IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES IN AFRICA: the Role of Adaptation

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Abstract
Climate change is having a multitude of immediate and long-term impacts on water resources in African countries. These include flooding, drought, sea-level rise in estuaries, drying up of rivers, poor water quality in surface and groundwater systems, precipitation and water vapour pattern distortions, and snow and land ice mal-distribution. These effects when compounded together have devastating impacts on ecosystems and communities, ranging from economic and social impacts to health and food insecurity, all of which threaten the continued existence of many regions in Africa. Vulnerability varies according to individual countries, geographical positioning and the capacity to mitigate or adapt to the changes. Coping, adapting and building the resilience capacities of African countries towards the impacts of climate change on water resources requires an holistic approach involving systems thinking and risk management strategies. Solutions pivot on taking urgent action to utilize science technology and innovation, policies relevant to water audit and management, and engagement of private, civil and international sectors if a major crisis is to be averted.

Introduction
Water is life. This is a popular axiom in Africa, underpinning the high level of importance the people of the continent place on the resource. In all its forms – rainwater, aquifers, streams, ponds, springs, lakes, rivers, ocean water, snowpack ice and water vapour – water is an essential and central resource.

The African continent, with a land area of nearly 30 million square kilometres, holds a wealth of natural resources which few other parts of the globe can match, including minerals, forests, wildlife and rich biological diversity. This natural wealth is largely unexploited, and is not reflected in measures of the welfare of the region's inhabitants (United Nations Environment Programme, UNEP, 2000). The continent also has some of the driest deserts, largest tropical rain forests and highest equatorial mountains in the world. Key natural resources are unevenly distributed. For example, more than 20 per cent of the remaining tropical forest is in a single country (the Democratic Republic of the Congo), while a major share of the continent's water resources are in a few large basins (such as the Congo, Niger, Nile, Zambezi and Lake Victoria). The Congo watershed contains 10 per cent of Africa's population but accounts for about 30 per cent of the continent's annual run-off (Hinrichsen *et al.*, 1997).

Many countries in Africa live under water stress, defined as those using more than 20 per cent of their renewable water resources (WBGU, 2003), while withdrawals of over 40 per cent mean serious water stress (Pittock, 2005). For example, reports show that water withdrawal in Nigeria during the 1990s was 28 cubic metres per person per year (Gleick, 2000; World Bank, 2003). The international Dialogue on Water and Climate (2004) noted that water stress will increase significantly in those regions that are already relatively dry (such as sub-Saharan Africa). Further, a region is in a state of high water-related criticality (susceptibility of a region or its population to crises) if water scarcity coincides with a low problem-solving capacity of the population (WBGU, 1998). About 25 per cent of the contemporary African population experiences water stress, while 69 per cent live under conditions of relative water abundance (Vörösmarty *et al*., 2005), but abundance does not necessarily mean availability. Relative abundance does not take into account other factors such as the extent to which that water is potable and accessible, and the availability of sanitation. According to UNEP (2003), about 1,100 million people do not have access to clean drinking water, and contaminated water is the cause of 5 million deaths every year, with the majority of these in sub-Saharan Africa.

Human and natural activities affect virtually all sections of the water cycle, often with additive effects. Over time, human activities such as forest clearing, afforestation, agriculture, etc, have disturbing influences on the water cycle including evapo-transpiration, flow regimes, groundwater table and sea level. Also, human activities influence cloud formation via the emission of aerosols and their gaseous precursors (Krüger and GraßI, 2002). Principal threats to water resources for humans include water pollution (the contamination of surface water and groundwater reservoirs with chemicals and microorganisms); water scarcity (the change of run-off regimes and the change – mostly lowering – of the groundwater table); and most importantly, global climate change with consequences such as redistribution of precipitation, rising sea levels, change in the CO_2 absorption of the oceans and increases in extreme precipitation events (WBGU, 2004; Stolberg *et al*., 2003; Palmer and Räisänen, 2002). Climate change has been defined by the Intergovernmental Panel on Climate Change, IPCC (2001) as statistically significant variations in climate that persist for an extended period, typically decades or longer. It includes shifts in the frequency and magnitude of sporadic weather events as well as the slow continuous rise in global mean surface temperature. Climate, water resources, biophysical and socioeconomic systems are interconnected in complex ways, so a change in any one of these induces a change in another. Anthropogenic climate change adds a major pressure to nations that are already confronting the issue of sustainable water resource use, such as in Africa.

Countries in sub-Saharan Africa are likely to suffer the most devastating impacts of climate change because of their geographical location, low incomes, low technological and institutional capacity to adapt to rapid changes in the environment, as well as their greater reliance on climate-sensitive renewable natural resources sectors such as water and agriculture (Eboh, 2009). African countries are particularly susceptible to climate change due to the desertification process, declining run-off from water catchments, declining soil fertility, dependency on subsistence agriculture, the prevalence of AIDS and vector-borne diseases, inadequate government mechanisms and rapid population growth (Anyadike, 2009). More than 70 per cent of those living in African, Caribbean

and Pacific (ACP) countries work in the agricultural sectors: for these people, understanding and responding to climate change is not a theoretic discussion, it is the difference between life and death (Spore, 2008).

Observational records and climate projections provide abundant evidence that water resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems (Bates *et al*., 2008). Numerous internal and external feedback paths occur between anthropogenic impairment of the water cycle and the environmental resources of the atmosphere, soils and the biosphere. Even without the additional stress of climate change, water security already is one of the most pressing issues in developing countries (WBGU, 1997). In many cases, water crisis can be traced back to a failure of state control, and therefore to crisis in governance (UNESCO, 2003).

According to climate model analyses, the number of people at risk due to water scarcity increases rapidly with rising temperatures towards the second half of the century, with impacts in arid and semi-arid regions expected to be much larger than the global averages suggest (IPCC, 2001; Parry *et al*., 2001). Thus in regions already under water stress today, including Africa, climate change will exacerbate the situation. For many of the water-distressed regions, global mean temperature increases above 1.5ºC are identified as leading to decreases in water supply and quality (IPCC, 2001). Bates *et al*. (2008) reported that warming over several decades has been linked to changes in the large-scale water cycle such as: increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff. In other words, the challenges related to water resources are: having too much of it, having too little of it, and having un-usable resources (e.g. due to pollution or stagnation). Each of these problems may be exacerbated by climate change. Available evidence has proved that looming climate changes are already having serious consequences on the water resources of most African countries, even when the continent of Africa contributes insignificantly to the greenhouse gas emissions responsible for these changes. For example, the whole of sub-Saharan Africa accounts for only 1.59 per cent of the global greenhouse gas emission (Spore, 2008). Understanding the African-climate change-water resources nexus will provide great opportunity to proactively address the situation and chart the way forward for sustainable water resource use in Africa.

The pertinent questions to ask therefore are: what are the effects of these entire climate change scenarios on water resources? What impact does climate change have on Africa's water resource systems? Are there clear manifestations and evidence-based effects/impacts of climate change on the water resources across the African continent? What are the ways forward in Africa towards ensuring effective and efficient water resource management today, for sustainable water resource availability tomorrow, even in the face of climate change? In the following sections we explore these questions.

Effects of climate change on water resources in Africa

Observable and potential effects of climate change on water resources in Africa include: flooding, drought, change in the frequency and distribution of rainfall,

drying-up of rivers, melting of glaciers, receding of water bodies, landslides, and cyclones among others. These effects are summarized in Table 1 according to the major effects experienced in different African countries.

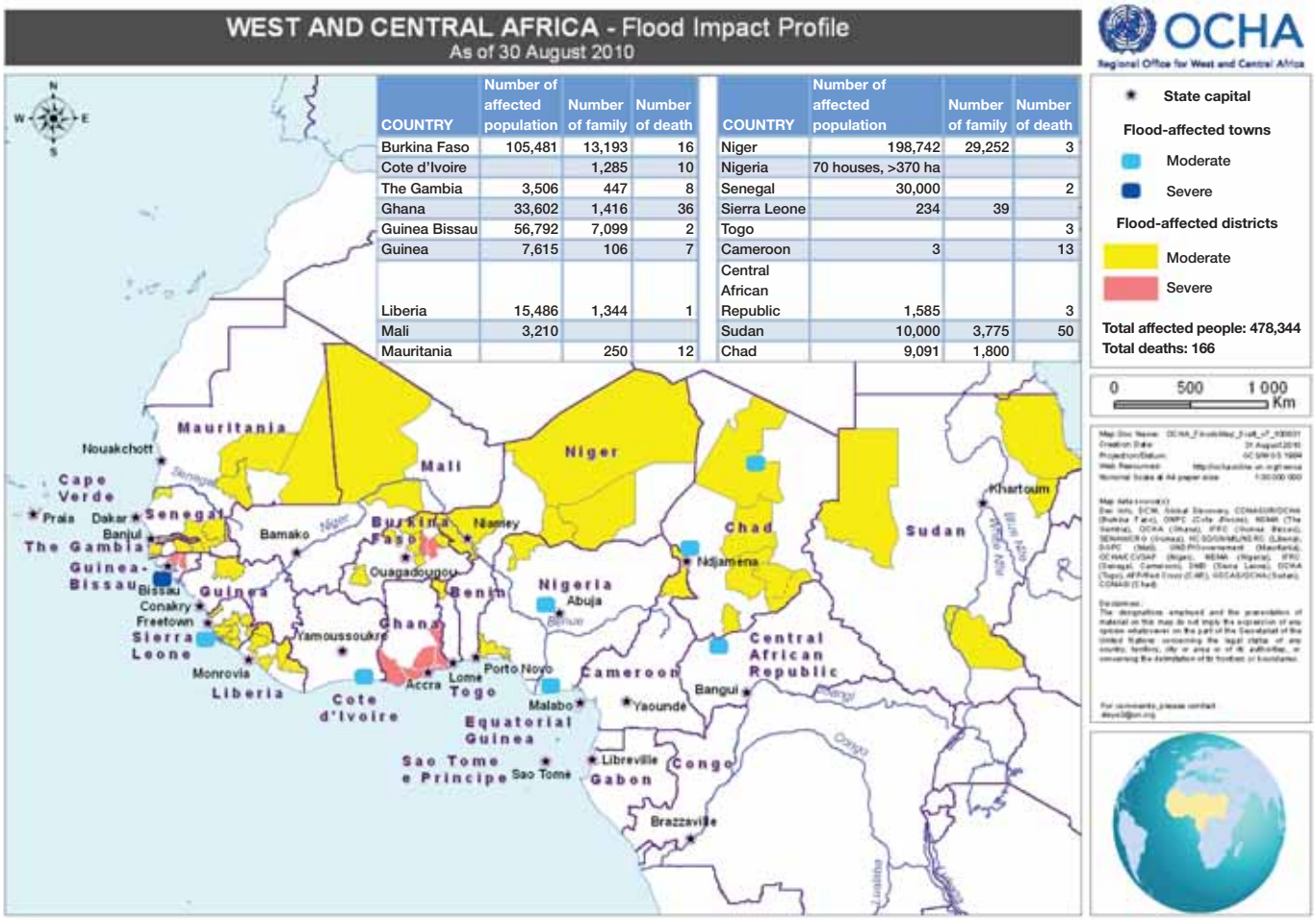
Flooding

For millennia, humans have settled in floodplains in order to till fertile soils, use the flat terrain for settlements, gain easy and safe access to water and use rivers for transport (Pavel, 2003). Riverine floods are a natural phenomena; they have always occurred, and populations have benefitted from them to whatever extent possible (for example, in ancient Egypt the natural annual flooding of the Nile brought much-needed nutrients to irrigated soils). In recent times, humans have become more exposed to flood risk as encroachment into flood plains and lack of flood response plans increase the damage potential.

