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African Climate Policy Centre

United Nations Economic Commission for Africa
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Working Paper 2

Vulnerability and climate change hotspots in Africa- mapping Based on Existing Knowledge

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VULNERABILITY AND CLIMATE CHANGE HOT SPOTS IN AFRICA: MAPPING BASED ON EXISTING KNOWLEDGE

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ACMAD	African Centre of Meteorological Applications and Development
ACPC	African Climate Policy Center
AR4	IPCC Fourth Assessment Report
CCAFS	Climate Change Agriculture and Food Security
CRU	Climate Research Unit
CV	Coefficient of Variation
DALY	Disability Adjusted Life Years
DJF	December-February
DRR	Disaster Risk Reduction
EACZ	East African Coastal Zone
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization
GCMs	Global Climate Models
GDP	Gross Domestic Product
GHGs	GreenHouse Gases
ICPAC	IGAD Climate Prediction and Application Center
IGAD	Intergovernmental Authority on Development
IPCC	Intergovernmental Panel on Climate Change
JJA	June-August
LGP	Length of the Growing Period
MAM	March-May
MCZ	Mediterranean Coastal Zone
MDGs	Millennium Development Goals
NAPAs	National Adaptation Programmes of Actions
NMHSs	National Meteorological and Hydrological Services,
OECD	Organization of Economic Cooperation and Development
RCCP	Regional Climate Change Programme
SADC-CSC	Southern Africa Development Community-Climate Service Center
SON	September-November
SRES	Special Report on Emissions Scenarios
SSA	Sub-Saharan Africa
SST	Sea Surface Temperature
UKMO	United Kingdom Met Office
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
WCACZ	West and Central African Coastal Zone
WHO	World Health Organization
WRI	World Resources Institute
WUE	Water-Use Efficiency

ABSTRACT: The climate of Africa varies from humid tropical climate to hyper-arid Saharan climate. The rainfall is highly variable in space. The coefficient of variation of rainfall is mapped in this paper and it revealed that rainfall variability is large in drought prone areas of the continent. The African rainfall is dominated by inter-annual and decadal variability for the past; however, the future rainfall projections indicated a decreasing trend in rainfall along the Mediterranean coast and southern Africa and projected an increasing trend in East Africa. It is uncertain how rainfall will change over the Sahel and the southern Sahara. The frequency of extreme events will increase in the various parts of the continent and Africa is very likely to warm in 21st century.

The African continent is vulnerable to climate variability and change due to the sensitiveness of all the economic sectors to climate and its low adaptive capacity. The water, agricultural and health sectors as well as the ecosystem are sensitive to varying and changing climate. The magnitude and frequency of extreme events such as drought and floods are increased with climate change and impacted the above sectors. The rise of mean sea level as a result of the global warming is threat for African coastal cities especially cities close to major river deltas. The agricultural sector is also very sensitive to rising surface temperature trend and varying rainfall pattern for attainment of food security of the continent. The climate sensitive diseases (malaria, meningitis and cholera) will expand to areas where these types of diseases are not common. Malaria will likely expand to highlands due to suitability of the mosquito to breed with increased temperature.

Risk and vulnerability mapping highlights the hotspots of current and future climate-related vulnerability for adaptation planning and knowledge disseminating processes. The climate change hotspots in Africa have been mapped based on existing knowledge. The mapping was done for the water, agriculture, health, coastal and marine sectors. Some adaptation strategies have been pointed out for the different sectors but an integrated approach has been suggested to minimize the cost of adaptation. Formulating policies that will enable climate information on variability and change to be mainstreamed into development will reduce risk of weather and climate related disasters. In line with this, the African Climate Policy Centre, in collaboration with existing institutions, can play a leading role by incorporating climate information into development programs through awareness creation, advocacy and capacity building.

KEYWORDS: vulnerability, adaptation, hotspots, climate change, climate variability

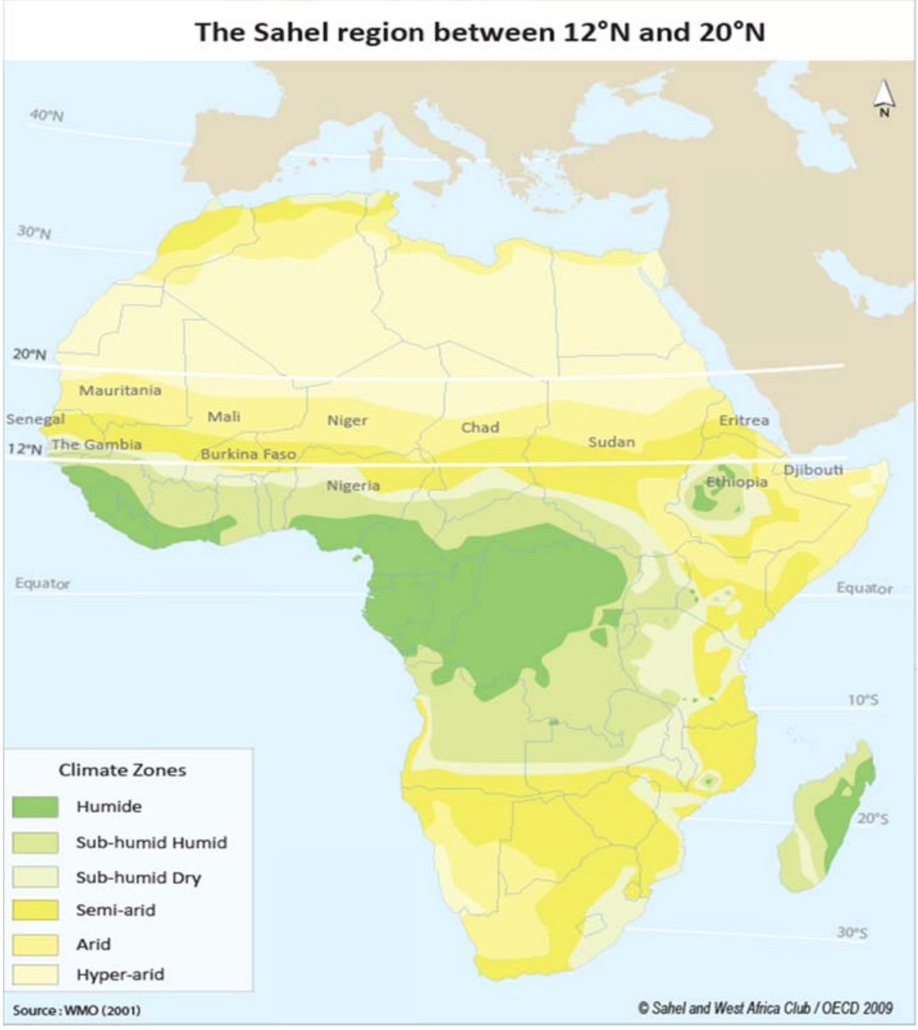
1. INTRODUCTION

According to the Intergovernmental Panel on Climate Change IPCC(2007), the warming of the climate system is unequivocal, as it is now evident from the observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. At regional scale it is observed that:

- Significantly increased precipitation in eastern parts of North and South America, northern Europe and northern and central Asia ;
- Frequency of heavy precipitation events has increased;
- Drying in the Sahel, the Mediterranean, southern Africa and parts of southern Asia; and
- More intense and longer droughts have been observed in the tropics and subtropics.

Furthermore, observational evidence from all continents and most oceans show that many natural systems are being affected by regional climate changes, particularly temperature increases. In association to these effects, there are also other effects of regional climate change on natural and human environments that are emerging.

According to WMO (2001), Africa is divided into 6 climatic zones (Fig. 1). The climate varies from humid tropical climate to hyper-arid Saharan climate. The rainfall is highly variable in line with the climate zones. The rainfall decreases significantly as one move from humid to hyper-arid. Climate change will also exacerbate the rainfall variability within each climate zones.



Source : WMO (2001)

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Figure 1: The Climate zones of Africa (source WMO 2001)

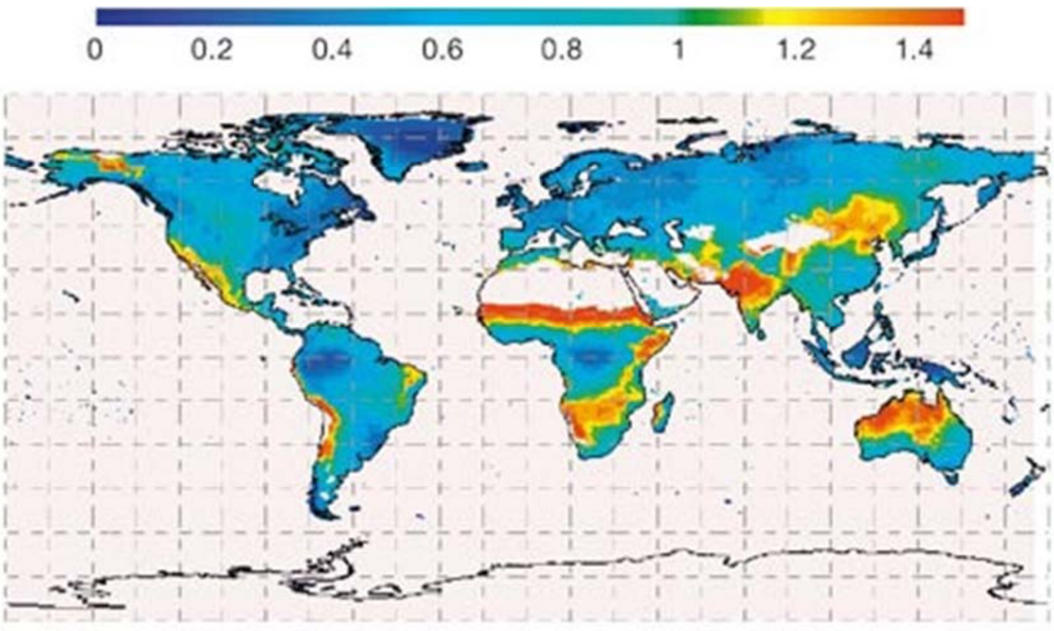


Figure 2: The Coefficient of Variation of rainfall over Africa (Data sources: Mitchell and Jones, 2005).

Figure 2 depicted that the rainfall is highly variable over much of Sahel, parts of eastern and southern Africa with Coefficient of Variation (CV) more than 1.2. High values of CV are evident for the drought prone areas of the continent, i.e., the Sahel, parts of eastern and southern Africa. From this one can infer that regions that have large rainfall variability are more vulnerable to drought. In much of the remaining parts of the continent, except the Sahara, the variability of rainfall is relatively small. As clearly shown on the variability map above (Fig. 2), the Sahel region extending from west to east is the region where very large CV values are obtained. Thus, it is interesting to demonstrate the low confidence in available modeling notably over region such as Sahel.

Climate change and increasing climate variability threaten the attainment of national sustainable development and in particularly the United Nations Millennium Development Goals (MDGs) in many African countries. Some of the worst effects on human health, livestock and agriculture especially food security will be in the vulnerable regions of Sub-Saharan Africa (SSA). As already noted, climate change increases the likelihood of extreme weather events such as droughts, floods, sea level rise and heat waves, as well as more gradual changes in temperature and precipitation (IPCC, 2007). Some of these impacts have already been observed in a number of African countries. The Nairobi Declaration on the African process for Combating Climate Change (UNEP, 2009) of the African Ministers of Environment called upon Governments of Africa to promote further the common African position on the comprehensive international climate change regime beyond 2012 and participate actively in the continuing international negotiations, knowing that failure to reach a fair and equitable outcome will have direct consequences for Africa. The Ministers also agreed that the African common position forms the basis for negotiations by the African group during the negotiations for a new climate change regime and should take into account the priorities for Africa on sustainable development, poverty reduction and attainment of the MDGs.

A number of African countries experience frequent extreme weather and climate conditions. Frequent droughts have been observed in the Greater Horn of Africa and Sahel. The Regional climate prediction centers such as the African Centre of Meteorological Applications and Development (ACMAD) in Niamey, Niger; IGAD Climate Prediction and Application Center (ICPAC) in Nairobi, Kenya; and Southern Africa Development Community-Climate Service Center (SADC-CSC), Gaborone, Botswana, in working with the National Meteorological and

Hydrological Services (NMHSs), have played a major role in the provision of climate predictions with respect to their regions. The severe events such as droughts and floods have been associated with climatic conditions such as the El Niño and La Niña which in recent years have become stronger and frequent. They affect the livelihood and economic development of the countries. Depending on the weather conditions that are experienced within that particular year or season, in certain occasions, the same countries also experienced severe flooding conditions. For example a country like Kenya has areas that on certain occasions have experienced droughts and other areas that have experienced floods.

