risks associated with increasing urbanisation under various climate change scenarios need to be assessed, and well designed 'adaptable cities' are required, particularly in coastal zones where cities will need to be prepared for the possibilities of storm surges and coastal flooding (see Box 5). Land use zoning, flood protection, and the creation of open spaces in city planning, will become increasingly important in these regions during the course of this century. Sprawling informal settlements concentrate large populations and are conducive to the transmission of vector and water borne diseases, such as cholera. With an increased frequency of extreme weather events projected in many coastal cities, effective sanitation, drainage and emergency preparedness is essential, with clear evacuation plans and well-developed medical support networks.

BOX 5:

COASTAL CLIMATE CHANGE: THE CASE OF BEIRA, CENTRAL MOZAMBIQUE

Mozambique is recognised as one of the countries in Africa that is most vulnerable to climate change. Hazards such as droughts and floods, variable rainfall and tropical cyclones already significantly affect the region (Tol, 2004). Following a first phase investigation by (INGC, 2009) aimed at defining and locally contextualising important drivers and impacts of climate change in Mozambique, the country's National Institute for Disaster Management (INGC) commissioned a second phase of investigation. While INGC Phase I focused on determining the impacts of climate change on Mozambique at the macro level, INGC Phase II (INGC, 2012) addressed elements at both the macro and the micro level, emphasising the definition and implementation of risk reduction and adaptation actions at local authority level. All the reports from both Phases I and II are downloadable from http://ingc.dirisa.org. Building on methods proposed by Coelho et al. (2006) and Coelho and Arede (2009), Rollanson (2012), Theron et al. (2012) provides a comprehensive and robust method to assess the risk and vulnerability of coastal cities and towns in low data availability environment. This is illustrated in a case study for Beira city (Figure 4), where the precautionary principle was applied to find sustainable solutions that are durable and affordable to the municipality and/or the state. Where possible a Public-Private Partnership was sought to implement relevant risk reduction and adaptation measures whilst encouraging economic growth to appropriate development. The city is located in a low-lying coastal land in the Sofala Province (central Mozambique) at the confluence of the Púngwè and Búzi Rivers. Local environmental settings include high population concentration in close proximity to the sea, low capacity to defend infrastructures, soft erodible coasts, inadequate and ageing coastal defences, susceptibility to high cyclone activity, storm surges, extreme wave action and tides. Recent publication by Newman et al. (2013), found that a medium Intergovernmental Panel on Climate Change (IPCC) scenario consistent with IPCC projections through 2050 could increase the frequency of the current 100-year storm, which is associated with a storm surge of roughly 1.9 metres, to once every 40 years. Among the aforementioned treats, salinity intrusion due to a combination of several factors affects different water urban systems and people daily life. Beira relies on the Púnguè River for its water supply. However, in the dry season frequently occurs that the intake of water has to be ceased because the salinity of the Pungue water is too high. Intrusion due to saltwater in central Mozambique may reach 16–20 km far inland and affect areas varying from 19 km^2 to 179 km^2. This fact has been documented to limit access to freshwater and have serious implication to agriculture activities in the area (INGC, 2009).



(Brooks *et al.*, 2006, WBGU) (INAHINA: National Institute of Hydrography and Navigation)

FIGURE 4. *Beira city in central Mozambique highlighted for better view in the case study*

Continued on next page

Scenarios

To determine the influence of future climate change on the vulnerability profile at Beira city (Figure 4), a scenario approach was followed. Using the approach described in Theron et al. (2012) publication, detailed vulnerability assessments for Beira were conducted. Based on the SLR projections available in the publication, four levels of SLR were considered, namely 0 m, 0.5 m, 1 m and 2 m. Other than SLR, the effects of climate change were also assessed by both including and excluding increases in "storminess" (i.e. wave height increase leading to increased wave attack). As cyclones are a major hazard along the Mozambique coast, the assessments were conducted both with and without taking cyclones into account.

The total number of scenario combinations thus assessed amounted to 16, as summarised in Table 1. In addition, a conceptual description of a coastal hazard/risk model (Theron et al., 2012) was proposed as a suitable assessment method to identify vulnerable coastal areas where there is a lack of environmental data. Three coastal flooding levels were calculated for Beira (Detail calculations in Theron et al., 2012) as elevations (in m above MSL): Low = 5.9 m; Medium = 7.4 m; High = 9.9 m and the hazard zones were defined (starting from the sea) as: High Hazard Zone (red), < = 5 m contour; Intermediate Hazard Zone (yellow), > = 8 m contour; Low Hazard Zone (green), > = 10 m contour (Figure 5).

To the authors' understanding, in a case study for Beira, the results form a useful framework for action-oriented decision-making. The approach also exposes gaps in vital data, thereby focusing data gathering activities, enabling prioritisation of risk reduction and adaptation options, and encouraging goal-orientated monitoring and evaluation programmes. Thus, the key adaptation measures found to be most suitable for Beira (Table 2), which includes four "Management options" (labelled A1 to A4), three "Soft engineering"/Restoration measures (B1, B2 & B3), four "Hard engineering" & armouring options (C1s, C1r, C2, C5), and two options more suitable for low/moderate wave energy sites (C11 & C12).