Much of Africa is vulnerable to flooding: flood is the most prevalent disaster in North Africa, the second most common in East, South and Central Africa, and the third most common in West Africa (AWDR, 2006). Figure 1 shows the flood map in West

Figure 1: Flood map of Central and West African regions

Source: United Nations Office for the Coordination of Humanitarian Affairs (OCHA) (2010). http://www.reliefweb.int/rw/fullmaps_af.nsf/luFullMap/123CEFD4A4BA7387C125779000474FA6/$File/map.pdf?OpenElement



COUNTRY	Number of affected population	Number of family	Number of death
Burkina Faso	105,481	13,193	16
Cote d'Ivoire		1,285	10
The Gambia	3,506	447	8
Ghana	33,602	1,416	36
Guinea Bissau	56,792	7,099	2
Guinea	7,615	106	7
Liberia	15,486	1,344	1
Mali	3,210		
Mauritania		250	12

COUNTRY	Number of affected population	Number of family	Number of death
Niger	198,742	29,252	3
Nigeria	70 houses, >370 ha		
Senegal	30,000		2
Sierra Leone	234	39	
Togo			3
Cameroon	3		13
Central African Republic	1,585		3
Sudan	10,000	3,775	50
Chad	9,091	1,800	

Table 1: Climate change related effects on water resources in Africa

	Country	Climate change related effects
1	Algeria	Mountainous areas subject to severe earthquakes; mudslides and floods in rainy season
2	Angola	Locally heavy rainfall causes periodic flooding on the plateau
3	Bassas da India	Maritime hazard since it is usually under water during high tide and surrounded by reefs; subject to periodic cyclones
4	Benin	Hot, dry, dusty harmattan wind may affect north from December to March
5	Botswana	Periodic droughts; seasonal August winds blow from the west, carrying sand and dust across the country, which can obscure visibility
6	Burkina Faso	Recurring droughts
7	Burundi	Flooding, landslides, drought
8	Cameroon	Volcanic activity with periodic releases of poisonous gases from Lake Nyos and Lake Monoun volcanoes
9	Central African Republic	Hot, dry, dusty harmattan winds affect northern areas; floods are common
10	Chad	Hot, dry, dusty harmattan winds occur in the north; periodic droughts; locust plagues
11	Comoros	Cyclones possible during the rainy season (December to April); Le Kartala on Grand Comore is an active volcano
12	Cote d'Ivoire	Coast has heavy surf and no natural harbours; during the rainy season torrential flooding is possible
13	Democratic Rep. of the Congo	Periodic droughts in the south; Congo River floods (seasonal); in the east, in the Great Rift Valley, there are active volcanoes
14	Djibouti	Earthquakes; droughts; occasional cyclonic disturbances from the Indian Ocean bring heavy rains and flash floods
15	Egypt	Periodic droughts; frequent earthquakes, flash floods, landslides; hot, driving windstorm called khamsin occurs in spring; dust storms, sandstorms
16	Eritrea	Frequent droughts; locust swarms
17	Ethiopia	Geologically active Great Rift Valley susceptible to earthquakes, volcanic eruptions; frequent droughts
18	Gambia	Drought (rainfall has dropped by 30% in the last 30 years)
19	Ghana	Dry, dusty, northeastern harmattan winds occur from January to March; droughts
20	Glorioso Islands	Periodic cyclones
21	Guinea	Hot, dry, dusty harmattan haze may reduce visibility during dry season
22	Guinea-Bissau	Hot, dry, dusty harmattan haze may reduce visibility during dry season; brush fires
23	Indian Ocean	Occasional icebergs pose navigational hazard in southern reaches
24	Juan de Nova Is.	Periodic cyclones

	Country	Climate change related effects
25	Kenya	Recurring drought; flooding during rainy seasons
26	Lesotho	Periodic droughts
27	Liberia	Dust-laden harmattan winds blow from the Sahara (December to March)
28	Libya	Hot, dry, dust-laden ghibli is a southern wind lasting one to four days in spring and fall; dust storms, sandstorms
29	Madagascar	Periodic cyclones
30	Mali	Hot, dust-laden harmattan haze is common during dry seasons; recurring droughts; occasional Niger River flooding
31	Mauritania	Hot, dry, dust/sand-laden sirocco wind blows primarily in March and April; periodic droughts
32	Mayotte	Cyclones during rainy season
33	Morocco	Northern mountains geologically unstable and subject to earthquakes; periodic droughts
34	Mozambique	Floods
35	Namibia	Prolonged periods of drought
36	Niger	Recurring droughts
37	Nigeria	Periodic droughts; flooding
38	Rwanda	Periodic droughts; the volcanic Virunga mountains are in the northwest along the border with Democratic Republic of the Congo
39	Saint Helena	Active volcanism on Tristan da Cunha
40	Senegal	Lowlands seasonally flooded; periodic droughts
41	Seychelles	Lies outside the cyclone belt, so severe storms are rare; short droughts possible
42	Sierra Leone	Dry, sand-laden harmattan winds blow from the Sahara (December to February); sandstorms, dust storms
43	Somalia	Recurring droughts; frequent dust storms over eastern plains in summer; floods during rainy season
44	South Africa	Prolonged droughts, floods
45	Sudan	Dust storms and periodic persistent droughts
46	Swaziland	Drought
47	Tanzania	Flooding on the central plateau and south-eastern coastal areas during the rainy season; drought
48	Togo	Hot, dry harmattan wind can reduce visibility in north during winter; periodic droughts
49	Western Sahara	Hot, dry, dust/sand-laden sirocco wind can occur during winter and spring; widespread harmattan haze exists 60% of time, often severely restricting visibility
50	Zambia	Tropical storms (November to April)
51	Zimbabwe	Recurring droughts; floods and severe storms are rare

Source: statistics compiled using: www.nationmaster.com

Some of the major effects shown in Table 1 are further discussed in detail below.

and Central Africa displaying the number of affected population, the number of families and the number of deaths in the area.

Floods can occur in arid areas as well as humid areas. In tropical near-coastal regions, they generally result from cyclones that can drop a year's worth of rainfall in a day. According to the BBC News (2007), about 14 countries, namely Burkina Faso, Chad, Ethiopia, Ghana, Kenya, Liberia, Mali, Niger, Nigeria, Senegal, Sudan, Togo, Uganda, and Rwanda, are the worst hit by flood in the African continent. Scores of people have died and hundreds of thousands have been displaced by the floods that have submerged much of the continent's most productive farmland, hence necessitating urgent food, shelter and medicare. In the same vein, episodes of flood accounted for 26 per cent of total disaster occurrences in Africa during 1971-2001 (Vordzorgbe, 2003) with devastating effects. In North Africa, the 2001 disastrous flood in northern Algeria resulted in about 800 deaths and economic loss of about $400 million. In East Africa, the El Niño-related flood in 1997/1998 destroyed infrastructure and property worth about $1.8 billion in Kenya. In Mozambique, the 2000 flood (worsened by two cyclones), reduced the annual economic growth rate from 10 per cent to 4 per cent, caused 800 deaths, affected almost 2 million people of which about 1 million needed food, displaced 329,000 people and destroyed agricultural production land, among other negative effects. The worst single episodes of flood in Africa occurred in East Africa: one event in 1997 killed 2,311 people in Somalia; another in 1999 affected 1.8 million people in the Sudan (AWDR, 2006).

Floods across Africa are reported to be the worst in decades in some places and extend in an arc from Mauritania in the west to Kenya in the east. At least an estimated 1.5 million people are so far affected (World Food Programme, WFP, 2007). According to the Cable Network News, CNN (2009), torrential rains and flooding since June have affected 600,000 people in 16 West African nations. The worst hit have been Burkina Faso, Senegal, Ghana and Niger, where many lives and property have been lost to severe flooding events.

Figure 2\: Carcasses of drought-stricken cows in Kenya.
REUTERS/Thomas Mukoya

Drought

The term drought may refer to a meteorological drought (precipitation well below average), hydrological drought (low river flows and low water levels in rivers, lakes and groundwater), agricultural drought (low soil moisture), and environmental drought (a combination of the above) (Bates *et al*., 2008). The socioeconomic impacts of droughts arise from the interaction between natural conditions and human-induced climate change factors such as changes in land use, land cover, and the demand for and use of water.

In some cases the frequency of occurrence of droughts is exacerbated by human-induced changes in land cover. Excessive water withdrawals can increase the likelihood and impact of drought. Droughts have both direct and indirect consequences for human livelihoods (Pavel, 2003). A direct consequence is crop loss, which can cause starvation if alternative food sources are not available. Indirectly, water shortages contribute to the spread of disease, because people lack water for basic hygiene. An example of a consequence of drought is shown in Figure 2, where nomads lost hundreds of their cattle due to drought.