The threat to the African coastal cities of the continued sea level rise is eminent. A number of studies, such as that of IPCC (2007), on the impact of sea level rise have indicated that some of these cities are likely to be serious affected by the projected sea level rise.

Many studies have mapped vulnerable areas and climate change hotspots in Africa (e.g. Thornton et al., 2008, and Thow and de Blois, 2008). The outcomes of most of these studies suggest, if tentatively, many vulnerable systems may be adversely affected by climate impacts, including the mixed arid-semiarid systems in the Sahel and rangelands in eastern Africa, the Great Lakes region, the coastal regions of eastern Africa and the drier zones of southern Africa. Some of these studies have been limited to sector specific areas. There is broader understanding that Africa encompasses some of the worlds' regions most vulnerable to climate change. However, identifying these regions and characterizing them provides useful information to suggest adaptation measures thus address key developmental issues such as the MGDs. The purpose of this particular paper is therefore to use existing knowledge and put together the vulnerability maps and climate change hotspots in Africa. The results will serve as an input to future studies that will further map vulnerable areas and assess climate change impacts over different parts of the African region.

2. AFRICAN CLIMATE TRENDS AND PROJECTIONS

In general, Africa has been dry for the last few decades (Nicholson, 2005; L'Hóte et al., 2002; Oguntunde et al., 2006). In fact, the existence of long duration records with good documentation and established quality for use as indicators of environmental change is limited. Although some studies have identified downward trends of rainfall amounts in some regions, the situation is non-uniform and is highly sensitive to which region/period of time is used for analysis. Results from recent studies of daily rainfall in Africa highlight the contrasting behavior across a range of spatial and temporal scales. Accordingly, in the Equatorial East, the daily rainfall records analysis over 34 stations within the period 1958–1987 indicated that there are large variations in spatial coherence of the seasonal rainfall cycle. Hence, inter-annual variations in the onset date of the rainy season have the biggest impact on the seasonal rains (Camberlin et al., 2009).

The daily rainfall records over 66 stations in the period 1955–2006 covering the western and central Africa, Guinea Conakry, Zimbabwe examined by Aguilar et al., (2009) showed that the total rainfall amount and the contribution of have rain events to the total rainfall amount has decreased over the years. However, the total rainfall amount in Zimbabwe is not showing any trend. New et al., (2006) have studied the rainfall of Southern Africa and Western Africa by using daily rainfall records from 63 stations for analysis period 1961 to 2000. The authors reported a slight decrease in total rainfall amount though the observed trend was not statistically significant. New et al., (2006) also reported an increase in rainfall intensity and dry spell duration of the rainfall of Zimbabwe. Kruger (2006) analyzed 95 years (1910–2004) of daily rainfall records from 138 stations over southern Africa. The authors revealed that some areas of southern Africa have coherent trends of either long dry- or wet spells although the region has no overall significant trend.

Most of the published regional climate studies of Africa address rainfall. Other climate variables in the region received relatively less research attention though few studies reported some informative results. For instance, the findings of IPCC (2007) report which indicated that the temperature of Africa rose by about 0.5°C in the last century This is a similar rate of level of warming which is reported to other parts of the globe, with the highest rates of warming in the 1910s–1930s and post-1970. There is evidence for a slightly larger warming in June–August (JJA) and September–November (SON) than December–February (DJF) and March–May (MAM). King'uyu et al., (2000) analyzed 71 long year records of daily maximum and minimum temperature for the eastern and southern Africa. They identified a significant rise in minimum temperature at several locations though such rise showed non-uniform spatial variability. Temperature of stations at many coastal areas and near large water bodies showed a significant decrease. Aguilar et al. (2009) reported an increase in warm extremes in western and central Africa, Guinea Conakry and Zimbabwe.

By 2080, most climate models project wetter conditions in West and East Africa with an increase in rainfall amount by 2% and 7%, respectively and drier conditions in southern Africa and the Sahara with a decrease in rainfall amount by −4% and −6% respectively (IPCC, 2007). However, individual models generate huge disparity responses in the Sahel and parts of central and the Horn of Africa, such that, at present, there is no clear signal of future rainfall patterns in these regions (Conway, 2011).

2.1 Surface Temperature

Surface temperature is strongly coupled with the atmospheric condition above it. This is especially evident at mid-latitudes, where migrating cold fronts and warm fronts can cause relatively large swings in surface temperature. The large scale distribution of annual mean surface temperature is largely determined by the distribution of insolation, which is moderated by clouds, other surface heat fluxes and transport of energy by the atmosphere and to a lesser extent by the ocean (IPCC, 2007).

African climate is relatively affected by the atmospheric mechanisms often coupled with the induced oceans temperatures. Figure 3 shows the global surface temperature anomalies for the past 4 decades, relative to the 1951–1980 base periods. On average, successive decades were warmed by 0.17°C. Similarly, the warming of the 1990s (0.13°C relative to the 1980s) was reduced by the temporary effect of the 1991 Mount Pinatubo volcanic eruption. In Africa, the temperature anomaly has seen a large increase ranging from -0.6 up to 1.5°C within four successive decades.

Warming in these recent decades is larger over land than over ocean, as expected for a forced climate change [Hansen et al., 2007; IPCC, 2007; Sutton et al., 2007], in part because the ocean responds more slowly than the land due to the ocean's large thermal inertia. From climate models and empirical analyses, GHG forcing trend translates into mean warming rate of ~0.15^{o}C per decade. El Niño Southern Oscillation (ENSO), increasing GHGs continue to be the dominant factors affecting inter annual and decadal temperature change.

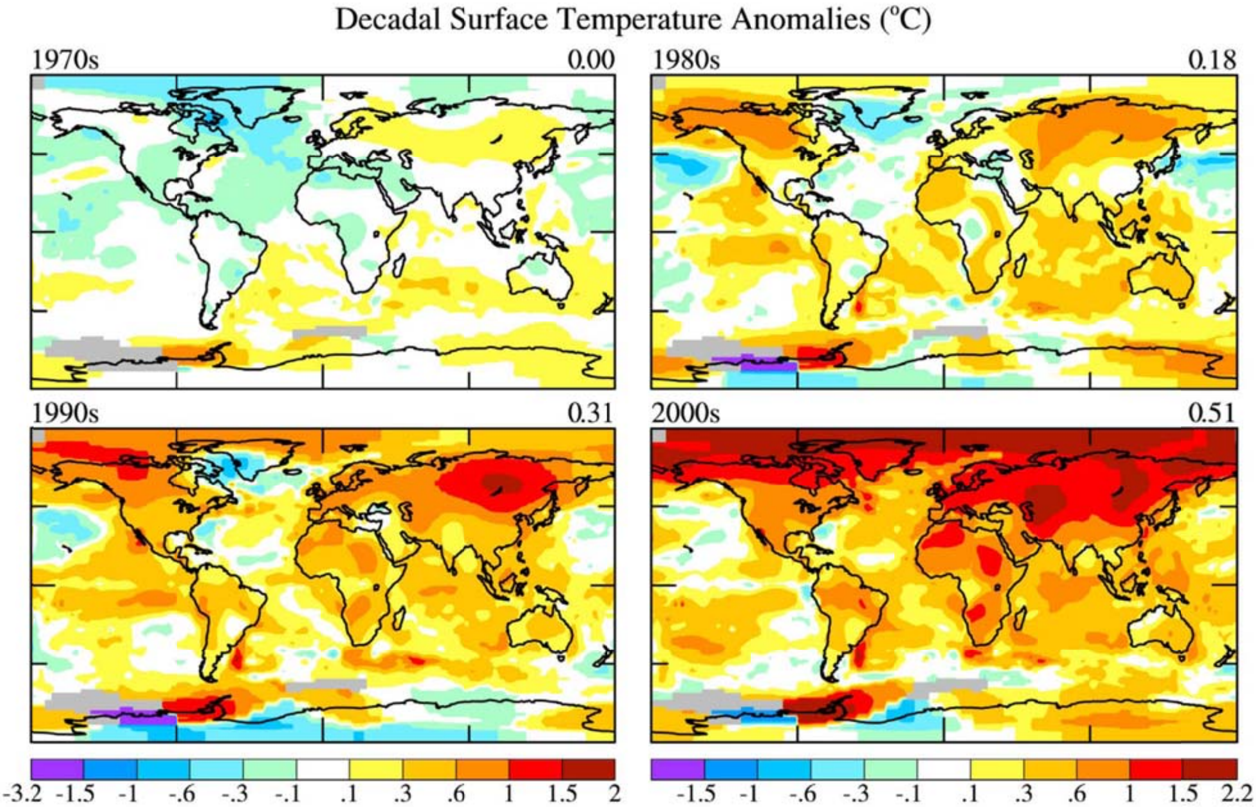


Figure 3: Global surface temperature anomalies for the past 4 decades, relative to the 1951–1980 base periods (Hansen et al., 2010).

Hence, it is globally estimated that the temperature is rising with an increasing rate in the past decade despite year-to-year fluctuations associated with ENSO. After reviewing the aforementioned studies, it can be concluded that there has been no reduction in the global warming trend of 0.15°C-0.20°C per decade that began in the late 1970s.

2.2 Rainfall

According to IPCC AR4-WGII (2007) and Sokona et al. (2011) rainfall exhibits notable spatial and temporal variability, with large inter-annual variability over most of Africa and substantial inter-decadal variability for some regions of Africa. Decline of rainfall amount has been observed in West Africa and tropical rain forests, but there is also an increase in rainfall amount along the Guinean coast. There do not appear to be any significant trends in Southern Africa, but rather there are signs of increased inter-annual rainfall variability, higher rainfall anomalies, more intense and widespread droughts, and a significant increase in heavy rainfall events including evidence of changing seasonality and weather extremes. East Africa has recently experienced an intensifying dipole rainfall pattern on the decadal time scale, with the characteristics of increased rainfall amounts over northern sector and declining amounts over the southern sector.

Advances have been made in understanding complex mechanisms responsible for rainfall variability. Understanding the effects of climate regime change on Africa's weather and climate, e.g., how the ENSO may influence climate variability, is crucial and deserves further research. Similarly it is important to understand the linkage between the drying of the Sahel and Sea Surface Temperature (SST), the intensity and locality of various jets, etc., and the influence of these linkages on, and of, climate variability. Furthermore, vegetation cover and land cover change, atmospheric dust loading changes also influence climate change and variability in many dynamic and complex ways.

Changes in the characteristics and timing of extreme climatic events, including floods and droughts, have significant implication on Africans and their economies. Several million people regularly suffer from the impacts of floods and droughts. One third of Africans live in drought prone areas. Droughts have mainly affected the Sahel, the Horn of Africa, and southern Africa, particularly since the end of 1960s. Recurrent floods in some countries, in certain cases, are linked to ENSO events.

Despite the lack of convergence in predicting future trends in precipitation in Africa, the following general conclusions can be drawn from Nkomo et al., (2006):

1. In northern Africa, a decrease in precipitation amount in June-August (JJA) (10-25% decrease) is projected for the 2010-2039 period;
2. In western Africa, there is an agreement between models to a progressive increase in precipitation (between 10 and 35%) for the December-February (DJF) period (which is normally dry);
3. In the Horn of Africa, a net increase in precipitations is projected for DJF period (between 10 and 30%);
4. In southern Africa, a net trend towards decreased precipitations is predicted for the JJA (less 15 to 62%).

The following two maps (Fig. 4) show the difference in summer (JJA) precipitation (mm/day) between 2041 – 2070 and 1960 – 1990 across AR4 ensemble and the Met Office Hadley Centre ensemble (left side).The colour indicates the strength of the signal while the colour-intensity indicates the consistency across the ensemble. For example, deep red colours indicated where nearly 100% of models agree on a precipitation reduction of more than 0.1 mm/day, dark green indicates where nearly 100% of models agree on nearly no change. West-most Sahel is the area where both the largest and the most reliable signal is noticed. The signal on west-most Sahel appears to be fairly similar to the one detected by AR4 while significant differences exists over Central and East Sahel where Met Office ensemble seems to suggest a consistent wetting.

