Climate Change Vulnerability and Impacts in River Basins and Aquifers Basins in Africa: Analysis of Key Response Strategies.

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Abstract:

This paper sets out the many challenges and implications of climatic variability and change for river basins and aquifers in Africa, with important impacts on water resources and hydrological systems, water availability and water resource management. The status of water resources in Africa has been changing for many decades, through decreasing water quality, falling groundwater levels, more or less rainfall, and changed timing of rainfall. Change is not new. Climate change, however, will strongly accelerate the rate of change, affecting the ability of people and societies to respond in a timely manner. Different models predict different climate change trends in the same areas, some, for example, predicting an increase and others a decrease in rainfall. Managing for high rates of change in a context of uncertainty is thus what is demanded of African governments. The key response to this must be to increase resilience, at the household, community, national, transboundary or regional level. Increased resilience will enable people living in poverty, in particular, to respond more effectively to change and to recover faster from disasters.

Keywords: Assessment methodologies, climate change vulnerability and risks, development challenges, environmental degradation, future projections and scenarios, impacts of climate change, resilience, adaptation, response strategies, transboundary rivers and aquifer basins in Africa.

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1. *Introduction:*

Integrating climate change risks and opportunities into development decision-making is a key challenge for adaptation, particularly in the African countries most exposed and vulnerable to the negative impacts of climate change. There are many implications of climatic variability and change for rivers and aquifer basins in Africa, with important impacts on water resources and hydrological systems, water availability and water resource management. However, even without climate change, many of Africa's water resources are facing overuse, pollution, and degradation. Poor land-use practices are contributing to this. Large numbers of people living in poverty in rural and informal urban areas are already vulnerable to water-related risks such as floods, droughts, poor water quality, and increasing water scarcity. Thus, managing the combined impacts of climate, demographic and economic change on freshwaters in Africa is as much a political and development challenge as a technical climate-change challenge.

The status of water resources in Africa has been changing for many decades, through decreasing water quality, falling groundwater levels, more or less rainfall, and changed timing of rainfall. Change is not new. Climate change, however, will strongly accelerate the rate of change, affecting the ability of people and societies to respond in a timely manner. The rate of change issue is compounded by uncertainty relating to the impacts of climate change. While there are a number of models that attempt to predict these impacts, many of them are on a very coarse scale and do not predict localised impacts, which may differ from the generalised picture. Although projection models are generally at a large scale and thus might not be directly applied at farm management level, they are important indicators of what is most likely to happen and could be the envelope of likely futures. Otherwise, worst case scenarios and an adaptive approach in the context of uncertainties can be used.

At the same time, different models predict different climate change trends in the same areas, some, for example, predicting an increase and others a decrease in rainfall. Managing for high rates of change in a context of uncertainty is thus what is demanded of African governments. Managing for uncertainty requires, however, continual improvement in the underpinning science in order to understand the drivers of change over time and to be able to address them effectively.

The key response to this must be to increase resilience, at the household, community, national and transboundary or regional level. Increased resilience will enable people living in poverty, in particular, to respond more effectively to change and to recover faster from disasters. The key elements of resilience are poverty eradication and access to appropriate information to support adaptation strategies, making adaptation to climate change primarily a development challenge.

2. *Methodology and Constraints:*

The need for risk assessment as a mechanism to support decision-making in the water sector is increasingly recognised as a central component of adaptation to climate change. Many alternative approaches to and methodologies for such assessments now exist, but a

general consensus is emerging about the utility of these methods for identifying future risks and vulnerabilities and developing adaptation strategies.

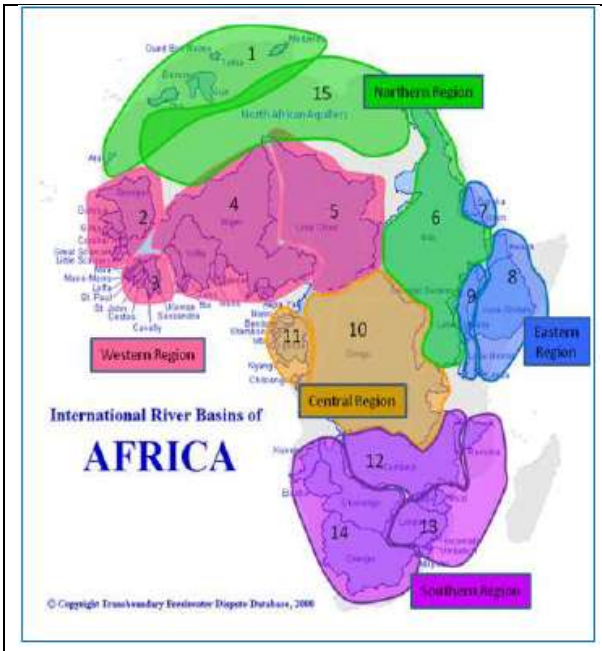
In order to determine the key freshwater climate change-related risk areas in Africa, a framework was developed that overlays four assessments: hydrological, socio-economic, institutional and climate change. The first three assessments looked at the current status, with some development projections into the future, and the climate change assessment looked at climate change projections. Regional specialists in each of five regions were appointed to compile the necessary information under the framework assessment. This was conducted at a desk-top level, through the sifting of existing information.

On the basis of a layering of the four assessments and a focus on the particular vulnerabilities of various sectors (figure 1), a set of risks for the worst-affected transboundary basins was identified. The results of this process were tested in a workshop held in November 2009 in Pretoria, South Africa, attended by a wide range of specialists from across the continent. The vulnerability assessment thus captures a combination of the projected climate change impacts on freshwater systems, the current status of these systems (e.g. whether or not they are already stressed), the current socio-economic status in the basin (on the basis that very poor societies have fewer resources available to adapt to major change), and the institutional capacity to respond to change.

Figure 1: Assessment methodology applied to determine key freshwater risk areas in Africa

Figure 1 shows the four assessments that were layered, focusing on six particular sectoral vulnerabilities of various sectors given in the middle section. From these a set of six thematic risks areas for the worst affected transboundary basins was identified.

The assessment was conducted at a high level on 15 clusters of transboundary basins and aquifers across Africa, grouped into 5 regions. These are outlined in Figure 2 below.



Northern Region: Cluster 1: Transboundary basins and associated aquifers in North Africa; **Cluster 15:** The aquifers of inland North Africa; **Cluster 6:** The Nile River Basin

Western Region: Cluster 2: Coastal rivers of West Africa from the Senegal to the Little Scarcies; **Cluster 3:** Coastal rivers of West Africa from the Moa to the Sassandra; **Cluster 4:** The Niger, Volta, and adjacent smaller basins; Cluster 5: The Lake Chad basin.

Eastern Region: Cluster 7: The Barakat and Gash rivers in East Africa; **Cluster 8:** Transboundary rivers and aquifers in the horn of Africa; **Cluster 9:** The river and lake systems of the Rift valley.

Central Region: Cluster 10: The Congo River Basin; **Cluster 11:** The coastal rivers west of the Congo River Basin.

Southern Region: Cluster 12: The Zambezi River Basin; **Cluster 13:** Transboundary river basins in the eastern part of Southern Africa, including the Ruvuma, Limpopo and Incomaputo; **Cluster 14:** The transboundary basins and aquifers of western Southern Africa from the Kunene to the Orange-Senqu.

Figure 2: Map of clusters and regions of transboundary basins and aquifers used in this study.

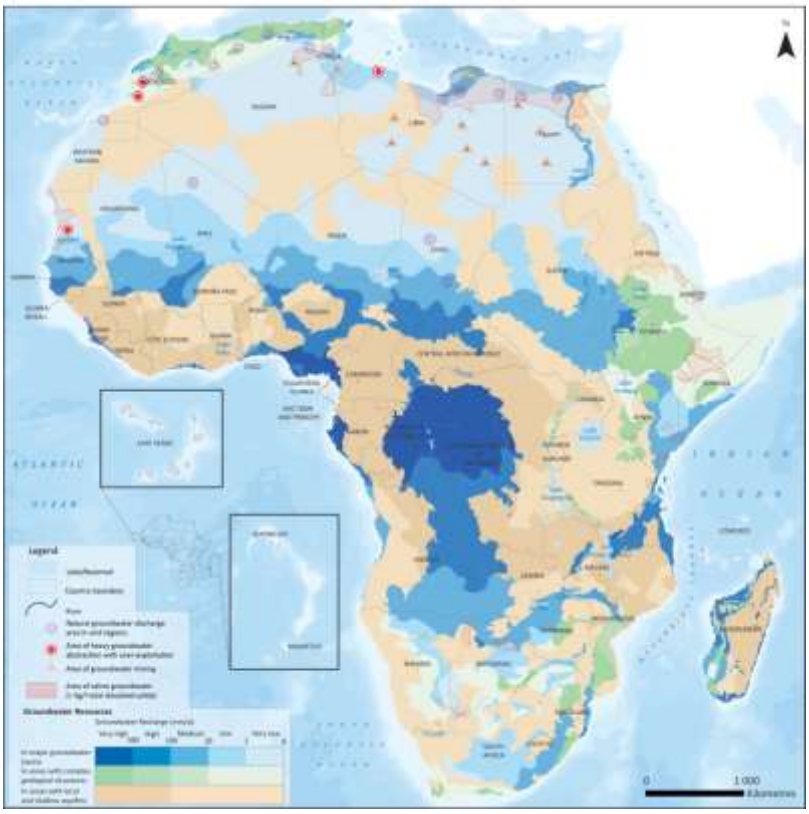


Figure 3: Map of groundwater availability in Africa (BGRM/UNESCO Paris 2008**)**

What we have captured in this report is a fairly comprehensive but high level exercise. However, the authors recognise that a more detailed examination at the basin level is necessary to increase confidence in the results of this assessment.