Climate change is projected to increase the risk of drought over much of Africa in the 21st century. The regions where droughts have occurred seem to be determined largely by changes in sea surface temperatures, especially in the tropics, through associated changes in the atmospheric circulation and precipitation as seen in Table 1. Since the late 1960s, droughts have caused much suffering in Africa. Severe droughts were experienced in 1973 and 1984 when almost all African countries suffered reduced rainfall, which particularly affected several million people in the Horn of Africa, the Sahel and Southern Africa (AWDR, 2006). Droughts are endemic in both Southern Africa and the Sahel region of western and northern Africa.

Water quality

Worldwide, climate-related warming of oceans, lakes and rivers has been observed over recent decades, with implications for freshwater ecosystems, such as changes in water salinity, water nutrient content, concentration of pesticides and other pollutants, salinization of groundwater, water chemistry and pH balance (Bates *et al*, 2008; Sommaruga-Wograth *et al*., 1997; Rogora *et al*., 2003; Psenner and Schmidt, 1992). With respect to fisheries and aquaculture, it has been projected that rising temperatures of around 1.5 to 2.0ºC will adversely affect fisheries in West African lakes (Christensen *et al*., 2007). In coastal regions that have major lagoons or lake systems, changes in freshwater flows and a greater inflow of saltwater into lagoons will affect inland fisheries or aquaculture (Cury & Shannon, 2004). Subtle changes in key environmental variables such as temperature, salinity, wind speed and direction, ocean currents and strength of upwelling due to climate change could sharply alter the abundance, distribution and availability of fish populations. Climate change, particularly if it is reflected in reduced rainfall in many parts of Africa, would further compound the inability of the continent to meet people's demand for potable water.

Surface and groundwater systems

Changes in surface runoffs and groundwater flows in shallow aquifers is part of the hydrological processes that can be linked to climate variability, with implications for permanent and seasonal water bodies such as lakes and reservoirs. There is evidence of a broadly coherent pattern of change in annual runoff at the global scale, with some regions, particularly at high altitudes, experiencing an increase (Tao *et al*., 2003a, b; Hyvarinen, 2003; Walter *et al*., 2004) while others experience a decrease, for example in parts of Africa (Milly *et al*., 2005).

While lake levels in other parts of the world have risen (e.g. in Mongolia and China) in response to increased snow- and ice melt, lake levels in Africa have declined due to the combined effects of drought, warming and human activities.

Precipitation and water vapour

Climate model simulations for the 21st century are consistent in projecting very likely temperature increases in high latitudes and parts of the tropics, and likely decreases in some sub-tropical and lower mid-latitude regions (Manase, 2009). Climate change effects resulting from warming have been easier to prove than changes in respect of precipitation. However, observational and modelling studies lead to an overall conclusion that an increase in the frequency of heavy precipitation events is likely to have occurred over most land areas over the late 20th century, and that this trend is

Figure 3: Children playing at the bank of receding lake Naivasha.
African Technology Policy Studies Network (2009)

more likely than not to include an anthropogenic contribution (IPCC, 2008). Inter-annual rainfall variability is large over most of Africa, and for some regions, most notably the Sahel, multi-decadal variability in rainfall has also been substantial. For example, while the Sahel displays large multi-decadal variability with notable drying, East Africa shows a relatively stable regime with some evidence of long-term wetting, and Southeast Africa shows a basically stable regime, but with marked inter-decadal variability (Hulme, 1996 cited in Pak Sum Low, 2005).

Snow and land ice

Water supplies stored in glaciers and snow cover are projected to decline in the course of the century, thus reducing water availability during warm and dry periods in regions supplied by melt water from major mountain ranges, where more than 17 per cent of the world's population currently live (IPCC, 2008). According to UNEP (2009), only 11 of the 18 glaciers that covered Mount Kenya's summit a century ago remain, leaving less than one third of the previous ice cover. The ice on Mount Kenya has also become thinner. All these effects are attributable to global warming, resulting mainly from anthropogenic activities.

Sea-level rise and ocean dynamics

With focus on coastal systems and low-lying areas, the Intergovernmental Panel on Climate Change (IPCC, 2007) maintained that coasts are projected to be exposed to increasing risks resulting from coastal erosion, climate change and sea-level rise. Low-lying cities situated near major rivers, deltas and estuaries are especially vulnerable to sea-level rise (Stern, 2006). For example, Lagos, currently the fifth largest city in the world and Africa's second most populous city, is highly affected by sea-level rise, coastal erosion, saltwater intrusion and flooding. Empirical evidence of sea-level rise in Lagos mega-city showed that severe coastal erosion which removed over 2 kilometres of the popular Lagos beach fronts and at times the adjacent road has been on the increase since 2004, resulting in acute disruption of traffic and flooding of properties. Also, the rock moles constructed between 1908 and 1912 to protect the natural Littoral Drifts at the Bar beach were continually washed away by the coastal surge, leading to an annual erosion rate of 25 to 30 metres (Shagun *et al*, 2009).

Changes in ocean dynamics could lead to changes in migrating patterns of fish and possibly reduced fish landings, especially in coastal fisheries (African Action, 2007). Both inland and ocean fisheries are very sensitive to varying degrees of climate fluctuations. In particular, increased ocean temperature may affect upwelling along the Gulf of Guinea, which could make the ocean waters become unsuitable for fisheries, causing a reduction in and possible collapse of fishing activities (African Action, 2007). An expected rise in temperature would also cause a change in the characteristics of the ocean waters and consequently adversely affect fish habitat in the coastal zone of Africa. Most of the water resources along the coast would become polluted by intrusion of saltwater, and water resources management would place greater emphasis on desalinization.

Impacts of climate change on livelihoods in Africa

In addition to its effects on the natural hydrological cycle, climate change is associated with changes in both ground and surface water supply for domestic,

agricultural and industrial uses, including irrigation, hydropower generation, navigation and fishing. The impacts depend on the baseline condition of the water supply system and the ability of water resource managers to respond also to population growth and changes in demands, technology, and economic, social and legislative conditions. (IPCC, TAR, 2001). Hydro-meteorological disasters such as floods and droughts have major effects on food supplies, health, economic and environmental losses, and social upheaval (Pavel, 2003). Thus, climate change impacts are complex, they can be both direct and indirect, and they can be a serious threat to achieving poverty reduction and sustainable development.

Economic impacts

Climate change can affect many important sectors of the economy by influencing the supply of and demand for goods and services (WBGU, 2008). Empirical evidence shows that there will be changes in the supply and demand of food commodities as a result of low yields resulting mainly from drought and flooding events. The changes will also affect the profitability of farming and the affordability of food. According to Miller and Yates (2005), future climate change could influence municipal and industrial water demands, as well as competing agricultural irrigation demands. Municipal demand depends on climate to a certain extent, especially for garden, lawn and recreational field watering, but rates of use are highly dependent on utility regulations. Industrial use for processing purposes is relatively insensitive to climate change as industry most often prefers to meet target outputs rather than consider the environmental implications of its activities.

The World Bank's Water Resources Sector Strategy quotes examples of impacts of climate variability on economic performance. In its 2003 report, the Bank noted that the drought in Zimbabwe in the early 1990s was associated with an 11 per cent decline in GDP; the floods of 1999 in Mozambique led to a 23 per cent reduction in GDP (Pavel, 2003). The scale of these losses highlights the need for water planners and managers to have a better understanding of the mechanisms of climate variability and their relationships with hydrological extremes such as floods and droughts. Economic losses from natural disasters, including floods and droughts, increased three-fold between the 1960s and the 1980s; and ten-fold between the 1950s and the 1990s (Pavel, 2003).

The poor are among those who suffer particularly from the effects of water stress due to their vulnerability and inability to adapt. An increase in surface temperature will affect the livelihoods of the 70 per cent of Africans who depend on rain-fed agriculture. This will lead to low productivity, low income, and a low standard of living, thus completing the vicious cycle of poverty.

Economic impacts from curtailment of hydropower generation from Lake Kariba as a result of the 1991-1992 drought were estimated to be the loss of US$101 million in GDP, US$36 million in export earnings, and 3,000 jobs (Benson and Clay, 1998, cited in Manase, 2009). In Mozambique, floods in 2000 cost the economy US$550 million, or 12 per cent of GDP (Grey and Saddoff, 2005, cited in Manase, 2009).

Where climate change brings with it an increase in the frequency of extreme weather events such as flooding and drought, the risk of damage to property and infrastructure

also rises. Insurance companies will need to significantly increase the amount of capital they hold to be able to provide insurance cover at a level comparable to that of today (WBGU, 2008).

Food security and agricultural production

Agriculture accounts for the biggest share of the economy of African countries. For example, in COMESA, CEN-SAD, EAC, ECCAS, ECOWAS and IGAD[1], agriculture accounts for between 25 per cent and 35 per cent of GDP. The availability of optimal water supply for crops determines the level of output obtained. Globally, over 80 per cent of agricultural land is rain-fed and crop productivity depends solely on sufficient precipitation to meet evaporative demand and associated soil moisture distribution (FAO, 2003). Where these variables are limited by climate, such as in arid and semi-arid regions of Africa, agricultural production is extremely vulnerable to climate change. With increases in temperature and precipitation distributed unevenly across the continent, food production has been declining in the last few decades, especially where it is accompanied by drought and flooding events. The productivity of agricultural, forestry and fisheries systems depends critically on the temporal and spatial distribution of precipitation and evaporation, and especially for crops, on the availability of freshwater resources for irrigation (Bates *et al*., 2008). Changes in precipitation, and thereby in water availability, influence both productivity and species distribution (Kaiser, 2001). African tropical forests may respond more sensitively than savannahs to changes in precipitation, because not only do they depend more heavily on the amount of precipitation, but also on the time of year that the precipitation occurs (Hély *et al*., 2006).

Production systems in marginal areas face risk of increased vulnerability due to degradation of land resources through soil erosion, over-extraction of groundwater and associated salinization, and overgrazing of dry land (FAO, 2003). Therefore, the impact of climate change on irrigated agriculture will be enormous because it accounts significantly for total food produced, especially grains and vegetables.

Mixed rain-fed systems in the Sahel, in the highland perennial systems of the Great Lakes region and in other parts of East Africa are particularly susceptible to climate change. Changes in the primary production of large lakes will have important impacts on local food supplies. Lake Tanganyika currently provides 25-40 per cent of animal protein intake for the surrounding populations, and it is estimated that climate change is likely to reduce primary production and possible fish yields by roughly 30 per cent (Bates *et al*., 2008).

By critically affecting crop productivity and food production, in addition to being a necessity in food production processes, water plays a critical role in food security. Therefore, food availability, accessibility and nutritional balance will be indirectly threatened by climate change.