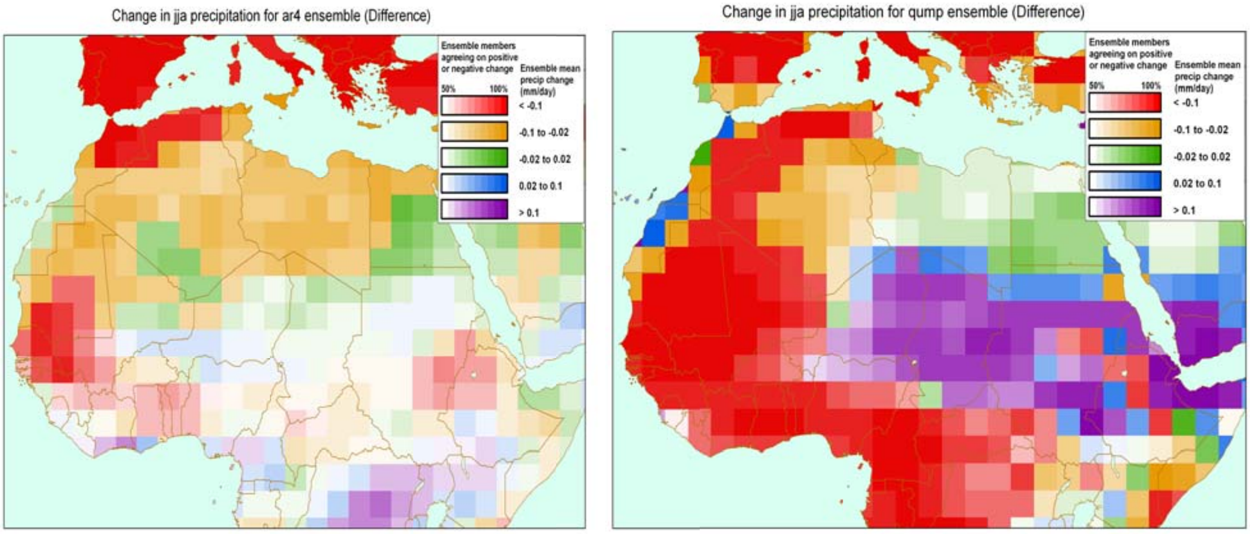


Figure 4: Difference in summer (JJA) precipitation (mm/day) between 2041-2070 and 1960-1990 across AR4 ensemble (right side) and the Met Office Hadley Centre ensemble (left side).

2.3 Mean Sea Level and Lake Levels

The oceans and seas that surround Africa have a huge impact on the coastal parts of Africa as a result of mean sea level rise. Especially, most of big cities of West Africa are located in the coastal line. The mean sea level of the global ocean is rising as a result of the thermal expansion of water due to the rising sea surface temperature and melting of sea ice, glacier and ice caps. IPCC (2007) indicted that the global average sea level rose by about 1.7mm per year for last century. The recent satellite measurements revealed that the mean sea level rose 3mm per year since 1993. Observations confirmed these increase.

Although the lake levels vary from season to season, there is general decrease in lake levels. For instance, Lake Chad is on the way to vanish and Lake Victoria level is falling recently (USDA, 2005). The trend of Rift Valley lakes of Malawi and Chilwa varied from time to time for the last 200 years i.e., there was no clear trend on the lake levels of the two lakes for the study period (Nicholson, 1998).

Satellite and hydrographic observations show that sea level is not rising uniformly around the globe. In some regions the rise in mean sea level is higher than the global mean while in other regions the mean sea level is falling. Spatial variability of the rates of sea level rise is mostly due to non-uniform changes in temperature and salinity and related to changes in the ocean circulation. For example, the analysis of 14 years altimeter data revealed a positive sea level trend of 2.1±0.6 mm per year in the Mediterranean Sea and a falling trend was shown in the Algeria basin and some African coastal areas (Aldeanueva et al., 2008). Furthermore, the southern Africa sea level trends vary, with the West Coast rising by +1.87 mm per year (1959–2006), the southern coast by +1.48 mm per year (1957–2006) and the East Coast by +2.74 mm per year (1967–2006) (Mather et al., 2009).

Sea surface temperatures are also virtually certain to rise significantly although at a smaller rate than the global mean temperature rise under different emission scenarios (IPCC, 2007). In all scenarios, the average rate of rise during the 21st century is very likely to exceed the 1961 to 2003 average rate of 1.8 ± 0.5 mm per year. The central estimate of the rate of sea level rise during 2090 to 2099 is 3.8 mm per year under A1B, which exceeds the central estimate of 3.1 mm per year for 1993 to 2003.

The projection of Lake Levels is uncertain for the future. For example, lake levels in Lake Tumba in the Democratic Republic of Congo (Inogwabini et al., 2006) and Lake Victoria (Birkett et al., 1999) have been attributed to climate variations and may become more variable in the future.

2.4 Extreme Events

African countries are plagued by extreme events such as floods, droughts and storms. Research indicated that the frequency and intensity of extreme events increased with time. For example, the analysis of Shongwe et al., (2011) revealed that there has also been an increase in the number of reported hydrometeorological disasters in East Africa, from an average of less than 3 events per year in the 1980s, to over 7 events per year in the 1990s, and almost 10 events per year from 2000 to 2006. For southern Africa, the analysis from them in 2009 indicated that the average annual number of reported natural disasters in the region has risen from about 5 reported disasters a year in the 1980s to over 18 a year from 2000 to 2006. Their further refined analysis revealed that drought-related disasters have risen from an average of about 1.5 per year in the 1980s to about 2 per year since 2000, while those related to floods have risen from 1.2 a year to almost 7 per year since 2000.

The assessment of IPCC (2007) showed that the frequency of heavy and very heavy rainfall events decreased in East Africa and West Africa while the frequency of heavy and very heavy rainfall events increased in southern Africa.

The expected increase in greenhouse gases in 21^{st} century due to population increase and development activities will further warm the planet. This in turn will increase the extreme weather in various parts of Africa. Shongwe et al., (2009) reported that the western part of southern Africa 10 years driest seasons projected to increase by 10%. Their study also indicated that significant increases in 10 years wettest events are found in eastern South Africa and farther north in northern Zambia, Malawi, and Mozambique. The same study for East Africa revealed that increases in both mean precipitation rates and the intensity of 10-years wettest events are simulated almost throughout the region, while dry extremes are becoming less severe.

IPCC (2007) reported that there is little modelling guidance on possible changes in tropical cyclones affecting the southeast coast of Africa in 21^{st} century. The distribution and intensity of tropical cyclone in the Indian Ocean remain uncertain, however, Oouchi et al. (2006) obtained a significant reduction in the frequency of tropical storms in the Indian Ocean using 20km horizontal resolution atmospheric general circulation model.

In summary, all parts of Africa are very likely to warm during this century. The warming is likely to be somewhat larger than the global, annual mean warming throughout the continent and in all seasons. Annual rainfall is very likely to decrease in much of North Africa and northern Sahara, while winter rainfall will very likely decrease in much of southern Africa. There is likely to be an increase in annual mean rainfall in tropical and Horn of Africa, while it is uncertain how rainfall in the Sahel and the southern Sahara will evolve in this century (Nkomo et al., 2006).

3. VULNERABILITY AND POTENTIAL IMPACTS IN DIFFERENT SECTORS

Vulnerability is a function of sensitivity to represent climatic variability, the risk of adverse future climate change and capacity to adapt. Many of the impacts of climate change are uncertain, vulnerability is dynamic and continually changing as a result of various factors. Thus, adaptation strategies need to promote responsive institutions that maintain a rich repertoire of policy options. Social resilience in the face of climate change should complement the aims of sustainable development and coping capacity. Planning adaptation must begin with an understanding of vulnerable populations and regions based on an assessment of the capacity of these groups to cope with climate variability and change (UNEP, 2001).

The information needed on vulnerability and adaptation begins with individual sectors and includes integrated assessments at the level of vulnerable socio-economic groups. The range of adaptation strategies and adaptive options needs to be identified and evaluated. Identifying vulnerable situations and planning and monitoring effective adaptation measures could be done using formal indicators of vulnerability and adaptive capacity. It will be appropriate if local to regional quantitative indicators could be obtained (UNEP, 2001).

Global climate change is likely to affect everyone on earth to some degree. The effect could be in the form of social, psychological, economic or environmental change, or a combination of these.

The people to be affected most will typically be the poorest and most vulnerable communities who may have little information about impending hazards and are often the least able to rebuild their lives and livelihoods after having suffered a setback. To be able to give enough attention to the impacts of a disaster ahead of time and actually do something about them requires identifying regions and communities most likely at risk of specific climate-related disasters (Baker et al., 2008). Impacts occur when certain thresholds are reached. These thresholds mostly depend on factors that include the age of the systems and existing conditions in a specific area, among others. The regions that are most vulnerable (i.e., potential hotspots) will be areas where existing gradients are large and projected changes are also large. The hotspots that are obviously linked with impacts could be in different sectors. These could be flood-risk, drought-risk, cyclone-risk, disease-risk among others. Areas of high population density that are also at risk hotspots could be interpreted to be at higher risk of future population displacement as a result of climate hazards.

Much of Sub-Saharan Africa is said to be at risk from more than one climate-hazard and thus warrant special concern (Baker et al., 2008).

Identifying these hotspots require actions to be taken that would prevent high incidences of hazards from resulting in high levels of human vulnerability. Baker et al., (2008) suggests some of the actions that could be taken include:

- Increased investment in disaster risk reduction (DRR). This means focusing on reducing vulnerability rather than just reacting to emergencies;
- Ensuring faster and more appropriate responses to disasters;
- Investing in improved hazard and vulnerability analysis and mapping systems. This will enable a better assessment of risks arising from climate change. Such investments include improving climate-monitoring technology in order to improve mapping, improving the reliability of forecasts and model good practice. This information needs to be translated into policy to ensure appropriate support to vulnerable populations affected by climate change;
- Mitigating climate change.

There are significant sensitivities and vulnerabilities of various sectors, in particular, water, health, agriculture, ecosystems, settlements and infrastructure, which are crucial sectors in Africa. The sensitivities and vulnerabilities of these sectors according to IPCC AR4-WGII (2007) and Sokona et al., (2011) and others are briefly summarized in sections below.

3.1 Hydrology and Water Resource of Africa

3.1.1 Sensitivity of Hydrology and Water Sector

The hydrology, water resources and water using sectors are strongly influenced by, and sensitive to, changes in climate and prolonged climate variability. Climate change will not have uniform impacts on water issues across the continent. In some parts it will aggravate water stress while in others it will reduce water stress. Changes in runoff and other components of hydrology are strongly associated with climate through complex interactions. Due to a lack of information, the interaction between climate change and ground water is not clear, however, there is no doubt that climate change affects the recharge and water balance, and as such it is a great concern for Africa as most of the rural water supply is dependent on ground water. Major concerns for the water sector in Africa include the limited access to water due to insufficient infrastructure to provide reliable supply of water for drinking, agriculture and other uses combined with limited governance capacity.

3.1.2 Development, Vulnerability, Impacts and Adaptation of the Water Sector

Water availability and access in different parts of Africa are variable. Arid regions of Africa, such as North Africa, are most associated with physical water scarcity, which means there is not enough water available in physical terms, and per capita physical water availability is less than 1,000 m^3 per person per year, which indicates the threshold of scarcity. However, the people in these regions appear to have better water management capacities for their limited resources. Many African countries may have good per capita physical water, but the major constraint is access to water due to poor infrastructure, which means they are constrained due to economic water scarcity. Climate change and variability have the potential to impose additional pressures on water availability, water accessibility and water demand in Africa. Even in the absence of climate change, present population trends and patterns of water use indicate that more African countries will exceed the limits of their “economically usable, land-based water resources before 2025”. The impacts of climate change on the water resources across the continent are not uniform. According to some assessments reported in IPCC AR4-WGII (2007), the total population at risk of increased water stresses across Africa for the full range of SRES scenarios is projected to be 75-250 million and 350-600 million people by the 2020s and 2050s respectively. Based on various reports and six climate models and SRES scenarios, IPCC AR4-WGII(2007) reports that there is likely to be an increase in the number of people who could experience water stress by 2055 in northern and southern Africa and a reduction in eastern and western Africa.