3. Summary of freshwater vulnerability

This section provides a summary of the freshwater vulnerability in the five regions described in figure 2, where vulnerability is drawn from a combination of hydrological, socio-economic, institutional and climate-change assessments as described in figure 1.

In terms of the hydrological assessment, the relationship between Africa's highly variable hydro-climatology and groundwater resources is still unclear. Braune and Xu (2009) point to the need to differentiate between recharge scenarios under different hydrological regimes in Africa. While the more humid regime has the full spectrum of recharge contributions (seasonal, annual and inter-annual), under arid and semi-arid conditions, the contribution is largely episodic (figure 3).

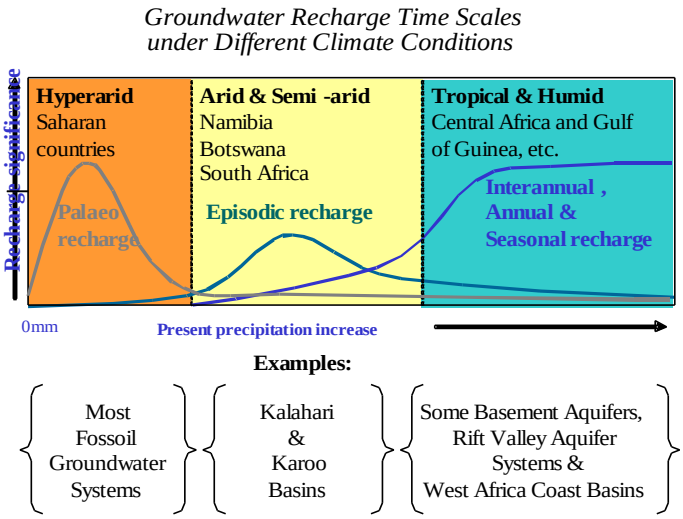


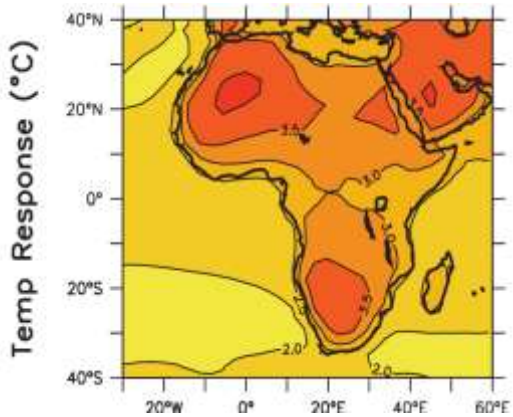
Figure 4: Sketch of groundwater recharge scenarios (Braune and Xu, 2009)

Renewable groundwater resources are intricately tied to the overall hydrologic cycle and could be directly affected by climatic change.

Projected climate change over Africa

Africa has already warmed by 0.6 o C over the 20th century. In addition to what has been observed, information about possible changes to the climate of Africa in the short-term and long-term future formed the basis for the climate change impact and vulnerability assessments. The current approach to predicting the future climate is by using Global Climate Models (GCMs) which use quantitative methods to simulate the interactions of the atmosphere, ocean, land surface, ice, etc.

Future changes in climate depend on greenhouse gas (GHG) emission levels which in turn depend on a number of factors including population growth, economic activity, technology and policy measures adopted by governments. The future states of these factors cannot be predicted precisely, but scenarios can be made. However, it is important to recognize the difference between a weather forecast and climate scenarios - scenarios are not predictions, but only plausible future states.



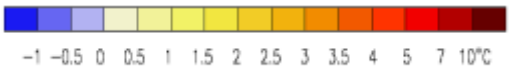


Figure 5: The annual mean temperature response in Africa in 21 MMD models (source *Christensen, J.H., et al., 2007*).

Figure 5 shows the temperature change from the years 1980-1999 to 2080-2099 under the medium (A1B) emission scenario, averaged over all available climate model outputs, while figure 6 shows the per cent change in precipitation (Christensen, J.H., et al., 2007).

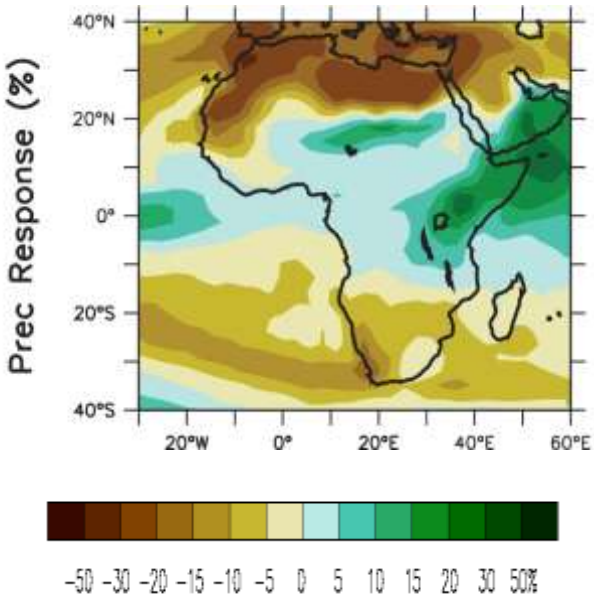


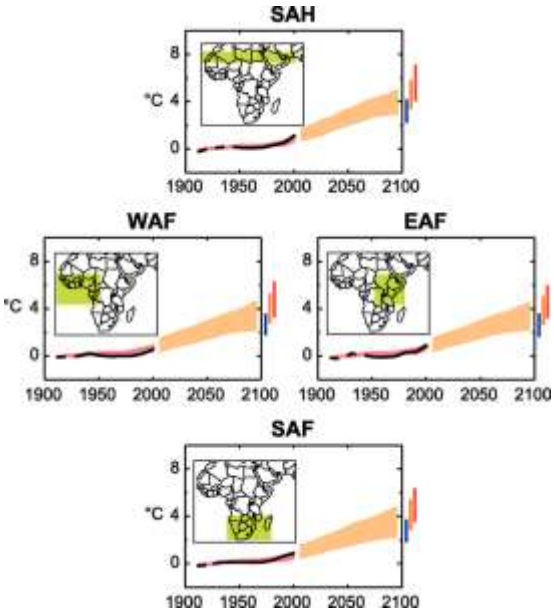
Figure 6: The annual mean precipitation response in Africa in 21 MMD models. (source Christensen, J.H., et al., 2007**).**

For a medium emission (A1B) scenario the mean annual temperature over Africa could increase by more than 3°C by 2080 compared to the 1980-1999 normal (Figure 5). Northern and Southern Africa are expected to see more warming than Equatorial Africa. Along with temperature changes rainfall also is going to change. In general terms Eastern Africa is expected to see an increase in mean annual rainfall while northern and sub tropical Africa are likely to experience a decrease compared to the 1980-1999 averages.

Such changes in climate will have significant consequences for the continent's economy, water resources, agricultural production, health and ecosystems. Increased risk of flooding, greater incidence of drought conditions and shifts in seasonal climate patterns are also likely to happen in various parts of Africa.

Northern Region (See figure 2)

There is substantial agreement that the northern region will become increasingly warm, with significant increase in a number of risk factors over the longer term.



Source: IPCC (2007)

Figure 7: Observed variability and trends in extreme climatic events and future projections in Africa.

A large part of this region is underlain by non-renewable groundwater resources, often of a transboundary nature (figure 3).

The following specific risk areas have been identified for this region:

Hunger & Poverty:
While this is of general concern across the region, the transboundary basins of Daoura, whose catchment area is 35 500 Km^2, and the neighbouring smaller Dra and bigger Guir catchments in Algeria and Morocco, are at particularly severe risk (UNEP 2005a and http://www.transboundarywaters.orst.edu/publications/register/images/africa.gif). Very much dominated by agriculture, these basins have large populations already facing severe water stress. Crop yields will decrease with increased temperatures and shortened growing periods. With little adaptive capacity through institutional structures and infrastructural capacity, these basins require urgent adaptation support.

Decreasing agricultural production may also result in increased food prices in urban areas with the potential to push workers in these areas into poverty.