FIGURE 5. *Satellite derived positions of the +5m, +8m and +10m (to MSL) contours at Beira city in Mozambique*

TABLE 1: Summary of scenarios assessed for coastal vulnerability

			Excluding cyclones		Including cyclones	
			Present wave climate	Increased storminess	Present wave climate	Increased storminess
			1	2	3	4
No climate change:		A	Present wave climate	Present wave climate	Present wave climate	Present wave climate
Climate change included	SLR = 0.5 m	B	Present wave climate	Increased storminess	Present wave climate	Increased storminess
Climate change included	SLR = 1.0 m	C	Present wave climate	Increased storminess	Present wave climate	Increased storminess
Climate change included	SLR = 2.0 m	D	Present wave climate	Increased storminess	Present wave climate	Increased storminess

Note: *Scenario A3 is the same as A4, therefore no. A4 scenario is included in the scoring*

TABLE 2: Potential options to respond and adapt to the impacts of climate change.
More detail including ball-park costs are presented in Theron *et al.*, 2012
and downloadable at: *http://ingc.dirisa.org*

A.	**Management options**
A1	"Accept and retreat" – repositioning infrastructure at risk, zoning, set-back lines, resettlement, etc.
A2	"Abstention" involves the 'do nothing' option (if the risk of loss of property or human life is very minimal)
A3	"Alternative" coastal developments: develop "safe" alternative coastal areas including services
A4	"Accommodation": increase resilience and accommodate impacts on infrastructure, e.g. raising property
B.	**"Soft engineering" or Restoration ("semi-natural" interventions in the littoral zone)**
B1	Sand nourishment: pump extra sand onto the beach to build it up and reduce wave impacts and flooding
B2	Managed (vegetated and/or reinforced dune. Construct/reinstate and/or manage vegetated dune areas)
B3	Mangroves, corals and wetlands. Expand/reinstate and manage/protect such natural defences
C.	**"Hard engineering" and armouring (construct: shore protection measures)**
C1	Seawalls and revetments: sloping, vertical or curved concrete/rock structures
C2	Dykes: sloped (landscaped and vegetated) loose standing sand/earthen mound
C3	Perched beach structures: artificially keep the upper part of the beach profile in place
C4	Shore parallel structures (e.g. artificial surf zone reefs, detached breakwaters, rock beams, etc.)
C5	Groynes (straight, curved, T, L, etc.) placed perpendicular or at angle to shoreline, can trap sediment
C6	Spending beach of very coarse sand, gravel or cobbles, dissipates wave energy and erosion
C7	Beach (and dune) dewatering mechanism. Sediment 'stability' can be increased
C8	Coastal flood control gates in "enclosed" areas (e.g. river mouths, small bays)
	In low to moderate wave energy environments
C9	Closely spaced piles or wave fences to dissipate wave energy
C10	Floating moored "breakwater" type structures
C11	"Geotextile" shore protection, usually sand-filled geotextile containers
C12	Gabions and/or rock filled wire basket and mattress structures
D.	**Combined options**
	A combination of two or more of the identified solution options may be required

Key messages for coastal and urban zones

1. African coastal states and small islands represent areas of rich natural and economic resources, increasing population growth and urbanisation, but are vulnerable to sea level rise and climate change impacts. Thus, African governments need to establish adaptation policies for population and development security for these areas which are already under several stressors from climate change such as coastal erosion, coastal flooding from storm surges, ecosystem degradation – wetlands, mangroves, coral reef, soil salinisation – delta areas, construction of buildings on wetlands.
2. African governments need to implement adaptation options such as cost effective coastal protection measures, resilient infrastructures and utilities, coastal and marine spatial planning, regulations/legislation and controls for marine pollution and sustainable development.
3. African governments need to promote the existing opportunities and partnership for the private sector engagement in the implementation of adaptation measures in coastal and urban zones.
4. African states with long ocean shorelines should develop blue economy by establishing landing berths, investing in fishing ships, training their fisher folks and protecting their territorial oceans from exploitation by others.

Human Health

Health systems in Africa

The African continent is largely characterised by relatively weak health systems which are barely holding up under existing stress caused by a high prevalence of infectious diseases, increasing incidence of non-infectious diseases, deficient health technologies, and low human resources for health. This is further worsened by poor sanitation, poor drainage systems, low access to potable water, poor urban planning and housing standards, as well as widespread poverty. All these constitute major constraints to the prevention and treatment of diseases. On another hand, despite a huge disease burden, the healthcare worker to population ratio is only 2.3 per 1000 as compared to 24.8 per 1000 in the Americas (Naicker *et al.*, 2009).

