IPCC WGII Fourth Assessment Report – Draft for Expert Review

Chapter 09: Africa

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Executive Summary

Increasing greenhouse gas accumulation in the global atmosphere and increasing regional concentrations of aerosol particulates are now understood to have detectable effects on the global climate system (Hulme *et al*, 2001). Climate change will impact negatively on resource-poor communities in Africa, affecting livelihoods and welfare. Although climate change may bring some benefits, it will also enhance and uncover current environmental and socio-economic risks and stresses and constrain development, for instance through variable agricultural productivity, heightened food insecurity, poor health status, and scarce water supplies. The need for effective adaptive strategies is thus crucial for Africa.

Past assessments (TAR)
The historical climate records of Africa show a warming of approximately 0.5° C during the 20th century, a decrease in rainfall over the Sahel, and an increase in rainfall in east and central Africa. Climate change scenarios indicate future warming of 0.2 to 0.5 °C per decade across Africa. Projected future changes in mean seasonal rainfall under intermediate warming scenarios show that by 2050 North Africa and the interior of southern Africa will experience decreases during the growing season. In parts of equatorial east Africa, rainfall is projected to increase in December–February (during the harvest) and decrease in June–August (during the planting season). The Third Assessment Report concluded that the African continent is highly vulnerable to climate change. This vulnerability is not caused solely by climate change but by a combination of several factors exacerbated by climate change. Such factors include poverty, food scarcity, environmental pressures, a high dependence on natural resources, inequitable land distribution, and an overdependence on rain-fed agriculture.

Current sensitivity

Africa Context:
Africa's Climate: Warming through the twentieth century in Africa has been at the rate of between 0.26 and 0.50ºC/century (Hulme *et al*., 2001, Malhi and Wright, 2004). There has been an increase in precipitation in the semi-arid regions of West Africa, and an increasingly wetting trend in East Africa (Nicholson, 2001; Hulme *et al*., 2001). For the northern and southern regions, rainfall is characterized by a linear downward trend during wet seasons over the period 1950-1999 (Hoerling *et al*., 2005). Interannual 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. ENSO (El Niño Southern Oscillation) is one of the controlling factors for interannual rainfall variability in Africa, at least for some regions (Dai and Wigley, 2000). There has also been an increase in the frequency and intensity of extreme events, such as floods and droughts, which have caused major disruptions in the economy of many African countries, thereby exacerbating vulnerability in the continent (Washington *et al*., 2004).

Economic and Social Vulnerability: Africa's vulnerability is not only linked to climate and the vagaries of climate. Several other factors serve to heighten vulnerabilities, many of which together with climate can constrain development. The African region has a wealth of natural resources, offering myriad opportunities for human, social and economic development. Its diversity of cultures and valuable indigenous knowledge provides the necessary human capital to realize these opportunities. Nevertheless, the continent has several other stresses to contend with such as its high population growth rate, high disease burden, particularly from HIV/AIDS and malaria, a growing poverty, inadequate technological development and insufficient institutional and legal frameworks to grapple with environmental degradation (Sokona, 2001).

Natural Systems: Africa is well recognized for its rich and diverse biological resources with enormous value for local populations, commercial enterprises, and for the development of tourism. However, these resources are declining rapidly under the pressures of habitat loss, over-harvesting of selected species, the spread of alien species, and illegal activities (Midgely, 2005; Thomas *et al*., 2004). Estimated rate of deforestation in Africa was approximately 0.78 % per year for the period 1990-2000 representing a loss of 5.2 million hectares per year. Demands for other natural resources such as water, are also increasing while the supply is not meeting the needs. Several factors serve to constrain water in Africa including climate, growing domestic consumption for water, irrigated agriculture and industrialization (UNEP, 2002). Africa's renewable water resources average between 4,050 cubic km per year providing in the year 2000 an average of about 5,000 cubic km per capita per year which is significantly less than the global average of 7,000 per capita per year (UNEP, 2002).

Human Systems: Food production in Africa has failed to keep pace with population growth, and potential declines in soil moisture with declining precipitation will aggravate the situation (Parry *et al*., 2004). Vector-borne diseases such as malaria and Rift Valley Fever are known to increase dramatically during periods of above-normal temperature and rainfall (Githeko and Ndegwa, 2001). It is estimated that the population at risk of malaria epidemic is 124 million resulting in an estimated 155,000- 310 000 deaths (Eves *et al*., 2004).Cholera outbreaks have continued in many countries in Africa. Over 160 million people are at risk of meningitis (Molesworth *et al*., 2003). In terms of Energy, several African countries are already facing crisis situations. In West Africa for instance, the average river discharge in the region has dropped by 40 to 60% (Niasse *et al*., 2004) and this sharp decrease in water availability combined with greater uncertainty in the spatial and temporal distribution of rainfall and surface water has limiting effects on hydroelectric power generation in the region.

Assumptions about Future Trends

Climate change scenarios: Most Global Circulation Models (GCMs) indicate a warming across Africa. By the 2070-2099 period, maximum warming is expected in Northern and Southern Africa (up to 9° and 7°C respectively) with minimum warming in the oceanic regions (up to 4.8°C in the tropical NE Atlantic and 3.6°C in the Indian Ocean). Precipitation projections are generally less consistent. While some studies show a continuing decline in JAS over sub-Sahara, consistent with a sensitivity to global SSTs (e.g. Giannini *et al*., 2003; Bader and Latif, 2003), other studies project an increase in rainfall, widespread across the sub-Saharan zone in the 2000-2049 time period (+10% above the 1950-1999 climatology) resulting from a change in inter-hemispheric SST (sea surface temperature) contrasts (Paeth and Hense, 2004, Hoerling *et al*., 2005). On the other hand, the southern African monsoon is projected to weaken further during the 2000-2049 period.

Socioeconomic Scenarios: We cannot fully understand how vulnerable Africa may be to climate change without knowing something about future socioeconomic conditions. Average incomes are projected to rise in all sub-regions, contributing to a drop in the percentage of the population that is hungry (UNEP, 2002). However, rapid population growth can lead to an increase in the hungry population, even as the percentage hungry declines. The projected GDP per Capita for the different regions in Africa under various SRES scenarios show that West and Central Africa consistently perform poorer than the other regions (Arnell *et al*., 2004). In terms of population growth, West Africa shows a consistently higher growth except for the A2 scenario, where the population of North Africa exceeds that of West Africa by 2070.

Summary of expected key future impacts and vulnerabilities, and their spatial variation

Water: Using a variety of SRES scenarios, Arnell (2004) for example, shows that under the A1, B1 and B2 scenarios East and West Africa will become water stressed by 2050 in the absence of climate change. When the effects of climate change are included in the assessments then considerably more people in northern, central and southern Africa will be water-stressed (Arnell, 2004).

Health: Climate change and variability may have both direct and indirect impacts on diseases that are endemic in Africa, with climate aggravating underlying health problems in many cases. Direct links to climate changes, such as heat waves are already becoming a concern.
Model projections indicate that malaria transmission will likely increase altitudinaly in the Eastern Africa region but decrease in the Sahel and southern-central Africa and may decrease in the long rain season but intensify in the short rain season. Intensified frequencies of El Niño events are likely to be associated with malaria, cholera and Rift Valley Fever epidemics. Vectors and intermediate hosts of animal diseases such as tsetse fly, ticks and snails are sensitive to habitat moisture content whose deficit in certain regions will reduce habitat suitability while warmer temperatures in the wet highlands may increase habitat suitability and diseases.

Agriculture: It is estimated that by the 2080s, the net balance of changes in cereal-production potential for sub-Saharan Africa will very likely be negative, with net losses of up to 12% of the region's current production and increasing the risk of food insecurity (Gitay *et al.*, 2001; Davidson *et al*., 2003). The negative impacts of climate change on marginal lands, along with the shortage of water resources will have critical impacts on poor rural societies, resulting in loss of jobs, unemployment, internal migration, loss of income, and political unrest. Not all changes will, however be negative and growing seasons in certain areas may lengthen under climate change. Increased temperatures will likely bring better livestock and fishing yields and crop production potential may increase (Fischer *et al*., 2002). As a result of reduction of frost on the alpine zones of Mt. Kenya and Mt. Kilimanjaro, it will be possible to grow more temperate crops e.g. apples, pears, barley, wheat, etc on the adjoining elevations (Parry et. al., 2004).

Coastal Zones: The increased movement of people to urban areas on the coasts makes the coastal zones a key area of vulnerability under climate change. By 2015, three coastal megacities (Lagos, Kinshasa and Cairo) with at least 8 million people will be present in Africa (Klein *et al.*, 2002). Projected rise in sea level will have significant impacts in these coastal megacities which, due to the concentration of poor populations in potentially hazardous areas, will be less resilient to climate change (Klein *et al.*, 2002). Combined with low GDP this will likely limit the adaptive capacity and the level of protection of the coasts (Nicholls, 2004) which in turn will constrain the future plans to develop tourism. Without any adaptive response, a global sea-level rise of only 37-38 cm by the 2080s will likely enhance the occurrence of coastal flooding (Nicholls *et al*., 1999).

*Ecosystems****:*** Ecosystems are not only the foundation of the economy of most African countries, but also contain a number of plants and animals that constitute about 20 percent of all known species (Biggs *et al*., 2004). With climate change, most of these species could be threatened. By 2032, more areas will likely experience greater risk of water-induced soil degradation as well as a reduction in the Natural Capital Index indicating overall habitat loss and increasing pressure on terrestrial and aquatic biodiversity (UNEP, 2002). Some expected key future vulnerabilities and impacts are: changes in aquatic ecosystem productivity of Lake Tanganyika (O'Reilly *et al*., 2003); lake level fluctuations in Africa and possible impacts on fish species (Mercier *et al*., 2002); environmental changes in North African wetland lakes (Flower *et al*., 2001); changes in extinction risks of known species (Thomas *et al*., 2003) and changes in desert environments (Thomas *et al*., 2005).

9.1 Summary of knowledge assessed in the TAR

The historical climate record of Africa based on the Third Assessment Report shows a warming of approximately 0.5° during the 20th century, a decrease in rainfall over the Sahel, and an increase in rainfall in east central Africa. Climate change scenarios for Africa indicate future warming across Africa ranging from 0.2 to 0.5 °C per decade. Projected future changes in mean seasonal rainfall under intermediate warming scenarios, show that by 2050 North Africa and the interior of southern Africa will experience decreases during the growing season. In parts of equatorial east Africa, rainfall was projected to increase in December–February and decrease in June–August. The Report concluded that the African continent is highly vulnerable to climate change. The report also noted that Africa's vulnerability is not caused solely by climate change but by a combination of several factors. including climate change. Such factors include widespread poverty, food scarcity, environmental pressures, a high dependence on natural resources, inequitable land distribution, overdependence on rain-fed agriculture, armed conflicts, external trade and dependency, development status, and HIV/AIDS. Additional factors include a high population growth rate, social and political conflicts and international economic pressures that make the current general situation of many African countries harder, and reduce their capacities to respond proactively to changes that are largely outside their control. The major vulnerabilities reviewed in TAR include:

Water resources: The report outlines a reduction in soil moisture in sub-humid zones and a reduction in runoff of major river basins. Recently, reservoir storage shows variations in runoff and periods of drought, while lake storage and major dams have reached critically low levels with consequent impacts on hydropower generation and industries. Model results indicate that global warming will increase the frequency of such low storage episodes. Population growth will likely exacerbate water demand.

Natural resources management and biodiversity: Resultant climate changes in ecosystems will affect the distribution and productivity of plant and animal species, water supply, fuel-wood, and other services. Losses of biodiversity are likely to be accelerated by climate change. Climate change is expected to lead to drastic shifts of biodiversity-rich biomes such as mountainous biomes, the mangrove vegetation along lagoons and shores and many losses in species in other biomes. Changes in the frequency, intensity, and extent of vegetation fires and habitat modification from land-use change may negate natural adaptive processes and lead to extinctions.

Food security: The continent already experiences a major deficit in food production in many countries. Food-importing countries are at greater risk of adverse climate change. As a result of water stress, inland fisheries will be rendered more vulnerable because of episodic drought and habitat destruction, while ocean warming is likely to have negative impacts on coastal marine fisheries.

Vector and water borne disease: Temperature rises will extend the habitats of vector and water-borne diseases such as malaria and cholera, particularly in areas where sanitary infrastructure is inadequate, and at high altitudes. Droughts, increased rainfall and floods will result in increased frequency of epidemics and other enteric diseases.

Coastal zones: Sea-level rise, coastal erosion, salt water intrusion, and flooding will have significant impacts on African communities and economies. Most of Africa's largest cities are along coasts and are highly vulnerable to storm surges, sea-level rise, and coastal erosion because of inadequate physical planning and escalating urban drift.

Desertification: Changes in spatial and temporal patterns in temperature, rainfall, solar radiation, and winds will enhance desertification process. Desertification is a critical threat to sustainable resource management in arid, semi-arid, and dry sub-humid regions of Africa.

Given the diversity of constraints facing many nations, the overall capacity for Africa to adapt to climate change currently is very low. Although climate change also offers some opportunities, and despite long traditions of adaptive capacity, current technologies and approaches, especially in agriculture and water, are unlikely to be adequate to meet projected demands, and increased climate variability will be an additional stress. It is unlikely that African countries on their own will have sufficient resources to respond effectively to the added stress of climate change. The report stressed the low confidence in climate change projections and called for the development and implementation of regional assessments of vulnerability, impacts and adaptation.

9.2 Current sensitivity/vulnerability *(VOGEL to coordinate)*

9.2.1 Africa context

9.2.1.1 Climate

Several reports have consistently noted the vulnerability of the African continent to the impacts of climate change (Desanker *et al.*, 2001; Washington *et al.*, 2004) which not only depends on climate factors but also on a number of non-climate stresses which are presented in this chapter.
The continent, the second largest and comprising a land area of 30 million km^2 exhibits large contrasts in its surface terrain and vegetation, which may be important in modulating the global climate (CLIVAR, 1999; AMCEN/UNEP, 2002). Its climate is controlled by the Hadley cell which is symmetrically located, as well as being influenced by the three oceanic basins surrounding it (Washington *et al.*, 2004; Jury and Mepta, 2005). The Sahara desert generates the largest mineral aerosol output globally, which is potentially implicated in tropical cyclone formation over the Atlantic as well as the transport of aerosols to the Americas and Europe. The Sahel is a key location for strong land surface - atmosphere feedbacks, probably due to large cross latitude albedo and the extent of these conditions zonal. Finally, Africa experiences strong shifts in climate from the humid tropics to the hyper-arid Sahara. Climate is a major factor controlling the economic development of Africa, which mainly depends on agriculture and water resources while extreme events (like floods and droughts) are responsible for major disruptions in the economy of the countries (Washington *et al.*, 2004).