Physical Security:
The nature of climate futures for the region is for more extreme events with flooding likely to become more frequent and severe. Lack of infrastructure to capture and attenuate such events exacerbates the problems. As the most densely populated areas of the region, the Medjerda and Tafna are at particular risk in this regard.

Environmental degradation:
Reduced runoff due to temperature and rainfall intensity changes may result in decreased aquifer recharge and have serious impacts on the various oases that are dotted across this region.

Migration:
The region has already seen a progressive migration of rural communities towards urban areas. The recent history of drying climates has resulted in increased pressure on these societies. The more arid transboundary basins are at particular risk in this regard, although some of these have fairly low population densities. Basins at risk include the Atui, Daoura, Dra and Guir.

National Development:
Extreme variability in climate threatens water supply for hydropower. With climate change, the potential for increased siltation arising from reduced vegetation and heavier rainfall events further threatens the sustainability of hydropower generation. This is of concern specifically in the Mejerda where both Algeria and Tunisia would like to develop hydropower.

Depletion of non-renewable groundwater resources as a result of pressures on total water resources must be seen as a threat to long-term regional stability.

The Nile Basin

The size and complexity of the Nile Basin dictates an array of vulnerabilities that also vary from country to country, including: long-term water security given the rapidly rising demand for water from a growing population such as in Egypt; food security in Ethiopia; the impacts of extreme events and to some degree food security in Sudan; and the impacts of extreme events, the impacts of rainfall variability on hydropower generation and livelihoods, and the impacts on food security and economic stability arising from decreasing fish resources in the Lake Victoria Basin.

Consideration of the historical water levels of Lake Victoria from 1900-2010 reveals the impact of changing rainfall patterns and water use in the region.

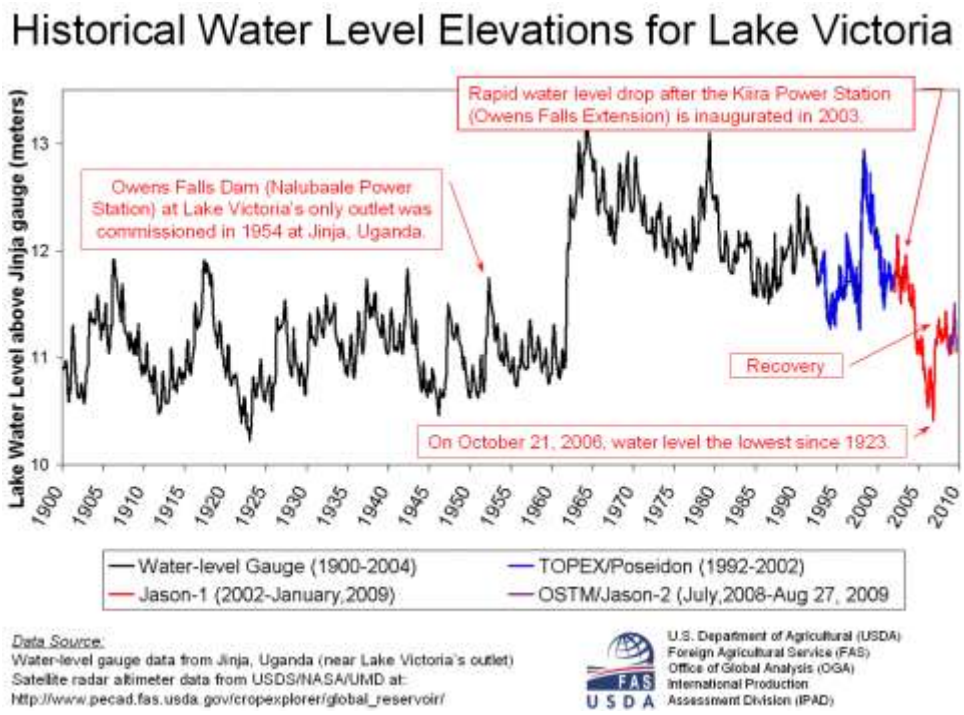


Figure 8: 1900- 2010, Historical Water Level Elevations for Lake Victoria

There is a sudden marked increase in water levels in Lake Victoria in the 1960s as shown on the Jinja gauge, followed by a steady decline well into 2005. This steady fall can be attributed to both human and climatic changes. The actual causative factors however require further study to ensure a high level of confidence in the reasons for this decline.

Some of the key threats in this region are:

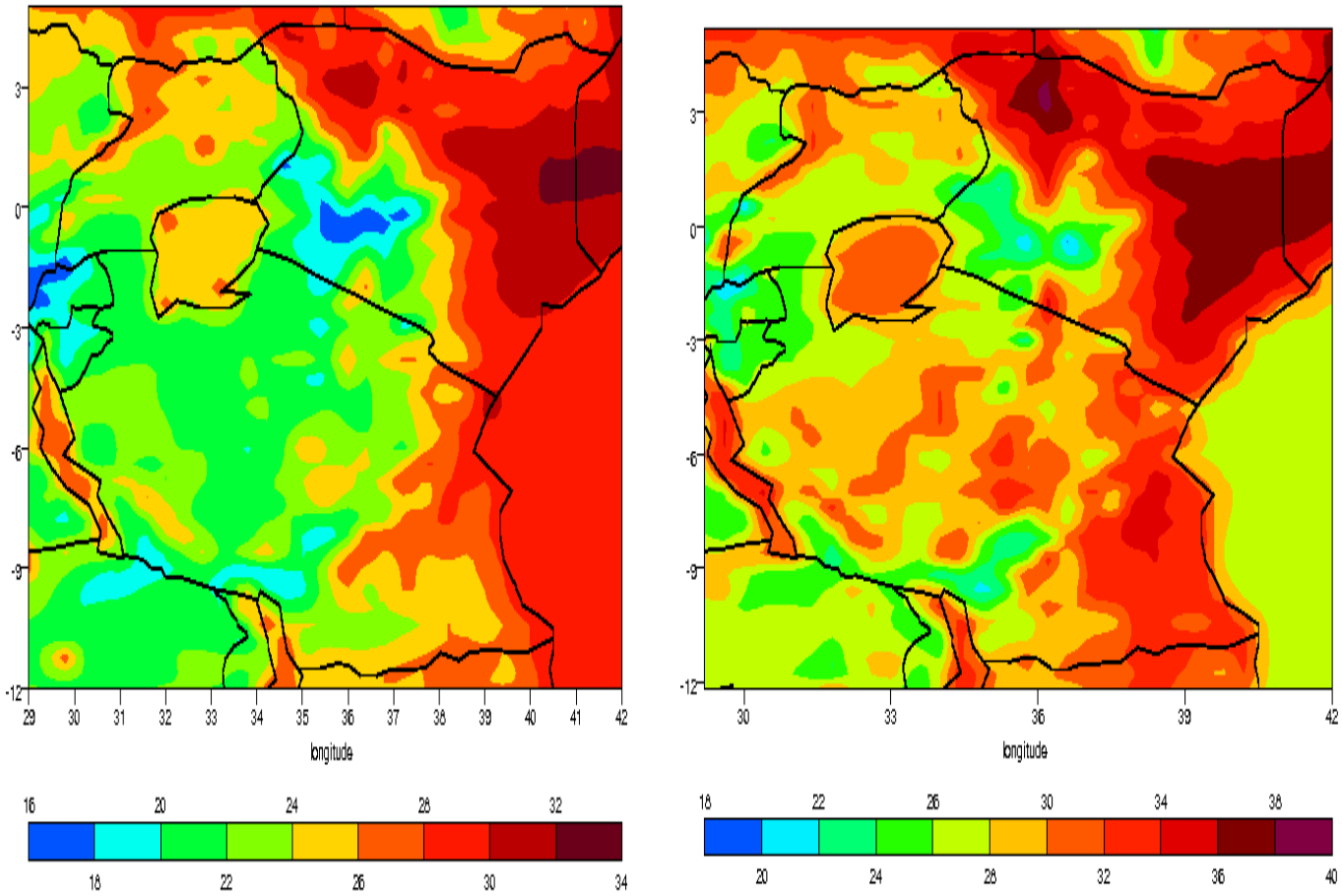
Hunger and Poverty:
While this is of general concern across the region, due to high levels of water stress and low levels of development in most riparian states, there is particularly high risk in Ethiopia, Sudan and the upper basin around Lake Victoria. The weak institutional capacity in these areas limits the possible adaptive responses.

Physical Security:
The nature of climate futures for the region is of more extreme events (floods and droughts). This is of particular concern in the mid-basin areas of the Sudan because of the dense population and the weak and fragmented institutional capacity.

National Development:
The ability across the basin to develop the full hydropower potential will be threatened by extreme events and lack of assured supply. The discord between the various member states (if it is not resolved amicably) may continue to weaken progressive and sustainable solutions for the basin, with implications for national development agendas and the ability to respond to climate change.

Eastern Region (See figure 2)

In this region there are notable changes in the climatic trends, leading to drier and warmer conditions (figure 8).