1. COMESA (Common Markets for East and Southern Africa), CENSAD (The Community of Sahel-Saharan States, EAC (East African Community), ECCAS (Economic Community of Central African States), ECOWAS (Economic Community of West African States), and IGAD (Intergovernmental Authority on Development).

Social impacts: conflicts and migration

Water resource use for domestic, commercial, or industrial purposes is known to have triggered numerous conflicts across Africa. A water crisis increases the probability of competition between water use sectors and, in the absence of systems regulating such competition, the likelihood of water conflict (WBGU, 2008). Climate change is anticipated to increase conflicts as a result of struggles for water use if increasing supply to meet growing demand for water resources cannot be assured, in addition to other pressures on natural and human systems, e.g. from population growth (Ozor, 2009).

In semi-arid Africa, pastoralism is the main economic activity, with pastoral communities including transnational migrants in search of water and new seasonal grazing (Bates *et al*, 2008). In drought situations, such pastoralists may come into conflict with settled agrarian systems. With reduced runoff and drying up of rivers, communities are forced to trek long distances from their own communities to look for water. This has created pressures and tensions at the new water sources with resultant conflicts (in addition to other effects on livelihoods such as loss in person-hours). One such example is in Nigeria between the Fulani cattle rearers and the farming communities competing over grazing land and access to water bodies (Ozor, 2009), leading to the deaths of several farmers and pastoralists in the region. Miller *et al*. (1997) noted that any substantial change in the frequency of floods and droughts, or in the quantity and quality or seasonal timing of water availability, will require adjustments that may be costly, not only in monetary terms but also in terms of societal and ecological impacts, including the need to manage potential conflicts between different interest groups. Therefore, where there is increased water demand the potential of conflicts in transboundary water systems will increase.

The effects of climate change are certain to displace some populations, with a significant increase in the number of environmental migrants over the coming decades. For example, between 1970 and 2004 about 14 per cent and 22 per cent of the populations in East and West Africa, respectively, were affected by the multiple effects of drought, extreme temperature, floods, slides, wave/surges, and wind storm (Raleigh, *et al*, 2007). In many countries, the increase in flooding events, submergence, drought, soil degradation and growing water scarcity in combination with high population growth, unstable institutions, poverty or a high level of dependency on agriculture means that there is a particularly significant risk of environmental migration occurring and increasing in scale. People living in low-lying islands and delta regions face the threat of being submerged by water, hence the only coping strategy will be to move out of the risk sites to more habitable areas (Ozor, 2009). This movement will greatly affect such people in many ways, including loss of livelihoods, loss of social systems and values, loss of property and age-long acquired wealth, injuries and sometimes death. At the transit and destination points, migration generates the potential for conflicts of different dimensions, hunger and starvation, and health problems including epidemics (Ozor, 2009). This situation is worsened where there are no effective and efficient emergency management services to take care of the displaced people.

Health

Human health, incorporating physical, social and psychological well-being, depends on an adequate supply of potable water and a safe environment. As discussed in earlier

sections, human beings are exposed to climate change directly through weather patterns (more intense and frequent extreme events), and indirectly through changes in water, air, food quality and quantity, ecosystems, agriculture, livelihoods and infrastructure. Health is a critical issue for three reasons: a) health is recognized by all cultures, religions, states and social groups worldwide as an asset worthy of protection; b) health is affected by all drivers of global environmental change; and c) a population's state of health can be used as an indicator to measure the impacts of climate change (WBGU, 2003; Krafft *et al*., 2002), in a manner comparable to the key role of health within the Human Development Index (HDI).

Climate change induces health problems as a result of hunger and starvation, water stress, pests and diseases, resource conflicts, injuries and stress from extreme weather events (Ozor, 2009). Analyses show that the greatest health burden arising in the regions where vulnerability and population growth are greatest are in sub-Saharan Africa and south Asia (see for example, WBGU, 2003).

Water-related aspects of health include increased cases of cataracts (eye disease) in the arid and semi-arid regions of Africa due to low cloud cover and greater intensity of solar radiation; increased cases of malaria and typhoid due to increased rainfall and temperature; and increased cases of water-borne diseases such as cholera and dysentery due to urban flooding and improper disposal of wastes (Anyadike, 2009). Warmer and more humid conditions could enhance the growth of bacteria and mould on many types of stored foods, and this would increase food spoilage and create some specific toxicological health hazards (Ozor, 2009). Due to the very large number of people that may be affected, malnutrition and water scarcity may be the most important health consequences of climate change (Bates *et al*., 2008).

Poor health increases vulnerability and reduces the capacity of individuals and groups to adapt to climate change. The World Health Organization (WHO) and UNICEF Joint Monitoring Programme currently estimates that 1.1 billion people (17 per cent of the global population) lack access to water resources (defined as the availability of at least 20 litres of water per person per day from an improved water source within a distance of 1 kilometre). An improved water source is one that provides 'safe' water, such as a household connection or a bore hole. In sub-Saharan Africa, 42 per cent of the population is without access to improved water (Bates *et al*., 2008).

Selected Case Studies

Nigeria (West Africa)

Climate change often appears very esoteric in many regions, but in Nigeria it is most evident in extreme variability in rainfall, sea-level increases and a rising number of heat waves. The seriousness of the issue is continually being revealed by scientific evidence, which is strengthening by the day and predicting risks that will be over and above those that are currently being considered (Medug, 2009). Nigeria's 800 kilometre low-lying coastline from Lagos to Calabar makes the region prone to sea-water intrusion into coastal freshwater resources and consequently inland fisheries and aquaculture are negatively affected. There is a high frequency of coastal erosion and flooding – both climate change-induced forms of land degradation. Declining rainfall in already desert-prone areas in northern Nigeria is causing increasing

desertification, the former food basket of central Nigeria is now threatened, and people in the coastal areas who used to depend on fishing have seen their livelihoods destroyed by the rising waters. The unusual weather change which brings about rain in different parts of the country is an indication of serious negative effects of climate change. In an interview with the *Daily Trust* national newspaper, Victor Fodeke, Director of the Climate Change Unit in the Ministry of Environment observed "the rains being experienced in different parts of the country at the time when it is not expected is an indication of serious impacts of global warming and climate change in the society [...] The results of the change are devastating to the socio-economic well being of the country, [...] it will affect the agricultural produce which will in turn affect every economic sector of the nation" (Yahaya, 2009).

Persistent droughts and flooding, off-season rains and dry spells have interrupted the growing seasons in a country dependent on a rain-fed agriculture. Plants that require low temperatures at some stage of their life cycle may adapt and survive in the short term, but in the long term, many could become extinct.

Figure 4: Farmers at Umulumgbe showing part of the Okeze Stream that is gradually drying up.
DelPHE 326 research photo by Dr. Nicholas Ozor, 2009

Most people are alarmed by the drying up of lakes and a reduction in river flow in the arid and semi-arid region (Figure 4). The result is reduced water supplies for use in agriculture, hydro-power generation and for other users. It is being observed that the late onset of the rainy season in northern Nigeria is spreading to more areas in the humid southern region. This region is now experiencing early cessation of the rains; shorter rainy and cropping season; water shortages and drought conditions. More so, desertification is spreading, resulting in changes and shifts between agro-ecological zones; progressive depletion of the forest resources of West Africa; and a threat to food production and security.

Cameroon (Central Africa)

The northern part of Cameroon is ecologically very fragile and vulnerable to climatic variability. The rainfall in this area is low and erratic. Consequently this has created a succession of droughts and floods which are increasing over time (Hassan, 2006). Climatic data has shown that over the years the rainfall has been on the decline. On the other hand, temperature trends in Cameroon have also been on the increase since 1930 with a net increase of 0.95ºC between 1930 and 1995 (Ayonghe, 2001). The droughts have become severe in the last decades and the effects of these droughts have caused the rapid shrinking of Lake Chad, the disappearance of Lake Fianga and the total crop failure in 1984 which necessitated the distribution of food aid. These demonstrate clearly how precarious and unpredictable the climate in Cameroon is (Ayonghe, 2001).

Maddicott (2009), the British High Commissioner to Cameroon, articulated the seriousness of climate change impacts by highlighting several cases: "The northern provinces of Cameroon have already experienced a change in conditions as a result of the reduction in rainfall and encroaching desertification. Land for rearing livestock is becoming increasingly scarce. This affects a large number of Cameroonians personally as beef prices have risen sharply to adjust to the new conditions. Reports show that the areas at greatest risk include the Sahel and the area around Lake Chad. Forty years ago, Lake Chad covered 25,000 square kilometres and the daily fish catch was some

230,000 tonnes, now it barely extends to 500 square kilometres with a catch of only 50,000 tonnes. This shrinkage has led to clashes between groups fighting for fishing rights and disputing ownership of 'new' land, illustrating that climate change also affects regional and world security" (Maddicott, 2009).

Studies in the area of Lebialem Highlands of Cameroon demonstrated that the rivers Bechuo, Bejie, Efrue, Begeu, Ntchembe along with other upland streams have lost much of their water and vitality. Moreover, in the lowlands many fast-flowing streams that once required cane bridges are now safe to cross today even during the rainy season, whereas water levels were hitherto dangerous and prohibitive. Essoh-Attah and Lebang chiefdom areas that were too cold for cocoa pods to ripen are now warm enough to support the growth of cocoa pods. The main concern of the Lebialem people is that these changes will continue, altering the entire system to a permanent drought-stricken area. Some other significant changes have been noticed in the Lebialem region. Towards the beginning of the dry season, the women would hunt for tadpoles and frogs because there are no fish in most Bangwa rivers. However, in recent years tadpoles and frogs are increasingly difficult to find, partly due to the warming rivers that have increased the amount of fish in an area they have never inhabited before.

Kenya (East Africa)

In a recent summit of the African Parliamentarians on Climate Change held at the UNEP offices, Nairobi (13 October, 2009), the President of Kenya attributed the impacts (floods, increased frequency and severity of droughts, increased food and water insecurity) to climatic changes already being experienced by African countries. In his remarks, the President stressed that the impacts are highest – in severity and magnitude – on the environment, agriculture, health, water, and infrastructure and energy sectors. This analysis resonates with the meteorology department which has noted that the current climate is characterized by large variability in rainfall with occurrence of extreme events in terms of droughts and floods. The country has experienced frequent and more severe droughts, the most notable being in 1983/84, 1991/92, 1995/96, 1999/2001, 2004/05 and 2008/09. The La Niña-related drought of 1999/2001 preceded by El Niño-related floods of 1997/98 was thought to be very severe (Ng'ang'a, 2006). Kenya experienced its worst drought in 40 years around this period and the President claimed it put 80 per cent of the Kenyan population at risk. The World Food Programme (WFP) confirmed that 3.3 million people were seriously affected. Acute shortages of food, water and insecurity forced 15 primary schools in Kenya's north-central Samburu district to close (World Water Day, 2001).