Climate change impacts on health

The IPCC (2007) states that "*Human health, already compromised by a range of factors, could be further negatively impacted by climate change and climate variability, e.g. malaria in southern Africa and the East African highlands*[7]." It is projected that climate change will alter the ecology of disease vectors, and consequently the spatial and temporal transmission of such diseases (Table 3). Research on climate-related health impacts has concentrated on malaria, and there is a clear need for a broadening of this scope. Flooding can be associated with outbreaks of diseases such as cholera, while drought has been associated with diseases such as scabies, conjunctivitis and trachoma (Patz *et al.*, 2008).

[7] This statement is made with high (80%) confidence.

TABLE 3. Key diseases impacted by climate change

Disease	Symptoms and Signs	Comments
Malaria	Fever Fatigue Sweating Chills	Malaria incidence is not simple to predict, but studies have indicated a correlation between increase in incidence and increases in temperature and rainfall (Chaves and Koenraadt, 2010). Research indicates that the regional penetration of malaria in Zimbabwe and South Africa will increase in the next century and previously malaria-free highland areas in Ethiopia, Kenya, Rwanda and Burundi could also experience modest incursions of by the 2050s, with conditions for transmission becoming highly suitable by the 2080s (IPCC, 2007). On the other hand, the range is expected to narrow in a large part of the western Sahel and much of southern Central Africa (IPCC, 2007).
Cholera	Diarrhoea Nausea Dehydration Fatigue	Cholera is an acute illness transmitted via contaminated water or food. Past outbreaks of cholera have been associated with record rainfall events (Tschakert, 2007), often during El Niño (Nyong, 2009). The risk of spread increases when water supplies and sanitation services are disrupted (Douglas *et al.*, 2008).
Dengue Fever	Fever Headache Rash Joint pain Fatigue	Like malaria, this is a vector-borne disease. The distribution of the mosquito vector is expected to change with projected changes in rainfall and temperature. Hales *et al.* (2002) showed significant increases in the proportion of the global population at risk of dengue fever transmission by 2085.
Meningitis	Fever Headache Neck stiffness Drowsiness and/or confusion	While the influences on the spread of meningococcal meningitis are still poorly understood, dryness and dusty conditions are factors that need to be taken into account (IPCC, 2007).
Rift Valley Fever	Fever Headache Joint pain Fatigue	Epidemics of this disease are associated with flooding and could increase with a higher frequency and intensity of El Niño events under future climate change scenarios (IPCC, 2007).

The impact of climate change on health can be categorised into direct and indirect impacts. An under-researched direct health impact of climate change is heat stress caused by high temperatures. Heat stress can be associated with generalised itching, heat cramps, fainting, exhaustion, heat stroke, and death. The young, the elderly and those with existing health problems are especially vulnerable (World Bank, 2013). Heat stress is of particular concern in urban areas where the built environment amplifies local temperatures (as the 'urban heat island effect'). Other groups vulnerable to heat stress include farmers, and construction workers (Myers 2012). Furthermore, the educational performance of school children is undermined by poor health and heat extremes. A study of the health of school children during school days in Yaoundé and Douala in Cameroon found that during the hot season, high proportions of children were affected by headaches, fatigue, or feelings of being very hot. Without any protective or adaptive measures, these conditions slowed down writing speeds and decreased concentration levels (Dapi *et al.,* 2010). Other direct health concerns related to climate change include the potential for increased injuries during extreme events such as flooding (McMichael and Lindgren, 2011).

Indirectly, flooding also can impact on access to health facilities, e.g. the floods in 2009 in Tana Delta in Kenya that cut off medical services to approximately 100,000 residents when a bridge linking the area with the district hospital at Ngo was swept away (Daily Nation, September 30 2009, cited in Kumssa and Jones, 2010). Notably, the increased prevalence of under-nutrition could be the most severe climate-related indirect threat to human health in Africa. Under-nutrition, the result of inadequate absorption or use of nutrients (due to diarrheal disease, for example), is already a significant challenge to human health across the region (Cohen *et al.,* 2008). Under-nutrition decreases the resilience of the body and thus increases susceptibility to disease. It stunts the growth of children with repercussions into adulthood and reduces cognitive development (Cohen *et al.*, 2008). Finally, in the case of displacements and mass migrations in response to climate change, infectious diseases can spread rapidly through vulnerable communities with some populations being exposed to new diseases not previously encountered and against which they lack immunity (McMichael *et al.,* 2012).

Health is defined by WHO (1989) as '*a complete state of physical, mental, and social wellbeing and not merely the absence of disease or infirmity*'. As such, the effect of climate change on human health extends beyond disease and disease agents. Climate change will have far reaching consequences on the wellbeing of people.