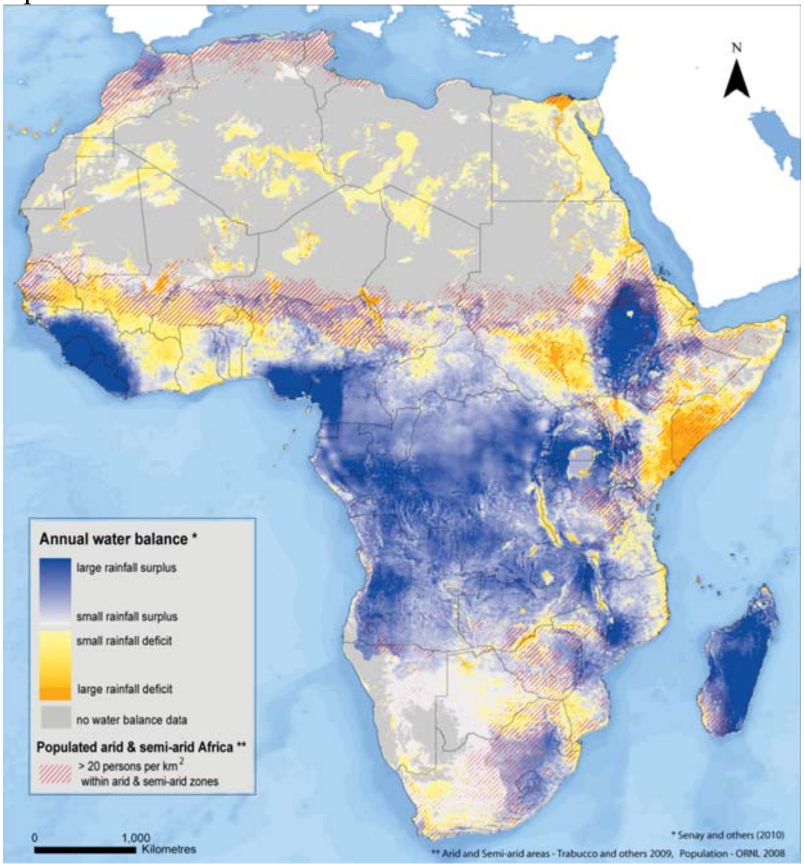
Some studies, in which are undertaken for different parts of Africa, show that with an increase of 1^{o}C in temperature while keeping the rainfall constant, there would be a reduction of runoff by up to 10%. However, given the great inherent uncertainty and complex factors such as population growth, predictability of climate change and related impacts, it is not possible to estimate this with confidence. The possible range of Africa wide climate change impacts on stream flow increases significantly between 2050 and 2100, with a range that includes stream flow decreases of 15% to increases of up to 5% above the 1961-1990 baseline. For 2100, the range is from a decrease of 19% to an increase of 14%.

3.1.3 Mapping Vulnerabilities

Mapping vulnerabilities due to climate change is a difficult task, as most of climate change related vulnerabilities manifest themselves through the medium of water such as in flood, drought, extreme variability, sea level rise, etc. A number of future threats exist in Africa with regards to water and climate change. These include sea-level rise affecting coastal areas; temperature rises induced increased water requirements, decreased water use efficiency and likely reduction of productivity; increased irrigation water demand due to population growth and insecurity of rain fed agriculture; a high degree of uncertainty about the flows in the rivers including due to the operation of hydropower schemes and generation of electricity. Figure 5 (UNEP, 2010) for example shows the population density and water balance over Africa to identify the hotspots based on population density. Similar type of maps for Africa for example related to water scarcity, hotspots due to flooding and other similar factors can be mapped. However, these require a good research on spatial, biophysical and socio-economic analysis.

Assessments of impacts on water resources currently do not fully capture multiple future water uses and water stress and must be approached with caution. Due to uncertainties, there are no clear indications of how the flows will be affected by climate change because of the uncertainty about rainfall patterns across basins and the influence of complex water management and water governance structures. The best preparedness is to invest more across Africa to improve water infrastructure in order to enhance the positive roles and mitigate the negative impacts of water.

Clearly, more detailed research on water hydrology, drainage, trans-boundary governance linked to climate change is required.



* Senay and others (2010)

** Arid and Semi-arid areas - Trabucco and others 2009, Population - ORNL 2008

Figure 5: Annual water balance
(is an estimate of the available runoff after evapotranspiration- water that is potentially available for water harvesting. The red hatching overlaying the water balance map shows where population density of greater than 20 per km^2 coincides with areas defined as arid or semi-arid).

3.2 Agriculture and Food Security

3.2.1 Present Agriculture

Agriculture is not only a vital source of food in Africa but also its prevailing way of life. One-third of the national income in Africa is generated by agriculture in which the poor from developing countries of Sub-Saharan Africa spend on average 60–80% of their total income on food (Odingo, 1990; WRI, 1998; FAO, 1999). Additionally, agriculture and household incomes are characterized by large inter annual and seasonal variations. The annual flow of income normally rises and reaches the peak during the harvest season. About 95% of agricultural lands are under rain-fed systems, hence non-agricultural and migrant, off-farm wage incomes are substitutes during the dry season. Thus, the period preceding the harvest is critical because unemployed farmers tend to migrate to urban centers as one of the strategies for coping with scarcity (IPCC, 2001).

Climate variability sets a heavy reliance on food aid, at the national and household levels, and enhances fluctuations in annual food production. Food aid constitutes a major proportion of net food trade in Africa. In Kenya and Tanzania, for instance, food aid constituted two-thirds of food imports during the 1990s. Relative to other regions, Africa clearly is among the regions with the lowest food security and the lowest ability to adapt to future changes (as indicated by the Human

Development Index). The state of food security is not uniform, and there has been considerable progress in some countries (FAO, 1999). For example, undernourishment in Ghana has declined more rapidly than in any other country in the world, fueled by economic growth and consequent improvements in cropped area and yields. Tormented by its population growth and conflict, Burundi is in severe contrast as the average daily food intake goes down.

3.2.2 Impact of Climate Change on Agriculture

The implications of the state of food insecurity in Africa for climate change are important because agriculture, food security and climate change are inseparable issues. The risks of adverse effects on agriculture, especially in semi-arid and sub humid regions and areas with more frequent and prolonged drought, become life threatening risks. Internal coping mechanisms are not likely to be adequate for many of the vulnerable populations. Therefore, resources for adapting to climate change may not keep pace with impacts (IPCC, 2001). Major impacts on food production will also come from changes in temperature, moisture levels, ultraviolet (UV) radiation, CO_2 levels, and pests and diseases. CO_2 enrichment increases photosynthetic rates and Water-Use Efficiency (WUE). The direct effects are largest on crops with C_3 photosynthetic pathway which may be less vulnerable to climate change (wheat, rice, and soybean) compared with C_4 crops (maize, sorghum, millet, and sugarcane) that may be more vulnerable to climate change. Moreover, decreased temperatures limit production in some high-elevation regions and increased temperatures affect yield and its quality in semi-arid and arid regions.

The possible impact of climate change on maize production in Zimbabwe was also evaluated by simulating crop production under climate change scenarios generated by GCMs (Muchena and Iglesias, 1995). Hence, analysis of potential impacts using dynamic simulation and geographic databases, has been demonstrated for South Africa and the southern Africa region (Schulze et al., 1993; Schulze et al., 1995; Hulme, 1996; Schulze, 2000). The results reaffirm the dependence of production and crop yield on intraseasonal and interannual variation of rainfall. A similar but an integrated analysis for Egypt is presented by (Yates and Strzepek, 1998). Linked to a dynamic global food trade model, the climate change scenarios generally had minor impacts on its aggregated economic welfare. Additional information on impacts over Africa can be found in the WG II (IPCC, 1998; IPCC, 2007) report in which:

- By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change (IPCC,2007);
- By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition (IPCC, 2007); and
- By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (high confidence) (IPCC, 2007).

3.2.3 Mapping of Vulnerability

The recent climate change hotspots and food insecure hotspots can be found in the Climate Change Agriculture and Food Security (CCAFS) report No.5 (2011) in which domain approaching to vulnerability is taken by overlaying related indicators.

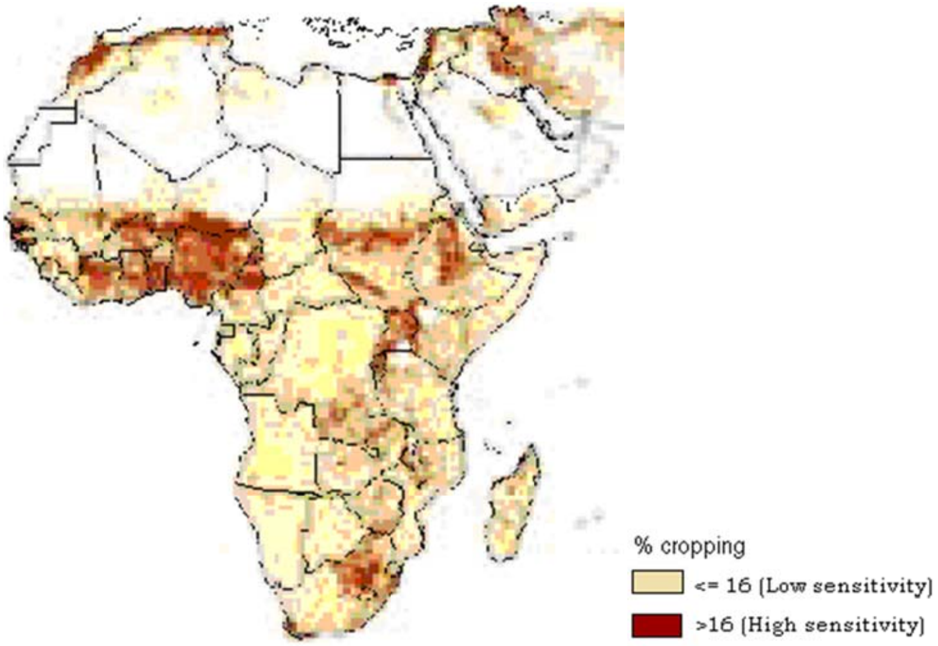


Figure 6: Areas with greater than 16% cropping
(assumed sensitive to change in climate. Note that data are unavailable for a few countries, appearing as white in the domain maps.).

Areas with more dependence on agriculture (both cropping and livestock based) are assumed to be more sensitive to a change in climate. Therefore, the greater an area is cropped (whether planted or grazed), the higher the sensitivity of that area. Based on the Ramankutty et al (2008) dataset, percentage cropping was used as a proxy for sensitivity: areas having greater than 16% of the pixels covered by a crop were considered as highly sensitive to a change in climate change (Fig. 6).

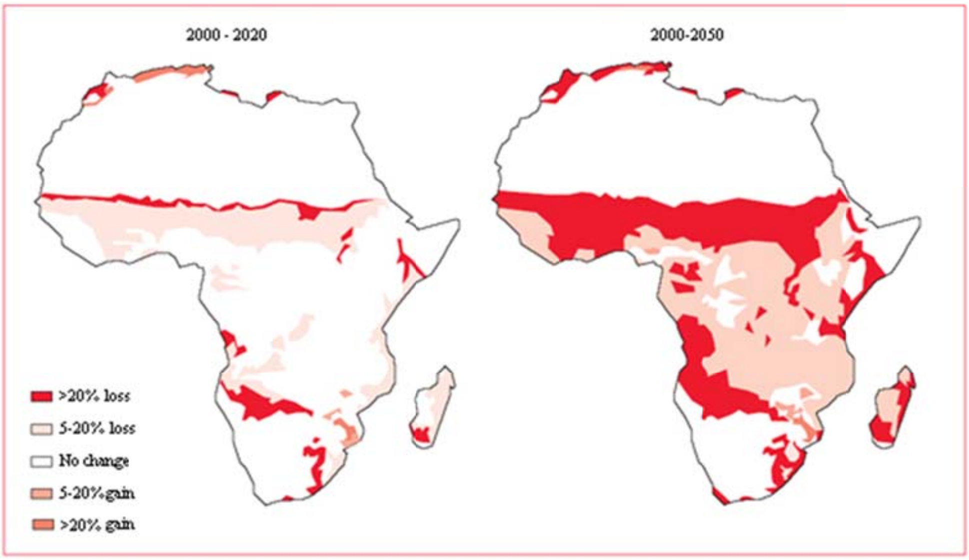


Figure 7: Reduction in the length of the growing period (Source: Thornton et al., 2006).