The availability of water resources in Kenya has been decreasing over time as a result of persistent droughts and land-use patterns. The climate scenarios show that rainfall variability and increased evaporation due to higher temperatures will lead to further decreases in the available water. Already there are dramatic reductions in the snow and glaciers of Mount Kenya, believed to be associated with global warming. These glaciers could vanish in the next 15 years. The disappearance of the glaciers will affect agricultural activities, the availability of water for both rural and urban populations, hydroelectric production and tourist activities (Ministry of Environment and Mineral Resources, 2009).

Rising temperatures and changing patterns of rain have also exacerbated the problem of disappearing wetlands and have increased food insecurity as a result of reduced crop yield. The famous Kenyan wildlife safaris, popular with tourists from around the globe, are at risk: the wildebeest migration in the Mara River, one of the Seven Wonders of the World, is now affected by changing rainfall patterns. The wildebeests are affected by the erratic rain patterns as they begin migration by following the smell of rain. The erratic climate has led to a loss in the numbers of wildlife, due to the rivers drying-up and insufficient vegetation for feeding (Climate Action Network, 2009).

The impacts are largely felt in the marginal rainfall areas of the country. The Maasai of Kenya, for example, have lived and coped in the dry lands for centuries, but the new weather patterns are threatening their traditional way of life. In recent decades, seasonal patterns have become unpredictable and rainfall levels have become lower. "In the past we used to experience drought after every 10 years, then it went down to five years but has since started taking place after every one year due to the climatic change," says Benson Ole Pasua, a Maasai livestock farmer from Enkiroka in Kajiado district (Mboyah, 2008). Pasua says that as the drought hits, many farmers lose their herds. Some people move their livestock to far distances for greener pastures, hence denying their families milk and blood, which serve as their main foodstuff, as well as source of income. Maasai herders are now a common feature in Nairobi, as they drop out of their pastoral lifestyle altogether and move to the city in search of employment (Mboyah, 2008). Worst affected are the women and children. Children are often removed from school to take the livestock to graze in areas where water and grass can be found. Women are highly exposed, walking further and further to seek and fetch scarce water for household use. In some cases they are forced to walk for over 10 kilometers in search of water. When drought events worsen and springs dry up, some women are forced to return home empty-handed (Wamatsi, 2009).

Swaziland (Southern Africa)

Swaziland is prone to occurrences of natural disasters, such as tropical cyclones, floods and droughts. The notable disasters in recent years are incessant lightning during rainy seasons, cyclone Domonia in 1984, drought in 1991-1996 and 2001-2005, and torrential rains and floods in 2000. The areas that are at high risk or severely affected by drought are in the Lowveld and lower Middleveld regions of the country, where rainfall is often very low even under normal rainy season conditions. Hail storms and strong winds are also common hydrological disasters in Swaziland. They tend to occur during the months of September to April, destroying crops and property (UNEP, 2008). In the 1992 drought, approximately 90,000 cattle died, greatly affecting the economy as cattle are a major source of wealth in the country.

Occurrences of floods are very frequent in many areas of Swaziland. The floods that happened after the cyclone Domonia hit in 1984 washed away and killed a number of people and destroyed property and infrastructure. Swaziland was also severely ravaged by torrential rains in 2000, which led to flooding in many parts of the country and destruction of property, with associated health risks due to increased pollution of water sources (UNEP, 2008).

Climatic models assessing the impact of climate change in the Great Usutu River, which supports about three-quarters of the population, reveal higher temperatures and more intense rainfall in early summer (October to January), dissipating in late summer and winter (February to September). The projections also indicate a maximum reduction in annual runoff of up to 12.6 per cent or 133.6 million cubic metres. The combined effect of high temperatures and low runoff, especially in winter, could adversely affect groundwater recharge, particularly in the Lowveld, and aggravate existing groundwater salinity. Taken together, these changes are very likely to negatively affect the agriculture-based economy as well as ecosystems (UNFCCC, 2004).

Anecdotal evidence is largely consistent with the analytical results. "It used to be the rains would fall in August and September, and the farmers would know when to plough; now it is October and November we see the rains fall. There are dry spells in January, just as the crops are maturing" (Dr Ben Nsibandze, Chairman, National Disaster Management Authority; IRIN, 2009). He maintained that experienced farmers "do not need weather service statistics to tell them there are now more hot days than when he was a herd boy on his family farm thirty years ago".

Egypt (North Africa)

The vast majority of the Egyptian population lives along the Nile Delta, located along the thin strip of the Nile Valley. The area also produces nearly 50 per cent of Egypt's annual agricultural product. This area is under serious threat as a large portion of it is now below sea level. Egypt has been ranked as the third most vulnerable country in the world, surpassed only by Bangladesh and Vietnam (Yahia, 2008). This is mostly because the whole of Egypt's agriculture depends on the River Nile which is now being threatened by incidences of climate change. Agriculture alone consumes about 53.85 K m^3/year out of the available 62.53 K m^3 of the renewable resource in Egypt (Sokka, 2004).

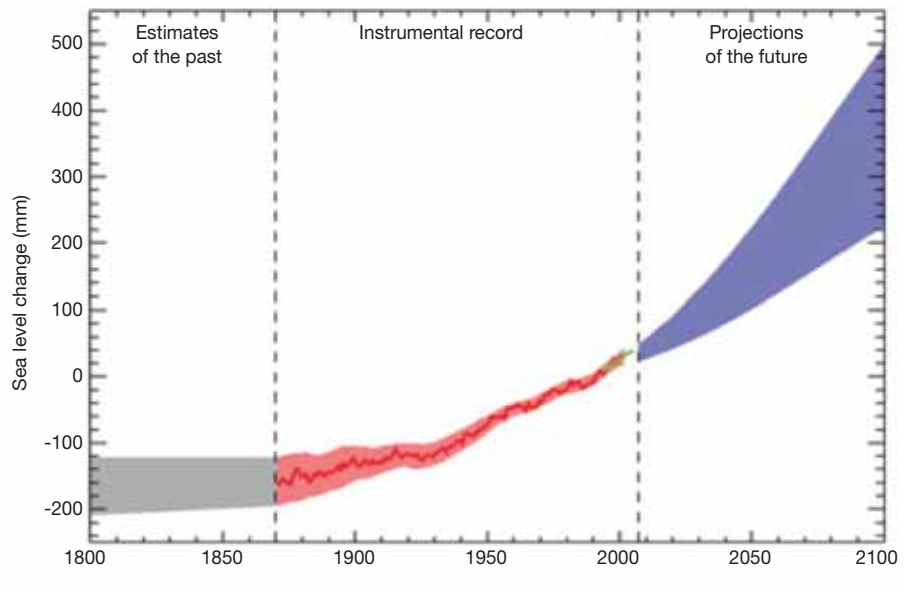


Figure 5: Past, present and predicted sea level trends in Egypt.
Boko, et al.*, 2007*

The most significant consequences resulting from climate change and variability will include the reduction in the flow of the Nile and the intrusion of sea water into the coastal aquifers. Others will include changes in temperature, precipitation, evapo-transpiration, runoff, regional water availability and other hydrological processes.

Notable evidence of climate change impacts on water resources in Egypt include the receding of the Nile Delta at a rate of 3-5 milimetres per year; the disappearance of lowland beaches in Alexandria due to sea-level rise; the retreating of the shores of Rasheed City, the location since the 1990s of the Rosetta stones that held the secrets of ancient Egyptian writings (Sterman, 2009). According to Omran Frihy, a coastal researcher in Alexandria, more than 58 metres have disappeared owing to sea-level rise since 1989. Even the water resources are also being greatly affected. As noted by an Egyptian fisherman, Reda Kandeel, "The fortune of the sea is disappearing, we used to fish for Denis fish in November when they were plentiful, now December is almost over and Denis fish are still very rare to catch, the ones we do manage to find are tiny" (Yahia, 2008). It is still being predicted (Figures 5, 6a, 6b) that a 0.25-metre rise in sea level would submerge about 60 per cent of Alexandria's population which is about 4 million, as well as 56.1 per cent of Alexandria's industrial sector (Sterman, 2009). About 40 per cent of the nation's industrial sector is located in Alexandria alone. Even without climate change, Egypt is projected to import 300,000-360,000 tonnes of fish by 2020, which is a third of its projected domestic production. With the onset of climate change this situation is likely to worsen as the global fish market tightens in response to the climatic changes (Sterman, 2009).

Figure 6a: Satellite map of the Nile Delta as at 2002.

Figure 6b: Satellite map of the Nile Delta showing the potential impact of sea-level rise with coastal inundation at 1 metre.
Simonett (2002)

Nevertheless, the Egyptian government has been responding strategically to tackle problems arising from climate change. Egypt has ratified the United Nations Framework Convention on Climate Change and also signed the Kyoto Protocol in 1994 and 1999 respectively. The government has been proactive in institutional reforms and in participating in African and Regional fora aimed at addressing climate change. The Egyptian Environmental Affairs Agency (EEAA) created in 1982, the Ministry of State for Environmental Affairs created in 1997, the setting up of Inter-Ministerial National Climate Change Committee in 1997, the Egypt's Climate Change Action Plan of 1999, and the National Communication on Climate Change of 1999, among others, attest to the Egyptian response to climate change impacts in the country.

Impacts on selected trans-boundary water resources

Lake Chad

Lake Chad is a trans-boundary lake that serves four countries, with the biggest share located in Chad, followed by Nigeria, then Niger and Cameroon. This lake was once considered to be one of Africa's largest freshwater lakes but it is now highly decimated. In 1960 it covered 45,000 square kilometres (about 17,000 square miles) but by 1998 it had shrunk to 10,000 square kilometres (about 4,000 square miles). After a particularly dry spell, it covered a paltry 550 square kilometres (Associated Press, 2006). The changes that have occurred in Lake Chad from 1963 to 2000 can be watched in a video clip (http://www.youtube.com/watch?v=JXW29zsr6xg).