The continent of Africa is warmer than it was 100 years ago, warming trends being not geographically uniform (King'uyu *et al*., 2000; Kruger and Shongwe, 2004). The warming rate is between 0.26 and 0.50ºC/century, with slightly larger warming in the June-August (JJA) and September-November (SON) seasons (Hulme *et al*., 2001, Malhi and Wright, 2004). In East Africa, a net warming trend of minimum temperatures is observed since 1939 (King'uyu *et al.*, 2000; Conway *et al.*, 2004). For precipitation, there is a more complex regional differentiation, A reduction in annual rainfall is observed at all latitudes between 6° and 20°N particularly in the semi-arid regions of West Africa (Nicholson *et al.*, 2000; Nicholson, 2001) as well as North Congo (Malhi and Wright, 2004), even though Chappell and Agnew (2004) question the reality of this decline in the Sahel. However, a positive trend is registered in the Soudano-Guinean zone (Nicholson *et al*., 2000) while in Southern Africa no long term trend is evident (Richard *et al*., 2001).

Interannual rainfall variability is large over most of Africa and for some regions, most notably the Sahel, multi-decadal variability has also been substantial. This variability depends on different teleconnections as explained by climate models (Vizy and Cook, 2001, McHugh and Rogers, 2001;

Rowell, 2003; Cook *et al*., 2004). These teleconnections are mainly linked to the El Niño-South Oscillation (ENSO), the North-Atlantic Oscillation (NAO) as well as sea surface temperature (SST) anomalies (Dai and Wigley, 2000; Nicholson, 2001; Richard *et al.*, 2001; Nicholson and Grist, 2003). The two regions in Africa with the most dominant ENSO influences are in eastern equatorial Africa during the short October-November rainy season and in southeastern Africa during the main November-February wet season. The recurrent drying of the Sahel region since the 1970s seems to be linked with a positive trend in the equatorial Indian Ocean sea surface temperatures (Giannini *et al.*, 2003). Moreover, feedback mechanisms -mainly deforestation/land cover change, dust - seem to play a role in climate variability and change (Wang and Eltahir, 2000; Nicholson, 2001; Prospero and Lamb, 2003).

Droughts and floods seem to have increased in frequency and severity over the past 30 years (AMCEN/UNEP, 2002). Droughts have mainly affected the Sahel, the Horn of Africa and Southern Africa particularly since the end of the 1960s (Brooks, 2004; Prospero and Lamb, 2003; L'Hôte *et al.*, 2002; Richard *et al.*, 2001; Nicholson, 2001). One third of the people in Africa live in drought prone areas (World Water Forum, 2000). During the mid-1980s drought's economic losses totalled several hundred million US$ (Tarhule and Lamb, 2003). Moreover droughts have largely contributed to human migration, cultural separation, population dislocation and the collapse of prehistoric and early historic societies (Pandey *et al.*, 2003). At the opposite side of the spectrum, floods are recurrent in some countries and linked with ENSO events. Even countries located in dry areas (Tunisia, Egypt, Somalia) have not been flood-safe (Kabat *et al.*, 2002).

9.2.1.2 Economic and social vulnerability

African development and progress is not only linked to climate and the vagaries of climate. Several other factors serve to heighten vulnerabilities, many of which together with climate can constrain development. Poverty is endemic in many areas of Africa and the number of Africans living below the poverty line has increased by 50% over the last 14 years, sub-Saharan Africa being the only region in the world where, overall, poverty, livelihoods and food security continue to deteriorate (Amoako, 2003, FARA, 2004, Sachs, 2005). Sixty percent of the people over the age of 15 are illiterate, and 47% of the population in sub-Saharan Africa lack access to safe water. Thirty-one percent of the population, most of them women and children, are undernourished (Conway and Toenniessen, 2003). All the African countries are listed in the medium and low human development categories (UNEP, 2004). Not only these problems will be exacerbated by climate change (Davidson, *et al*, 2003) but also they strictly limit the adaptive capacity in the continent.

Due to high population growth rate of 2.4% (almost twice the world average of 1.3%) the growing population in Africa will exert continued pressure on the provision of safe water, education and health services, as well as threaten food security (UN, 2005). The rapid rate of urbanization in Africa, largely sustained through rural-urban migration, will lead to increases in aggregate commercial energy demand and emission levels (Davidson *et al*. 2003), as well as extensive land use and land cover changes especially from largely uncontrolled urban settlements with poor housing, water supply, sanitation, waste disposal (du Plessis *et al.*, 2003). Concurrently, this deprives rural households of a significant proportion of their adult-male labour force with consequent stagnation of production and decline of real incomes in rural areas which combine with lack of investment in agriculture and overexploitation of ecosystem services (Cadisch *et al*, 2002). Sustained rural-rural migration particularly from the drier regions to the wetter sub-humid regions puts undue pressure on land resources both for farming and pasture. This has largely resulted in communal conflicts between pastoralists and sedentary farmers, further weakening the economy of the already impoverished rural areas (Fiki and Lee, 2005; Moore, 2005).

Most African countries have not accorded adequate priority to science and technology for development. The lack of access to affordable appropriate technologies seriously constrains sustainable development in the continent. In the agricultural sector, for example, many African countries depend on inefficient irrigation systems as the efficient ones are too costly for most farmers, resulting in wastage of water (UNEP, 2004). Internet access is still very low, with an average of one user for every 200 people, compared to a world average of about one for 30 (Jensen 2001). In most cases, institutional and human capacities are too weak to ensure proper management of scientific progress and technological innovation for developmental purpose.

Africa is characterized by insufficient institutional and legal frameworks to grapple with environmental degradation (Sokona, 2001). The low level of food production in Africa and the frequent famine are not simply due to climatic variability or poor African soils, as sometimes suggested, but also to policy and institutional failure. There is now substantial evidence that institutional weakness in many African countries, mainly in terms of public service delivery, corruption and democratic governance (Collier and Gunning, 1999), is a critical obstacle to economic performance.

Environmental disasters and armed conflicts that have become so frequent in Africa threaten livelihoods and also contribute to rural-urban migration, generating new types of refugees, the environmental refugees which move away from vulnerable regions (Myers 2001; McLeman & Smit 2005).

The pressures outlined above could lead to an erosion of the natural resource base because incentives to conserve natural resources are weaker than the immediate rewards of simply extracting them. A vicious circle arises, characterized by (a) agricultural practices that are detrimental to important ecosystem services, such as water conservation, biodiversity management, carbon sequestration; (b) a level of resource degradation that threatens the medium- to long-term ecological sustainability of agriculture in the region; and (c) the failure to generate sufficient financial and social capital for rural communities to secure health and education of their members, and catalyze economic development at local levels and beyond. Climate change thus may not be viewed as a priority as its full effects may only be felt 30-100 years down the line when compared to current and political urgencies (Davidson *et al*., 2003).

9.2.2 Natural systems

Africa is well recognized for its rich and diverse biological resources and these natural systems form the foundation of the economy of most countries, from which the majority of the population derive their livelihood (Desanker, 2003). Africa contains about one-fifth of all known species of plants, mammals, and birds, as well as one-sixth of amphibians and reptiles. Biodiversity in Africa, which principally occurs outside formally conserved areas, is under threat from climate change and other stresses. Savannahs, tropical forests, coral reef marine and freshwater habitats, wetlands and East Africa mountain ecosystems are all at risk. Africa's social and economic development is now even more in danger because climate change, habitat loss, over harvesting of selected species, the spread of alien species, and illegal activities such as hunting and deforestation threaten to undermine the integrity of the continent's rich but fragile ecosystems (UNEP, 2002; Huq *et al*., 2003; Thomas *et al*., 2004; Midgely, 2005). Estimated rate of deforestation is about 0.78 % per year for the period 1990-2000, representing a loss of 5.2 million hectares per year. Demands for other natural resources such as water, are also increasing while the supply is not meeting the needs. With the extinction of plant species used in traditional medicines in Africa, it is expected that the change in climate will impact on people's ability to tackle illness. The World Health Organisation estimates that 80 per cent of the world's population in developing countries rely on these plants for primary health care. In Mali, traditional medicines have declined because many medicinal plants have been wiped out by constant drought.

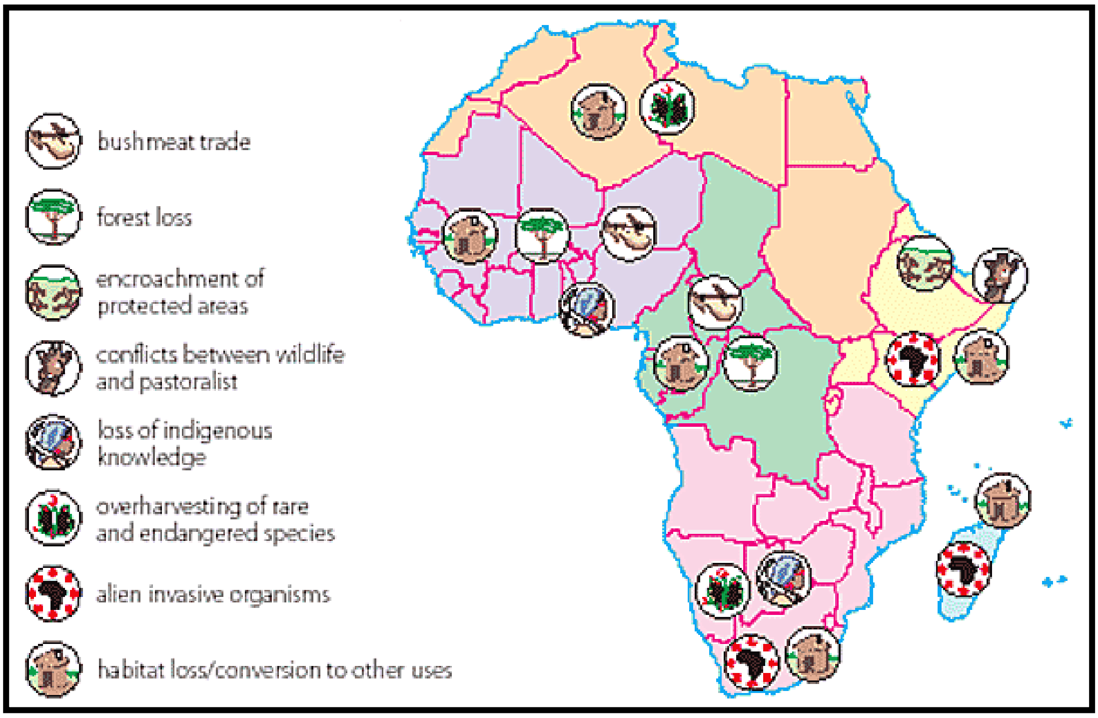


Figure 9.1: *Ecosystem vulnerability in Africa: (Source: UNEP, 2002)*

Current sensitivity of Africa's ecosystem system includes:

- in Western and Central Africa the main issues are loss and fragmentation of forest habitat and poaching of endangered species to meet the growing demand for bushmeat
- in Eastern Africa, encroachment of human settlements into protected areas and pastoral areas outside of reserves and their cultivation are priority concerns
- in Southern Africa, loss of indigenous knowledge and inadequate protection of intellectual property rights are hampering conservation measures, as are over harvesting (legal and illegal) of medicinal plant species, rare and endangered plants, and "trophy" animals and exotic pets
- over harvesting of certain species, particularly medicinal plants, is also the primary cause of biodiversity loss in Northern Africa
- alien invasive organisms are a widespread problem throughout the region, particularly in closed ecosystems including Lake Victoria and the Western Indian Ocean Islands.

9.2.3 Human systems

Climate variations and changes occur within certain biophysical and socio-economic contexts. In this section, various human dimensions, driving and exacerbating change, are tracked for various sectors (e.g. agriculture, health, disasters and energy).

9.2.3.1 Agriculture

The agricultural sector is critical in Africa contributing an average 21% of the GDP (Mendelsohn *et al*., 2001). In many parts of Africa, agro-ecological systems are characterized by recurring drought events, floods, soil degradation and water supply shortages. For farmers therefore, one's geographical location determines the particular configuration of risks and vulnerability to be faced. In semi-arid regions of sub-Saharan Africa, farmers and pastoralists have to contend with extreme natural resource challenges (limited water, poor soil fertility, and availability of inputs and improved seeds). They also have few technology options, and are constrained by limited infrastructure and links to markets. Traditional production systems of rural households are geared for subsistence, and are generally sustainable under conditions of low population pressure and isolated markets. However, this equilibrium is stressed by population growth, which in turn triggers either intensification of agriculture or expansion into marginal lands. In addition, expansion into marginal areas brings risk of conflicts, crop failure, environmental degradation and loss of biodiversity (Fiki and Lee, 2005, Moore, 2005).

Inappropriate crop and land management practices under either of these scenarios strip the soils of nutrients and organic matter and leave them vulnerable to degradation, reducing both productivity and sustainability of agricultural systems over time (FARA, 2005). For over three decades the region has faced a structural food deficit whereby food production has failed to keep pace with population growth; potential declines in soil moisture will aggravate the situation (Parry *et al*., 2004). To compensate for the shortfall in food supply, Africa receives the highest per capita quantity of food aid in the world amounting to over three million tons of food per year (Conway and Toenniessen, 2003).

9.2.3.2 Health

In Africa it has been estimated that the population at risk of epidemic malaria is 124,748,180, furthermore out of the 12.4 million cases of malaria due to epidemics results in an estimated 155,000-310,000 deaths (Worrall *et al*., 2004). Climate variability and change have been shown to explain the prevalence and distribution of malaria in the highlands of Eastern Africa (Zhou *et al.*, 2004), Ethiopia (Abeko *et al.*, 2004), and in the highlands of western Kenya (Githeko & Ndegwa, 2001). Floods can cause malaria epidemics in arid and semi arid areas (Warsame, 1995, Connor *et al* 1999). There are indications that in areas that have two rain seasons, March April and June (MAJ) and September October and November (SON), more rain is being experienced in SON than before. The later period is relatively warm and such a trend is likely to increase malaria transmission in the SON period. An increase in malaria incidence and prevalence can be expected to increases poverty, where a five-fold difference in the GDP between malarious and non-malarious countries has been noted (Sachs and Malaney, 2003). A significant population of individuals in Africa is also co-infected with malaria and HIV. The proportional increase of malaria during pregnancy attributable to HIV was estimated to be 5.5% and 18.8% for populations with HIV prevalences of 10% and 40%, respectively. It has been observed than maternal malaria is associated with a two-fold higher HIV-1 viral concentration (ter Kuile, 2004). Thus an increase in malaria, in HIV infected populations, will increase morbidity risks.

Factors that predispose populations to meningococcal meningitis are still poorly understood but climatic conditions associated with the epidemics are dryness, very low humidity, dusty and conditions. About 162 million people in Africa live in areas with a risk of meningitis (Molesworth *et al*., 2003. A recent study has demonstrated that wind speeds in the first two weeks of February explained 85% of the variation in the number of meningitis cases (Sultan *et al*., 2005).