Climate change models also predict a reduction in the Length of the crop Growing Period (LGP). Figure 7 shows the reduction in the length of the growing period from 2000 to 2020 and 2000 to 2050. Parts of Sahel, Angola, eastern and South eastern Africa, southern Madagascar will see a reduction of more than 20% between 2000 and 2020, with similar reductions across nearly all of Sahel and Angola by 2050. As a matter of fact, the mixed systems become more vulnerable and will have a considerable impact on livelihoods and food security. However, it was projected that most of the north and south of the continent are not sensitive to climate change.

3.2.4 Adaptation

The nature and processes of human adaptation to long-range climate change are poorly understood, especially in Africa (but see Chemane et al., 1997; Vogel, 1998). Therefore, a promising approach for much of Africa is to cope with current climate variability through the use of seasonal climate forecasting (e.g., Mason et al., 1996; Mattes and Mason, 1998; Washington et al., 1999; Dilley, 2000). Better adaptation to climate change was also highlighted through the practice of the climate smart-agriculture which was emphasized during the Global Conference on Agriculture, Food Security and Climate Change in 2010. A showcase of climate smart-agriculture includes farming under a full canopy of trees, providing solutions to food scarcity by intensifying agriculture systems and increasing drought resilience. Planting certain trees, such as the African acacia, while sequestering carbon from the atmosphere, supports existing production by providing fertilizer and fodder (because agriculture is the only emitting sector that has the ability to sequester carbon).

Practically, among Burkina Faso climate adaptation efforts water retention schemes and small-scale irrigation that allow cultivation outside normal growing seasons, production of season-adapted seeds and the use of organic fertilizers. However, Madagascar outlined efforts to reduce methane emissions from rice production and animal husbandry, using the alternate wet/dry irrigation system. Malawi presented its climate smart agriculture practice through development of short-maturing and drought-tolerant maize and rice crops in order to increase productivity which is also recommended in the areas predicted to have a decline in precipitation (Omenda et al., 1998).

3.3 African Coastal, Terrestrial and Marine

3.3.1 The African Coastal System, Terrestrial and Marine

The African coastal system includes a narrow low-lying coastal belt. It also incorporates the continental shelfs and coasts of 33 mainland countries and 7 islands. Madagascar has the longest coastline; Egypt and Mozambique are following second and third respectively (Vafeidis et al., 2008; Brown et al., 2011). It is composed of a variety of ecosystems, including barrier (lagoons), deltas, mountains, wetlands, mangroves, coral reefs and shelf zones. These ecosystems, which cover the land up to 10m above mean sea level, vary in width from a few a hundred meters in the Red Sea area to more than 100km, especially in the Niger and Nile deltas (IPCC, 1997). The coastal system spans a broad range of habitats and biota.

The African coastal zone could be divided into the Mediterranean Coastal Zone (MCZ), the West and Central African Coastal Zone (WCACZ), and the East African Coastal Zone (EACZ) (Ibe and Awosika, 1991). The MCZ contains big cities such as Alexandria, Algiers, Benghazi, Tripoli and Tunis. Although it is narrow, it has high economic value due to its vital agriculture, industrial, and recreational value. As a result, the coastal cities in the region are densely populated (Ibe and Awosika, 1991). The WCACZ extends from Morocco to Namibia. Forty percent of the population of West Africa lives in coastal cities (IPCC, 2007) and most of the economic activities that form the backbone of national economies are located within the coastal zone. The EACZ ranges from Sudan to South Africa including the island Madagascar, Mauritius, Reunion and Seychelles. The ecosystem of this coastal zone includes the richest coral reefs in the world at the desert margin of the Red Sea and extending further south from Kenya to the Tropic of Capricorn. The coral reefs are well distributed around most of the oceanic islands (IPCC, 1997). Most of East African big cities are located inland; however, due to industrial development in various sectors, the population of coastal cities is increasing (Brown et al., 2011).

The other terrestrial ecosystem in Africa is composed of woodlands, grasslands, savannas and rainforests. African rainforest covers 7% of the total land area; however, the West African forest is being lost faster than any other region (FAO, 1997). The African rangeland contains grasslands, woodlands and combinations of both. It is the grazing land of most of the livestock and a tourist site in many of the countries which contribute significantly for the gross domestic product.

Africa has two big deserts; Sahara Desert in the north and Kalahari Desert in the southwest which lies in the descending branch of Hadley cell which is classified as the hottest deserts in the world with average monthly temperature above 30^0C while during the warmest months the extremes exceed 50^0C (IPCC, 1997). The biota in the desert shows specialized adaptations to aridity and heat such as obtaining their moisture from fog or dew (IPCC, 1996).

The African continent has a variety of topographical features. Most of the highlands are located in the Horn of Africa particularly in Ethiopia whereas the highest mountain Kilimanjaro is located in East Africa. Atlas, Ahaggar, Mount Cameron, Tibetsi and East Africa highlands as well as the Drakensberg Mountains are the outstanding ones (Brown et al., 2011). In Africa, most mid-elevation ranges, plateaus and high-mountain slopes are under considerable pressure from commercial and subsistence farming (Rogers, 1993).

The African nations possess a variety of lacustrine, riverine, and marine habitats with more than 800 freshwater and marine species. The riverine system in Africa is dominated by four big rivers of Nile, Niger, Congo and Zambezi. Among the riverine system Congo River contains the most diverse fish fauna with about 690 species of which 80% are endemic (Lowe-McConnell, 1987). The lacustrine systems in Africa, particularly the Rift Valley lakes, contain the most diverse and unique fish assemblages found anywhere in Africa, if not the world.

3.3.2 The Impact of Climate Change on Coastal Areas, Terrestrial and Marine

Measurements form coastal tidal gauge and satellite indicated that the mean sea level is rising in the last century due to thermal expansion and melting of ice caps and glaciers (IPCC, WGI, 2007). It is estimated that the mean sea level rose by 0.17m on average for the last century. The mean sea level is projected to rise by about 0.48m at the end of 21st century for A1B scenario (IPCC, WGI, 2007); however, Rahmstorf (2010) corroborated that the projection made by IPCC in the fourth assessment report is underestimated.

The projected mean sea level rise will exacerbate the existing physical, ecological(biological) and socioeconomic stresses on the African coastal zone by inundating and eroding low-lying areas or increasing flooding caused by storm surges and intense rainstorms. This will also impact the coastal ecosystems such as mangroves, estuaries, deltas and coral reefs which play important role in economic activities of tourism and fishery. In West Africa, the big cities are located at coastal areas which will be impacted with the projected mean sea level rise; particularly poor peoples are concentrated in the hazardous areas of the coast which are vulnerable to this change by coastal flooding, unavailability of clean water due to the surge of saline sea water along the river deltas.

In assessments of the potential flood risks that may arise by 2080 across a range of scenarios and climate change projections, three of the five regions shown to be at risk of flooding in coastal and deltaic areas of the world are those located in Africa: North Africa, West Africa and Southern Africa (IPCC, 2007). Cities such as Logos and Alexandria will be probably impacted.

Indian Ocean Islands could also be threatened by the potential changes in location, frequency and intensity of cyclones; while East African coasts could be affected by potential changes in the frequency and intensity of ENSO events and coral bleaching (Klein et al., 2002) as well as the intensification of tropical cyclone along the Mozambique channel. The projected sea level rise will impact the tourism oriented economy of East Africa as a result of the coral reef bleaching, flood risk and water pollution related diseases.

The African forests which are the sink of CO_2 will decrease significantly in the coming century due to the increase of farmland and the utilization of fuel wood and charcoal as a source of energy under the increased population pressure. This will exacerbate the rising earth's surface temperature. However, tropical forests are increasing the amount of carbon which they store annually as a result of climate change (Lewis et al., 2009) that will help for cooling effect of the earth if we keep our forest in the coming century. Mountain ecosystems appear to undergo significant observed changes, aspects of which are likely to be linked to complex climate-land interaction and which may continue under the projected climate. For example, the ice cap of Mountain Kilimanjaro could disappear by 2020 (IPCC, WGII, 2007).

The expected rise of the surface temperature of earth will affect both freshwater fisheries and marine fisheries (Hernes et al., 1995). The impacts are a shift in the center of production and composition of fish species as ecosystems move geographically and change internally and economical values are expected to fall.

3.3.3 Mapping Vulnerability of Coastal Areas, Terrestrial and Marine

The projected mean sea level rise of 0.48m by the end of this century will threaten coastal areas. Figure 8 indicates coastal zones and their degree of vulnerability. Areas shaded in red color are more vulnerable compared to areas shaded in yellow color. Moreover, areas shaded with light blue color are inland areas below mean sea level which will also be vulnerable to mean sea level rise because of the shorter distance from the sea (Fig. 8). From the figure, we can further infer that the coastal zones especially at river deltas of Nile, Niger, Zambezi, Senegal and Congo are extremely vulnerable to mean sea level rise. IPCC (2007) also pointed out that the Nile delta is a hotspot of societal vulnerability in coastal zones in Africa as a result of multiple natural and human-induced stresses such as subsidence or declining natural defense.

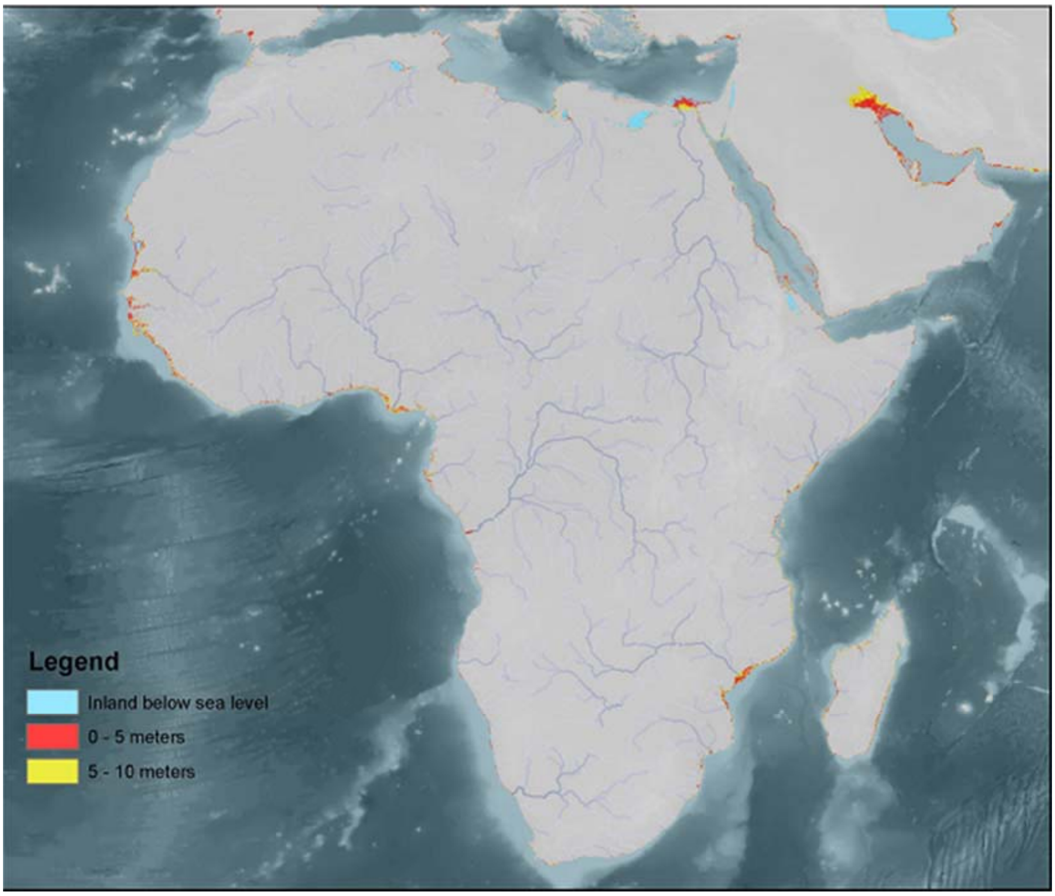


Figure 8: Vulnerability map of the coastal zones of Africa.
(Areas shaded in red color have an altitude of less than 5m and shaded in yellow color have an altitude of between 5 and 10m. The light blue is inland area below mean sea level (source of data http://srtm.csi.cgiar.org).