Fish stocks have shrunk remarkably and, as one fisherman pointed out, fishermen once risked having their oar-propelled wooden canoes tipped over as the fishes were giants;

now they are lucky to take home small fishes the size of the hand. "A catch that included 20 types of fish has diminished to half a dozen of lesser quality. Two-thirds, more, of the different types of fish have just disappeared in my lifetime" (Ibrahim, quoted by Associated Press, 2006). Chadian government officials in Bol insist the lake is disappearing solely because of global warming, with severe droughts since the 1970s and temperatures rising up to 50ºC, which causes large volumes of water to evaporate. But international experts say other factors have also contributed (Associated Press, 2006). Some of these factors may include: population pressure in the surrounding countries which has led to heavy irrigation for farmland, the demand for power which has seen many rivers dammed for hydroelectric schemes, and human mismanagement of the natural resource (Somerfield, 2010).

The lake has receded to the extent that villagers have to walk a distance of 30 kilometres while hitherto the waters came right into the homes and at times flooded them. Also, many villages have sprung up in these areas where the lake has disappeared and this has been causing a lot of tension among villagers of the different countries. According to Mayor Adam Youssouf Terri of the lakeside capital, Bol, some 30 million people struggle to survive along the lake. Friction has arisen with the newcomers from further north and across borders. There are arguments over territory between fishermen and fishermen, farmers and fishermen, farmers and farmers, cattle herders and farmers, Chadians from elsewhere in Chad and those with deeper roots in this region, and between Chadians and foreigners (Associated Press, 2006).

Most fishermen have converted to farming but this may not be sustainable either, as with a drier climate and less rainfall, agricultural areas become more desperate for water to irrigate their crops, and will continue draining what is left of Lake Chad. The problem is expected to worsen in the coming years as population and irrigation demands continue to increase. "Africa does not produce any significant amount of greenhouse gases, but it's our lakes and rivers that are drying up. America has refused to ratify Kyoto and it is our lakes that are drying up" (BBC News, 2007b). According to Jacob Nyanganji of Nigeria's University of Maiduguri, "I don't know what global warming is, but what I do know is that this lake is dying and we are all dying with it," says one of the fishermen (Murray, 2007).

Lake Victoria

Lake Victoria, the world's largest tropical lake at 68,790 square kilometres and the second-largest freshwater lake in the world, is losing water at an alarming rate – at least six feet in the past four years (Stuteville, 2008). The lake is prone to climate impacts because it generally has a large surface area compared to its volume. The maximum depth in this lake is no more than 84 metres and the mean depth is only 40 metres. This increases the rate of evaporation from high temperatures.

The once-abundant tilapia and Nile perch are slowly disappearing from the Kenyan part of the lake. The Nile perch, introduced in the 1950s to increase fish yields, became a predator of several indigenous species such as the striped haplochromis (Stuteville, 2008).

Part of the problem is caused by the outflow resulting from two hydroelectric dams at Jinja, Uganda but the largest problem is attributable to years of drought and rising

temperatures, conditions that starve the lakes of inflowing water and have caused evaporation to increase in the lake (Hanley, 2009). "Sometimes we just fish naked because it's so hot," Obiero, a Kenyan fisherman exclaimed, after catching a single catfish one morning. "When I was growing up it wasn't like this – there was plenty of rain." Meanwhile, receding waters have raised tensions between the lake's three neighbouring countries. "We see (this issue) as a time bomb," Muramuzi said. "There will be conflicts in the region, among communities and among countries if these problems are not addressed soon." Obiero, for example, spent seven days in a Ugandan jail, where he was beaten and released after paying a $70 bribe. His crime was following fish into Ugandan waters. Obiero was asked, "Who has given you permission to come and catch our fish?" and he told them, "It is our hunger that has brought us here" (Stuteville, 2008).

Way forward and the role of adaptation

The story we have told so far is a depressing one but a number of strategies have been identified to help African countries to cope with the impacts of climate change on water resources. However, it should be noted that no single approach will solve the problems we have described. Many of the impacts are anecdotal, but the way forward clearly calls for a holistic approach to the challenges through the application of integrated methods. The hope is to achieve a water sustainable Africa before 2030.

Global responsibility and action

We had hoped that the impact of climate change on water issues would be at the forefront of COP 15, the United Nations Conference on Climate Change, Copenhagen, Denmark, in December 2009. Sadly, this was not the case and the international community has so far failed to seize the opportunity to develop binding commitments to avert this crisis and to compensate developing countries in Africa who are on the receiving end of climate change impacts on water resources. It is therefore recommended that future Conferences of the Parties should strongly consider urgent actions to conserve water resources, especially in the most vulnerable societies we have discussed. Although historically there has been little evidence to link water scarcity and violence, if water scarcity trends worsen water will be a major contributing factor to conflicts and wars in future (Lonergan, 2003). However, the theory that conflict is not directly caused by climate change is one which many Africans cannot afford to test.

Science, technologies and innovation adoption

A number of developmental reports suggest that science, technology and innovation (STI) underpin every one of the Millennium Development Goals and hence their application becomes a prerequisite for development (UN Millennium Project, 2005). STI can help us to adapt and mitigate most of the challenges posed by climate change on water resources, especially in Africa. For instance the application of STI to the recycling and reuse of water has enabled the resource to be utilized efficiently. Besides, the various water harvesting technologies adopted by both rural and urban households in many countries can be attributed to efforts in STI as a result of increasing water challenges in those areas. Technology and innovation need not be expensive, but simpler forms such as soil and water conservation and water harvesting technologies need to be scaled up. Other applications of STI elsewhere with potential for use in African countries include:

- nanotechnologies to purify drinking water (as in India where several institutes and firms are using nanotechnology for arsenic removal, reduced water pollution, and river cleaning projects, Padma, 2007).
- smart infrastructure development (as in Brazil where a company managing 300 kilometres of highways in Sao Paulo state has designed roads to funnel rainwater into 250 containment dams with a capacity of 2 million cubic metres. The system allows the rainwater to seep slowly into the ground, assisting in replenishing the Guarani aquifer while saving money in terms of reduced road maintenance, UNEP, 2009b)
- bacteria used to disinfect water.

Institutions and policy instruments

A clear and comprehensive structure that promotes and guides sustainable resource management is fundamental. It requires a robust legal and institutional framework that unambiguously stipulates the main principles and strategies that need to be adhered to for sustainable use and conservation of natural resources such as water. One of the principal institutional structures for effective and efficient water resource management is that operational responsibility for the allocation and management of water resources should be devolved to the river basin level with policy development being retained at national level (World Bank, 2007). Policy instruments to achieve water management objectives should be structured to offer both incentives to enhance innovation in efficient water management and on the other hand, disincentive for malpractices. For instance, zero rating VAT for gutters would encourage household water harvesting

A compensation mechanism for upstream users towards downstream users would discourage future unbalanced abstraction of water. Institutions like the agricultural extension organizations should take on new challenges in sensitizing and training local farmers on the best practices to adopt in order to minimize water stress. Extension services should embark on vigorous campaigns to train local people on sustainable water harvesting strategies. Ozor (2009) recommended that staff of extension organizations should be re-trained to acquire the necessary skills and knowledge in climate risk management. This would enable them to know how to apply the necessary interventions in order to scale up or replicate coping/adaptation strategies. Their training role will empower vulnerable communities to take actions that will enable them to acquire the capability to deal with issues of climate change.

Water inventories and standards

Maintaining a water inventory is important for all the surface and groundwater resources in terms of assessing both quality and quantity. This entails the identification of the availability of water from different sources (water supply), the water needs of different users (water demand), and the tools (facilities) to store and/or carry water to the users (Azim, 2008). Water supply assessments include available water resources from surface water (from canals, drainage reuse and wastewater reuse), groundwater and rainfall. Water demand assessments should include agricultural, municipal (drinking and domestic uses), industrial, and other uses such as for navigation, fishing, hydropower generation etc. Benchmarks could then be established, consistent with international standards against which monitoring and assessments would be

undertaken regularly. This would go a long way in facilitating water planning and effective implementation.

System-wide approach to interventions

The multi-dimensional nature of climate change demands a systems-wide approach that addresses the spatial and temporal effects of climate change. Climate change affects all sectors of development and it therefore requires the integration of sound policies, strategies and measures that should be mainstreamed into all the development processes and sectors.

Disaster management and preparedness

From the available evidence, climate impacts which are already being felt in Africa will continue even if global warming is halted. It is imperative that disaster management becomes an integral part of the adaptation and development process. This can take the form of reducing the impacts through erecting proper infrastructure to deal with risks and disasters when they happen, and mitigating the problem among poor communities and spreading it more widely through market mechanisms such as global insurance and capital markets. This will reduce the vulnerability of the poor communities and empower them to harness their potential for innovative ways to protect these vital resources.

Conclusion

This paper has described in detail the place of water resources in Africa, noting that throughout the continent people value water as much as they value life. It has explained the various forms of water availability in Africa and the different purposes to which the resource is put. Climate change can affect the availability and quality of water resources adversely and the evidence suggests that the causes of climate change are complex, involving both natural forces and anthropogenic activities. Human activities are rated to have significant effects and while African countries have contributed little to the magnitude of the global problem they stand to bear some of the serious consequences.

Climate change consequences on water resources manifested themselves in such events as flooding, drought, sea-level rise, drying up of rivers, poor water quality, changes in surface and groundwater systems, changes in precipitation and water vapour, and changes in snow and land ice. These alterations are already having serious impacts on the economy of several African countries, on food security throughout the continent, as well as on social welfare and the health status of many disadvantaged people.

Although no conclusive evidence is yet available to prove the cause and effect relationships between climate change and water resources as shown above, the impacts in Africa are likely to be the greatest, especially when they co-occur with a range of other stress factors such as population growth, unequal access to resources, food insecurity, poor health systems and poverty. These conditions will increase the vulnerabilities of many people in Africa. Further, Africa's low capacity in science, technology and innovation will further deepen the vulnerability and impacts of climate change on water resources.