Disasters in Africa are also increasingly becoming more complex and compound in nature with many disasters usually a combination of drought, conflict, disease outbreaks etc (Benson and Clay, 2004). In 2002, droughts, for example, accounted for 90% of people affected by disasters, while epidemics accounted for 80% of human life loss while contributing to 37% of the number of disasters. Flood and windstorms contributed 28% and 11% to the total number of disasters respectively (Natural Disaster Notebook, 2002). Women and children account for a disproportionate 80% of the populations affected by disasters which result in considerably high maternal and infant morbidity and mortality (WHO, 2002).

9.2.3.3 Energy

The generally drier climates projected by most GCMs for Africa have the potential of modifying the regional hydrological cycle, leading to a highly variable climate with a likelihood of more extreme weather events. The intensification of these changes would impact severely on the energy sector in a variety of ways. Since biomass fuels (fuel-wood, charcoal, dung and agricultural residues) contribute more than 90% of the household energy needs in most African countries, disruptions of the hydrological cycles are likely to reduce plant productivity, leading to a decline in land cover in most ecological zones with severe impacts on access to biomass-based energy (source). When added to the demand for biomass for other needs (housing, furniture, implements, etc) this could further compound the land use change and its impact on the climate system.

As the climate becomes drier and rainfall continues to decline in parts of the region, increased dependence on biomass for livestock, wood and other needs will likely lead to the stripping of the soils bare and consequently increases soil albedo. This could result in exacerbated and increased atmospheric subsidence, which in turn prevents further rainfall. The net outcome of this is the disappearance of vegetation with a strong potential for increase in desertification. Additionally, increased urbanization, together with direct heat generation from human activity in urban centres could lead to urban heat island effect. The continuing explosive growth of such cities as Cairo (Egypt), Johannesburg (South Africa), Lagos (Nigeria), Nairobi (Kenya) among others imply an increasing heat stress in urban and rural areas. This eventually leads to increased human discomfort, which in turn makes for increased demand for energy to support artificial space cooling by air conditioning systems. In response to these, countries would have to increasingly depend on fossil fuels or the development of new small-scale biomass driven electricity generation for small communities. Mansur *et al* (2005) however indicate that consumers could switch from gas, oil and other fuels to electricity as the climate warms, and that the overall energy (and especially electricity) demand increases. Alternatives to non-sustainable use of biomass and fossil fuels without threat to the energy security of the region include the introduction of alternatives such as wind, solar PV/PT, biogas, and other sustainable use of biomass. These could be used to develop an integrated energy system for the sub-region under frameworks such as the New Partnership for Africa's Development (NEPAD). Additionally options to increase efficiency in consumption sectors may need to be explored by countries in the region so that the gross per capita consumption will be stabilized even with increase in consumption patterns. Countries in the region would also need to improve human and institutional capacity to develop existing and new energy technologies locally.

9.2.3.4 Settlement and Infrastructure

The low levels of technological innovations and infrastructural developments in Africa suggest a high dependence of human systems on natural systems for essential amenities like clean water, food, transportation, energy and shelter (Ruth & Kirshen 2003; Sokona & Denton 2001). Changes in the ecosystem set off by climate variability disrupt human systems and affect livelihoods. African economies are often clustered around natural resource rich zones that are very sensitive to climate variability with more than a quarter of the population residing within 100km of a sea coast (Desanker *et al*. 2001; Karanja et. al. 2004; Davidson *et al*. 2003; Benson & Clay 2003; Denton et. al. 2001). These economic activity nodes form the nucleus of settlements, urbanization and development in the continent and are associated with high concentrations of infrastructure systems and population (Ruth 2003). Africa's recent and projected rapid urban growth rising up to 54% of the population by 2030(UN World Urban Population Report 2004) will lead to increases in aggregate commercial energy demand and emission levels (Davidson *et al*. 2003), as well as extensive land use and land cover changes especially from largely uncontrolled urban, peri-urban and rural settlements (UNEP, 2002; du Plessis *et al*. 2003) thus altering existing surface microclimate and hydrology and exacerbate the scope and scale of climate change impacts.

As livelihoods are threatened and habitats altered due to drought, inundation, floods, large scale subsidence, erosion, desertification and other climate related events, Africa will face a new set of refugees: environmental refugees (Myers 2001; McLeman & Smit 2005) as populations move away from vulnerable regions. Fresh challenges will emerge for new settlement types, sizes and distributions to cater for this population group severally characterised by McLeman and Smit (2004) as repetitive migrants - as part of ongoing adaptation to climate change, short-term shock migrants - responding to a particular climate stimulus and large-scale migrants - a gradual build-up following climate variability, but coupled with other socio-economic factors. This throws up the need for the adoption of coordinated, integrated and strategic land use planning in tandem with observed and projected climate change scenarios.

9.3 Assumptions about future trends

9.3.1 Climate change scenarios

The climate of Africa is highly variable and unpredictable making it difficult to produce simple outlooks and future scenarios (Washington *et al.*, 2004). The first vulnerability and adaptation studies mainly used AOGCMs and the IS92 (and especially IS92a) emissions scenarios mainly because the SRES scenarios were not available (Swart *et al.*, 2002). Very limited experiments of regional to sub-regional climate change scenarios have been conducted in Africa mainly due to restricted computational facilities and human resources (Hudson and Jones, 2002)

A consistent warming is noted for the African continent with higher levels of warming for Northern and Southern Africa (up to 9°C and 7°C respectively for the 2070-2099) than in the oceanic regions (up to 4.8°C in the tropical NE Atlantic and 3.6°C in the Indian Ocean for the same time slice) (Ruosteenoja *et al.*, 2003). But as demonstrated by Hudson and Jones (2002) for the southern Africa region (equator to 45°S and 5° to 55°E), slightly different results could be obtained from regional climate models due to their better predictability of climate variability. With the Hadley Centre Regional Climate Model and A2 SRES emissions scenario they obtained for the 2080s a 3.7°C increase in summer mean surface air temperature and a 4°C increase in winter.

Precipitation projections are generally less consistent, which is explained by the low ability of global AOGCMs to predict regional climates and reproduce the main factors responsible for the high natural variability of precipitations, like orography (Lebel *et al.*, 2000; Ruosteenoja *et al.*, 2003), dust aerosols concentrations or sea surface temperature anomalies particularly important in the Sahel region (Prospero and Lamb, 2003; Hulme *et al.*, 2001) or deforestation in the equatorial region

(Semazzi and Song, 2001). These uncertainties make difficult any precise estimation of future runoff especially in arid and semi-arid regions where slight changes in precipitation can result in dramatic changes in the runoff process (Fekete *et al.*, 2004).

However the main agreements between the global experiments are as follows (Hulme *et al*., 2001; Giorgi *et al.* 2001; Ruosteenoja *et al.* 2003):

- Precipitation is expected to decrease in northern and southern Africa. For example, a 10-25% decrease in June-August period is projected in Northern Africa and for the 2010-2039 time slice. This declining trend increases with time (up to 60% for the 2070-2099 time slice) and extends progressively to the other periods (SON then MAM). In Southern Africa and by the 2080s, the Hadley regional climate model estimates a summer (DJF) drying over much of the western subtropical region (between 10° and 20°S and close to eastern Angola) due to a decrease in both the number of rain days and the intensity of rainfall while equatorial regions tend to become wetter, mainly due to an increase in rainfall intensity (Hudson and Jones, 2002). These results are confirmed by downscaling experiments made by Hewitson and Crane (2005);
- In Eastern Africa, a 10 and 30% increase in precipitation is projected for the DJF and SON periods;
- In the Sahara, considerable increases in precipitation (up to 540%) are predicted but could not be significant given the very limited rains actually occurring.
- In the tropical NE Atlantic and in the Indian Ocean, positive trends are projected for the MAM period (20 to 100% and 3 to 18% respectively). But a decline of 5 to 11% in JJA precipitation is projected for the Indian Ocean in the 2070-2099 time slice, while a positive trend is projected for the SON period (between 4 and 8%).

For Western Africa and the Sahel, there is still controversy between the global circulation models. While some models project a significant drying (Held *et al*., 2005), others simulate a progressive wetting of the Sahel (Maynard *et al*., 2002; Wang *et al*., 2004, Kamga *et al*, 2004; Hoerling *et al*, 2005). However, Kamga *et al* (2004) stressed that land use changes and degradation, which are not simulated by their model, could induce drier conditions. The effects of a stabilization of the atmospheric CO_2 concentrations at 550 (by 2150) and 750 (by 2250) ppm have been assessed using the HadCM2 AOGCM together with the IS92a scenario (Mitchell *et al.,* 2000). For the Sahel region (10-20°N, 20°W-40°E), the projected reductions in warming are respectively 2.9° and 2.1°C. Regarding summer (JJA) precipitation a shift from negative to slight positive changes (from –0.09 mm per day to +0.12 and +0.18 mm per day respectively) is projected. Stabilization at 750 ppm could delay warming by around 40 years across Africa (Arnell *et al*., 2002).

9.3.2 Socioeconomic scenarios

While climate change scenarios for Africa shows projected future climates one cannot know what the climate-changed future will be like for human societies unless we know something about future populations and how they will live. Indeed, we cannot fully understand how vulnerable Africa may be to climate change without knowing something about future socioeconomic conditions. By exploring an array of possible future scenarios, policy-makers in the continent can get a clearer picture of what the future might bring in terms of human well-being and environmental security and what the impact of their decisions is likely to be (UNEP, 2002). Socioeconomic scenarios, like climate change scenarios, are descriptions of journeys to possible futures. They reflect different assumptions about how current trends will unfold, how critical uncertainties will play out and what new factors will come into play (UNEP, 2002). They are not predictions; rather they paint pictures of possible futures and explore the differing outcomes that might result if basic assumptions are changed. The IPCC SRES scenarios adopt four story lines, producing four 'scenario families' that describe the world population, economies and political structure may evolve over the next few decades (IPCC, 2000). Arnell *et al*. (2004) have, for example, downscaled the SRES scenarios national and regional scales, covering Africa.

Four socio-economic scenarios, somewhat similar to the SRES scenarios were developed by the Global Scenario Group and used in UNEP's GEO-3 (UNEP, 2002). A comparison of both sets of scenarios shows that the GEO-3 scenarios show a greater variability between regions than the SRES scenarios (Arnell *et al*., 2004). The projected GDP per Capita for the different regions in Africa under the various SRES scenarios are presented in Figure 1. In all cases, average income is likely to rise throughout the century, though West and Central Africa consistently perform poorer than the other regions. The Projected population is presented in Figure 3. All the scenarios assume a continued growth population projections, with the Western Indian Ocean Islands having the lowest growth rates. West Africa has a consistently high population growth except for the A2 scenario where the population of North Africa is likely to outgrow that of West Africa by 2070.