Adaptive options

For effective adaptation, a further understanding of key diseases and their spread is essential. A general strengthening of national health systems, particularly emergency responses, will be necessary with increased likelihood of environmental disasters. For many diseases, infrastructure (e.g. effective sanitation, proper urban planning, housing standards, and drainage systems) and adaptive technologies can assist (see Box 6). Also, improved incentives must be offered to retain human resources for health within the continent. In addition, given her rich biodiversity, drug discovery and manufacturing is fundamental to effective response to emerging health challenges expected from the impact of global warming.

These technologies will require state funding to ensure widespread and effective use, particularly if the most vulnerable communities are the least likely to be able to afford the investment required. Prediction of outbreaks of diseases such as cholera is vital for disaster preparedness. Innovative use of various sources of data from laboratory testing, meteorological measurements to satellite imagery (e.g. Simonis and Van der Merwe, 2011) assist with the

BOX 6:

EFFECTIVE, COST AFFORDABLE ADAPTIVE TECHNOLOGIES FOR HEALTH PROTECTION: INSECTICIDE-TREATED NETS

Malaria causes illness and death in many parts of the world, particularly in Sub-Saharan Africa. One success story in the campaign against malaria is the use of insecticide-treated nets (ITNs). This affordable technology was shown by various field studies to limit malaria risk even among unprotected individuals by suppressing the density, survival, human blood indices, and feeding frequency of the malaria vector Anopheles mosquito (Killeen et al., 2007). A study in Asembo, western Kenya by Hawley et al. (2003), showed that to maximise the public health impact, high coverage with treated nets is essential as this strengthens the community effect. As Curtis et al. (2003) argue, scaling-up the coverage of ITNS in Africa requires state or donor investment, as the burden of this cost cannot be placed upon the most vulnerable, particularly when retreating of the nets with insecticide is necessary, and torn nets need to be replaced, for effective community protection.

prediction of disease outbreaks and facilitate preparedness in contrast to the current focus on 'after the event' relief. Prediction however is not sufficient, as these findings need to be communicated effectively for responsive action. Improved approaches of sensitisation, reporting, and data dissemination is necessary for effective health management responses in the future.

Key messages for health

1. Strengthening national health systems and management for effective prevention and treatment of diseases would significantly improve the responsiveness to and mitigation of health hazards associated with climate change in the region. There should be improved approaches to sensitisation and education, data reporting and dissemination which are all critical for effective health management and response.
2. Improving and modernising existing infrastructure (especially drainage systems, sanitation, and water resource management), is critical for mitigating the adverse effect of climate change on health in Africa, and should be at the heart of any adaptive options.
3. Medical research into existing and potential diseases due to climate change must be commissioned and/or supported. With the projected population growth in the region, and expected rise of climate change related health challenges, the development of the African pharmacopeia, mixed drug sources and manufacturing industry (given the rich biodiversity of Africa) and health technologies for effective treatments and prevention should be central to any cost-effective and sustainable adaptive option.
4. There is need for innovative approaches, including improved remuneration, towards the training and retention of human resources for health in Africa.
5. Health insurance will be a much needed tool to ensure an improvement in the access to healthcare on the continent. This will serve as a useful adaptation if the health of the people is further challenged by the impacts of climate change.

4 Towards sustainable development in Africa in a changing climate

The vulnerabilities of rural and urban African populations are clear, yet Africa is a continent that is characterised by poor scientific and economic infrastructure and institutional and legal frameworks that are, in many cases, insufficient to deal with existing environmental degradation and disaster risks. This needs to be addressed urgently with effective policy and appropriate allocation of resources. The costs of environmental degradation have been significant for African countries. For instance, it is increasingly acknowledged that meeting the first Millennium Development Goal (MDG) of eradicating extreme poverty will not be possible if the world does not confront the challenges posed by climate change.

In September 2014 at its 69th session, the United Nations General Assembly agreed that 17 Sustainable Development Goals (SDGs) which are prospective successors to the MDGs will constitute the basis for negotiations of the Post 2015 Development Agenda. In addition to SDG 13 which requires that states take urgent action to combat climate change and its impacts, sustainability and climate change considerations cut across all the other SDGs. Climate change has the potential to undermine previous development efforts in Africa and to put additional pressure on limited resources. The challenges to achieving the SDGs across the continent are greatly increased in the context of expected climatic changes. Without explicit recognition of the links between climate change, food security, poverty and underdevelopment, and policy that incorporates these cross-cutting issues within its framework, achievement of the SDGs will be no more than a pipe dream.

Below we present key recommendations for consideration by African policymakers in their quest for sustainable development in the context of climate change.

Informed, Precautionary Policymaking

Science and knowledge are critically important to enable society to understand and respond to threats posed by climate change. Priorities for the agenda for adaptation governance need to be driven and informed by the realities of the regions that are directly affected by climate change. Decision makers need sound information on regional impacts of climate change grounded in the best science available. This must include investments in the downscaling of global climate models, to ensure appropriate regional responses. Equally important is sound information on the potential social and economic impacts of climate change, particularly on more vulnerable groups like the extreme poor.