1961-1990 2070-2100

Figure 8: Mean Baseline and future mean surface temperature for the December-February season under A2 Special Report on Emissions Scenarios (SRES) in the Eastern region Source: Abebe Tedege (2010)

Generally the mean baseline and future mean surface temperatures for this region show increases over a 50 year period.

Considering the climate change projections for the region, a number of climate and development threats emerge:

Hunger and poverty

The region is densely populated and has large rural communities reliant on fishing, small community gardens and limited livestock. Due to the current levels of water stress and lack of institutional support from government, these communities are already vulnerable. Increased variability of rainfall events will exacerbate this situation. Wetter conditions could increase erosion and the water-logging and salinisation of crop-lands, reducing crop productivity and increasing poverty and hunger. It will be difficult for poor communities to harness the additional water without the necessary infrastructure to capture and channel

it. There is, however, an opportunity here that can be exploited in terms of assisting communities to develop such infrastructure on a local basis, where this is appropriate, for example through rainwater harvesting (either in tanks or in-field) which can support improved food production at the household level.

Decreasing agricultural production may result in increased food prices in urban areas with the potential to push workers in these areas into poverty.

Physical security

With more extreme events, in an area already typified by climate variability and flooding, future flood events in areas such as the Juba and Shebelle basins, which are arid to semi-arid with a semi-nomadic life-style and some local sedentary cultivation., present a very real risk to human security and property. Coastal centres are likely to be affected by both floods and sea-level rise.

Disease

Wetter conditions may result in new vectors for water-borne or water-dependent diseases such as malaria, placing humans and livestock at further risk.

National development

The high levels of conflict between countries such as Ethiopia and Eritrea, or internally, as in Somalia, restrict the ability of governments to develop effective institutional support mechanisms for managing transboundary basin climate-change challenges.

There are significant opportunities to develop hydropower in the region. Some has been developed, and several countries are further investigating hydropower opportunities. However, the climate uncertainties place these at some risk. This region is also woefully short of infrastructure to mitigate extreme floods and droughts, placing economic development at the mercy of annual rainfall which is projected to become more variable as a result of climate change.

Western Region (see figure2)

The key climate-change vulnerabilities for this region are set against a high level of uncertainty regarding the potential change in rainfall in large parts of the region.

Observed precipitation changes in Sahelians cities for three time periods

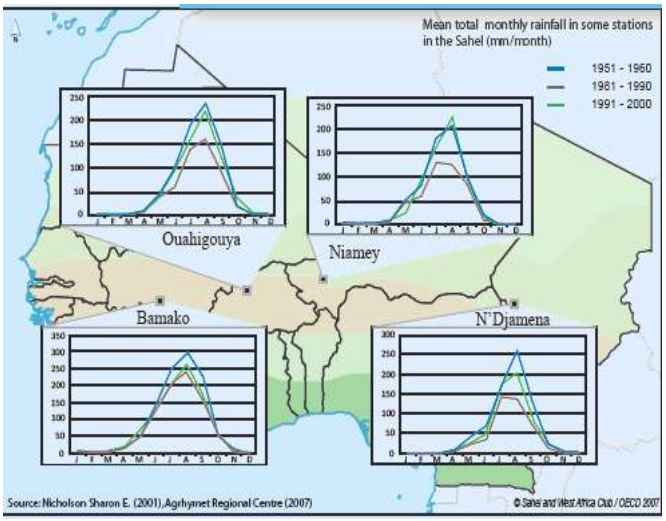


Figure 9: Ten-year average cumulative rainfall for four stations in the Sahel and in the 1950s, 1980s and 1990s.

Figure 9 shows that over the past 50 years, the largest decline in rainfall was observed during the 1980s; the 1990s marked a return to the situation of the 1950s. Similarly, the main rivers in the region show a remarkable decline in flow during the period same period (figure 10 (c)), even more pronounced than that of rainfall. (Club du Sahel, 2008)

Simulations of projected change in June, July and August (JJA) rainfall and temperature for two time periods 2020-2030 and 2050-2060 are presented in Figure 10 (a) and (b).

The model datasets are obtained from the AMMA-ENSEMBLE initiative as part of the CORDEX project. We have used the ICTP-RegCM3 (Pal et al, 2007) model simulation results to project future climate trends in West Africa. The lateral forcings are from the new ERA Interim re-analyses.

The distributed projected changes in rainfall (a) and temperature (b) are for the West African region between 0-15N and 15W-5E and for the June July and August season. The Guinean areas (Sierra Leone, Liberia, Southern Côte d'Ivoire and Ghana) will experience wetter JJA months during the 2020s than during the period 1990-2000, the southern Mali and Burkina (below 12N) will be drier, and the northwest of Côte d'Ivoire and northern Sahel (above 12N) will be wetter. During the 2050s, the dry areas are projected to expand to cover the whole domain except over the northwest of Côte d'Ivoire and the north of Ghana, Togo and Benin.

Projected precipitation change: the south and the whole western region from the south to the north of Cote d'Ivoire is likely to become wetter by an estimated 20% in 2020-2050, whereas the north-east and central part of the country will become drier, as shown in figure 10 (a). For the north-east region of Côte d'Ivoire, the area of maximum rainfall decrease is estimated at about 25%, and the drying front will progresses in two opposite

directions: the south (Côte d'Ivoire) and the north (Burkina Faso). In the mid-term future i.e. the 2050s, the drying trend will be exacerbated, covering most or all the areas in the two countries.

Projected temperature change: the entire region exhibits a steady increase in temperature. The upper latitudes (the Sahel regions) are projected to experience higher temperature increases than the lower (Southern) latitude regions. Warming is greatest over the north-east of Côte d'Ivoire and the south of Burkina Faso and least rapid in the coastal zone along the Atlantic during the 2020s. The region is projected to experience the most pronounced temperature increase, of about 2°C, during the 2050s.

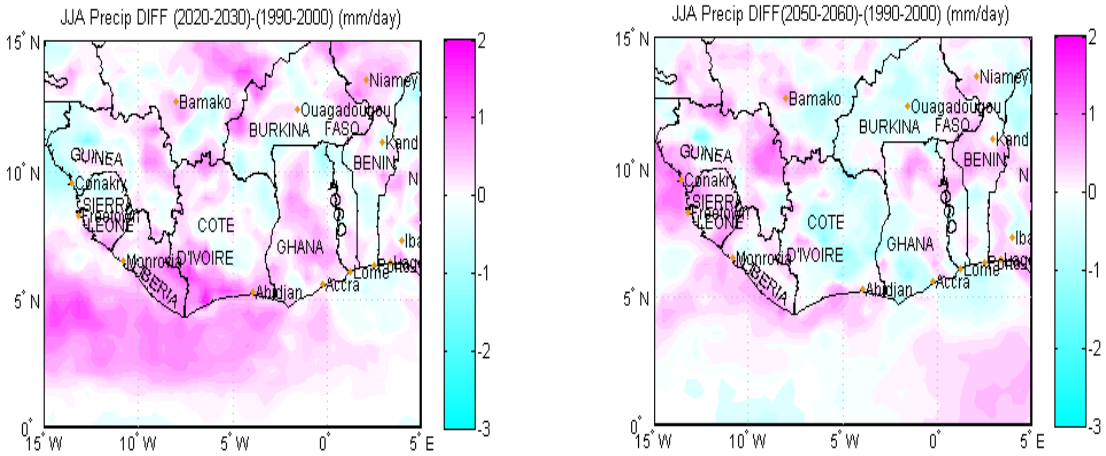


Figure 10(a): Projected change in JJA precipitation in West Africa for 2020-2030 and 2050-2060, compared with 1990 – 2000. Source: Abdourahamane Konare (2010)

Figure 10 (a) top and 10 (b) below show the projected changes according to the A1B scenario, in mean June-July-August rainfall (top) and temperature (bottom) from the reference period, 1990-2000 for two decades: 2020-2030 and 2050-2060.