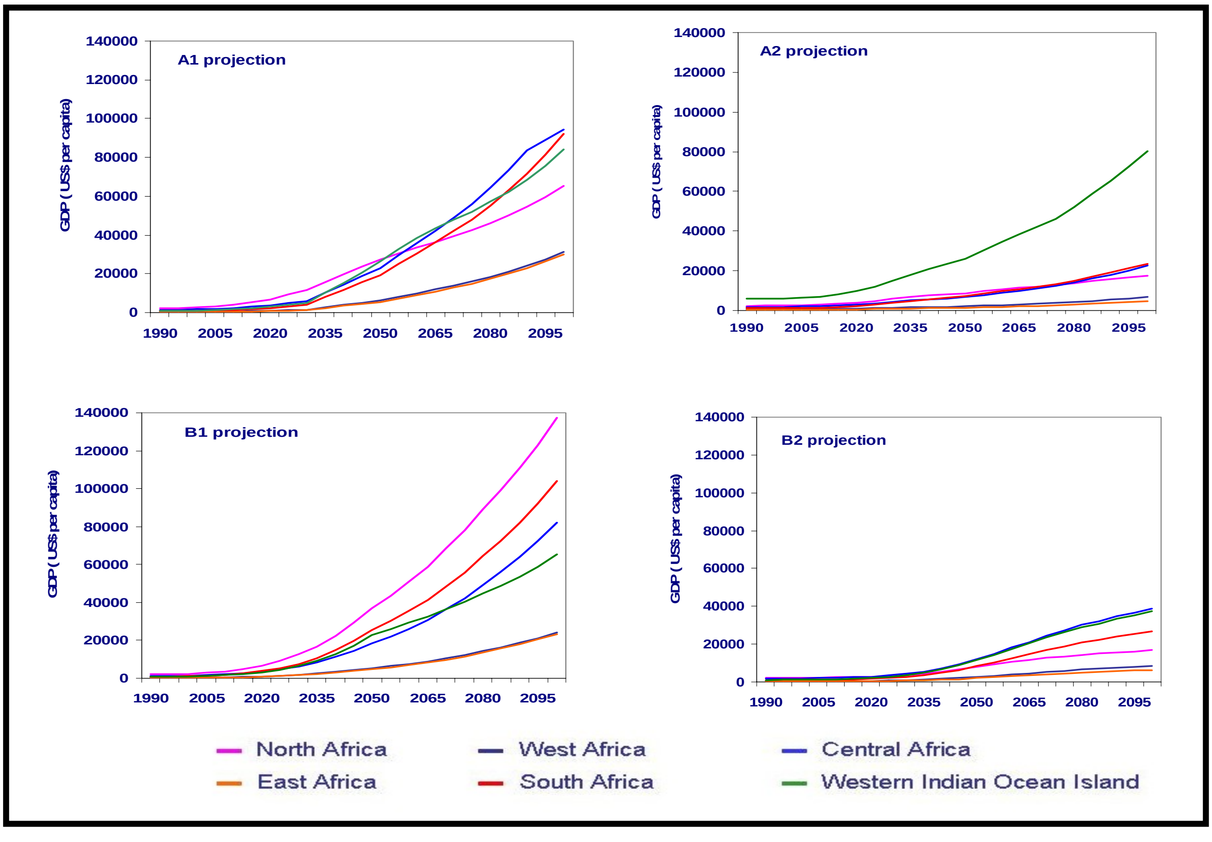


Figure 9.2: *Downscaled GDP for Africa using SRES Scenarios*

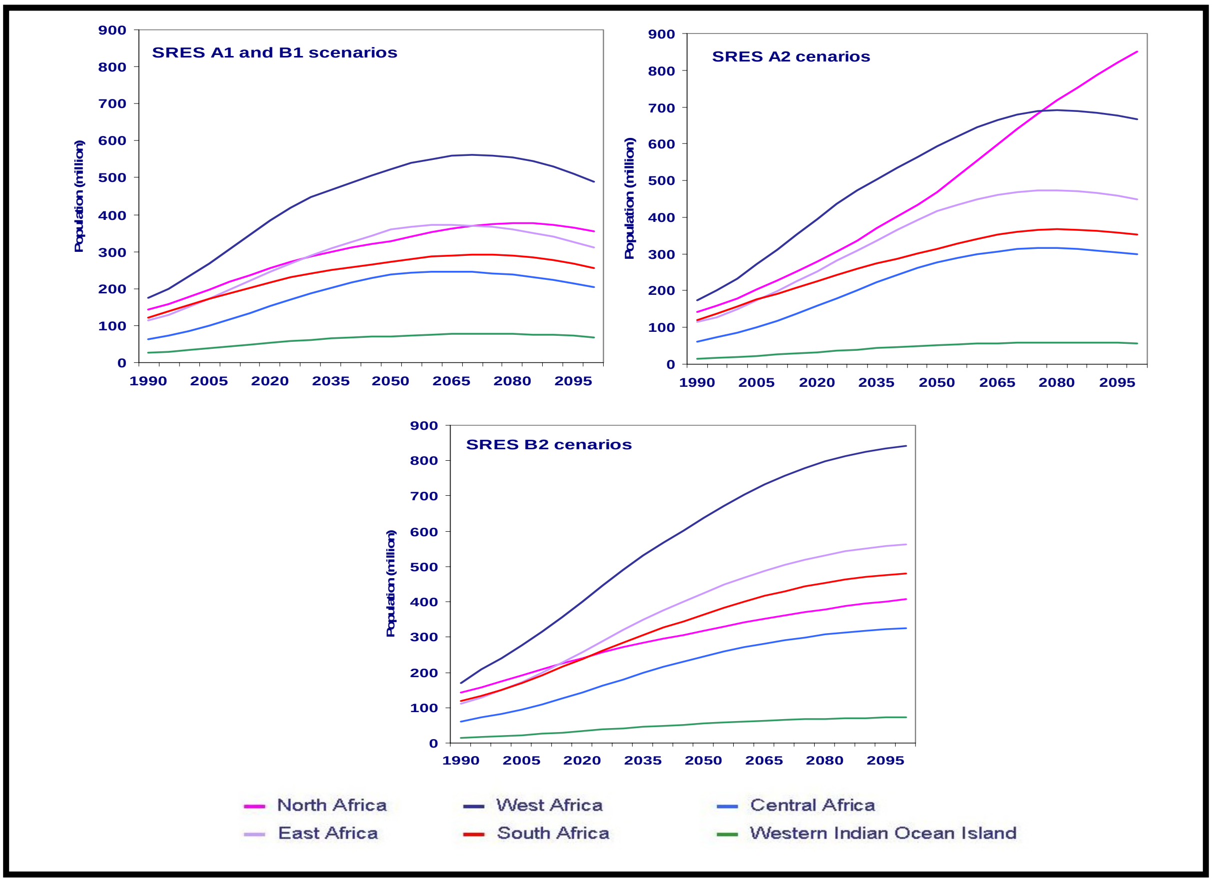


Fig. 9.3: *Downscaled Country-Level Population Projection for SRES A1/A2, B1 and B2 Marker Scenario.*

9.4 Summary of expected key future impacts and vulnerabilities, and their spatial variation

Having provided some background of the scenarios and model capabilities being used, attention now focuses in this section in trying to tease out some of the impacts and vulnerabilities that may arise with these scenarios.

9.4.1 Water

Impacts

Water is one of the current and future critical issues in Africa. Water supplies from rivers, lakes and rainfall are being changed by the unequal natural geographical distribution of water, unsustainable water usage and accessibility. Climate change has the potential to impose additional pressures on water availability and accessibility in both supply and demand sides in Africa. The observations of the water situation in Africa in TAR were based on IS92a scenarios. Arnell. (2003; 2004) describes the implications of the IPCC's SRES emission scenarios for river-runoff projection for 2050 using HadCM3 climate models. These experiments indicate a significant decrease in runoff in North Africa and South Africa, while the runoff in eastern Africa and parts of semi-arid sub-Saharan Africa is projected to increase by 2050. These results are consistent with those of Smith and Lazo (2001) and Huq *et al*. (2003). Besides, the results also indicate that the percentage of the years with runoff below the current drought runoff is likely to increase by about 30% across much of southern Africa by the 2050s.

By 2025, nine countries, mainly in eastern and southern Africa, will face water scarcity (less than 1,000 m^3/person/year) and 12 countries will face water stress (1,000 to 1,700 m^3/person/year, and the population at risk could be up to 460 million people, mainly in Western Africa (UNEP, 2002). It is estimated that the proportion of the African population at risk of water stress and scarcity is likely to increase from 47% in 2000 to 65% in 2025 (Ashton, 2002). This could increase the number of existing conflicts over water, particularly in the arid and semi-arid regions.

Clearly the assessments outlined above are for large-scale coverage and may hide several local variations. It is perhaps in the more local studies that a clearer picture emerges. For example, in the southwestern Cape, South Africa, water supply capacity is shown to decrease non-linearly as either precipitation decreases or potential evaporation increases. The most likely change being a reduction of 0.32% per annum to 2020 with climate change associated with global warming predicted to raise water demand by 0,6% per annum in the Cape Metropolitan Region (New, 2002).

Vulnerability

Population growth and concentration will lead to increased demands for domestic, industrial and agricultural water, and increased environmental demands. By the year 2025 it is projected under SRES scenarios that about 370 million African people will experience increases in water stress, while about 100 million people are likely to experience a decrease in water stress by 2055, as a result of a likely increase in precipitation (Arnell, 2004). The projected number of people likely to experience water stress by 2055 in Northern Africa and southern Africa under various climate scenarios and degrees of warming are presented in Figure 4. This projected future water stress and scarcity will have serious impacts on the socio-economic development of the countries affected and will likely adversely affect their food production levels and development plans (Huq *et al*., 2003).

Poor water quality, projected to intensify under climate change, could lead to water related diseases, a reduction in agricultural production, and could limit economic development options, such as water-intensive industries and tourism, a situation that could potentially increase water stresses and become disastrous to developing countries in Africa (UNEP, 2002). Poor water supply systems and low infrastructure also will add extra pressures on water availability in African countries.

Moreover, several African countries share more than 50 major watersheds, river basins and lakes in Africa. For instance, the 17 countries in West Africa share 25 transboundary rivers and majority of the West African countries have a water interdependency ration of more than 40% (Nisaae, 2005). The water dependency ratio represents the share of a country’s total renewable freshwater that is generated outside its borders. The dependency ratio for countries like Niger and Mauritania is about 90%. Most of these shared transboundary rivers are without any agreements on equitable use and/or environmental protection. Few have effective institutional arrangements for consultation and cooperation. Procedures for avoiding or resolving international disputes over water are largely lacking. The absence of institutional management of water resources may be the reason of many current conflicts between African countries (Niasse, 2005), and more conflicts are expected to happen under climate change impacts on water resources and water scarcity in Africa.

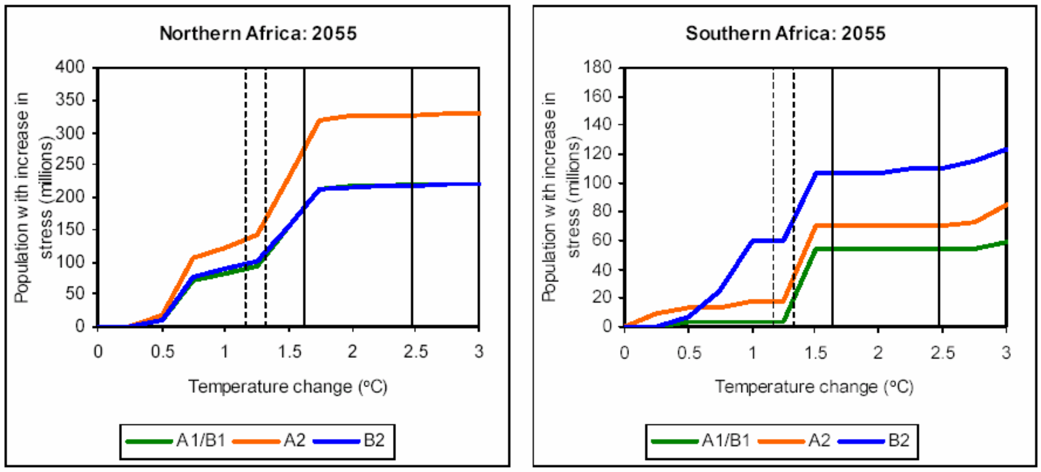


***Fig. 9.4:** Number of people (millions) with increase in water stress (Arnell, 2005)*

Box 9.1: Water Situation in Egypt

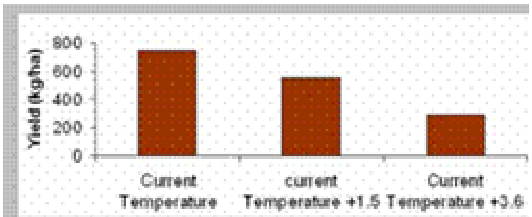
Egypt is one of the African countries that could be vulnerable to water stress under climate change. Egypt's water requirements will increase with time as a result of population increase, improvement in living standards as well as the government's policy to reclaim new land and encourage industrialization. Accordingly, a major challenge that is facing Egypt is to close the rapidly increasing gap between the limited water availability (water share is 700 m^3/ capita/year) and the escalating demand for water that various economic sectors needs (Abou Zeid, 2002).

Current annual water situation in Egypt		
	Item	Billion m^3
Supply	Nile share	55.5
	Aquifer	3.6
	Rain	1.4
	Reused drainage water	5
	Total	**65.5**
Demand	Agriculture	55.6
	Demotic and industry	7.7
	Navigation	1.8
	Total	**65.1**

Agriculture is the main water consumer, about 85% of the annual total water resources. It plays a significant role in the Egyptian national economy (20% of GDP). More than 70% of the cultivated areas depend on low efficient surface irrigation systems, which cause high water losses, land productivity reduction, high ground water levels, and salinity problems. Moreover, the quality of water resources is affected by unsustainable agricultural practices, and improper irrigation management. Reduction in irrigation water quality has reversed harmful effects on irrigated soils and crops.

The agriculture expansion in Egypt has definitely contributed substantially to poverty alleviation, hunger reduction, and food security. However with increasing population any near future plans for future agricultural expansion will require an increase in irrigation supply that will probably depend on water savings from improving irrigation efficiency, agriculture drainage reuse, and development of new groundwater resources (Abou Zeid, 2002). Egypt is optimizing the use of freshwater and exploring the use of new non-conventional water resources such as desalinization, wastewater reuse, and agriculture drainage water. But with climate change, an array of serious threats is apparent:

- SLR will reduce areas of the Nile delta, and 12-15% of the existing agricultural land in the delta could be lost.
- temperature rises are likely to reduce the productivity of the major crops, and increase its water requirements thereby directly decreasing crop water use efficiency.
- irrigation demands incensement.
- 10% decrease in flow of the Nile
- Egypt's population is projected to be between 115-179 million by 2050 (SRES scenarios), this will increase water stress in all sectors.
- institutional water buddies are working on the following targets through the national improvement plan till 2017:
  - Improving water sanitation coverage for urban and rural areas.
  - Wastewater management.
  - Optimizing use of water resources by improving irrigation efficiency and agriculture drainage water reuse.



Predicted wheat yield under current temperature and with +1.5 and +3.6 temperature increase, with 400 mm/season water requirements (IPCC/ AIACC, 2005).

9.4.2 Energy

As the climate becomes drier and rainfall continues to decline in parts of the region, increased dependence on biomass for livestock, wood and other needs leads to the striping of the soils bare and consequently increases soil albedo. The continuing explosive growth of such cities will imply an increasing heat stress in urban and rural areas. This eventually leads to increased human discomfort, which in turn makes for increased demand for energy to support artificial space cooling by air conditioning systems, which increase dependency on fossil fuels or the development of new small-scale biomass driven electricity generation for small communities.

Concerning some futuristic prospective in the energy sector in Africa, South Africa as one of the most energy consuming countries in Africa, and energy sector contributes about 15% of the total GDP and economy heavily depends on the energy. It is intended to achieve 5% renewable energy share of electricity production by 2010 where only the potential of imported cleaner energy sources (gas and hydro) has been considered (Davidson *et al*, 2002). Electricity supply will increase at a rate of 2.8% per annum. On the other hand, it is predicted for the hydropower contribution percent of the total energy resources to be decreased from 4.34% in 2001 to 3.39% in 2025 (de Villers *et al*. 2000).

It is estimated that Africa would double its population over the next 50 years; which means that energy demand growth would show little signs of slowing down through 2050, increasing by 344.4% with respect to 2000. The region would continue to rely significantly on oil and gas, of which it has abundant resources, but which to a significant extent will still be exported. Biomass production and other renewable energy production would represent about 40% of total primary energy by 2050

(OECD, 2003).

9.4.3 Health

Impacts

Human Health: Christopher *et al* (2004), using the MARA/ARMA models for suitability of malaria in Africa and GCM projections showed that there will be expansion and contraction of climate suitable areas for malaria by 2020, 2050 and 2080. According to their model by 2050 and continuing into 2080, a large part of Western Sahel and much of southern-central Africa would likely become unsuitable for malaria transmission but suitability will increase in Southern Africa and the East African highlands in areas that are currently malaria free. Tanser *et al.* (2003) using parasite survey data in conjunction with HAD CM3 GCM projected scenarios estimated a 5-7% potential increase (mainly altitudinal) in malaria distribution with little increase in the latitudinal extents of the disease by 2100. Hartman *et al*. (2002) using sixteen climate scenarios showed that by 2100 changes in temperature and precipitation could alter the geographic distribution of malaria in Zimbabwe, with previously unsuitable areas of dense human population becoming suitable for transmission. This result is supported by the experiments of Thomas *et al*., (2004), where by the 2050s, continuing into the 2080s, a large area of south–central Africa and the western Sahel were projected to be no longer suitable for falciparum transmission. Strong southward expansion of the transmission zone will likely continue into South Africa. Previously malaria-free highland areas in Ethiopia, Kenya, Rwanda and Burundi could experience modest changes to stable malaria by the 2050s, with conditions for transmission becoming highly suitable by the 2080s. By this period, areas currently with low values for stable transmission in central Somalia and the Angolan highlands could also became highly suitable. Among all scenarios, the highlands of eastern and southern Africa will likely become more suitable for transmission.

Animal health: Livestock in Africa is an important economic activity, a critical form of food security and wealth. Mixtures of indigenous and exotic livestock are kept and these have varying sensitivity to livestock diseases. Generally exotic species although more economically productive are more susceptible to diseases of livestock in Africa. There has been little research on the impacts of climate change on pests and diseases of livestock in Africa. However, tsetse fly, the major African livestock pest, is associated with sub-humid regions, and may be further limited by increased aridity. Other animal diseases in Africa are trypanosomiasis, babesiosis, theirelia (East Coast Fever (ECF), fasioliasis, strongyloidiasis, haemonchosis, anthrax, foot and mouth disease, bluetongue, Rift Valley Fever, and African horse sickness.