There remains significant debate on future climate scenarios, particularly in regional or local contexts. The impacts of a 4°C or 5°C warming remain poorly understood, mainly due the complexities of positive feedbacks and tipping points. However, forward-thinking policies must take cognizance of worst-case climate scenarios, and the associated possibilities of epidemics, famine, mass migration, and conflicts. They should also draw on prediction models and simulations to inform adaptation and the design of preventive measures and policies.

Integrated Responses: From the Local to International

Climate adaptation strategies must be locally specific, such that they relate to the local environmental context and are sensitive to local cultures and lifestyles, and resources and expertise need to be deployed to facilitate local actions (Box 7). Further, most African countries

BOX 7:

QUARTERLY CLIMATE CHANGE PREPAREDNESS WORKSHOPS

The Suid Bokkeveld community who inhabit the arid Northern Cape Province of South Africa, farms with livestock and indigenous rooibos tea. For the past decade, community members have regularly met every three months to share their experiences of weather impacts, to get information about the expected weather for the coming three months and to share learnings and plan how best to prepare for what lies ahead. These workshops have been facilitated by two local NGOs, Indigo and the Environmental Monitoring Group, and the long term forecasts have been provided by the South African Weather Service.

The facilitating NGOs have consistently explained the limitations of the long term forecasts whilst also clarifying their usefulness. Over time, the workshops have evolved into a crucial point of convergence for the members of this scattered community, a safe environment in which reflection on experience has contributed to the evolution and sharing of individual and collective adaptation strategies and techniques. Some of these have been adopted as best practice by the farmers' rooibos cooperative, and others have been incorporated into the requirements that members must comply with to meet the cooperative's organic standards.

Preparedness for climatic extremes, whether these are floods or droughts, frequently involves similar agricultural practices. Willingness by farmers to adopt and invest in these practices is determined by the information that is available to them, and to their experience of the impacts of decisions that they have taken in the past. The workshops provide farmers with opportunities to experience the impacts of decisions by simulating real circumstances via games and exercises. Experience sharing by the land users of successes and failures enhances their ability to make sound choices in the light of realistic expectations. Mentor farmers employed by the cooperative to advise their fellow-farmers regularly join the workshops and are able to assist in problem solving and information sharing.

Workshop participants compiling a seasonal calendar and reporting their farming strategies during a workshop. (Photo credit: Bettina Koelle)

Farmers evaluate the impacts of decisions by simulating real circumstances via a climate change adaptation game during a workshop.(Photo credit: Noel Oettle)

lack a coherent policy framework for climate change adaptation. Where such plans do not exist, adaptation tends to be addressed by fragmented environment and development policies (Madzwamuse, 2010). It is advised that explicit policy frameworks are developed with far-reaching application from land use decisions, building and infrastructural development codes to disaster response procedures and that resources are allocated accordingly. These frameworks ideally can integrate with macroeconomic discourses through cost-benefit analyses that show that the benefits of facilitated local adaptations outweigh the costs, particularly in the case of extreme weather events. Climate change has multiple, trans-boundary impacts that crosscut the agricultural, infrastructural, and health sectors. Policy frameworks thus would benefit from cross-regional negotiation and international collaboration and application. One form of collaboration could be investments by developed nations and international agencies in local adaptation projects for particularly vulnerable communities in Africa.

Climate Research

Current research does not always respond to national knowledge gaps on climate change due to the emphasis on foreign-led studies that respond to international research interests and agendas. It is vital that local research institutes have the necessary support to conduct local research that answers key questions to assist policymakers on culturally and environmentally appropriate climate change adaptation strategies. However, the push to strengthen local research institutions should not preclude the conduct of climate change-related research at the regional and continental levels where economies of scale are significant. Furthermore, although the causes and drivers of global warming are local, their effects and costs are often global and transnational, calling for concerted actions which may be cost-effective in most cases. Similarly, policymakers must communicate key questions that can guide relevant research. Local knowledge and existing adaptive strategies need to be interrogated and local research resources tapped through participatory research techniques to assist in aligning research recommendations with realities on the ground. There is a further need to also enhance institutional absorptive capacity in the various regions, providing opportunities for scientists to apply their knowledge on climate change impacts, vulnerability, and adaptation to policymaking processes (IPCC, 2007).

Integrated meteorological monitoring, remote sensing data and enhanced investment in forecasting capabilities can further inform climate change adaptation strategies (see Box 8 below). One of the key challenges of regional climate forecasting in Africa is that the present state cannot be assessed due to the lack of measurement data and data integration across regions. In many cases existing networks are being decommissioned due to competing demands for limited resources and to the failure to recognise the importance of these networks for climate change predictions.