The time to act therefore is now. African countries need to face the challenge holistically through science, technology and innovation, and establish appropriate governance, policies, regulations and measures to adapt to the challenges posed by climate change, especially as they affect water resources. It is essential to ensure greater resilience by keeping an audit or inventory of water resources with the aim of tracking the effects of climate change. This will directly aid and inform the development of location-specific strategies to cope with the effects and impacts of climate change. For responding to immediate humanitarian emergencies, African governments need to set up special risk management units to assist people displaced and affected by climate change impacts to enable them to live their lives normally again. In the global arena, Africa needs to have a cohesive agenda and strategy for achieving favourable negotiations at international meetings to avoid the tragic failures experienced by African nations at the Conference of the Parties (COP 15) in Copenhagen, Denmark.

Finally, there should be a culture of systems thinking in Africa that will engage the quadruple helix – science technology and innovation experts, policy makers, private sector organizations and civil society organizations. Africa as a continent of 53 nations should utilize the collaborative and partnership opportunities available with international agencies and organizations in order to respond to the multitude of complex impacts of climate change, especially on water resources.

References

Adejuwon, James (2009) Adapting to Climate Change in Africa. Nairobi; Joto Africa. 1st Issue, July, 2009.

Africa Action (2007) Africa Policy Outlook. Available at www.africaaction.org (viewed 5 April 2009).

African Water Development Report, AWDR (2006) Freshwater Resources in Africa: 380pp. Available at: http://www.uneca.org/awich/AWDR%202006/Freshwater%20Resources%20in%20Africa.pdf (viewed 14 November 2009).

Anyadike, R.N.C. (2009) Climate change and sustainable development in Nigeria: Conceptual and empirical issues. Debating Policy Options for National Development; Enugu Forum Policy Paper 10; African Institute for Applied Economics (AIAE); Enugu, Nigeria: 13-18. Available at: http://www.aiaenigeria.org/Publications/Policypaper10.pdf (viewed 13 November 2009).

Associated Press (2006) Shrinking of Lake Chad. Global Policy Forum. Available at: http://www.globalpolicy.org/component/content/article/198/40377.html (viewed 18 November 2009).

Ayonghe S.N. (2001) A quantitative evaluation of global warming and precipitation in Cameroon from 1930 to 1995 and projections to 2060: Effects on environment and water resources. In Lambi, C.M. (ed.), *Environmental Issues: Problems and Prospects.* Bamenda: Unique Printers: 142-155.

Azim, R.A. (2008) *Water Resource Inventories 2006- 2007*. LIFE Integrated Water Resources Management Task Order No. 802,EPIQ II: Contract No. EPP-T-802-03-00013-00 USAID.

Bates, B.C., Kundzewicz, Z.W., Wu, S., and Palutikof, J.P. (eds) (2008) *Climate Change and Water.* Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva: 210pp.

BBC News (2007a) Rains Threaten Food-hit Africa. Saturday, 15 September. Available at: http://news.bbc.co.uk/2/hi/6994995.stm#anchor (viewed 2 September 2010).

BBC News (2007b) Lake Chad Fishermen Pack up their Nets. Monday, 15 January. Available at: http://news.bbc.co.uk/2/hi/africa/6261447.stm (viewed 4 September 2010).

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. and Yanda, P. (2007) Climate change 2007: Impacts, adaptation and vulnerability. In Parry, M.L., Canziani, O.F., Palutikof, J.P., Van der Linden, P.J. and Hanson, C.E., *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental*, 433-467. Cambridge: Cambridge University Press.

Cable Network News, CNN (2009) West Africa flooding affects 600,000. UN reports. Available at: http://edition.cnn.com/2009/WORLD/africa/09/08/west.africa.flooding/index.html (viewed 16 November 2009).

Christensen, J.H., Hewitson, B., Businoc, A. and Chin, A. (2007) Regional climate projections. In: Solomon, S. (ed.) *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group 1 of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge: 840-847.

Climate Action Network (2009) Kenya: A country of Growing Despair: FRONTLINE VIEW. Voices from communities in developing countries most affected by escalating climate change impacts. Available at: climatenetwork.org/eco/barcelona-2009-ecos/Voice2.pdf (accessed 16 November 2009).

Cury, P. and Shannon, L. (2004) Regime shifts in upwelling ecosystems: observed changes and possible mechanisms in Northern and Southern Bengalese. *Progress in Oceanography* 60: 223-243.

Dialogue on Water and Climate (2004) Climate Changes the Water Rules. Available at: www.waterandclimate.org/report.htm (viewed 13 November 2009).

Eboh, Eric C. (2009) Introduction: Debating Policy Options for National Development; Enugu Forum Policy Paper 10. African Institute for Applied Economics (AIAE), Enugu, Nigeria: 9-12. Available at: http://www.aiaenigeria.org/Publications/Policypaper10. pdf (viewed 14 November 2009).

Fomin, Legwengoh Alexander (not dated). Agro-ecological evidence of climate change in the Lebialem Highlands of Cameroon. Available at: www.mtnforum.org/rs/ol/counter_docdown.cfm?fID=741.pdf (accessed 17 November 2009).

Food and Agriculture Organization, FAO (2003) *World Agriculture Towards 2015/2030*. http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/004/y3557e/y3557e00.htm (viewed 19 November 2009).

Gedney, N., Cox, P.M., Betts, R.A., Boucher, O., Huntingford, C. and Stott, P.A. (2006) Detection of a direct carbon dioxide effect in continental river runoff records. *Nature* 439(7078): 835-838.

German Advisory Council on Global Change, WBGU (1997) *Targets for Climate Protection 1997. A Statement for the Third Conference of the Parties to the Framework Convention on Climate Change in Kyoto.* Special Report 1997. WBGU, Bremerhaven.

German Advisory Council on Global Change, WBGU (1998) *World in Transition: Ways Towards Sustainable Management of Freshwater Resources.* Report 1997. Springer, Berlin, Heidelberg, New York.

German Advisory Council on Global Change, WBGU (2003) *Climate Protection Strategies for the 21st century: Kyoto and Beyond.* WBGU, Berlin, Germany: 77pp.

German Advisory Council on Global Change, WBGU (2004) *World in Transition: Fighting Poverty through Environmental Policy.* WBGU, Berlin, Germany: 289pp.

German Advisory Council on Global Change, WBGU (2007). World in Transition: Climate Change as a Security Risk. WBGU, Berlin, Germany: p13.

German Advisory Council on Global Change, WBGU (2008) Climate *Change as a Security Risk*. Berlin, Germany, Earthscan: 248pp.

Gleick, P.H. (2000) *The World's Water 2000-2001*. The Biennial Report on Freshwater Resources. Island Press, Washington, DC.

Hanley, C.J (2009). Vast African Lake Levels dropping fast. U.S Climate Emergency Council. Available at: http://www.climateemergency.org/joomla/index.php?option=com_content&task=view&id=171&Itemid=172 (accessed 18 November 2009).

Hassan, R. (2006) Climate hydrology and water resources in Cameroon. CEEPA Discussion Paper No. 33. CEEPA, University of Pretoria.

Hély, C., Bremond, L., Alleaume, S., Smith, B., Sykes, M.T., and Guiot, J. (2006) Sensitivity of African biomes to changes in the precipitation regime. *Global Ecology and Biogeography* 15: 258-270.

Hinrichsen, D., Robey, B., and Upadhyay, U.D. (1997) *Solutions for a Water-Short World. Population Reports*, Series M, No. 14. Baltimore, Johns Hopkins School of Public Health, Population Information Program, Maryland, United States. Available at: http://info.k4health.org/pr/m14/m14print.shtml

Hyvarinen,V. (2003) Trend and characteristics of hydrological time series in Finland. *Nordic Hydrol*. 34: 71-91.

Integrated Regional Information Networks, IRIN (2009) Swaziland: Facing Climate Change. A project of the UN Office for the Coordination of Humanitarian Affairs. Available at: http://www.irinnews.org/Report.aspx?ReportId=73337 (accessed Monday 16 November 2009).

Intergovernmental Panel on Climate Change, IPCC, (TAR) (2001) Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change. Parts 1, 2 and 3, Synthesis Report and Policy Makers Summaries. Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change, IPCC (ed.) (2001) Climate Change 2001: Impact, Adaptation and Vulnerability. Contribution of Working Group II of the Intergovernmental Panel on Climate Change to the Third Assessment Report of IPCC. London: Cambridge University Press.

Intergovernmental Panel on Climate Change, IPCC Fourth Assessment Report AR4. Climate Change (2007): Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK: 976 pp.

Intergovernmental Panel on Climate Change, IPCC (2008) Climate Change and Water. IPCC Working Group II Technical Support.

Johns Hopkins (1998) Solutions for a Water-Short World. Population Report, Vol. XXVI, No. 1, September 1998. Johns Hopkins Population Information Program, Baltimore, Maryland, United States. http://www.jhuccp.org/popreport/m14sum.stm

Kaiser, J. (2001) Ecological restoration: NCR Panel pokes holes in Everglades scheme. *Science* 291(5503): 959-961.

Krafft, T., Bissel, R. and Rosenberg, M. (2002) Health and the Environment. Cross Cutting Issues in Global Change Research. German National Committee for Global Change Research (NKGCF), Munich.

Krüger, O. and GraßI, H. (2002) The indirect aerosol effect over Europe. Geophysical Research Letters 29(19), 1925: doi:10.1029/2001GL014081.

Labat, D. et. al, (2004) Evidence for global runoff increase related to climate warming. Adv. *Water Resources* 27: 631-642.

Lonergan, S. (2003) Water and War. Division of Early Warning and Assessment, UNEP. http://www.unep.org/ourplanet/imgversn/154/lonergan.html (accessed 18 November 2009).

Maddicott, Syd (2009) Climate Change: The Challenge of our generation. During a speech at the The Queen's Birthday Party (QBP), Britain's official National Celebration, in Cameroon.http://ukincameroon.fco.gov.uk/en/working-with-cameroon/uk-foreign-policy/climate-change/climate-change-by-hc (accessed 17 November 2009).

Manase, Gift (2009) Documentation of Research on Climate Change and Water Resources in Southern Africa. Final Report prepared for the Danish Water Forum (DWF) by the Council for Scientific and Industrial Research (CSIR).

Mboyah, Duncan (2008) Climate change wreaks havoc to pastoralist communities in Kenya. Published by Africa Science News Service (online science newspaper) http://www.awcfs.org/new/features/features-archive/453-climate-change-wrecks-havoc-to-pastoralist-communities-in-kenya (accessed 3 September 2010).

Medugu, Nasiru Idris (2009) The Effects of Climate Change in Nigeria. All Africa.Com. http://allafrica.com/stories/200910010424.html (accessed 17 November 2009).