Important vectors of diseases in Africa include tsetse flies (trypanosomiasis), ticks (babesia, theileria) culicoides (bluetongue and horse sickness) and mosquitoes (Rift Valley fever). In addition snails are intermediate vector for fasioliasis. Anthrax spores can remain the soils for 10-20 years while foot and mouth disease is transmitted by direct animal to animal contact or by wind. Outbreaks are often associated with alternating heavy rainfall and drought, and high temperatures while foot and mouth disease is transmitted by direct animal to animal contact or by wind. Diseases whose part of the lifecycle is spent outside the animal are directly or indirectly affected by climatic and environmental conditions. In general many are affected by moisture, humidity, temperature, vegetation types and hydrology. Climate change and variability could result in a dynamic rearrangement of the current vectorial systems to align with the on-going change.

Climate change is expected to affect both pathogen and vector habitat suitability through changes in moisture and temperature (Bylis and Githeko 2005). Consequently changes in disease distribution range, prevalence, incidence and seasonality, can be expected. However there is low certainty on the degree of change. Notwithstanding Rogers (1996) modelled tsetse fly distribution for the year 2050, and suggested that there will be a net decline in habitat suitability for *Glossina morsitans* in southern Africa, but with localized gains in some, particularly the highland areas. Similarly by 2050 the brown–ear tick, *Rhipicephalus appendiculatus*, the primary vector of theileria (ECF) in eastern and southern Africa, will likely disappear from the south-eastern part of its range (south-eastern Zimbabwe and southern Mozambique) but newly permissive areas will likely appear in more western and central parts of southern Africa (Rogers, 1996). Rift Valley Fever epidemics are associated with flooding and could increase with a higher frequency of El Niño events. Heat stress and drought are likely to have a negative impact on animal health, production of dairy products, meat and reproduction as already observed in the USA (St-Pierre *et al*., 2003).

Vulnerability

Malaria and pregnancy: Severe malaria-associated disease is more common in areas of low to moderate transmission such as the highlands of East Africa and other areas of seasonal transmission. In such areas severe disease in pregnant women has been associated with 20-30% maternal mortality and high risk of spontaneous abortion, premature delivery and neonatal death (Looareessuwan 1985). An epidemic in Rwanda, at an altitude of 2300 m above sea level, in 1998 led to a four-fold increase in malaria admissions among pregnant women and a five-fold increase in maternal deaths due to malaria (Hammerich *et al*., 2002).

Protective gene polymorphism: Certain gene polymorphisms such as sickle cell genotype and glucose-6-phosphate dehydrogenase (G6PD) deficiency confer protection against the severe form of malaria. Over time the frequency of these genotypes has increased in areas of intense transmission. In Western Kenya the prevalence of the sickle cell genotype was 26% in a malaria-holoendemic lowland area compared with 3% in a neighbouring highland area. Similarly the prevalence of G6PD deficiency was 7% in the lowlands and only 1% in the highlands (Moormann *et al.*, 2003). As the rate of malaria transmission increases in the highlands the likelihood of severe disease may increase due to lack of protective polymorphism in the newly affected populations.

Immunity: Parasite density is a good indictor of a human population's level of immunity. Under very intense transmission in holoendemic areas the peak asexual parasite density is observed in children aged 6-11 months (Githeko *et al.*, 1992, Bloland *et al*., 1999). At lower transmission rates the peak parasite density shifts to older children and in areas of unstable transmission parasite density may be equal across all age groups indicating low immunity.

9.4.4 Agriculture

Impacts

It is believed that agriculture and agro-ecological systems are most vulnerable to climate change in Africa where there is recurrent drought and land degradation. The main effect of climate change on semi-arid or tropical agro-ecological systems is a significant reduction in crop yield, particularly in marginal areas. Eid and EL-Marsafawy (2002), reported that climate change could decrease national production of many crops (ranging from -11% for rice to -28% for soybeans) by the year 2050 compared to their production under current Egyptian conditions.

The agricultural sector in Africa is critical, contributing an average 21% of the GDP, ranging from 10-70% (Mendelsohn *et al*., 2001). Using previous levels of carbon dioxide and their project impacts on GDP, the Sahel and EGAD regions are the most vulnerable to climate change and will likely suffer from losses of between 2 and 7%, as a fraction of the GDP. West Africa and Central Africa are also vulnerable ranging from 2 to 4%. In contrast, Northern and Southern Africa are expected to have losses of 0.4%-1.3% (Mendelsohn *et al*., 2000). In southern Africa major impacts on food production in a changing and more variable climate will be linked to changes in temperature, moisture levels, ultra violet radiation, changes in CO_2 levels, pests and diseases. Africa will not benefit from CO_2 stabilization since cereal crop yields will still decrease by 2.5 to 5% by the years 2080s (Arnell *et al.*, 2002). The food security threat posed by climate change is greatest for Africa, where agricultural yields and per capita food production have been steadily declining, and where population growth will double the demand for food, water and forage in the next 30 years (Davidson *et al*. 2003). It is estimated that climate change will place an additional 80-125 million people (±10 million) at risk of hunger by the 2080s, 70-80 percent of whom will be in Africa (Parry *et al*. (1999).

Not all changes will, however be negative and growing seasons in certain areas may lengthen under climate change. Increased temperatures will likely bring better livestock and fishing yields and crop production potential may increase (Fischer *et al*., 2002). As a result of reduction of frost on the alpine zones of Mt. Kenya and Mt. Kilimanjaro, it will be possible to grow more temperate crops e.g. apples, pears, barley, wheat, etc on the adjoining elevations (Parry et. al., 2004).

African livestock systems are very diverse, ranging from arid-zone pastoralism to intensive peri-urban dairy systems. They are very complex both in terms of their biophysical bases - grasslands are complex systems at the biophysical level, composed of mixes of plant and animal species - and the management practices, often based on indigenous knowledge, that are used. Pastoral systems in particular are already premised on coping with climate variability, but their ability to cope in future with either climate variability or climate change may be constrained by socio-economic and policy factors. Impacts of climate change will therefore be location- and system-specific, hard to predict, and dependent on whether there is an enabling environment for adaptation. Livestock is also closely linked to rainfall and changes in annual precipitation. Changes in rain-fed livestock numbers in Africa will be directly proportional to changes in annual precipitation. The impacts of drought on animal survival and productivity, and on peoples' livelihoods, will depend largely on socio-economic and policy factors, such as whether land tenure systems continue to permit mobility, and whether markets can be managed to allow greater outflow of livestock during drought-onset (Barton *et al.* 2001).

Fisheries could be affected by different biophysical impacts depending on the resources on which they are based (Niang-Diop, in press). In coastal regions that have major lagoon or lake systems, changes in freshwater flows, more intrusion of salt waters in the lagoons will affect species which are the basis of inland fisheries or aquaculture (Hulsbergen *et al.*, 1992; Republique de Cote d' Ivoire, 2000; Republique du Congo, 2001, Curry and Shannon, 2004). Recent simulations based on the NCAR GCM and for a doubling of CO_2 indicate that extreme wind and turbulence could decrease productivity by 50-60% while turbulence will likely bring a 10% decline in productivity on the spawning ground and slightly increase by 3% on the main feeding grounds (Clark *et al.,* 2003).

Vulnerabilities

Africa is already experiencing a major deficit in food production in several regions, and potential declines in soil moisture will aggravate the situation (Parry *et al*., 2004). Climatic variability, particularly the changes in the frequency and intensity of extreme meteorological events such as droughts and floods is one of the factors contributing to crop losses (Jagtap and Chan, 2000). As a result, more than half of the African population in the rural areas depend mainly on subsistence agriculture where locally grown crops and foods are harvested from the immediate environment. Consequently, there is widespread malnutrition, a recurrent need for emergency food aid, and increasing dependency on food grown outside the region. However, questions still remain on the uncertainty associated with the projections since the estimations are made at the global scale. Hence the issue is whether it will be necessary to develop local/regional models to reduce the uncertainty and permit decision making from more precise information.

9.4.5 Ecosystems

Ecosystems are not only the foundation of the economy of most African Countries, but also contain a number of plants and animals which constitute about 20 percent of all known species (Biggs *et al.*, 2004). With climate change, most of these species are threatened. In Africa, terrestrial animal biodiversity is concentrated in the savannas and tropical forests while unique native environments host very high biodiversity. The small islands as well as Madagascar host very rich ecosystems and species.

Terrestrial Ecosystem: In South Africa, isolated plant communities, particularly at high altitudes will be affected by temperature rise. Changes in the seasonal distribution of rainfall could affect fire regimes and plant phonological cues, especially in the southern Cape (Tyson *et al.*, 2002). Models indicate that in South Africa, the savannah and the Nama-Karoo biomes will advance at the expense of the grasslands. In Malawi, climate change could induce a decline of nyala (*Tragelaphus*) and zebra (*Equiferus*) in the Lengwe and Nyika national parks because these species could not adapt to climate induced habitat changes (Dixon *et al.*, 2003). There is already clear evidence to show that wildlife from the poles to the tropics is being affected by climate change. Species migrations, extinctions and changes in populations, range and seasonal and reproductive behaviour are among a plethora of responses that have been recorded, and these are likely to continue apace as climate continues to change in decades to come (Hockey, 2000).

Coastal and marine ecosystems: The main coastal ecosystems in Africa are mangroves and coral reefs and chapter 6 gives their main potential responses to sea level rise. In Senegal, potential changes in the substrate (from mud to sand brought in by increased coastal erosion) and increases in salinity are considered as the main factors of mangrove degradation (Niang-Diop *et al*., 2005). In other countries, colonization of lagoons by mangroves is expected due to a better communication with the ocean (République du Congo, 2001). Endangered species like manatees and marine turtles could be at risk as well as migratory birds (Government of Seychelles, 2000; Republic of Ghana, 2000; République Démocratique du Congo, 2000). However, climate change will not seriously affect the Cameroon mangroves (Republic of Cameroon / UNEP, 1998), anthropogenic activities (deforestation, urban extension) being much more damaging (Din *et al*., 2001; Din and Blasco, 2003). The important bleaching event following the 1997-98 extreme El Niño event in the Indian Ocean and the Red Sea increased the attention towards potential impacts of climate change on coral reefs (Wilkinson *et al*., 1999; Lough, 2000; Muhando, 2001; Obura, 2001). In the western Indian Ocean region, an average of 30% mortality of corals was recorded and losses in tourism in Mombasa and Zanzibar were estimated at about US$ 12-18 million (Payet and Obura, 2004). (could go under current sensitivity) Another potential consequence of coral bleaching could be an increase in the number of people affected by intoxications (ciguaterra) due to the consumption of marine animals (Union des Comores, 2002). Losses in biodiversity (République de Djibouti, 2001) as well as disappearance of low lying corals (Payet and Obura, 2004) are also expected. On the long term, all these impacts will have negative effects on fisheries and tourism.

Any changes in primary production would propagate into the marine food web and, consequently, will have impacts on the productivity of marine ecosystems (Hitz and Smith, 2004). These changes could induce "regime shifts" by which large marine ecosystems which are climate-related change their state – at large spatial scales and at different trophic levels - over a 10–30 year period (Caddy and Garibaldi, 2000) and to which fish and other marine biota respond by changes in their dynamics (Beamish and Mahnken, 1999; de Young *et al*., 2004). Regime shifts in marine ecosystems are thus relatively coherent with climate change (Polovina, 2004). As pointed by Curry and Shannon (2004), changes in circulation, intensity of upwelling, availability of planktonic food (related to turbulence), temperature and suitable habitat are all factors playing possible roles during “regime shifts”. These “regime shifts” could also be triggered by changes in fishing pressure (Larkin, 1996), as well as ecological and behavioural changes (Cury *et al*., 2003). Regimes generally persist for between 10 and 40 years which is expressed, for example, by the sustained dominance of particular small pelagic fish species in the northern and southern Benguela ecosystems over periods of 10–30 years (de Young *et al*., 2004). In most upwelling regions, in particular the Benguela systems, where anchovy and sardine co-exist, there has been alternation between regimes of high sardine and high anchovy abundance (Lluch-Belda *et al*., 1992).

9.4.6. Coastal zones

Impacts

The first generation of vulnerability and adaptation (V&A) studies only considered the impacts of sea level rise and few of them used socio-economic scenarios (Niang-Diop, in press). Land losses either due to coastal erosion or inundation represent between less than 0.1 to 3% of the total area of each country. Salinization of soils, surface and ground waters is another important physical impact but, due to lack of data, expertise or models, very few countries assessed these impacts (Frihy, 2003). Using the Oude Essink model, it was estimated that by the year 2100 the length of the salt wedge in the Wouri estuary would have decreased by 2.6% (39 km against 40 km actually) in case of a rainfall increase of 15% while it would have advanced by 26% (67.5 km) in case of a rainfall decrease of 11% (Republic of Cameroon/UNEP, 1998). In the Gambia river, the saline front could migrate by about 200 km upstream (US Country Studies Program, 1999). In the Gulf of Guinea, sea level rise could induce overtopping and even destruction of the low barrier beaches which limit the coastal lagoons while changes in precipitation will affect the discharges of rivers feeding them. These changes will affect the ecosystems (mangroves) as well as lagoonal fisheries and aquaculture (Republique de Côte d’Ivoire, 2000). Indian Ocean islands will be threatened by potential changes in the location, frequency and intensity of cyclones while east African coasts could be affected by projected changes in the frequency and intensity of ENSO events (Klein *et al.*, 2002).

Population at risk represents between 0.5 and 17% of the total population but these are minimal values since population growth rates were generally not considered. With the exception of the second Senegal study (Niang-Diop *et al.*, 2005), economic values at risk are actual values but they always represent a high percentage of the national GDP (between 5.8 and 542%). This confirms previous results (Hoozemans *et al.*, 1993; Nicholls, 1993, 1995; Nicholls and Mimura, 1998) stressing the high vulnerability of the socio-economic system of African coastal states due to their relative low economic development. Those that are less affected (Mauritius for example) are countries with a relatively high GDP. Coastal agriculture (plantations of palm oil and coconuts in Benin and Côte d’Ivoire, shallots in Ghana) could be at risk of inundation and soils salinization. In Kenya, losses for three crops (mangoes, cashew nuts and coconuts) could attain 472.8 million US $ for a 1 m sea level rise (Republic of Kenya, 2002). In Guinea, it was estimated that by 2050, depending on the inundation level considered (4.6 to 5.7 m), between 132.6 and 234 km^2 of rice fields (17 and 30% of the existing rice fields area) will be lost due to permanent flooding (République de Guinee, 2002). In Nigeria a total of 5,955 km^2 of agricultural lands (75% of the total agricultural area) will be at threat with a 1 m sea level rise (Awosika *et al.*, 1993). In the Niger delta, about 259 producing oil fields will be located in threatened areas, representing a value at risk of 10,790 million US $ for a 1 m sea level rise (French *et al.*, 1995).