The expansion of desertification in sub-humid and semi-arid parts of Africa, melting of ice cap in the mountains and the deforestation activities will make the African continent more vulnerable. The expected rise of the surface earth temperature will affect the ecosystems and rich biodiversity. Some of the flora and fauna will not cope with the rising surface temperature and will extinct out unless appropriate measure is taken.

3.3.4 Adaptation

Producing resources and services for human livelihoods and ecosystem in a sustainable manner at coastal zones with changing climate and mean sea level rise will be coped by adaptation and mitigation. There are different options for adaptation. Among these are technology based protections such as building seawalls and building dikes; policy changes such as development planning and integrated coastal zone management. To determine the appropriate adaptation responses to sea level rise, the cost of protecting the coastlines from sea level rise should be compared with the benefits in terms of the value of the land and structures that would be inundated or lost to erosion.

Most of the African countries are developing and do not have the capacity to adapt to climate change and rising mean sea level. Ibe (1990) has found that large scale protective engineering measures are impractical because of the high cost. Instead, low cost, low-technology, but effective measures such as permeable, non-concrete, floating break waters, artificial raising of beach elevations, and installation of rip-rap, timber groins and so forth are considered more viable. IPCC (2007) indicated that the cost of adaptation could amount to at least 5-10% of the GDP of coastal countries.

Expansion of reserve systems can potentially reduce the vulnerability of ecosystems to climate change (IPCC, 2007). Adaptation possibilities are determined by the conservation priorities of each reserve and by the magnitude and nature of the change in climate. A primary adaptation strategy to climate change and even current climate variability is to reduce and manage the other stresses on species and ecosystems, such as habitat fragmentation and destruction, over-exploitation, eutrophication, desertification and acidification (IPCC, 2007).

3.4 Vulnerability and Potential Impact on Human Health

It is difficult to understand the links between infectious disease and climate due to the paucity of baseline disease data, the multivariate nature of climate change, and the nonlinear thresholds in both disease and climate processes. Associations between disease and climate do not necessarily imply causation, but correlation studies and short-term experiments can help separate the effects of climate from other components of global change. It has been hypothesized that climate warming will affect host-pathogen interactions by (i) increasing pathogen development rates, transmission, and number of generations per year; (ii) relaxing overwintering restrictions on pathogen life cycles; and (iii) modifying host susceptibility to infection. Changes in these mechanisms could cause pathogen range expansions and host declines, or could release hosts from disease control by interfering with the precise conditions required by many parasites.

It is very challenging to associate climate warming with disease prevalence or severity due to the difficulty in separating directional climate change from short-term variation. However, studies on human, crop, and forest pathogens, for which long-term data exist, has shown sensitivity of some pathogens and vectors to climate factors (Harvell et al., 2002).

More importantly, climate change will affect some of the most fundamental pre-requisites for good health: clean air and water, sufficient food, adequate shelter and freedom from disease. The most severe risks are to developing countries, with negative implications for the achievement of the health-related MDGs and for health equity. The fundamental impacts include the following (i) Extreme air temperatures and air pollution are hazardous to health, (ii) Floods, droughts and contaminated water raise disease risk, (iii) climatic effects on agriculture threatens increasing malnutrition, (iv) A more extreme and variable climate can destroy homes, communities and lives, (v) Climate Change brings new challenges to the control of infectious diseases, (vi) Not all of the effects of climate change will be harmful, but on balance health damages are projected to outweigh the benefits (WHO, 2008).

Recognized climate-health associations (i.e., climate variability and non-infectious health effects) include: (i) the risk of a regional heatwave. An example is the European heatwave of 2003. Projected climatic changes indicate a potential for more frequent and/or more severe heatwaves in a future warmer world, (ii) changes in land-cover can sometimes exert the largest impact on climatic conditions (including exacerbating the effect of greenhouse-gas-induced warming). For example, urban heat islands and dark surfaces such as asphalt roads or roof tops can cause increases in temperature over large areas. Exposure to both extreme hot and cold weather is associated with increased morbidity and mortality, compared to an intermediate ‘comfortable’ temperature range, (iii) climatic influences on regional famines. Regional famines could lead to malnutrition. Drought and other climatic extremes have direct impacts on food crops, and can also influence food supply indirectly by altering the ecology of plant pathogens. Projected climatic changes will exacerbate regional food supply inequalities (Patz et al., 2005).

Climate variability and infectious diseases: Infectious agents (such as protozoa, bacteria and viruses) and their associated vector organisms (such as mosquitoes, ticks and sandflies) have their reproduction and survival rates strongly affected by fluctuations in temperature. Temperature dependencies are observed in terms of high correlations between disease rates and weather variations over weeks, months or years and in close geographic associations between key climate variables and the distributions of important vector-borne diseases.

Several studies of long-term trends in malaria incidence and climate in Africa, have not found a link to temperature trends. This emphasizes the importance of including other key determinants of malaria risk such as drug resistance, human migration and immune status, inconsistent vector- or disease-control programmes, and local land-use changes. However, an association between increasing malaria prevalence and incidence with concomitant warming trends from 1968 to 1993 has been documented for the highland Debre Zeit sector of central Ethiopia. Similarly, malaria transmission has been associated with anomalies of maximum temperature in the highlands of Kenya. However, Patz et al. (2005) stated that the association of malaria and past climate in the African Highlands remain controversial.

El Niño/Southern Oscillation and infectious diseases: In East Africa, Rift Valley fever epidemics between 1950 and 1998 have coincided with unusually high rainfall amounts that were associated with ENSO-related Pacific and Indian Ocean sea surface temperature (SST) anomalies. Although more than 75% of the Rift Valley Fever outbreaks between 1950 and 1988 occurred during warm ENSO event periods, some epidemics have also occurred during no El Niño periods, and the model has not been validated against new epidemics. Other diseases such as childhood diarrhoeal disease (a water-borne disease) and cholera are also affected by ENSO (Patz et al., 2005).

The projected changes in climate by the IPCC (2001) included the fact that warming on land will alter aspects of climate relevant to disease, particularly humidity and precipitation.

With regards to marine organisms, they will be affected by (i) temperature increase, (ii) sea level rise and subsequent changes in ocean circulation, and (iii) decrease in salinity. Coastal ocean temperature increases are supposed to be slightly lower than that for land (Harvell et al., 2002).

3.4.1 Climate Sensitive Disease and Their Impact on Climate Change

The impact of climate change is most likely to be felt by free-living, intermediate, or vector stages of pathogens infecting terrestrial animals. Among these pathogens, vector-borne diseases are most likely to be affected more than any other. The changes could result in altered abundance and geographic range shifts because rising temperatures will affect vector distribution, parasite development, and transmission rates. Many vector-transmitted diseases are climate limited because parasites cannot complete development before the vectors die. Vector-borne human pathogens such as malaria, African trypanosomiasis, Lyme disease, tick-borne encephalitis, yellow fever, plague, and dengue have increased in incidence or geographic range in recent decades. In a similar manner, vector-borne diseases of livestock, particularly African horse sickness and blue-tongue viruses, have also expanded their spatial domains in recent times. Spatial domain of most of these diseases have expanded into higher latitude regions, in each case accompanied by apparent expansion in the ranges of mosquito, tick, and midge vectors. The issue is whether these expansions are due primarily to climate change or other anthropogenic influences such as habitat alteration or drug-resistant pathogen strains. Another challenge is the prediction of future distributional changes in disease prevalence. For example, location-specific, long-term data show that climate did not change in an African highland area where malaria incidence increased. Factors such as expansion of anti-malarial resistance and failed vector control programs are as important as climate factors in driving recent malaria expansions. There is laboratory evidence to support the hypothesis that warming in recent decades has caused latitudinal shifts of vectors and diseases. The correlations (although not perfect) between warmer, wetter conditions associated with El Niño events and outbreaks of malaria, dengue, Rift Valley fever, African horse sickness, and plague, is another line of evidence supporting strong links between climate and vector-borne diseases. Links have been observed between pathogens and changing ocean temperatures, including human diseases such as cholera and emerging coral pathogens (Harvell et al., 2002).

The severity of threats associated with climate warming would be increased by the links between climate and disease. Increased disease can contribute to population or species declines, especially for generalist pathogens affecting multiple host species. Geographic domain expansion of pathogens such as Rift Valley fever, dengue, and eastern oyster disease is the most detectable effect of directional climate warming on disease. It is worth-noting that, non-climatic factors such as land use, vegetation, pollution, or increase in drug-resistant strains could also be responsible for these range expansions. Nonetheless, the numerous mechanisms linking climate warming and disease spread support the hypothesis that climate warming is contributing to ongoing range expansions. Climate warming has altered and will alter disease severity or prevalence (Harvell et al., 2002).

The risk of different health problems in Africa could increase by 2030. For instance, an increase of 10% is projected for diarrhoea. An additional 21-67 million people may be at risk of malaria by the 2080s due to climate change. In Zimbabwe, previously unsuitable areas for malaria could become suitable for transmission with slight temperature and precipitation variations. Similarly, the area suitable for malaria in South Africa will double and 7.8 million people will be at risk (Niang et al., 2007). Cameroon could experience a significant reduction in malaria by 2100 in the light of a projected decrease in precipitation and an increase in temperature. Varying reasons have been suggested for the observed malaria resurgence in East Africa. The reasons include changes in temperature, drug resistance, disruption of health services, population migration and land-use changes (Niang et al., 2007).

3.4.2 Mapping the Vulnerability (Hotspots)

Under a changing climate, the resulting health risks to human populations depend on where and how people live.

- *Small Islands*: Populations in Small Island developing states and other low-lying regions are vulnerable to death and injury and destruction of their public health infrastructure from increasingly severe tropical storms, as well as salinization of water resources and agricultural land from sea level rise.
- *Urban areas*: Rising global temperatures combined with urban heat island effect make urban populations, particularly those of tropical megacities, very vulnerable to a combination of health risks such as heatwaves, floods, infectious diseases and air pollution.
- *Mountainous areas*: The widespread retreat of glaciers threatens to deprive mountain and downstream populations of reliable summer fresh water for household use and for agriculture. Also, increasingly high temperatures are intensifying the risks of transmission of vector-borne diseases, such as malaria, among high-altitude populations that lack immunity against such diseases. Thus, mountain populations are at increased risk of water insecurity, floods and landslides, and infectious disease.

- *Children*: Children are among the most vulnerable to the health risks that will result from climate change. They will be exposed longer to the health consequences of a degraded natural environment. The health issues of worthy of note include
    1. *Climate-sensitive diseases already place an enormous burden on child health.* Children in developing countries, who are 5 years or less, bear about 90% of the burden of malaria and diarrhoea and almost all the burden of diseases associated with undernutrition.
    2. *Major diseases of children are highly sensitive to variations in temperature and precipitation*. Populations that are directly dependent on rain-fed subsistence agriculture or who have low incomes and therefore high sensitivity to increases in food prices when harvest are diminished by floods and drought, are most vulnerable to undernutrition and associated diseases. In developing countries, higher temperatures or at times, low water availability (makes hygiene more difficult) and flooding (contaminates freshwater sources) significantly increase childhood diarrhoea.
    3. *Climate Change threatens to further intensify disease burdens*. One way to reduce vulnerability of children is through progress in the health-related MDGs, from reduction of childhood mortality to eradication of extreme poverty and hunger. While progress is slower than hoped for, climate change also threatens to create further setbacks. For instance, the population of Mali at risk of hunger is projected to increase from 34% to 64-72% by 2050 due to climate change if adaptation measures are not implemented. Also rising temperatures and changing rainfall patterns are projected to likely increase significantly the population at risk of malaria in Africa and the number of months of exposure to transmission. The resulting disease burden is expected to mainly affect children.
    4. *Children have little impact on many adaptation and mitigation decisions*. Children bear little or no responsibility to past and present emissions of greenhouse gases that are now causing climate change. The responsibility to protect and enhance the health of children therefore lies with adults, who take decisions on climate change mitigation and adaptation (WHO, 2008).

Africa has a high disease burden and many diseases are sensitive to climatic parameters. Examples include malaria, meningitis, cholera and Rift Valley fever. Africa accounts for about 85% of all deaths and diseases associated with malaria. In a year, malaria alone accounts for about 1 million deaths and 300-350 million clinic cases. The most vulnerable populations are located in the fringes of the current infected areas. Africa also has the highest Disability Adjusted Life Years (DALY) value of 3072 thousands per million of people in 2000 against a global mean of 920. However, the vulnerability of Africa to diseases, apart from climatic or geographic conditions, is also due to its socio-economic status. Africa has the lowest GDP expenditure on health of all the regions (5% in 1998 compared to about 10% in OECD countries) (IPCC, WGII, 2007).