Civic Engagement and Education

Civic engagement in climate change adaptation is vital. At present, the development of adaptation policies and strategies is dominated by state actors, while civil society organisations and local communities generally have played a limited role. This situation undermines key governance principles such as equity, stakeholder participation, accountability and transparency. An understanding of gender issues and cultural specificities is key to adaptation response frameworks and these are often forgotten in a top-down approach. Adaptive frameworks and cultural contexts need to be in a constructive dialogue, mutually supporting each other in their development. Enhanced stakeholder engagement provides policy context and increases the likelihood of sustainable solutions on the ground through local buy-in and implementation.

Stakeholder engagement can be enhanced through capacity-building exercises in vulnerable communities, the supply of environmental information and participatory processes (Oettle *et al.,* 2014). This information needs to be presented in a way that makes sense to both technical and non-technical users. Local media including radio stations, agricultural extension

BOX 8:

REGIONAL SCIENTIFIC CLIMATE SERVICE CENTRES IN AFRICA

WASCAL (West African Science Service Centre on Climate Change and Adapted Land Use) and SASSCAL (Southern African Science Service Centre for Climate change and Adaptive Land Management) aim to strengthen the analytical capability of the two regions (Figure 6) by improving the networks of weather stations and developing qualitative and quantitative tools and models that can link biophysical and socio-economic processes and their feedbacks. These models are used to develop and evaluate scenarios of the impacts of climate change, including the assessment of alternative land use/land management options as a means to help society to cope with the vagaries of climate change, including climate trends, climate variability and extreme events.

The research activities of the WASCAL Research Programme are grouped into six research clusters that include: Climate and Weather, Landscape Dynamics, Agricultural Systems, Markets and Livelihoods, Risk Management and Integrated Assessment. This research programme is implemented by a team of scientists from a consortium of German universities and institutions and their African counterparts of the WASCAL Competence Centre. Under this programme, more than 200 junior and senior scientists from 42 African and European countries (mostly from Germany) are working together.

In nearly five years, more than 200 studies were carried out under 21 work packages in the WASCAL Research Programme (including the German Consortium Core Research Programme, the Competence Centre and the Graduate Study Programme).

SASSCAL is the respective initiative for Southern Africa. The 151 tasks in the research and capacity development portfolio of the network are grouped into five thematic areas: Climate, Water, Agriculture, Forestry, as well as Biodiversity and Wildlife. The initiative envisages becoming the regional driver for innovation and knowledge exchange to enhance adaptive land management and sustainable economic development under global change conditions. It provides data (e.g. network of weather stations at WMO standards in the region, (see Figure 7) as well as information on current states and projections of future trends to a broad range of stakeholders and decision makers from local to regional level through its Open Access Data Centre (OADC). The research findings of WASCAL and SASSCAL are being communicated to the relevant scientific circles and broader public through journal articles, book-chapters, conference and symposia contributions, discussion papers and short communications.

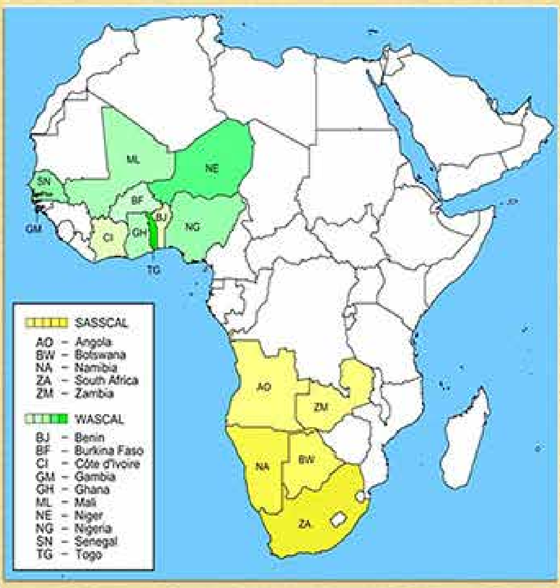


FIGURE 6. *WASCAL and SASSCAL regions*

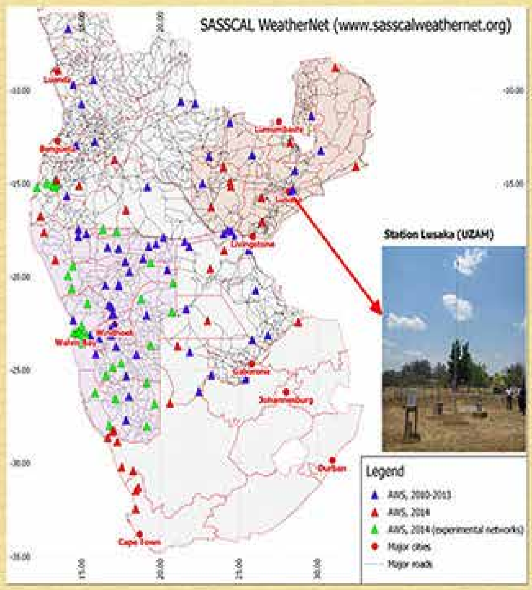


FIGURE 7. *SASSCAL network of weather stations*

services and co-operation with local farming and water use associations can assist here. Educational interventions have multisectoral benefits and can be described as a 'no regret option' in the campaign for climate change adaptation. It is recommended that climate change be incorporated into school curricula and explicitly addressed in a wide range of courses at undergraduate university level. Focused Masters level courses on climate change could facilitate local research on key local issues.