Vulnerabilities

In Africa, high productive ecosystems (mangroves, estuaries, deltas, coral reefs) which constitute the basis for important economic activities (tourism and fisheries) are located in the coastal zone. 40% of the population of West Africa lives in coastal cities and it is expected that the coast between Accra and the Niger delta (about 500 km) become a continuous urban megalopolis with more than 50 million people by 2020 (Hewawasam, 2002). By 2015, three coastal megacities (Lagos, Kinshasa and Cairo) with at least 8 million people will be present in Africa (Klein *et al.*, 2002). Projected rise in sea level will have significant impacts in these coastal megacities which, due to the concentration of poor populations in potentially hazardous areas, will be less resilient to climate change (Klein *et al.*, 2002). Combined with low GDP this will limit the adaptive capacity and the level of protection of the coasts (Nicholls, 2004) which in turn will constrain the future plans to develop tourism.

9.4.7 Tourism

Climate change puts tourism at risk in two environments which are vital for tourism activities and where tourism is an equally vital component in regional and local economies - coastal zones and mountain regions. Important market changes could result (WTO, 2003). According to 2004 statistics, Europe earned a bit over half of worldwide tourism receipts (52%), the Americas 21%, Asia and the Pacific 20% and Africa and the Middle East 3% each (WTO, 2005). Seaside tourism seems likely to suffer damage from most of the effects of climate change, notably beach erosion, higher sea levels, greater damage from sea surges and storms, and reduced water supply. However, while some regions may see a diminution of demand from the leisure traveller, others - currently less important as tourism destinations - may see an increase.

Table 1 is a summary of climate changes and their probable negative and positive impacts on the Middle East, North Africa and Sub-Saharan Africa.

Table 9.1: *Summary of climate changes and their probable impact on African regions*

DESTINATION REGION	CLIMATE CHANGE INDICATIONS	IMPLICATIONS/CONSEQUENCES FOR TOURISM INDUSTRY
MIDDLE EAST AND NORTH AFRICA	- Warmer winters - Much warmer summers - Drier summers in North Africa - Wetter summers in Arabian - Peninsula	- Probable decline in peak summer visits - Stronger winter tourism market - Stronger tourism demand in shoulder months
SUB-SAHARAN AFRICA	- Inconsistent temperature predictions except (a) warmer winters in West Africa and (b) warmer "summers" (Jun-Aug) in Southern Africa - Increased rainfall in West and East Africa in winter - Small decrease in rainfall in "summer" (Jun-Aug) in Southern Africa - Wetter summers in Sahara	- Little clear indication of climate - changes affecting tourism - Hotter and drier "summer" months in - Southern Africa could diminish demand - slightly? - Wetter "winters" in East Africa could - diminish demand for 'safari' and beach holidays?

Source: WTO (2003)

WTO's forecasts contained in *2020 Vision* are the only long-term tourism predictions that exist. Over that period, and in the longer term, the performance of the tourism sector will clearly be influenced by social change, political developments, economic growth, environmental change and demographic trends. Because there is no tourism forecast beyond 2020, no analysis has been done of the effect of these various factors on tourism growth. In the context of climate change predictions for the whole of the 21st century, forecasts to 2020 are clearly of limited use. Nonetheless, *2020 Vision* predicts that global international arrivals will rise on average by 4.1% a year to a total of 1.56 billion arrivals in 2020, with the Middle East growing fastest (7.1% per annum) and Europe slowest (3.0% per annum). In the longer run beyond 2020, these rates seem certain to decline. International arrivals are expected to reach over 1.56 billion by the year 2020. Of these worldwide arrivals in 2020, 1.2 billion will be intraregional and 0.4 billion will be long-haul travellers (WTO, 2005).

9.4.8 Settlement and Infrastructure

Climate change will impact infrastructure and settlements in Africa through sea level rise, shortage of water resources, extreme events, food security, health risks and temperature related morbidity in urban centres (Magadza, 2000). Gradual changes in weather and increasing variability of extreme events will impact infrastructure through out the region (Mirza 2003; Freeman & Warner 2001) Marginal variations in climate are likely to cause substantial damages to infrastructure due to coupling with other stressors like land cover change, localised population concentrations, and poor quality infrastructure. The bigger threat of climate variability to infrastructure is expected from the little characterised and unpredictable rapid-onset disasters like storm surges, flash floods and tropical cyclones coupled with localised population concentrations (Freeman 2003), which are forecast in various regional scenarios for Africa. Table 1 summarizes the climate events with high likelihood of occurrence across Africa and the expected impact on infrastructure. The materials for the table were drawn largely from the different National Communications of the non Annex 1 parties to the UNFCCC.

Sea Level rise, Shoreline recession and coastal erosion: The IPCC TAR (2001) discusses the situation in 2 regions and suggests adaptive options. This report seeks to highlight the severity of the incidents of Sea level rise. A summary of the national communications to the UNFCCC indicates that coastal settlements in at least 10 of Africa's 32 coastal countries are at risk of partial or complete inundation due to accelerated sea level rise. Africa's coastal areas are very sensitive to erosion and tend to retreat at variable rates. Coastal erosion or sea advance have led to changes in the layout of roads and destruction of hotel facilities and houses in the residential region of Akpakpa in Benin (Niasse & Afoudou 2003). In Eritrea, a 0.5-1.0m rise in sea level will cause infrastructure damage of about $256.83million due to the submergence of infrastructure and other economic installations within the Red Sea coast Port city of Massawa, 1 of the country's 2 port cities (Eritrea, 2001). The situation is far worse in the Gambia, where presently there has been considerable damage to sea wall and other coastal protection infrastructure, shoreline retreat with substantial threat to the country's major road networks, large scale boulder deposits on the beaches, sinking of buildings, as well as the unearthing of sub structure installations including cemetery contents. Here, it is projected that a 1m sea level rise will result in the complete submergence of Banjul, the country's capital city, with land loss costs totalling about $217million (Gambia, 2003). In Tunisia, 2/3 of the population live in coastal areas and 90% of the country's tourism infrastructure are situated along the coastline.

An identifiable adaptive measure to the slow-onset event of sea level rise would be an appraisal and redevelopment of coastline construction guidelines in the affected areas prior to the application of coastline stabilization systems. Proper land use planning to reduce vulnerability of settlements and infrastructure developments within the vulnerable areas should be adopted and closely monitored. It is also pertinent that existing or new frontline institutions and institutional frameworks be strengthened for the purposes of further research, policy and solution generation as well as knowledge improvement and dissemination on the phenomenon in the affected regions.

Precipitation and wind events, Flooding and Infrastructure: More intense and variable precipitation events with increased mean and peak precipitation intensities for tropical cyclones leading to increased runoffs and flash floods are expected in areas within the continent (Karanja *et al*. year?; Denton *et al*. 2001). Increased frequency, persistence and intensity of El Niño warm phase events with reduced precipitation in East Africa and increased winter rains in some parts of southern Africa (UNEP, 2002). Freeman & Warner (2001) observe that for climate related events; infrastructure is the dominant loss category with flooding and windstorms having the most widespread impacts on buildings, bridges, roads and water systems. In 1999, following torrential rains, devastating floods swept through the Kainji, Jebba and Shiroro dam floodgates causing heavy human and material losses (source?). At the same time in Ghana, floods over the White Volta River region claimed lives and caused extensive damage to buildings (source?). All these followed similar events in 1998 with a 2001 repeat in the Komadugu-Yobe valley (Sahel region of Northern Nigeria) that resulted in the death of over 200 persons and displacement of over 35,000 (Niasse & Afoudou, 2003). The well documented floods of early 2000 in Mozambique with the high fatality rate and devastation of livelihoods, infrastructure and settlements are perhaps the clearest indications yet of the trend, spread and scale of devastation wrought by floods in Africa. In Malawi, landslides occur during prolonged torrential rains mainly in the southern parts of the country. In the 1992/1993 rainy seasons, landslides caused a loss of over 500 lives and severe damage to socio-economic structures in Mulanje - Phalombe areas (Malawi, 2002).

Increased warming, variable precipitation and water availability: Increased drying trend, culminating in droughts and tropical peak wind speed intensities are expected over some parts of Africa (Freeman & Warner 2001; Malhi & Wright 2004). This drying trend coupled with other socioeconomic factors like population growth, economic development and rapid urbanization will exacerbate water scarcity in Africa. Presently 9 countries in Africa are classified as water stressed. However, UNEP (2002) observes that by 2025, the number of countries experiencing water stress in Africa will rise to 18, affecting 600 million people. This will impact adversely on hydropower plants, irrigation schemes, and industrial and domestic water supply. Attempts at mitigation and adaptation may include the development of appropriate measures to manage ground water exploitation, regulate end-use consumption, possibly through consumption tariffs and water recycling. National and inter-regional inter-basin water transfers to make up water supply short falls may also be adopted to ameliorate the scarcity. These will however require technological and institutional changes that may not be developmental priority for the majority of the affected areas.

The recent national communications to the UNFCCC have provided more region specific knowledge about the impacts of climate variability on different human and natural systems. They have also provided information on extreme events and unfolding climate related events that were hitherto unavailable from existing knowledge and models. The concern for infrastructure and settlement vulnerability to climate variability will grow as small changes in climate variability are expected to cause large increases in infrastructure damage. (Freeman & Warner 2001) Difficulties in adapting and implementing remedial or preventive measures arise due to the lack of political will attributable to the moderate understanding and low developmental priority and capacity levels associated with climate related issues. These pose a great challenge to mitigation and adaptation strategies.

Table 9.2: *Summary of Projected Impacts of Climate Change on Settlements and Infrastructure in Africa*

Climate event	Confidence	Surface effect	Regions affected	Impact on infrastructure
Increase in Temperature	High	Increased Surface temperature Soil and surface water evaporation Transpiration Snow cap melting	All regions Tanzania (Mt. Kilmanjaro), Morocco	Increase in urban heat islands Reduced water supply for irrigation and hydro-power reservoirs Soil (especially clay) shrinkage causing damage to building foundations and road networks Expansion of overhead power lines causing sagging, thus increasing risk of wind damage Increased demand for commercial energy for air-conditioning Misalignment of rail tracks
Erratic and variable Precipitation	High	Increased Flash floods Runoff Soil erosion Soil subsidence Aridity/drought Soil shrinkage Reduced Ground water recharge	Benin, Gambia, Ghana, Malawi, Morocco, Nigeria, Tanzania, Uganda, Lesotho, Mauritius Mozambique, Seychelles Sahel Region, Lesotho, Botswana Morocco, Kenya	Destruction of building, communication, dam and civil works structural and non-structural components Unearthing of underground telecommunication, power and sewage lines Buckling of highways and misalignment of rail tracks Widespread water shortage to hydro power stations & irrigation reservoirs results in disruptions to power supply Water supply shortage for industrial and domestic water plants
Accelerated sea level rise (ASLR)	High	Increased Inundation Coastal erosion Shoreline retreat Higher water table runoff and flooding Storm/wave surge Land deformation due to extraneous deposits Ground and surface water salinization	Egypt, Djibouti, Eritrea, Gambia, Ghana, Benin, Nigeria, Mozambique, Mauritius Tunisia, Nigeria, Ghana, Togo, Benin, Gambia, Senegal, Tanzania, Seychelles,	Significant damage and complete loss of buildings, economic, tourist and civil infrastructure Temporary and permanent unavailability or road networks due to flooding by running sea water Substantial damage to drainage, waste and sewage lines Destruction of coastline defence structures Direct adverse effects on the performance of sub-surface structures like building foundations due to soil subsidence Compromises the quality of water supply
ENSO events	High	Increased incidence of • Tropical storms, Torrential rainfall • Drought	Mauritius, Malawi, Mozambique, Madagascar, Zimbabwe, Botswana, South Africa Malawi	• Substantial damage to building and engineering structures
Wind events	High	• Tropical cyclones • Thunderstorms • Hail • Tidal waves	Malawi, Mozambique, Madagascar, Seychelles Nigeria, Morocco Lesotho, Mauritius	• Destruction of building elements, power lines and communications networks

Source: Adapted from The different Initial National Communications to the UNFCCC, Freeman and Warner (2001), IPCC 2001

9.5 Adaptation

9.5.1 Adaptive capacity

Adaptive capacity is the ability of people and systems to adjust to climate change, for example, by individual or collective coping strategies for the reduction and mitigation of risks or by changes in practices, processes or structures of systems. Adaptive capacity may reflect resilience, stability, robustness, flexibility and other characteristics of a system (Smit and Pilifosova, 2001). The developed countries have higher adaptive capacities and are better prepared to cope with the adverse impacts of climate change as they have already shown with lesser climate phenomena, compared to the developing countries. Under-development has a debilitating effect since it reduces the capacity, coping abilities and resilience of poorer societies and weak governments (Sokona, 2002). Africa is characterized by low coping capacity, this is due to the extreme poverty of many Africans, frequent natural disasters such as droughts and floods and agriculture heavily dependent on rainfall (Dieudonne, 2001). A general assessment of the determinants of adaptive capacity in Africa including factors such as wealth, technology, education, information, skills, infrastructure, access to resources and management capabilities will expose our strengths and weaknesses in developing successful and sustainable climate change adaptation strategies.

Africa's indigenous knowledge: Africa is endowed with huge natural resources, diversity of cultures and rich indigenous knowledge. People who have been working fields for years in the traditional manner have usually developed more or less successful coping strategies based on managing risk. They often have traditional 'seasonal forecasting' methods based on bird, animal and plant observations (Williams, 2005). The maintenance, of tradition seems even more necessary as the Sahel faces a series of economic shocks and political cataclysms. The Sahelian farmer or pastoralist, battling against drought, degradation, pests, markets, changing land laws, and who knows who else, shows that it is the flexibility and absorptive capacity of this tradition that are its most remarkable and greatest strengths (Batterbury and Warren, 2001). However, there is also the risk of unprecedented shocks, which can shake their historically developed knowledge, such as the flooding experienced in East Africa following extended drought.

Economic Resources: While poverty may not be equated with vulnerability, it is a well-accepted fact that poverty is one of the greatest impediments to climate change adaptation. In terms of the availability of economic resources to adapt, the scale is significantly unfavourably tilted against Africa. In terms of the availability of economic resources to adapt, the scale is significantly unfavourably tilted against Africa. The low national earnings are compounded by high levels of foreign debt and international conflicts, creating a situation where most national governments in Africa commonly have insufficient financial capacity to address current needs and priorities, and climate change is obviously often not considered an immediate priority. Climate variability, drought and poor people's vulnerability should not be seen as separate emergency issues (DFID, 2004).

Technology: Many of the climate change adaptive strategies already identified directly or indirectly involve technology (e.g., warning systems, protective structures, crop breeding and irrigation, settlement and relocation or redesign, flood control measures). African countries are at the lower end of the distribution of technological development, with Chad, Guinea-Bissau, Congo and Somalia occupying the last place (UNCTAD, 2003). Some of the technological developments developed in the west and imported to Africa have proven very inappropriate and unsustainable. The failure of some of the genetically-modified drought-resistant crop varieties that have been introduced into Africa is a typical case in point.