3.4.3 Adaptation Strategies

From an African perspective, adaptation means increasing the resilience of communities and ecosystems against adverse climate. This requires a holistic long-term perspective that considers risks, opportunities and limitations posed by current and future climate conditions as well as societal changes due to social, economic and environmental stresses such as changes in demographics, the availability and access to technology and the systems of governance. Thus adaptation strategies should have a mixture of technical, legal and institutional solutions and more importantly build on existing adaptation experience, incorporating the indigenous knowledge of the local populations (IPCC, WGII, 2007).

WHO (2008) lists a number of things that need to done with regards to protecting human health from climate change. The list includes:

- The need to place human health needs at the centre of environment and development decisions;
- Identify the range of risks that climate change poses to human health and make effort to prevent these risks from translating into increased disease burdens;
- Economic growth and public health planning. Continued economic growth in the poorest countries is vital to protecting health from climate change. This is because countries with a higher level of economic development tend to have better health, including reduced vulnerability to many climate-sensitive diseases. Since economic growth is itself at risk from climate change, it can increase environmental risks to health and leave large sections of the population vulnerable. It is necessary to pay much attention to public health planning to safeguard the health of the most vulnerable population groups, which is, in turn, a contribution to sustained economic development;
- Many of the actions on adaptation and mitigation necessary to protect health from climate change are mainly public health interventions of proven effectiveness. These range from controlling vector-borne disease, to providing clean water and sanitation and reducing reliance on energy sources that pollute the environment and harm health. All would improve health now, as well as reducing vulnerability to climate change in the future; and
- Adaptation measures that both promote health and cut greenhouse gas emissions are likely to have widespread support. For instance, shifting to cleaner energy sources, could have important health “co-benefits” to communities and individuals, for example through reduced air pollution. These local and immediate benefits can offset a large part of the costs of mitigation and provide a strong motivation for action (WHO, 2008).

3.5 Integrated Assessment of Potential Impacts and Vulnerability

Many parts of Africa are presently highly vulnerable to climate variability and climate-related shocks. The Intergovernmental Panel on Climate Change (2007) defines climate vulnerability as “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate stress, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.” The assessment of vulnerability then includes a measure of exposure to the risk factors and sensitivity to the factors, together comprising the potential impact of such risks, and the capacity to manage and respond to those risks (Fig. 9).

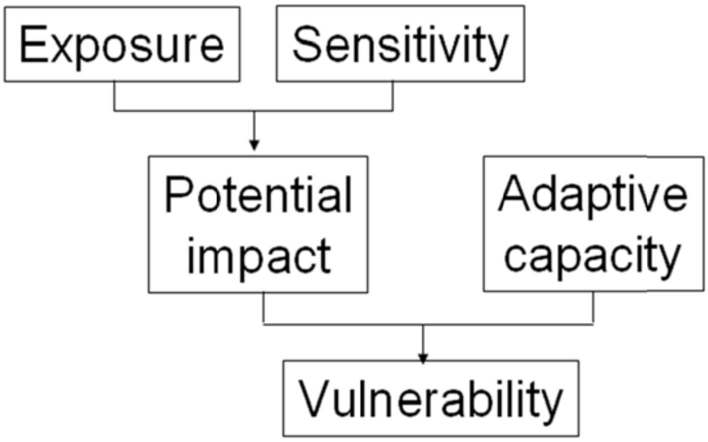


Figure 9: Components of vulnerability (adapted from Schröter et al., 2005).

In Africa, vulnerability arises from poverty and limited livelihood options, high reliance on rain-fed agriculture and natural resources, widespread food insecurity, a high burden of disease, and other forms of human insecurity. Thus, under-development is a major driver of vulnerability of systems and population groups – climate change is an additional stressor. Climate change is likely to exacerbate existing vulnerability and also lead to new emerging vulnerability.

Despite these common drivers across the continent, vulnerability manifests in highly heterogeneous and complex ways. The outcomes depend on contrasting biophysical circumstances, including large gradients of rainfall, temperature and exposure to climate variability and climate extremes, as well as widely differing ecosystems and natural resource bases, farming systems, other economic activities, and, importantly, social circumstances. The complex interactions (forwards and backwards) between climate (1st order), natural resource fluxes and health (2nd order), land-based production systems (3rd order) and socio-economic ramifications (4th order) (as depicted in Fig. 10) are difficult to capture in conventional (often sector-based) risk and vulnerability assessments. However, climate change will exert its effects throughout this continuum, the components of which are also spatially variable. Adaptation planning should be as spatially explicit as possible, thus ensuring that the focus is trained on natural and human systems most in need of strengthening. In the regional context, tools are also required to identify transboundary systems (e.g., river basins) sharing common vulnerabilities. This opens up opportunities to guide a regional or at least bi-lateral or multi-lateral focus on adaptation.

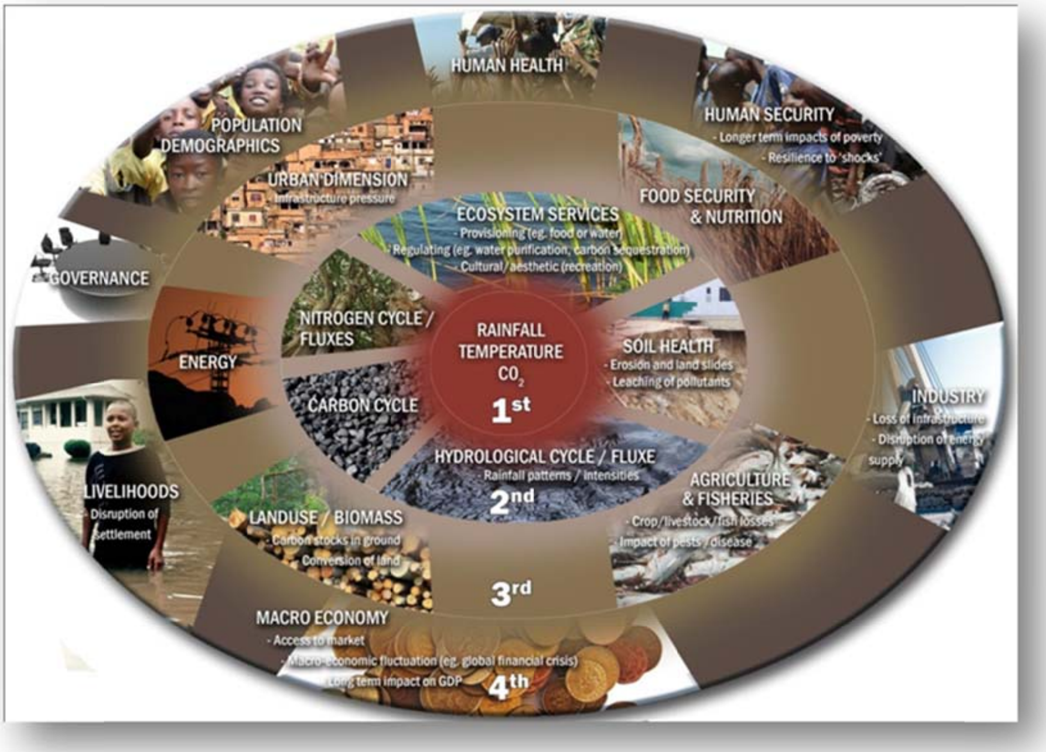


Figure 10: Conceptual 1st to 4th order framework for studying the impacts of climate change on natural and human systems. Graphic by OneWorld Sustainable Investments.

3.5.1 Mapping the Integrated Vulnerability

Scientifically robust, integrated and context-relevant information is required that will allow policy makers and planners to make informed choices on how they might respond to the way climate change will impact on local populations and livelihoods. There is a need for this response to be greatest in areas likely to be most severely hit by climate change.

Risk and vulnerability mapping (based on Geographical Information Systems, GIS) based on indicator databases can provide one such tool to depict, analyse and synthesise the spatial nature of differing vulnerabilities across the continent, within an integrated 'systems'-based approach. It achieves this by distilling and visually presenting key messages arising from complex interactions between biophysical and socioeconomic drivers of climate vulnerability. Through this approach areas of differential vulnerability can be spatially disaggregated at regional, national, sub-national and transboundary scales, and those regions which are most impacted and/or least able to or help themselves in the face of shocks are identified. It appeals to policy makers by being relatively insensitive to uncertainties inherent in the commonly used climate modeling approach, and by being well aligned with policy priorities, namely those relating to people (e.g., reducing poverty) and the economy.

As an example, the Regional Climate Change Programme (RCCP) for Southern Africa has successfully developed a GIS risk and vulnerability baseline for the Southern African Development Community (SADC) region (Davies et al., 2010). Other examples for Africa include the mapping performed by Thornton et al. (2006) and Busby et al., (2010). These maps were developed using indicators representing the components of vulnerability: exposure to climate variability and extremes (current and future - 2050), sensitivity to such exposure leading to impacts (exposure + sensitivity = impacts), and capacity to adapt to the impacts (impact + adaptive capacity = vulnerability). These authors used 51 data layers which were mapped at 1 km^2 resolution across the

SADC region. The focus was on geo-spatial indicators for agriculture, water, food security, human health, and ecosystem services.

The maps highlight 'hotspots' of current and future climate-related vulnerability, many of which transcend national boundaries. 'Hotspot' regions broadly aligned with climate and land use systems are evident across political boundaries, but moderated by socio-economic and governance factors at national level. Highly vulnerable regions to climate are likely to remain highly vulnerable in the future unless adaptive capacity can be substantially improved. Regions which indicate development of hitherto unknown vulnerability require specific attention.

The risk and vulnerability maps have been extensively utilized across the region for adaptation planning and knowledge disseminating processes. Use of this analysis continues to influence prioritization processes and awareness raising across a wide spectrum of audiences, including regional institutions and member states.