Miller, K.A., Rhodes S.L. and MacDonnell, L.J. (1997) Water allocation in a changing climate: institutions and adaptation. *Climatic Change*, 35: 157–177.

Milly, P.C.D., Dunne, K.A. and Vecchia, A.V. (2005) Global pattern of trends in stream flow and water availability in a changing climate. *Nature* 438(7066): 347-350.

Ministry of Environment and Mineral Resources, Kenya (2009) Kenya: Understanding and responding to climate change. http://www.environment.go.ke/ 7 July 2009.

National Investment Brief Swaziland (2008) High-Level Conference on: Water for Agriculture and Energy in Africa: the Challenges of Climate Change Sirte, Libyan Arab Jamahiriya, 15-17 December 2008.

Ng'ang'a J. (2006) An Analysis of Climate Change Impacts, Vulnerability and Adaptation Assessment in East Africa. Presented at the United Nations Framework on Climate Change Convention (UNFCCC) African Regional Workshop on Adaptation, 21-23 September 2006, Accra, Ghana by the Department. of Meteorology, University. of Nairobi.

Ozor, N. (2009) Implications of Climate Change for National Development: The Way Forward. Debating Policy Options for National Development; Enugu Forum Policy Paper 10; African Institute for Applied Economics (AIAE); Enugu, Nigeria: 19-32. Available at: http://www.aiaenigeria.org/Publications/Policypaper10.pdf (viewed 14 November 2009).

Padma, T.V. (2007) India 'must regulate nanotechnology' urgently. Scidev.net. http://www.scidev.net/en/news/india-must-regulate-nanotechnology-urgently.html (accessed 18 November 2009).

Pak Sum Low (2005) *Climate Change and Africa*. New York; Cambridge University Press, p.30.

Parry, M., Arnell, N., McMichael, T., Nicholls, R., Martens, P., Kovats, S., Livermore, M.,

Rosenzweig, C., Iglesias, A., and Fischer, G. (2001) Millions at risk: defining critical climate change threats and targets. *Global Environmental Change* 11: 181-183.

Pavel Kabat (2003) Climate changes the water rules: How water managers can cope with today's climate variability and tomorrow's climate change. Published in The Netherlands by the Dialogue on Water and Climate; *Nature*: 106 pp.

Pittock, A. B. (2007) *Climate Change: Turning up the Heat*. Australia, EARTHSCAN: 316pp.

Presidential Speech (2009) African Parliamentarians on Climate Change held at the United Nations Environmental Programme (UNEP) offices, Nairobi, on the 13 October 2009. http://www.statehousekenya.go.ke/speeches/kibaki/oct09/2009131001.htm (accessed 17 November 2009).

Psenner, R. and R. Schmidt, (1992) Climate-driven pH control of remote Alpine lakes and effects of acid deposition. *Nature* 356: 781-783.

Raleigh, Clionadh, Lisa Jordan, and Idean Salehyan (2007) Assessing the Impact of Climate Change on Migration and Conflict. *Exploring the Social Dimensions of Climate Change;* Washington D.C., 49Pp.

Rogora, M., R. Mosello and S. Arisci, (2003) The effect of climate warming on the hydrochemistry of Alpine lakes. *Water Air Soil Pollut.* 148: 347-361.

Schwab, K. (ed.) (2009) *The Global Competitiveness Report 2009-2010.* World Economic Report. World Economic Forum. 479pp.

Science Daily (2001) Africa's Lake Chad Shrinks By 20 Times Due To Irrigation Demands, Climate Change. Science Daily LLC. http://www.sciencedaily.com/releases/2001/02/010228080245.htm (accessed on 18 November 2009).

Senan Murray (2007) Lake Chad fishermen pack up their nets. BBC News website, Lake Chad. http://news.bbc.co.uk/2/hi/africa/6261447.stm (accessed 18 November, 2009).

Shagun Mehrotra Claudia E. Natenzon Ademola Omojola Regina Folorunsho Joseph Gilbride Cynthia Rosenzweig (2009) Framework for City Climate Risk Assessment: Buenos Aires, Delhi, Lagos, and New York. World Bank Commissioned Research, Fifth Urban Research Symposium Cities and Climate Change: Responding to an Urgent Agenda Marseille, France: 84pp.

Simonett, Otto (2002) Nile Delta: Potential Impact of Sea Level Rise, UNEP/GRID-Arendal, http://maps.grida.no/go/graphic/nile_delta_potential_impact_of_sea_level_rise (accessed 4 June 2009).

Sokka, Laura (2004) Climate Change and Water Availability in Egypt. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Sommaruga-Wograth, S., K.A. Koinig, R. Schmidt, R. Sommaruga, R. Tessadri and R. Psenner (1997) Temperature effects on the acidity of remote alpine lakes. *Nature* 387: 64-67.

Somerfield, Mark (2010) Global Warming in Africa: Lake Chad Shrinking as Climate Changes. Read more at *Suite101*: http://climate-change.suite101.com/article.cfm/global-warming-in-africa-lake-chad-shrinking-as-climate-changes#ixzz0yZ0Z0CuH (accessed 4 September 2010).

Spore, (2008) *Climate Change.* A bi-monthly magazine of the Technical Centre for Agricultural and Rural Cooperation (CTA). Wageningen.

Sterman, David July (2009) *Climate Change in Egypt: Rising Sea Level, Dwindling Water Supplies*. Climate Institute. Washington D.C. http://www.climate.org/topics/international-action/egypt.html. Accessed on 17th, November, 2009.

Stern, Nicholas (2006) *The Stern Review on the Economic Effects of Climate Change.* Report to the British Government, Cambridge: Cambridge University Press.

Stolberg, F., Borysova, O., Mitrofanov, I., Barannik, V., and Eghtesadi, P. (2003) Caspian Sea. GIWA regional assessment 23. Global International Waters Assessment (GIWA). Available at: http://www.giwa.net/areas/reports/r23/giwa_regional_assessment_23.pdf

Stuteville (2008) Lake Victoria beset by environmental problems. Chronicle Foreign Service. Hearst Communications Inc. http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2008/06/23/MN1F112I0F.DTL (accessed 18 November 2009).

Tao, F., Yokozawa, M., Hayashi, Y. and Lin, E. (2003a) Changes in agricultural water demands and soil moisture in China over the last half-century and their effects on agricultural production. *Agri. Forest Meteorol.* 118: 251-261.

Tao, F., Yokozawa, M., Hayashi Y. and Lin, E. (2003b) Future climate change, the agricultural water cycle, and agricultural production in China. *Agri. Eco. Environ.* 95: 203-215.

United Nations Economic Commission for Africa, UNECA, (2009) *Developing African Agriculture Through Regional Value Chains.* Addis Ababa, Ethiopia, UNECA: 193.

United Nations Educational, Scientific and Cultural Organization, UNESCO (2003) The UN World Water Development Report. Water for People, Water for Life. World Water Assessment Programme. UNESCO, New York.

United Nations Environment Programme, UNEP (2000) GEO-2000 Global Environmental Outlook. Available at: http://www.unep.org/geo2000/english/0051.htm (retrieved 14 November 2009).

United Nations Environment Programme, UNEP (ed.) (2003) GEO-Global Environmental Outlook. UNEP website: http://www.unep.org/geo/geo3/English/index.htm

United Nations Environment Programme, UNEP (2008) Indigenous Knowledge in Disaster Management in Africa. UNEP. Compiled and edited by Peter Mwaura.

United Nations Environment Programme, UNEP (2009a) Kenya: Atlas of Our Changing Environment. UNEP, Nairobi, Kenya: 16.

United Nations Environmental Programme, UNEP (2009b) UNEP Year Book, 2009 makes the Green Economy Case. UNEP/GRID. http://www.grida.no/news/press/3470.aspx (accessed 18 November 2009).

United Nations Framework Convention on Climate Change, UNFCCC (2004) Swaziland's First National Communication to the United Nations Framework Convention on Climate Change.

UN Millennium Project (2005), *Innovation: Applying Knowledge in Development*; Task Force on Science, Technology and Innovation, EarthScan, London, Sterling VA.

Vordzorgbe, S.D. (2003) Managing Water Risks in Africa, Paper presented at the Pan-African Implementation and Partnership Conference on Water, 8-13 December.

Vörösmarty, C.J., E.M. Dougla, A.A. Green and C. Ravenga (2005) Geospatial indicators of emerging water stress: an application to Africa. *Ambio* 34(3): 230-236.

Walter, M.T., D.S. Wilks, J.Y. Parlange and B.L. Schneider (2004) Increasing evapo-transpiration from the conterminous United States. J. Hydrometeorol. 5: 405-408.

Wamatsi Ebby Nanzala (2009) Africa Climate Change Threatens Life and Health of Maasai Women. Women News Network (WNN). http://womennewsnetwork.net/2009/09/14/africa-climate-change-threatens-life-and-health-of-maasai-women/ (accessed 14 November 2009).

World Bank (2003) World Development Report 2003. Sustainable Development in a Dynamic World. Transforming Institutions, Growth, and Quality of Life. World Bank, Washington DC.

World Bank (2007) Strategic Environmental Assessment and Integrated Water Resources Management and Development. Economic and Sector Work Environment Department World Bank, Washington DC.

World Food Programme, WFP (2007) Floods across sub-Saharan Africa hit 1.5 million people. Available at: http://www.wfp.org/stories/floods-across-sub-saharan-africa-hit-15-million-people (retrieved 16 November 2009).

World Health Organization, WHO/World Water Day (2001) Too little Water: Floods and Droughts. World Health Organization. http://www.who.int/water_sanitation_health/hygiene/emergencies/floodrought/en/index2.html (accessed 16 November 2009).

WRI, UNEP, UNDP and WB (1998). World Resources 1998-99: A Guide to the Global Environment (and the World Resources Database diskette). Oxford University Press, New York, United States, and Oxford, United Kingdom .

Yahaya Nasidi Adamu (2009) Unusual Rain, Evidence of Climate Change. All Africa.com. http://allafrica.com/stories/200901220158.html (accessed 17 November 2009).

Yahia, Mohammad (2008) Egypt's Looming Climate Change Nightmare. Islam Online.net. http://www.islamonline.net/servlet/Satellite?c=Article_C&cid=1199108579572&pagename=Zone-English-HealthScience%2FHSELayout (accessed 17 November, 2009).