Knowledge and Skills: In many communities in Africa, Increasingly, traditional ways are being replaced by dominating modern economic interests, often increasing vulnerability and exposure to hazards and weakening coping capacities. Traditional coping strategies may not be sufficient in this context and will lead the poor to rely on ad-hoc and unsustainable responses. This not only reduces resilience to the next climatic shock but also to the full range of shocks and stresses that the poor are exposed to (DFID, 2004) Moreover, in most national meteorological services, the application of climatic knowledge in agriculture, health, water and other sectors is a low priority activity, poorly staffed and weakly focused (Williams, 2005).

Infrastructure: Improvements in the physical infrastructure will generally, improve the adaptive capacity e.g. improved communication and road network provide better access and improved exchange of knowledge and ideas. The opposite is true, for instance, in most urban centres in Africa, the general deterioration in infrastructure, threaten the supply of water during droughts (Burton,2001). Moreover, in the absence of any real infrastructural or institutional capacity, most people in sub-Saharan Africa will be at particular risk (Sokona and Denton, 2001).

Institutions: Generally, there are social and institutional constraints to resources among various vulnerable groups in Africa (Sokona and Denton, 2001). Moreover there is considerable uncertainty within most of the existing institutional and legal frameworks because of the edge problems and the different levels at which decisions can be made, or without a consistent application of coordination (ISDR, 2004). Certain institutions and policy measures could contribute to coping capacity , for example in the Sahel, the removal of state subsidies on artificial fertilisers encouraged people to turn to integrated crop and livestock management, leading to increase in animal numbers and more manure, which is used instead of artificial fertiliser (Mortimore 2001).

Equity: Equity derives from a concept of social justice. It means that everyone should have fair and equal access to common resources and opportunities, and that no individuals or groups of people should be asked to carry a greater environmental burden than others (Beder, 2000) .Adapting to climate change is usually for a common benefit and the poor often do not have the privilege of a long-term planning horizon that is required for such activities (ADB, 2003).This, in addition to other factors such as the high dependence on agriculture for livelihoods, and the low financial resource base and capacity to adapt to or mitigate these effects rendered Africa inequitably the most vulnerable to adverse climate change effects (Vordzorgbe, 2002)

9.5.2 Current Adaptation options

Many countries in Africa Sahel tend to have a much higher share of their economy dependent on climate-sensitive sectors such as agriculture, this contributed among several other factors to the vulnerability of society and the sensitivity of the environment. Hence with regards to agriculture, adaptation measures would be aimed at coping with long-term climate-induced crop yield losses and livestock production systems. Measures that are currently adopted include: adjustments to planting dates; changes in fertilization; irrigation applications; cultivar traits, selection of animal species, and reduced utilization of marginal lands.

Studies have examined the efficiency of some of these measures. Investigations into planting times and yield have also been undertaken (e.g. Muchena, 1994; Matarira *et al*., 1996). Shifts toward earlier planting and the avoidance of late planting are important results in some cases e.g. Beit Bridge (where the season would shift toward earlier planting to avoid high temperatures and water stress at the height of the summer) (Makhado, 1996 and Matarira *et al*., 1996). Irrigation is one means to increase crop yields. But much of Africa is water stressed, with rainfall on the downward trend and droughts common in large parts of the continent. The high costs and unavailability of chemical fertilizers prevent farmers from using these inputs to boost their yields. Mixed farming and intercropping involving cereals and leguminous crops are common practices which help reduce risk of crop failures and increase land productivity. High yielding varieties are available but they are not adopted by small-scale farmers due to lack or high costs of improved seeds.

Early Warning Systems (EWS) are the primary means of detecting timely drought related stress on livelihoods and of eliciting response (intervention). Several agricultural research institutions are located in Africa and these institutions have been consistently producing seasonal climate forecasts to help farmers. Past experience shows that the great majority of EWS failed to fulfil this purpose. The warning signal frequently came too late and the response was often inappropriate and usually too late (Buchanan-Smith and Davies 1995). In other cases, farmers have not been able to use the forecast information (Tarhule and Lamb, 2003).

The green revolution has demonstrated that technological change in agriculture can be a powerful force in increasing crop yields and reducing poverty. Of particular importance to Africa today is whether recent advances in biotechnology can be safely harnessed to produce foods that have greater yields, resist pests and diseases and offer other positive nutritional, health and environmental attributes (Brink, Woodward and DaSilva 1998). In Africa, biotechnology research could yield tremendous benefits if it leads to drought- and pest-resistant rice, drought-tolerant maize and insect-resistant millet, sorghum and cassava among other crops (ECA 2002). Application of biotechnology has already had success in several African countries. In West Africa, for example, rice is the main staple food for over 250 million people. New rice varieties- dubbed NERICA (NEw RIce for AfriCA)- developed by the West Africa Rice Development Association (WARDA) offer hope for much higher yield (WARDA Annual Report, 1999). NERICA varieties mature 30-50 days earlier than the current varieties thus evading unfavourable environmental conditions. In addition, the varieties resist pests and drought- important for farmers cultivating rain-fed rice. The new varieties also grow better on infertile and acid soils, which account for 70% of West Africa’s upland rice fields.

Research on development of drought resistant and early maturing crop varieties (maize, sorghum, millet, soybeans) is also in progress in most parts of Eastern and Southern Africa and offers potential for countering the adverse environmental conditions currently affecting the region. These varieties could be relevant for adaptation to the changing climate conditions in the region (Monyo 2002). The development and diffusion of modern, high-yielding varieties of maize have transformed this important cereal from a minor crop in the early 1900s into the continent’s major source of calories today (Gabre-Madhin and Haggblade, 2004).

Currently, there is considerable uncertainty about the possible extent and rate of climate change (DFID, 2004) and about what the most effective adaptation responses might be. While drought may affect production in some years, climate variability does not explain the continuous decline of food production for three or four decades (Brooks, 2004). As local climates become more unstable, farmers have greater difficulty knowing what and when to plant and harvest. Risk of crop, and hence, livelihood failure increases. Generally, a system that is more exposed to a particular climate stimulus will be more vulnerable than a system that has more adaptive capacity, because of the ability to moderate effects. Nevertheless, it has long been recognized that adaptation is the most viable option in reducing Africa’s present vulnerability to the adverse impacts of climate change Sokona (2001*)*. Moreover, lessons from adaptation to short-term climate variability would build capacity to respond incrementally to longer-term changes in local and regional climates.*(Hulme et al., 2000, Williams, 2005*). In many locations cash crops have been replaced by food crops, and more resilient crop varieties have been introduced (DFID, 2000). Soil conservation and well-managed tree plantations are also emphasised (Mortimore, 2001).

While rural communities may have adapted their livelihoods over centuries and developed sophisticated coping strategies to deal with local risks, unexpected hazards such as seasonal storms or droughts invalidate those strategies and increase risk. A case study in Niger indicated that the diversification away from agricultural production is a common response to unpredictable harvest and that access to resources is maintained by switching between capital assets (ADB, 2003). In some countries cash crop farmers act to minimise livelihoods risks from their exposure to economic as well as environmental shocks, evidence from Mali and elsewhere suggests that cotton and other cropping systems are adaptable (Benjaminsen, 2001). Other measures identified in Mali include the implementation of early warning system to identify the risk of crop deficit, choice of different crops in agreement with available water and increase the mobility of populations in case of extreme drought (Van Drunen, 2005).

9.5.3 Future adaptation Options

Mainstreaming adaptation into development policies

Africa is the most vulnerable region to climate change, as a result of the low adaptive capacity of the African population. This low capacity is due to the extreme poverty of many Africans, frequent natural disasters such as droughts and floods and agriculture heavily dependent on rainfall. The main impacts of climate change will be on the water resources, food security and agriculture, natural resource management and biodiversity, and human health (Dieudonne, 2001). Considering that Climate Change has started and it is becoming apparent that insufficient funds and competing urgent needs will make it impossible for most African countries to establish new stand-alone climate change adaptation strategies. If Africa needs to focus on increasing adaptive capacity over the long term, ad hoc responses (short-term responses, uncoordinated processes, isolated projects, etc.) are not a solution. The solution is to mainstream adaptation into national development processes as well as integrate adaptation into all relevant strategies, policies, programs and projects.

To assist developing countries to adapt to future climate change a number of regional and international initiatives have been identified. The New Partnership for Africa's Development (NEPAD) is a commitment by African leaders to the people of Africa. It recognizes that partnership among African countries themselves and between them and the international community are key elements of a shared and common vision to eradicate poverty, both individually and collectively, on a path of sustained economic growth and sustainable development. NEPAD's Action Plan of the Environment Initiative calls for the development of sustainable agriculture and stresses the need to promote interactions between researchers and farmers, participation of women in decision- making processes on agriculture, use of appropriate technologies for sustainable agriculture, early warning systems for drought or floods, access to affordable funding and credit, and access to international markets for agricultural products. Moreover, The Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC) have established the National Adaptation Programmes of Action (NAPA) to assist the least developed countries (LDCs) to assess and communicate their most urgent adaptation needs. LDCs are expected to use the NAPA process to produce a set of adaptation projects that address their highest priorities and to propose for international support in the face of climate change, and the urgent need for adaptation. Most of the Least Developed Countries have already started to design their National Adaptation Programme of Action (NAPAs).

Mainstreaming adaptation to climate change requires: integrating NAPAs into national sustainable development strategies, translating information from the scientific research sector into accessible – and politician-friendly – language, involving the general public – especially marginalized groups in remote regions – in providing the widest possible stakeholder input into NAPAs , facilitating a greater role for LDCs in the Global Environment Facility, particularly on funding issues ,sharing the results of NAPAs with other LDCs, both regionally and globally and initiate dialogue between LDCs and bilateral funding agencies to ensure that adaptation to climate change is central to development funding (Huq *et al* 2003). The fact that most of the countries in Africa have recently formulated Poverty Reduction Strategies Papers (PRSPs), can help using a combination of 'Top Down' and 'Bottom up' approaches, PRSPs and sustainable development strategies are closely linked as PRSPs are intended to integrate economic, social and environmental factors. According to the World Bank Environment Strategy "integrating environmental considerations into the new Poverty Reduction Strategy Papers is an urgent task "Currently for the sub-Sahara, there are 11 interim PRSPs and 19 full PRSPs (World Bank, 2000) Many African countries have also formulated National Biodiversity Strategies and Action plans (NBSAP) and National Action Plans to combat desertification (NAPs) in accordance with the United Nations Conventions on those issues.

Costing adaptation

Many researchers have expressed concern over the way that adaptation has been represented in costing studies. Although it is recognized that adaptation has a pivotal role in reducing the costs of climate change, many studies pay little attention to adaptation (DeCanio, 2000) .The African economy is highly dependent on the health and sustainability of the natural resource, such as agriculture, fisheries and forestry .Climate change will present new opportunities and challenges for each of these sectors. This will lead to a range of economic impacts, and new investments in adaptation will be required. At present, it is difficult to derive quantitative estimates of the potential costs of climate change impacts (Yohe, 2002). Limitations are imposed by the lack of agreement on preferred approaches and assumptions, limited data availability, and a variety of uncertainties relating to such things as future changes in climate, social and economic conditions, and the responses that will be made to address those changes. Attempts to quantify adaptation cost in Africa including the evaluation of a set of adaptation measures implemented in some African countries Egypt, Ghana and Senegal) are cited in (Van Drunen, M.A. 2005). The assessment of the impact of climate change on the low lying lands on the northern fringes of the Delta in Egypt showed that without adaptation 5.4 million people would be at risk of loosing their homes and need to migrate due to flooding in 0.5 m SLR scenario by 2050 and the capital at risk was estimated at US$2.5 billion (at 1992 prices), in addition to a loss of up to 14% of GNP. However, the cost of protection (adaptation measures) was estimated at 5-10% of GNP. The cost of protecting and replanting the dune areas in Senegal was estimated at US$250 for 40 CM SLR in 2050 with 3% discount rate, while risk without adaptation goes up to US$ 490 million in 2050 with the area at risk equal to 948 km2 (.5% of the total area of the country). In Ghana a cost of US$ 590 million was estimated in 1998 (no estimate of capital at risk without adaptation), (Van Drunen, 2005).

9.6 Case Studies

9.6.1 Food Insecurity in Africa

The links between climate variability and change and food production have been long debated particularly for Africa (e.g. Downing, 1992; Rosenzweig and Parry, 1994; Rosenzweig and Hillel, 1998). Many would agree that there is a strong link between climate, agriculture and food production (e.g. Mendelsohn *et al*., 2000a and b; Fischer *et al*., 2002; see also Kurukulasuriya and Rosenthal, 2003; Devereux and Maxwell, 2003; IRI, 2004, for a review of impacts and adaptations related to climate change and agriculture).

Indications for possible changes in food production with varying climate are improving over time as model simulations from GCMs and other sources, and essential sensitivity studies of climate improve. Food security, however, is not only linked to food production and supply. Over time there has been a shift in thinking of food security from the departure point of 'food production' to also considering issues of 'access to food' (both collectively and at the household level) (Devereux, 2004; Devereux and Maxwell, 2003). A shifting focus thus from a 'food first' approach to a 'sustainable livelihoods' approach has meant consideration of issues such as vulnerability to food insecurity within a 'security' focus, a better understanding of livelihood security and the range of options people may have to secure or have entitlement over a resource (e.g. food) and the role of multiple factors impacting on food access e.g. market access, globalisation etc (Devereux and Maxwell, 2003; IUCN *et al*., 2003).

Several groups, including academics and humanitarian organisations (e.g. Save the Children, Oxfam, Care and others), have been actively working on improved understanding of food security in Africa, particularly in those areas that have undergone and are experiencing chronic food insecurity (e.g. Sudan, parts of southern Africa). Their research and resultant interventions have been strongly shaped by a multiple-stressor approach (that is food security is not only viewed as being driven by climate stress but can and is also influenced by such factor as conflict, globalisation and HIV/AIDS (e.g. FIVIMS SA, 2005; Marsland, 2004; Gommes *et al*., 2004; SARPN, 2004; Devereux, 2004; Maxwell and Devereux, 2003):

> "The scope of vulnerability assessment in Southern Africa has changed over the last three years in particular. From an initial consensus that vulnerability in question was vulnerability to food insecurity, ideas have now changed to encompass a broader concept of vulnerability which includes non-food sectors and a concern to link vulnerability assessment with poverty monitoring and instruments like Poverty Reduction Strategy Papers (PRSPs). These changes pose methodological and institutional challenges and imply a changing role for VA (vulnerability assessment) in the region" (Marsland, 2004, 6).