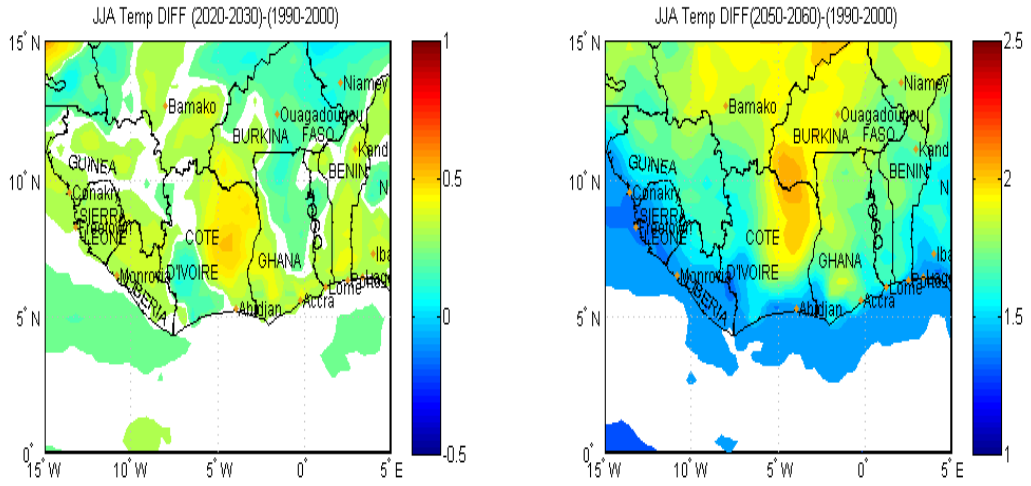


Figure 10(b): Projected change in JJA temperature in West Africa for 2020-2030 and 2050-2060, compared with 1990- 2000

Source: Abdourahamane Konare (2010)

The vulnerabilities are, therefore, likely to vary depending on which scenario (wetter or drier) turns out to be correct in these areas. The vulnerabilities lead to a range of risks in the area:

Poverty and Hunger

The countries in this region are largely dependent on rain-fed agriculture, and large portions of the rural population are subsistence farmers. Depending on whether rainfall increases or decreases across the region, climate change may either improve or negatively impact on agricultural productivity. An increase in rainfall with a limited increase in temperature may make agriculture more productive, but a larger increase in temperature will reduce productivity.

In the coastal countries, increased rainfall in the monsoon season is likely to have negative impacts on agriculture. In the rest of the region, decreased rainfall and increased temperatures will also have negative impacts. The damage to agricultural productivity and household food production arising from climate change will increase poverty and hunger in the region, on the back of already high levels of poverty.

Under a drying scenario the Sahel is particularly at risk, as is the Lake Chad basin (Figure 10 (c).). Other areas at risk include the coastal areas, and the Volta and Niger basins.

Environmental degradation

The reduction of continental wetlands (Niger River Inland Delta, floodplain of the Senegal River Valley, Lake Chad) combined with a decline in the rate of river flow will lead to modification of the ecological niches and the life-cycles of fish in particular. Human population growth, unsustainable resource use and development, and desertification are already threatening the Niger River and leading to drastic declines in the productivity of

fisheries. Deforestation and farming of fragile soils are leading to sedimentation of river channels. Drought and reduced water availability have forced rural communities, such as farmers and cattle herders, to migrate south to areas with more humid conditions, increasing pressure on the remaining floodplains and wetlands. A circular relationship between poverty and environmental degradation characterises the region. The combination of increased human pressures and drought is exacerbating desertification and increasing poverty and hunger.

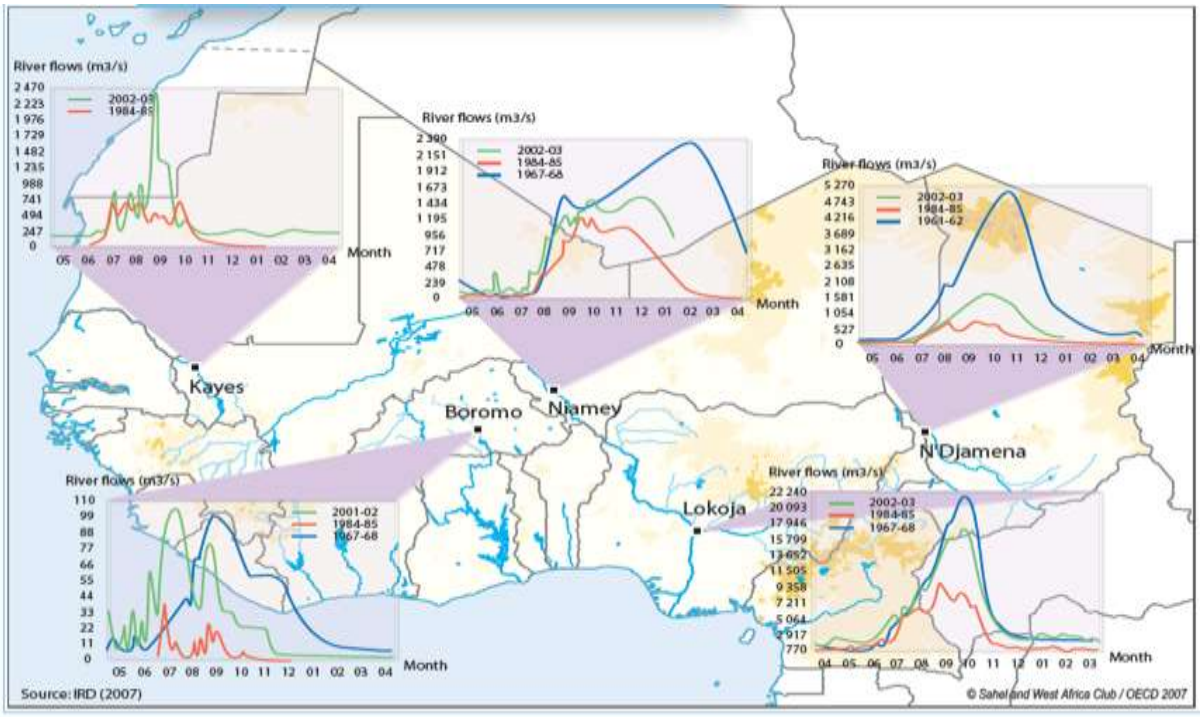


Figure 10 (c): Changes in rate of flow in West African rivers

Source: Sahel and West Africa Club. (IRD 2007)

A threat unique to coastal areas is the ingress of seawater into coastal aquifers as a result of sea-level rise and consequent salinisation of the vital coastal groundwater resources.

Physical Security

The combination of increased flood risks and sea-level rise places the residents of coastal cities particularly at risk. Loss of mangroves which protect the coastline from storm surges and coastal erosion will add to the risks. The number of people at risk may be increased by migration from rural areas where crop production has fallen as a result of climate change.

Disease

Niger and Togo anticipate the resurgence of malaria, and an upsurge in epidemics of meningitis and measles as well as respiratory diseases.

Migration

Migration from rural to urban areas is likely to be increased by the drop in agricultural productivity in many areas. Where this migration is to coastal cities that are most likely to

experience sea-level rise and increased flood risks, an increased number of people will be put at risk of disease, hunger, poverty and physical harm.

National Development
Hydroelectric power generation could be affected in countries such as Ghana, Côte d'Ivoire, Togo and Benin. Interrupted, unreliable, or limited electricity supply can directly impact on the development trajectories of countries, limiting economic growth potential.

In a number of countries, negative impacts on agriculture will also impact on the national development picture. However, in some countries, the presence of oil may in due course reduce the dependence and pressure on agriculture.

Central Region (See figure 2)

Water resources in the Central Clusters 10 and 11 are abundant and currently massively under-utilised. Flooding is a natural phenomenon, with various strategies currently employed to adapt to (and benefit from) seasonal flooding. Accordingly, the central region is not as highly at risk from climate change as some of the other regions. That does not imply that there are no potential risks. Three important risk areas can be identified:

Physical Security
Given the weak institutional environment in much of the region, and the low levels of services and infrastructure, urban areas and particularly peri-urban informal settlements are at risk from flooding, particularly in the large cities of Kinshasa, Brazzaville and Kisangani and some of the smaller towns and urban centres on the margins of river-courses. Rural villages on the river banks are in some cases better adapted to these flooding conditions, as they are often more advantageously placed (on higher-lying ground) and have systems and practices adapted to periodic / seasonal flooding.

The impacts of such flooding include loss of life, damage to infrastructure (homes and social infrastructure), isolation and inability to move to more favourable environments, disease effects, and reduced quality of life.

Flooding can occur either from heavy local rainfall that results in local flooding and ponding, or from increased run-off and flooding of the river, with bank-flow exceeded and extensive flooding of surrounding low-lying areas.

Environmental Degradation
Lake Tanganyika is globally recognised as a hotspot of biodiversity and endemism, and has significant tourism potential. In addition, the lake shore and surroundings are relatively highly populated, with the lake's pelagic fishery a key source of livelihoods. However, regional warming patterns since the beginning of the twentieth century have resulted in reduced mixing, decreasing deep-water nutrient upwelling and entrainment into surface waters. This has resulted in about a 30% decrease in fish yields. These climate-change effects are projected to intensify with increased temperatures, with further profound effects on the pelagic fishery, local incomes and regional protein supplies.

Freshwater invasive aliens are common in the three river systems in the area, the most significant of which is water hyacinth. The combination of higher temperatures and CO_2 fertilisation resulting from climate change may have significant effects on the proliferation of invasive species (particularly water hyacinth), both in Lake Tanganyika and within the river systems of the Congo, Sanaga and Ogooue. While these effects may be systemic, it is most likely that proliferation will be a local response. In addition to the biodiversity and ecological impacts of such proliferation, effects on hydropower may be experienced, particularly where extensive proliferation clogs and damages turbines.