Technologies for Adaptation

The IPCC (2007) ascertains with a high (80%) confidence level that existing climate adaptation strategies in Africa will not be sufficient for survival in the context of projected environmental changes during the 21st century. Poor access to technology is a major hindrance to advances in climate adaptation in Africa, and this is particularly evident in the agricultural sector (Sachs *et al.,* 2004). These technologies could include water-harvesting systems, dam building, drip irrigation, drought-resistant and early-maturing crop varieties, as well as alternative crop and hybrid varieties. Infrastructural developments are also relevant under this category – piped water supply and energy supply allow for a reallocation of household resources while communication and road networks promote the exchange of goods and information. These can enhance household resilience through resource savings (e.g. time saved on collection of firewood and water) and economic diversification. Technological and infrastructural investments could range from enhancement of local, existing technologies to transfer of frontier technologies. Investment in scientific and technological infrastructure for a timely acquisition and use of frontier technologies will be critical as well. Adaptation comes with a range of initial costs and often sustained maintenance expenses. External investment (either by the state or by donors) is likely to be necessary to facilitate technology transfers, to enhance capacity-building, and to ensure effective usage and maintenance of these technologies.

Economic Diversification

An overarching climate adaptation strategy is economic diversification, which is particularly effective in the context of short term shocks to prevent conflicts and environmental degradation. Diversification has also been used to reduce growth volatility and broaden the tax base to raise fiscal revenue to the level required to sustainably finance critical development programmes such as climate-resilient infrastructure and scientific infrastructure. Diversification is achieved by broadening the range of activities that support households. In practice it involves a gradual shifting of resources from the traditional sectors (agriculture, natural resources and increasingly informal production) to the more technologically advanced sectors dominated by manufacturing. Diversification of farming activities could include mixed cropping or both crop and stock farming, so that farmers have an alternative output if there is a poor season for one crop or a stock disease outbreak. Households dependent on tourism could engage in additional income generating activities or maintain household food production for episodes when tourism is limited (e.g. in the case of drought or an acute event such as a tropical storm). In addition to sustaining households, economic diversification has the potential to limit stresses on climate sensitive resources, such as rainforests, as communities can focus on other food sources or income generating activities during periods of environmental stress as opposed to mining these resources to destruction. This of course assumes that not all options are facing the same stresses, a possibility if economic diversification remains directly dependent on climate sensitive natural resources. Diversification thus should not be limited to natural resource based options but could include increased engagement in the local and even regional markets, wage economy, and capital exchange. Although the latter options do come with concerns related to market instabilities and failures, facilitated diversification beyond agriculture and natural resource reliance is likely to be a key for household survival and to limit local conflicts in the context of acute climate events and long term changes.

Financing Climate Change Adaptation

Current levels of climate finance directed to sub-Saharan Africa (SSA) are likely to be insufficient to meet the region's demonstrated need for adaptation finance, estimated by the World Bank as at least USD 18 million per year until 2050. Resource mobilisation efforts at regional level should focus on identification and involvement of regional institutions well positioned to provide financial or technical support or both. African governments can increase their chances of success to the extent that they are able to mobilise the regional bodies and intergovernmental economic and political groupings such as the East African Community (EAC), Southern Africa Development Community (SADC), New Partnership for Africa's Development (NEPAD) and African Union (AU). These bodies are well placed to provide financial and technical support to countries and to link with broader capacity-building efforts. Public sector grant-finance will play a crucial role in realising the significant environmental, developmental and social, including gender, co-benefits of climate actions in the region, particularly for adaption measures (Schalatek *et al*., 2012). Chances of success in mobilising the resources at global level will be greatly facilitated to the extent that African governments are able to demonstrate that climate change adaptation programmes can generate, across scales, outputs and outcomes that are sustainable and beneficial. The global climate finance architecture is complex: finance is channelled through multilateral funds – such as the Global Environment Facility and the Climate Investment Funds – as well as increasingly through bilateral channels.

5 Conclusions

Africa faces a myriad of development challenges that are exacerbated by projected climate changes across the region. Of particular concern, is the direct reliance of a significant proportion of the population on natural resources, particularly, in arable and pastoral agricultural practices, but also through fishing and harvesting of natural vegetation for shelter, fuel, medicines and crafts. Present issues related to food and water security, health and safety are likely to be compounded by projected climate changes. At the same time, populations continue to grow, placing additional stress on resources. Climate change clearly needs to be integrated into multi-sectorial policies and macro-economic frameworks for these issues to be adequately addressed. The focus must lie on informed, forward-thinking policies that integrate the best understandings of regional risks and vulnerabilities, together with local understandings of the environmental context and cultural needs. This balance is only possible through civic engagement and the active participation of local stakeholders in decision-making processes and policy development. These forms of engagement increase the likelihood of the success of adaptation interventions through local buy-in.