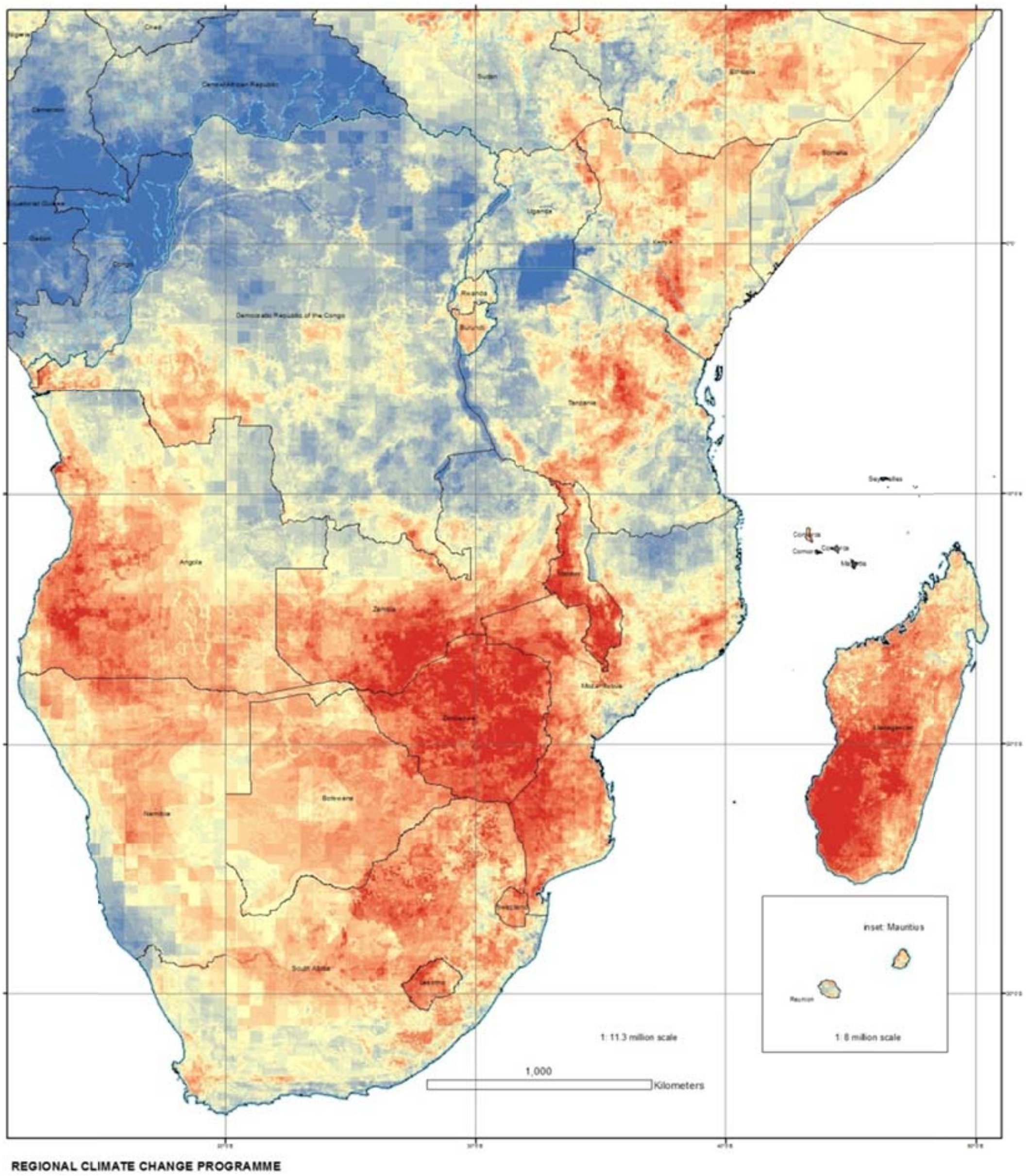
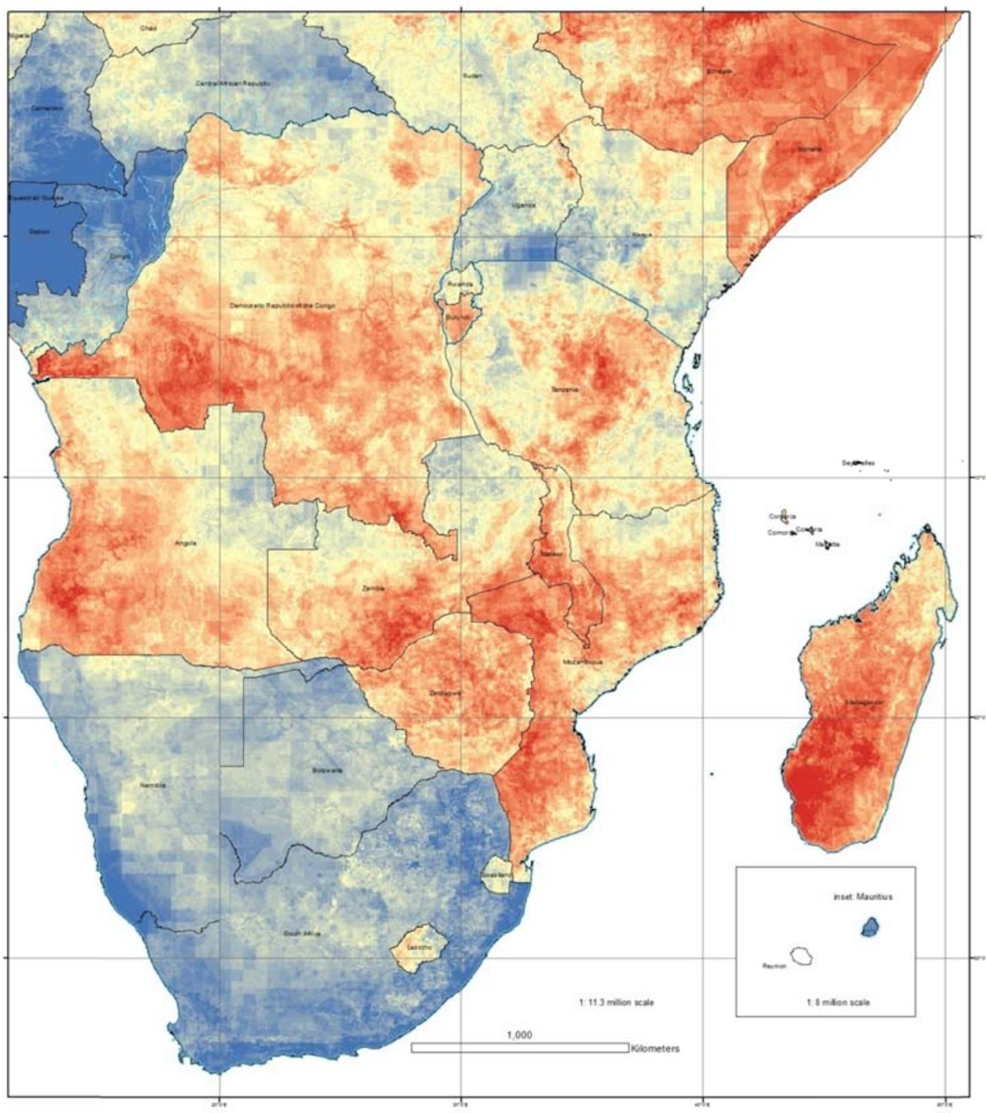


Figure 11: Projected (2050) impacts of climate change (combination of climate exposure and sensitivity to climate stressors). Red areas represent areas of higher impact, blue areas represent lower impact.



REGIONAL CLIMATE CHANGE PROGRAMME

Figure 12: Projected (2050) vulnerability to climate change (combination of climate impact and adaptive capacity). Red areas represent areas of higher vulnerability, blue areas represent lower vulnerability.

3.5.2 Major challenges for Africa

A number of themes emerge from the risk and vulnerability maps for southern Africa. These themes most likely remain valid for other regions of Africa. We highlight three themes of great importance to the future of the continent:

Climate risk and vulnerability is high across many of the most productive agricultural regions which are characterized by high reliance on rain-fed agriculture and rapidly rising population densities. Increasing agricultural production to supply a growing demand for food will become more challenging unless adaptive capacity in this sector is significantly stimulated, for example through the development and use of suitable and affordable technologies. Areas of high productive potential and apparently high climate resilience, coupled with potential access to local and regional markets, should be investigated for development as stable future food baskets for the region. Growing populations that remain highly vulnerable or become even more so under climate change are more likely to turn increasingly to natural resources for food and income, and/or to compromise sustainable land use practices. Therefore, improved natural resource and land use management will become critically important in the most vulnerable areas. The maps for southern Africa indicate areas which are likely to suffer rapid declines in resource availability per person. Regional strategies and policies do not yet sufficiently incorporate these projections.

Adaptive capacity is strengthened by potential access to water resources; differential vulnerabilities within river basins (particularly transboundary basins) should inform water resource management and adaptation planning within national and regional development contexts. Southern Africa (and other regions of Africa) is characterized by large multi-country river basins – their water flows should be equitably shared to benefit all and especially the populations in the most vulnerable sub-basins for purposes of development and adaptation. Southern Africa is making good progress towards developing institutions and policies to support transboundary integrated water resources management in the face of climate change, but this requires further political commitment, investment, research, and institutional strengthening.

Increasing vulnerabilities of some countries will drive increasing migration to more resilient regions (in the case of southern Africa this is mostly southwards). Current flows of environmental refugees and migrants within the region are likely to intensify, particularly during and following climate-related disasters. This will demand pro-active responses from both sending and receiving countries. Human security and conflict management could become increasingly important regional priorities. The region should strive to achieve the necessary high level of political engagement, strength of institutions, policy frameworks and supporting data and monitoring programmes to manage any significant impacts of climate change on regional security.

4. THE ROLE OF ACPC ON VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE HOTSPOTS

As it can be deduced from the above, there are significant gaps in Africa in understanding the science of climate change and the effects of climate variability and change. The major obstacle to integrate climate issues into development activities in Africa has been lack of appropriate institutions that facilitate incorporating science into policy and ensuring that scientific knowledge is effectively shared with policy-makers in a timely and relevant manner. ACPC, working with various institutions and stakeholders will play roles to enhance science, focus on adaptation actions to the vulnerable climate change hotspots by identifying relevant interventions, brokering knowledge, play advocacy work, build capacity, mobilizing resources and devising ways to formulate appropriate policies by African governments.

4.1 Advocacy and Knowledge Generation for the Need of Adaptation of Climate Change Hotspots

ACPC can play a significant role in collaboration with African governments for defining appropriate agenda of intervention in adaptation, advocacy of adaptation in international agreements so that African countries can cope with the effect of climate variability and change. ACPC may play significant roles by:

- Advising to strengthen National Adaptation Programmes of Action (NAPAs);
- Creating awareness about climate change and variability with policy makers of African government;
- Facilitating research activities to innovate new technology for adaptation;
- Integrating adaptation strategy with development;

- Devising ways for the African governments and non-governmental organization involved in environmental activities to reach the community level to adapt climate change;
- Initiating the media for the advocacy work on adaptation;
- Organizing workshops and conference for advocacy work ; and
- Assisting the African negotiators to prioritize adaptation in international climate change negotiations.

4.2 Mobilize Resources for Adaptation

Most of the national report of NAPAs indicated that adapting vulnerability requires substantial amount of their GDP which is too expensive to be covered by most of the African governments. Consequently, there must be alternative fund resource for adaptation. ACPC will assist the African governments in the project development and its implementation:

- By mapping the vulnerable areas;
- By studying the source of finance for adaptation;
- By making aware of the possible sources climate finance for adaptation to the African governments policy makers; and
- By capacity building.

4.3 Devise Ways to Make Policies by African Governments

As it is discussed in the above sections, climate change may exacerbate the disaster due to extreme events. Mainstreaming climate information in policies and programmes is vital for African governments. ACPC with its partners can assist the African governments to come up with integrated policies through:

- Capacity building and knowledge support to policy makers;
- Capacity building and knowledge support for negotiators;
- Capacity building of regional communities;
- Inclusive and informed policy making;
- Training and awareness raising;
- Effective communication;
- Outreach to all levels;
- Advising African governments in mainstreaming of climate information in their governmental policies; and
- Guiding the African government to integrate climate information for their development.

5. CONCLUSION

The African climate is highly variable in space. Hence, the impacts of climate change in Africa are not same everywhere. Risk and vulnerability mapping based on indicator databases can provide one such tool to depict, analyse and synthesise the spatial nature of differing vulnerabilities across the continent, within an integrated ‘systems’-based approach. This is achieved by distilling and visually presenting key messages arising from complex interactions between biophysical and socioeconomic drivers of climate vulnerability. Through this approach areas of differential vulnerability can be spatially disaggregated at regional, national, sub-national and transboundary scales, and those regions identified which are most impacted and/or least able to or help themselves in the face of shocks. It appeals to policy makers by being relatively insensitive to uncertainties inherent in the commonly used climate modeling approach, and by being well aligned with policy priorities, namely those relating to people (e.g., reducing poverty) and the economy.

The highly vulnerable state of Africa to climate change is mainly because of its strong dependency on climate-related activities and products coupled with its low adaptive capacity. The low adaptive capacity is linked to low economic status, weak institutions, lack of implementation of legal decisions, cultural values that resist technological innovations among others.

Factors influencing adaptation strategies in Africa include adaptive capacity, traditional adaptation strategies, technology and the need to incorporate climate change issues in a sustainable development framework.

Adaptation needs include:

1. Building capacity to collect and analyze climate change related data. The target should be to develop climate models and scenarios as well as conduct vulnerability and impact assessments;
2. Making research relevant to local needs, more practical and policy-driven. The research should utilize better inter-sectoral approaches and integrated vulnerability and adaptation assessments that will allow for comprehensively addressing all the impacts of climate change;
3. Better management of natural resources;
4. Readjusting existing management strategies to cope with climate change. Examples include the water management strategies in Egypt or the desertification management measures in Botswana;
5. Involving local populations and communities in management strategies. This allows for management measures to be linked with the social, cultural and economic context in Africa;
6. Considering potential impacts of adaptation measures. For instance, the intensification of agricultural land management and the expansion of agricultural land area will induce additional greenhouse gas emissions and increase environmental pressures as well as losses of natural ecosystems and biodiversity;
7. The need to develop and sustain an insurance system as a way to share climate-related risks in Africa; and
8. The development of regional approaches to combat the adverse impacts of climate change. An example is the Nile Basin Initiative.

ACPC can play a significant role on vulnerability assessment of climate change hotspots and develop strategies for adaptation in collaboration with African governments and existing regional centers. ACPC is also to assist government in project development, implementation and in mainstreaming climate information into policies and programmes as well in the advocacy of climate change awareness.

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