Southern Region (see figure 2)

Climatic records from subtropical southern Africa have shown that both temperature and the amount of rainfall have varied over the past millennium. Moreover, the pattern of rainfall in this region has varied significantly over long periods. Droughts have started abruptly, were of multi-decadal to multi-centennial length, and the resulting changes in the hydrological budget were of large amplitude (Holmgren 2006).

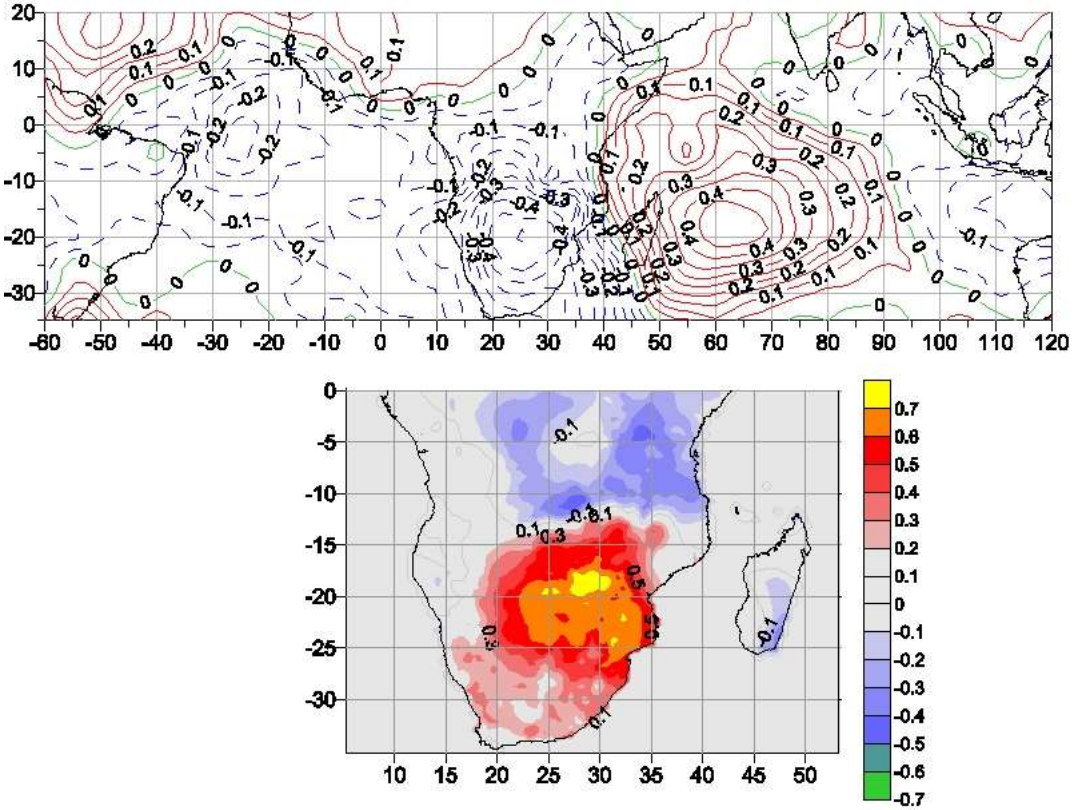


Figure 11: Observed sea level pressure and precipitation over the past decade in the southern region (Source: Holmgren. 2006)

Changing water resources in semi-arid regions clearly have regional influences on both ecological and socio-economic processes. The risk areas are:

Hunger and poverty

The area of the Limpopo, Pungwe and Buzi River basins in the central zone of Southern Africa is projected to become significantly drier and is flagged as a key risk area. This coincides with an area of the sub-continent where water resources are already heavily

utilised. While the area of the Save River basin is only projected to become moderately drier, it supports a large rural population which will be particularly vulnerable to any change in climate, given their reliance on subsistence agriculture.

Most rural areas throughout Africa, including the Southern Region, rely on groundwater resources for drinking water supply. These areas also generally have the highest shortage of secure water supplies, with severe health and socio-economic implications.

The urban explosion (throughout Africa) is creating unprecedented challenges, among which provision of water and sanitation has been the most pressing. Groundwater resources play a key role here, particularly in the large informal urban areas containing up to 70% of the total urban population (Alabaster, 2008). Poor protection of groundwater supplies is already posing a serious threat to sustainable development of these areas (Braune and Xu. 2009).

Environmental degradation

There is a lack of agreement on projections of the Zambezi's future climate, which in itself should be highlighted as a concern for policy-makers. That said, the Kafue catchment is flagged as being at risk for several reasons. A drying climate, which has been predicted by some experts, will negatively affect the Kafue wetlands and flood plains in particular.

The environmental impacts of different climate-change futures are significant and will play out at key sites such as the Orange River mouth where the ability to implement current and future Ecological Flow Requirements may be seriously affected (figure 11).

Climate change in this region will also place stress on rural communities that have a very direct relationship with the environment, and on key environmental sites such as Etosha Pan, the Okavango Delta and the Makgadikgadi Pans.

National development

While future hydropower schemes might be useful, their net value may be reduced by the effects of climate change as power decreases with reduced rainfall and increased evapo-transpiration. Planned developments in Angola and Namibia should be flagged as areas at risk from predicted reductions in rainfall.

In the Orange-Senqu River basin, development is expected to increase, particularly within the Gauteng in South Africa. A dryer future for this region will result in already heavily-utilised resources being extremely stressed. In addition, large areas of irrigated agriculture may become unviable under hotter and drier scenarios, which will necessitate major shifts in water-use patterns.

Assessment of regions most at risk

Africa has been recognised by the International Panel on Climate Change as the continent most vulnerable to climate change. It is, therefore, imperative for all African governments to be ready to manage the various impacts of climate change on freshwaters. There are, however, three key areas in the continent that have been identified as being particularly at risk, because of the extent of the impact, the size and vulnerability of the affected

population, and the lack of adaptive institutional capacity to manage the impacts. There is also one area that has been identified as holding potential opportunities, but which is under threat, not from climate change, but from development and human impacts, and which requires protection.

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Regions most at risk

Coastal Areas: The coastal areas of West Africa (from Senegal to Nigeria), of eastern and southern Africa (from Mozambique to Tanzania) and the Nile delta, are at risk from flooding, sea-level rise, storm surges (except the Nile delta), and saline intrusion into surface and groundwater. Currently more than 70 million people in these areas are at risk, and the population of the coastal region of West Africa is projected to grow to around 100 million by 2050 because of population growth and migration from increasingly arid inland areas. In the coastal areas of West Africa, institutional capacity is extremely limited, resulting from impoverished societies and decades of conflict. Combined with the extremely high population increase expected in the region, these challenges make it the most vulnerable of the coastal regions.

While 40 million people currently live in the Nile delta, and are also at risk from sea-level rise and flooding, the institutional capacity in Egypt is significantly higher than that in West Africa, allowing for greater adaptation capacity.

The east coast of Africa, while also very poor in terms of institutional capacity and per capita income, has a smaller population exposed to risk than the projected population in West Africa. However, the high levels of HIV/AIDS in these parts of sub-Saharan Africa mean that these populations are already weakened and vulnerable.

Great lakes: The great lakes of the Rift Valley (Lakes Victoria, Turkana, Tanganyika, and Malawi) and Lake Chad are extremely vulnerable to climate change. Around 50 million people currently depend on these lakes, most of which are already experiencing a reduction in fish stocks, decreasing water quality, and reduced water levels. Temperature changes are predicted to result in lower wind intensity which, in turn, will reduce turnover in the lakes. This raises the possibility of a collapse of the fisheries, massive loss of biodiversity, increased eutrophication and decreased water quality. The impact of these lakes in terms of contribution to protein consumption in rural communities, and international trade through export of tropical fish, is significant, and a collapse of the lake systems would have massive impacts on local and national well-being.

The semi-arid regions: In the semi-arid regions of the Sahel, central and eastern Southern Africa, and the Horn of Africa, large rural and peri-urban communities are largely dependent on rain-fed agriculture, and bio-mass derived energy. Their water supplies are often insecure and may depend on local rivers or groundwater. Increased climatic variability in these regions, combined with more intense droughts and floods, increased temperatures and lower rainfall overall, would put these communities significantly at risk,

as can been seen in the current severe drought affecting the Horn of Africa. In southern Africa the vulnerability of these communities to climate change is exacerbated by extremely high rates of HIV/AIDS.

Protecting the 'water towers'

On a more positive note, there is a need and an opportunity to protect the critical 'water towers' of central, west and eastern Africa, (the Congo forests, the Fouta Djallon mountain areas in west Africa and the Eastern Africa and Ethiopian highlands). Protection of these areas is important for protecting the quantity and quality of water, while also contributing to climate change mitigation through the conservation and restoration of critical forest areas, and protecting biodiversity. These areas are currently at risk from deforestation and poor land-use management, resulting in decreased effectiveness of these areas as critical catchment areas.