There is a clear need to enhance the resilience of African communities such that they are able to survive environmental shocks and recover afterwards without increasing their vulnerability in the future. Development of social resilience (through institutional support) and economic resilience (through provision of financial assistance, insurance options and livelihood diversification) needs to be facilitated and enhanced. Facilitated adaptation can take the form of service delivery, provision of aid, education as well as provision of technologies and other forms of institutional support to sustain communities in times of upheaval. Access to technologies and capacity-building for their effective use and management is vital to promote adaptation in Africa in the future. The search for simple but effective technologies that can be produced and disseminated cost effectively is key, but the development of institutional frameworks supporting their effective use and maintenance is as important for sustainable application. Such measures will require a redistribution of centralised public funds to regional and local initiatives. International investments and aid may be necessary in some regions where extreme climate change and vulnerable communities coincide.

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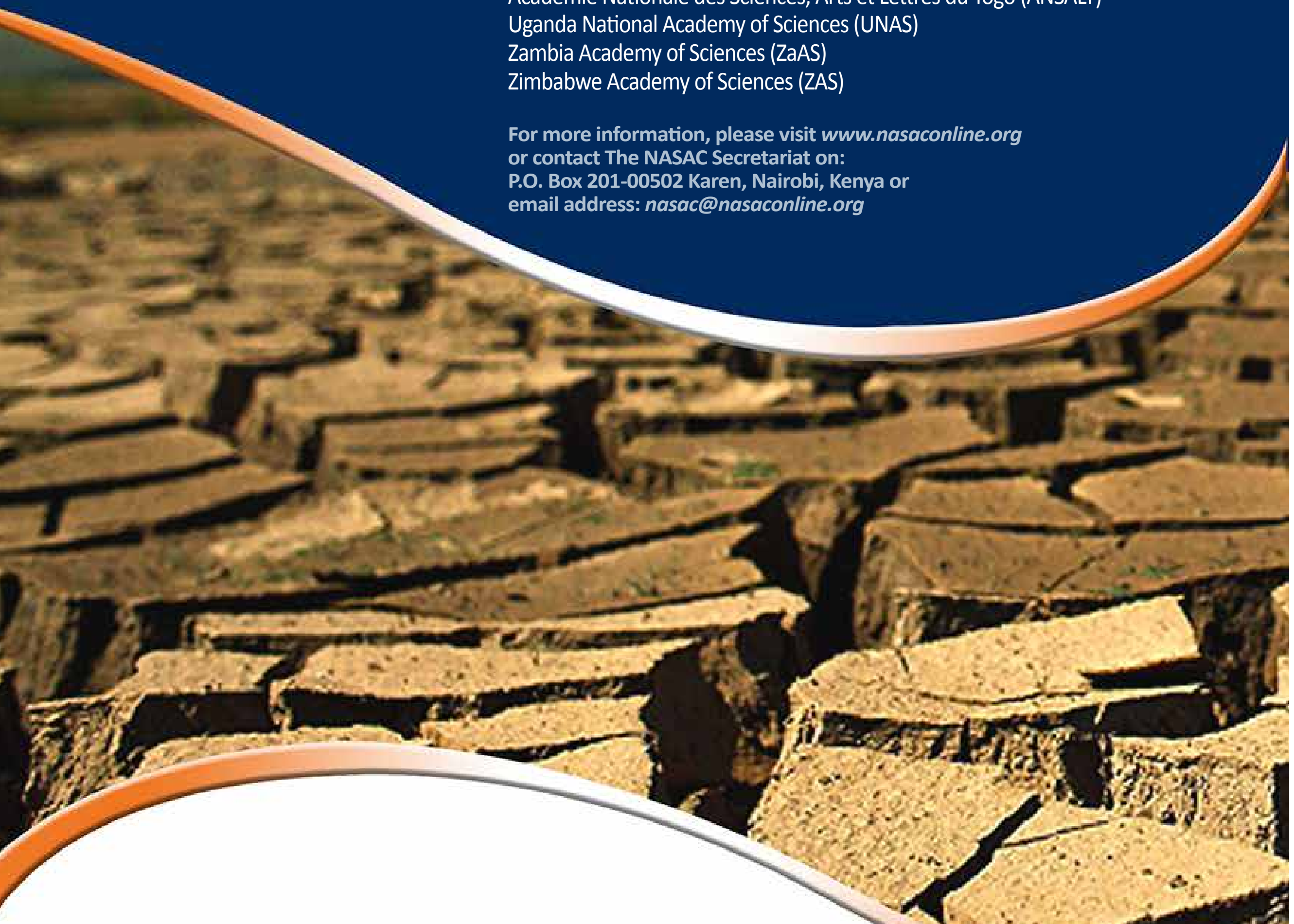

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