4. Analysis of key responses strategies

While it is important to recognise many of the weaknesses across the continent that may complicate effective responses to climate change, such as poor institutional capacity, high levels of poverty, paucity of data, and limited modelling of climate change impacts at the local scale, it is equally important that immediate action is taken to improve the resilience of communities and societies to the impacts of climate change.

The following section describes some key actions that could be taken in response to the main risks identified. This is by no means a comprehensive list, but offers some critical intervention points that should be addressed.

The actions that are proposed here lie within the field of water management. However, some of the most successful responses to the water-related impacts of climate change and the building of resilience may lie outside the water sector, such as social grants for affected communities. It is, therefore, important for integrated adaptive approaches to be developed, not approaches limited only to the water sector.

Good Water Management

The first point of intervention that is critical in addressing the key water-related vulnerabilities to climate change in Africa is to improve water management across the continent, particularly in the most vulnerable areas. There is no magic bullet that will help to address the impacts of climate change, and any response must be built on a foundation of solid and effective water management. A key requirement is to ensure that water management plans are aligned with national development and poverty reduction strategies, and that implementation of these strategies is driven hard to address the current development and poverty challenges.

A second requirement is to improve the ability to manage the current challenges of climate variability. This will significantly improve the ability to manage the longer-term impacts of climate change. Such measures include:

- ensuring that appropriate legislation (and agreements at the transboundary level) is in place,
- ensuring the institutional capacity to manage water effectively (both water resources and water services),
- achieving greater multiple and conjunctive use of water resources[7],
- developing sufficient skilled and experienced staff to manage water effectively,
- ensuring sufficient financial resources to develop, operate and maintain the necessary water infrastructure to respond to climate change, and
- ensuring that appropriate information is available, which requires effective monitoring and data collection, particularly important for monitoring climate trends.

Where human and financial resources are limited, as they are in many parts of Africa, it is important to identify and focus on managing the most vulnerable areas and the most critical issues, rather than attempting to spread limited resources over too large an area or too many issues.

It is also critical that water resource management is practiced in the context of the large number of transboundary basins that are vulnerable to the impacts of climate change. This will require improved relations between riparian countries, the sharing of information, and joint processes to address critical areas.

A number of areas that constitute good water management and that are critical in the face of climate change are highlighted below.

Invest in Infrastructure and Technology and Create Incentives

There are a number of areas in which investment in infrastructure is necessary to support development and thereby build resilience to the impacts of climate change. Different infrastructural responses will be appropriate in different areas, depending on the vulnerabilities and challenges of these areas. Key to the building of infrastructure, however, is an understanding that infrastructure is required primarily to support development, and through that process, if designed and managed correctly, to increase the capacity to adapt to climate change. It is also important to recognise that infrastructure refers not only to large dams and Inter-basin transfers, but also to small scale infrastructure such as wells and pumps, rainwater harvesting structures, and small-scale irrigation systems.

In many areas climate change is likely to bring increased likelihoods of floods, and increased flood intensity. A number of management actions are required to improve flood management, including the development of early warning systems and the rehabilitation of degraded catchments. In some areas the development of flood attenuation infrastructures

[7] Conjunctive use of water refers to the optimal use of both groundwater and surface water

may be appropriate, and protection of infrastructure against floods is also critical. In flood conditions, water services infrastructures (for water and sanitation) may be damaged, leaving communities vulnerable to poor quality water or lack of drinking water, and lack of functioning sanitation facilities. The flood-proofing of water supply and sanitation infrastructure should be considered in vulnerable areas.

The other side of the coin is that some areas will see decreasing rainfall and increased droughts. In most of Africa, water storage is, currently, insufficient to disconnect economic growth from rainfall. Even if climate change were not a reality, Africa requires increased storage (both large dams and small storage facilities) in order to overcome the impacts of frequent droughts. With the possibility of climate change extending the periods of droughts and increasing their intensity, the need to invest in increased storage becomes all the more important. In this regard, finding the financial resources for the development of infrastructure remains a critical challenge and one where African governments, the private sector, and international financing agencies all have a role to play.

At the farm level, increased investment in and access to information about appropriate irrigation technology, including drip irrigation and rainwater harvesting, is required to improve water use and productivity in the face of climate change. In many areas, a shift from rain-fed to irrigated agriculture may be necessary to protect rural livelihoods and food security. In the case of groundwater, specific policies, research and development cooperation are required to overcome key obstacles such as the high costs of well construction and limited understanding of groundwater resources that currently restrict development of groundwater for irrigation in many parts of Africa (Kampala Statement, 2008).

Artificial recharge of groundwater sources presents an important step in the sustainable management of resources that are in danger of over-exploitation and degradation. The primary objectives are to increase groundwater availability and sustain a good quality for improved security of domestic supplies and to drought-proof and protect rural livelihoods. This is part of the large number of possible (technical) solutions to develop the buffer function of groundwater, covering the broader process of retaining and intercepting rainfall and runoff, conserving it in the soil or storing it underground to supplement the groundwater, or in tanks at appropriate places for re-use during dry periods (Van Steenbergen and Tuinhof, 2009).

A systematic scaling-up of locally appropriate solutions is critical in order to make an area- and region-wide impact on poverty alleviation, climate change adaptation and economic development.

Investment in natural infrastructure, for example to protect and rehabilitate aquifers and wetlands, can also contribute significantly to building resilience to climate change.

Recognising the disproportionate burden that poor women will bear arising from climate change, it is critical that investment in infrastructure and technology reflects women's priorities and needs and that women are actively involved in decisions relating to infrastructure development. Other technological developments designed to increase

resilience to climate change should also take into account the specific needs and requirements of women.

The introduction of appropriate incentives can contribute to reducing greenhouse gas emissions, easing pressures on ecosystems and increasing environmental resilience and resource sustainability, including land and water protection.

Disaster Preparedness

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

Women are particularly at risk from natural disasters, for a number of reasons, including their lack of property, land or savings to buy new shelter after a disaster. As a result, women are more likely to be put in crowded shelters than men, and face the possibility of rape and physical abuse in such circumstances. Women are also physically less able to escape from floods, for example due to the nature of their clothing, their need to carry babies or small children or their already weakened state in a context of food shortages. Cultural practices may also prevent women from seeking healthcare. Women in countries with high gender disparities are most vulnerable. As a result, it is essential that disaster plans are specifically gender-sensitive and address the particular needs of women.

Flexible / Adaptive Development Planning

Of key importance in managing the water-related impacts of climate change is the need to ensure alignment between national development objectives and water availability. Because of the difficulty of predicting climate change impacts on water with any accuracy at this point in time, the challenge is to ensure that a flexible approach is taken to planning which allows adaptation to a changing climate over the years. This requires access to relevant and updated climate-change information for the key water-related development planning departments, (e.g. agriculture, mining, power generation, municipalities), and also requires strong alignment and cooperation between water departments and departments responsible for development planning.

It will be critical to integrate local resource development and management issues into macro-planning to ensure their systematic consideration, integration and financing.

Given the vulnerability of poor women in particular to climate change, development plans and climate change response plans should proactively address the issue of gender and the protection and support of women and girl children in particular.

Flexible and Clear Allocation Systems

Water allocation takes place at a number of levels. In the basins and aquifers under consideration in this report, the first level of allocation is between riparian states. While there are a number of transboundary agreements in place in transboundary basins in

Africa, there are also a large number of basins in which there are no such agreements. Even where agreements are in place, some lack effective dispute resolution mechanisms, and many lack effective institutional capacity at the national or transboundary level for effective implementation and optimal sharing of water resources and the benefits derived from them. In basins facing water stress as a result of climate change it is important that effective transboundary water allocation systems are put in place, supported by good, shared data on the status of the basin.

At the sub-basin or local level, a range of water allocation systems operate in Africa, with parallel formal and customary systems in many countries. It is important that these systems are sufficiently flexible to enable adjustments in allocation to manage climate variability and climate change in support of national development objectives. It is also important, however, bearing in mind the limited institutional capacity in Africa, that these systems are sufficiently simple to be effectively implemented and managed within the capacity constraints.

Responsive Institutions

Climate change in Africa is projected to result in significant changes in the demand for and availability of water. As has been seen in the earlier part of this report, institutional capacity to manage this change is limited in most parts of the continent. Institutional capacity must be built, including ensuring that appropriate legislation and policy is in place, that sufficient infrastructure is in place for storage and flood attenuation, and ensuring appropriate technical and managerial capacity. The last of these requires appointing and training people able to manage adaptively and in the face of uncertainty. This is a different mode of water management from the traditional approach, and requires the encouragement of innovation and creative responses to change.

It is also critical that stakeholders are involved in the water resource management process so that there is full support for the approaches to be taken and so that the exchange of information between stakeholders and authorities enables quick responses to situations and optimal adaptive responses.

However, the key challenge in developing responsive institutions lies in building the adaptive capacity of such institutions. An effective response to climate change will be based not on the ability to accurately predict the changing climate and its water-related impacts, but rather on the ability to respond to change, to enable innovation at all levels, and to create flexible and responsive water management systems. In this regard, flexible allocation systems that allow amendments in water use to adjust to short-term climate variability and longer term climate change are of critical importance.

Improved Science and Information

The approaches mentioned above depend on improved science and information-sharing across vulnerable transboundary basins and aquifers in particular. One of the challenges in terms of managing climate change in Africa is the lack of models for predicting climate change at the local level. It is critical that the capacity to model climate change is enhanced so that management options can be based on scientifically sound

information. This will require increased investment in the science of climate change and in understanding the impacts in Africa, and there may be a role for an African centre of excellence in this regard.

A critical aspect of improved information is the ability to define the current state, identify emerging trends, and anticipate the possible future path and the resulting vulnerabilities and risks. This requires an appropriate monitoring system, which can deliver the necessary information at the appropriate scale. This system should extend beyond simply monitoring climate trends, to also monitoring the status of the resource, to detect emerging trends, and to identify necessary management actions to be put in place, including monitoring of crucial environmental variables and processes related to water, and to ecosystem-based climate change adaptation that must be expanded and supported over the long term.

Commensurate with groundwater's critical role in climate change adaptation, better knowledge, in particular coherent region-wide information on groundwater resources, their recharge and sustainable use, is urgently required.

A critical part of an improved information system is the development of early-warning systems, in particular for floods. That said, however, bearing in mind the limitations of institutional capacity in Africa, another key challenge is to develop monitoring and information systems that are appropriate to the financial and human capacity constraints and can deliver appropriate information without unsustainable resource demands. In this regard, a partnership with stakeholders, and the use of widely accessible technology such as cell phones, can be used to supplement limited government data and information.

It is also critical that information is exchanged widely across the continent, developing the understanding of climate change and adaptation to climate change between countries and within countries.

Investment in People

Adaptation takes place at a number of levels, from the creation, for example, of major storage infrastructure, to the household level, particularly in rural areas and areas where governments fail to reach. In this regard, while governments might not be able to extend the necessary services to vulnerable populations to protect them from climate change, the provision of information itself can assist communities and households to prepare themselves for the coming changes.

The provision of information and training for rural communities is particularly important because of their high levels of vulnerability and because they are often out of the information loop. Information could include new crops to use, improved cropping or livestock management techniques, local water-resource use and protection, and flood warnings.

It is important to realise that access to technology and information is not gender-neutral and that, in most African countries, girls and women have less access to information and communication technology than men, because of social and cultural bias, lack of

technological infrastructure in rural areas, lower levels of education, especially in the fields of science and technology, and the lack of disposable income to buy technological services.

There is, thus, a particular need to invest in the training and empowerment of women as the ones who protect family health and well-being, and who are key drivers of adaptation in their own right. Gender mainstreaming and understanding the particular vulnerabilities of women should form a key part of all climate change adaptation strategies.

With the adaptation focus on the local level, attention to local institutions is critically important in the design of adaptation projects and policies. Such institutions are necessary enablers of the capacity of households and social groups to deploy specific adaptation practices.

Transboundary Basin Management and Regional Integration

The building of trust, shared knowledge and a shared vision of the basin across boundaries is very important, particularly in highly vulnerable areas and those that already lie in conflict zones. While there are a number of transboundary basins in Africa in which international agreements have been concluded and transboundary institutions are in place, many of these agreements and institutions are weak, and are not necessarily appropriate to cope with the impacts of climate change.

The generally neglected localised groundwater resources require an urgent strengthening of institutional structures at continental (e.g. Africa Groundwater Commission) and regional scales, and the development of legal and institutional frameworks to enable sound governance and equitable sharing of the transboundary resources.

In many areas the solution to the climate change and development challenges will come not only from transboundary co-operation, but from a greater exploitation of regional competitive advantage, seeing development opportunities within the context of a region, rather than a country. Climate change, in this regard, offers a key driver for the expansion of regional integration across the continent.

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

Understanding the Energy/Water Nexus

A number of African countries depend on hydropower, even though the hydropower potential of Africa is still hugely underdeveloped. However, as has been seen in the regional reports, hydropower is under threat in some areas from diminishing stream flow or increased flow variability. As a result, the ‘climate change-proofing’ of current infrastructure is an important measure to protect the energy supply of many countries, and hence to protect economic and social development potential. Such climate change

proofing might include, for example, amended operating rules to take into account changing rainfall patterns, the raising of dam walls or changes to environmental flow releases, At the same time, further hydropower potential is under development, but this must take place with a clear understanding of the potential impacts of climate change, and in such a manner as to be able to withstand these impacts.

It is important to ensure both water and energy security in an integrated manner taking into account the likely impacts of climate change. It is particularly important, in the context of the large number of transboundary basins in Africa, for such understanding to be at the basin as well as the national level, for joint planning for a water- and energy-secure future. Energy sources that do not demand water should also be seriously considered.

Harnessing Groundwater

Access to groundwater is perhaps the most critical factor enabling many rural as well as urban populations to maintain sustainable livelihoods. Groundwater is strategically important for adaptation, because it is the key resource for local coping strategies. These are critical because local communities are the first to experience the impacts and will have to rely, to a large extent, on local resources and experience. Yet, because it has remained a poorly understood resource, groundwater is still poorly integrated into Integrated Water Resource Management (IWRM) and development planning and is often neglected in practice. This needs to be addressed strategically through appropriate regional, sub-regional and national policies, through proper integration into the IWRM process, structures and institutions, and through its prioritisation in adaptation initiatives and in the utilisation of adaptation funding.

Conclusions

The IPCC has recognized that Africa is the continent most vulnerable to the impacts of climate change – partly because of the actual climatic changes that are projected, but significantly because of the high levels of poverty and low levels of institutional capacity across the continent. The challenges of climate change overlay an already fragile human condition, with high levels of poverty and hunger, poor service delivery, and, in many places, already stressed water resources. Not only is climate change adding to the existing pressures of development on limited water resources, but as the climate change pressures intensify, they will do so in the face of growing populations and economies, both of which place greater stress on water resources. The challenge of managing water in Africa over the coming decades is thus both a climate change challenge and a development challenge.

With this in mind, an overview has been provided that identifies some of the most vulnerable areas in Africa, and some approaches that may help to ameliorate the impacts of climate change. The already vulnerable poor, particularly, but not only, in rural areas, are the people most at risk from the impacts of climate change. Any action which increases the resilience of these communities will help them to respond more effectively to

the impacts of climate change, including removing barriers to the integration of climate change adaptation into development planning and decision-making frameworks.

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

Following Specific Recommendations for Action, as clearly identified by the Global Water Programme (GWP) in May 2009 should be looked at more specifically:

- **Adaptation in a broad development context**

Climate change is one of several significant drivers of change, especially in many agriculture-based developing countries where changes in economic growth are closely linked with variations in climate and water availability and where the overall vulnerability is high.

- **Building resilience**

Resilience and adaptive capacity of rural poor households, communities and land and water management systems need to be improved widely. Furthermore, vital ecosystem functions and services are under high pressure from population growth, energy demands and exploitative land-use practices resulting in deforestation and land degradation. Increasing the resilience to climate change in land and water management therefore calls for integrated ecosystem-based approaches that address farmers' poverty-related barriers to adaptation, promotes land-use diversification and intensification, and increases water storage systems and improves their management.

- **Improving Governance**

Building resilience in land and water management systems to climate change stresses the need for decision-making processes that respect the principles of subsidiarity, decentralisation and adaptive management. Climate-change concerns and adaptation for land and water management needs to be mainstreamed and integrated in national policies and implementation frameworks, bridging across institutional and sectoral divides.

- **Improving and sharing knowledge and information**

Vulnerability and adaptation to the risks and impacts of climate change are shaped by a complex interaction between local land and water resource characteristics, economic conditions and the often highly diverse livelihood capitals and strategies of individual households. Effective adaptation planning and implementation in land and water management systems is therefore highly context-specific and knowledge-demanding.

Adaptation should be knowledge-based, including and integrating both scientific and local knowledge. Local knowledge systems on adaptation have in many places evolved from

the experiences of generations with adaptation to changing climate conditions. Furthermore, the uncertainties over short- and long-term climate change and impacts must be reduced, especially at local levels and in terms of precipitation and water availability.

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

- **Addressing the economic and financial aspects**

Recognising adaptation as an additional development challenge, additional and substantial increases in financing are needed to improve the adaptive capacity and resilience of rural households and land and water management systems. The full range of financing options needs to be utilised, including innovative financing mechanisms, private sources and public sector funding from developed countries. All opportunities in the United Nations Framework Convention on Climate Change (UNFCCC) negotiations covering mitigation and adaptation need to be utilised. The scope of the Clean Development Mechanism and/or emerging Market Mechanisms for Sustainable Development should therefore be expanded to include avoided deforestation, agro-forestry and soil carbon sequestration practices. It is important that funding for climate change adaptation is substantially scaled up.

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