In a review of famines over a number of decades Devereux (2000), for example, shows that the causality of severe periods of food insecurity including famines were characterised by two significant shifts: first, in terms of causality they were more complex than before made up of a number of causes and second, during the latter part of the century, the locus of food insecurity has shifted to sub-Saharan Africa "…where interactions between drought and civil war, in particular, became the dominant causal trigger of famine" (Devereux, 2000, 3).

Various household-level studies, as well as regional agro-climatalogical studies in Africa, for example, have been undertaken that show that resource poor farmers and communities use a variety of coping and adaptive mechanisms to ensure food security and sustainable livelihoods. In Southern Mali, Abdulai and CroleRees (2001), for example, show results that resonate with other investigations (e.g. Ellis, 2003 and others) that poorer households have fewer opportunities in non-cropping activities than their counterparts closer to local markets. 'Access' to food via markets and other inputs is thus a key determinant to overall food security. In other cases ensuring a diversified livelihood strategy has also been shown to be key overall food security. In the Sahel, for example, Mortimore and Adams (2001) show that farmers adaptive capacity to changes in the Sahel are based on a variety of driving or causal mechanism including 'negotiating the rain' (where farmers have to carefully adapt their labour and farming to a variety of periods such as weeding, harvesting and planting). Livelihood diversification, a key coping and adaptive mechanism to periods of changing rainfall and other pressures has been further enabled in the Sahel with increased mobility as people become more urbanised (Mortimore and Adams, 2001).

By adopting a wider approach to food security, a more nuanced view to food security, linkages between agriculture, climate and other macro- and micro structural factors (e.g. globalisation) and possible policy and other interventions is thus emerging (e.g. Raikes and Gibbon, 2000; Seaman, Petty and Acidiri, 2004; Weatherspoon and Reardon, 2003; and several studies showing links to livelihoods and food security e.g. in Ethiopia see Devereux, 2004). Issues of globalisation, farm subsidies abroad and other factors (e.g. climate variability and risk) are currently key points of concern at several international economic fora. Such macro issues permeate through the 'food and economic system' to impact on food security at various levels. Attainment of the MDGS (Millennium Development Goals), including the first goal which is to eradicate extreme poverty and hunger, will therefore require improved science as well more usable science.

9.6.2 Drought in the Sahel

Droughts and drought periods have been well researched for the Sahel with a number of historical sources recording periods of serious drought. What is most uncharacteristic of the Sahel, among other arid lands, is the intensity and multi-year persistence of drought conditions; mean rainfall, for example, decreased by 25–40% between 1931–1960 and 1968–1997 and since 1970 nearly every year has been anomalously dry (Nicholson, 2000; Hulme, 2001). This has resulted in significant socio-economic challenges and has attracted diverse international interest groups emphasizing the need to understand the complex causes of desiccation (Nicholson, 2000; Batterbury and Warren, 2001; Foley *et al*., 2003).

One of the early theories on drought was that it was due to land-use pressure leading to desertification. However currently there is stronger consensus that desertification might be responsible for the persistent drought has not been supported (Nicholson, 2000; Xue and Fennessy, 2002). The droughts of the 1970s and 1980s were embedded within a process of regional desiccation which many authors blamed on the systematic abuse of the Sahelian environment by its inhabitants (Brooks, 2004). Land degradation resulting from overgrazing, unsustainable use of fuel wood, and other "inappropriate" land use practices was invoked as the driving force behind a progressive regional desertification associated with the southward expansion of the Sahara (e.g. Lamprey, 1975; Charney *et al*, 1977). But there has been a steady build up of dust in the region which is thought to be linked to the decline in vegetation cover due to the desiccation but also anthropogenic activities (Hiernaux and Turner, 2002). Studies have also pointed out the possible effect of this dust to areas further from the Sahel, for instance the potential link between the Sahel dust and rainfall in the Caribbean (Prospero and Lamb, 2003). While the radiative role of the dust has been demonstrated the direct link with climate in the Sahel is yet to be achieved (Nicholson, 2000; Foley *et al*., 2003).

From the mid-1980s onwards it became increasingly apparent that the Sahelian drought was driven predominantly by global and regional patterns of sea-surface temperature, with local feedback processes perhaps playing a minor role in reinforcing drought conditions on short timescales (Folland *et al*., 1986; Zeng *et al*. 1999; Taylor *et al*., 2002). Recent research has identified surface temperatures in the Indian Ocean as a major driver of rainfall variability in the Sahel (Giannini *et al*., 2003). Remote sensing studies have further demonstrated that the extent and seriousness of irreversible land degradation and desertification in the Sahel have been overstated, and that changes in the land surface in recent decades in reality represent responses to rainfall variability rather than to land use (Nicholson and Tucker, 1998). Recently, there has been a regional trend towards increasing rainfall, and remote sensing studies indicate an increase in vegetation cover in much of the Sahel (Rasmussen *et al*., 2001; to *replace with reference to be inserted from forthcoming paper in Global Environmental Change).* Nonetheless, rainfall remains highly variable, and drought and associated food insecurity is still a major problem in many areas (FAO, 2005).

More recent paradigms on drought in the Sahel have focused on indications that the environmental histories of the Sahara and Sahel have been characterized by sudden, abrupt changes, including several dramatic regime shifts that occurred with no apparent warning (Claussen *et al*., 1999; Foley *et al*., 2003; Lioubimtseva and Adams, 2004). The abrupt transition from wet to dry conditions has, for example, also been demonstrated from outputs of modelling studies where nonlinear coupling between vegetation and the atmosphere were included (Claussen *et al*., 1999). The results from modelling work which however, require further validation, suggest that the climate– vegetation system crossed a threshold about 5500 years ago, when gradual reductions in rainfall caused by slow changes in the Earth's orbit were suddenly amplified through land-surface feedback mechanisms (Claussen *et al*., 1999). From these simplified models the oceans are shown to have had a limited role in this process (Foley *et et al*, 2003).

Following through on the Sahel regime shift theory, it has been suggested that a second regime shift occurred around 1969 resulting in subsequent droughts that are going on now. Using a combination of evidence from different studies including a comparison of the Sahel and Southern Africa rainfall regimes it has been concluded that the 3-decade-long drought in the Sahel could be a result of complex interactions among the atmosphere, land, and ocean (Foley *et al*, 2003). Some of the evidence used to reach this conclusion includes:

- The fact that one-way, cause-and-effect explanation of drought in the Sahel, based on the land or the ocean are in-adequate for e.g.: GCM sensitivity studies used idealized and highly unrealistic scenarios of land-cover change that greatly exaggerated the degree of land degradation (Taylor *et al*.,2002; Foly *et al*., 2003); For oceans a year-by-year link between SSTs and rainfall patterns exit but at a decadal-scale variations in SSTs linked to rainfall are minor compared to shorter time scales (Foley *et al*., 2003).

- Based on outputs of a simplified model of the atmosphere, ocean, and terrestrial vegetation cover, there are strong suggestions that vegetation feedbacks amplify the interdecadal variation of the Sahel precipitation but act to reduce year-to-year variability. Therefore vegetation interactions have a role on the decade-to-decade persistence of drought (Zeng *et al*., 1999; Wang and Eltahir, 2000).

- It is likely that the 1969 drought was initiated by changes in SST patterns but the magnitude and multidecadal persistence of drought are driven by nonlinear feedbacks between the natural vegetation cover and the atmosphere (Zeng *et al*., 1999).

The hypotheses on the current Sahel climate regime is thus emerging that includes the role of changing SSTs or land degradation that acts as a trigger for climate transition, while the role of vegetation–atmosphere feedbacks is to reinforce the impact of the trigger during the transition process. These feedbacks then act to maintain the new climate system and this will go on until driver pushes the system into the transition zone for an alternative regime to take over (Foley *et al*., 2003). This hypothesis needs more work to prove, particularly how the land surface and atmosphere are coupled.

Living with climate change and variability in the Sahel

The Sahel thus provides us with examples of both recent climate change, complex interacting drivers of change and of cases of coping and adaptation to change. Tarhule and Woo (1997), for example, concluded that rainfall deficits of more than 1.3 standard deviations from the local long-term mean are generally associated with serious societal impacts. The environment is, however exceedingly complex, with changes being driven, both in the past and the present, by a host of interacting stressors. The 1950s and 1960s, for example, were characterised by high rainfall, and saw an expansion of farming into previously marginal areas that proved unviable for agriculture in the longer term. This expansion of agriculture also served to push nomadic populations into historically more marginal areas, making both farmers and herders more vulnerable to drought and increasing the likelihood of conflict between these groups (Thébaud and Batterby, 2001). By the early 1970s, rainfall had declined dramatically, and severe droughts in 1972-73 and 1983-84 were associated with widespread human mortality, loss of animal stocks, and the destruction of livelihoods, particularly in the pastoral sector. Drought was one of a number of factors that led to conflict between mobile and sedentary populations in some Sahelian countries (Keita, 1994).

Farmers have developed a variety of coping and adaptation mechanisms to live in such a harsh environment. Some farmers, for example, in northern Nigeria and Niger have adapted successfully to both increased aridity and economic liberalisation through agricultural intensification based on increased livestock densities, the use of natural fertiliser, soil and water conservation, and crop and income diversification (Mortimore and Adams, 2001). Local markets have also played a crucial role in supporting agricultural innovation. Wage labour, often associated with seasonal migration, provides a source of income for smaller households in times of stress, and larger farms have benefited from the labour of those who have lost their livelihoods to drought. This represents a process of increasing social and economic stratification as those who lost their livelihoods have in some cases become dependent on a few key employers. The Sahelian droughts of the late twentieth century, and the human responses to them, illustrate how adaptation tends to often occur reactively after massive societal disruption has already occurred. This process also transforms the nature of societies and communities and thus requires greater understanding of the complex drivers of change in the region.

9.6.3 Indigenous Knowledge Systems

- concept of indigenous knowledge
- indigenous knowledge in natural resource management
- integrating indigenous knowledge into mitigation and adaptation.

9.7 Implications for Sustainable Development

9.7.1 Link between climate change and sustainable development (Gina)

The term sustainable development was brought into use by the World Commission on Environment and Development (WCED)-the Brundtland Commission- in 1987 and calls for development that meets the needs and aspirations of the present generation without compromising those of future generations. The African contextual definition of sustainable development is that African cultural heritage and tradition acts as a reminder that resources must be regarded as a sacred trust bequeathed to us by our ancestors and that this resource base must be handed to future generations intact or in an enhanced condition (Francis and Paul, 2000).

Okigbo (1995) believes that, in an African context, it is important to define sustainable development with a historical perspective, and it is not enough to compare the present with the future since residual effects of past practices must also be considered. Since the United Nations Conference on Environment and Development (UNCED), sustainable development has remained elusive for many African countries. Africa's effort to achieve sustainable development has been hindered by conflicts, insufficient investment, limited market access opportunities and supply side constraints, unsustainable dept burdens, historically declining ODA levels and the impact of HIV/AIDS . Generally poor people in Africa are particularly vulnerable to individual and collective risks which are expected to further aggravate with climate change. Development itself reduces vulnerability, particularly through rural infrastructure and rural development, but there will always be parts of the community that need protection, either through the creation of work programmes or through financial transfers. Combating climate change is vital to the pursuit of sustainable development; equally the pursuit of sustainable development is integral to lasting climate change mitigation, thus it is critical to address mainstreaming issues of climate change and sustainable development, into achieving Millennium Development Goals (MDGs) and WEHAB. The African Environmental Outlook 2002, prepared by AMCEN and UNEP in cooperation with other African institutions, identifies the "Endorsement and promotion of the principles of sustainable development" among the major actions to reduce poverty and protect the environment (AEO, 2002).

Adaptation to climate change should be pursued within a sustainable development framework (ADB, 2002). This is necessary in order to allow poverty reduction strategies, which are an immediate priority in developing countries, to be addressed at the same time as strategies that support adaptation to climate variability and change over a longer time scale. It is critical that adaptation strategies are assessed in a holistic manner in order to evaluate their feasibility and opportunities for synergy in a range of development priorities. This should be done in conjunction with a thorough assessment of what the trade-offs between climate change response and other sustainable development policies will be (Munasinghe and Swart, 2005). Some research suggests that projects that integrate climate change with economic development and capacity building should receive priority over those addressing the issues separately (Kuzma and Dobrovolny, 2005).

A sustainable development framework can help to avoid maladaptation and ensure that development activities do not undermine the capacity of the poor to respond to climate variability. Within this framework, gender equity should be ensured to help promote sustainable development (Simms *et al*, 2004). This is only happening slowly in the climate change debate due to the lack of participation of women in decision making.

9.7.1.1 Relationship between climate change and the World Summit on Sustainable Development (WSSD) outcomes

The United Nations World Summit on Sustainable Development (WSSD), also known as Earth Summit II or Rio +10, took place in Johannesburg, South Africa between August 26th and September 4th 2002. This was some 10 years after the Rio Earth Summit .The Johannesburg Summit (WSSD) states, "…the adverse effects of climate change are already evident, natural disasters are more frequent and more devastating and developing countries are more vulnerable….". While climate change will have global impacts, poor countries and poor people will be most vulnerable because of their high degree of dependence on natural resources that are directly impacted by climate change, their limited capacities – human, institutional, and financial – to cope, in some cases, their geographical location. Climate change is also expected to contribute to chronic impacts, including severe water and heat stresses that have profound impacts on the livelihoods and health of the poor, including their assets and quality of life. This enhanced vulnerability of the poor limits the effectiveness of development interventions and raises the questions of how to most effectively integrate climate change concerns into development planning. The Summit reaffirmed sustainable development as a central element of the international agenda and gave new impetus to global action to fight poverty and protect the environment.

The *Johannesburg Plan of Implementation*, negotiated by governments, the main Commitments with regard to climate change agreed in the Plan of Implementation are: Increasing 'substantially' the use of renewable energies in global energy consumption; and setting up a ten-year framework for programmes on sustainable consumption and production. The agreement also referred to the need to ratify the Kyoto Protocol, though various organizations and nations were hoping for more concrete plans. The WSSD provided the opportunity for revitalizing the global climate regime. The key interest of Africa in the WSSD is to enhance the capacities of communities and countries to combat and respond to global climate change, with particular attention on adaptive capacity that enhances the resilience of the poorest and most vulnerable groups. The most pressing challenge in this regard is to strengthen the social, economic and technical resilience of the poorest and most vulnerable against extreme climatic events.

9.7.1.2 Relationship between climate change in Africa and the Millennium Development Goals

Among the key commitments, targets and timetables from the Johannesburg plan of implementation is the sustainable development for Africa by improving sustainable agricultural productivity and food security in accordance with the Millennium Development Goals, in particular to halve by 2015 the proportion of people who suffer from hunger

Table 9.3: *Potential Impacts of Climate Change on the Millennium Development* Goals (Anonymous, 2002)

Millennium Development Goals: Climate Change as a cross-cutting issue	
Millennium Development Goal	*Examples of links with Climate Change*
Eradicate extreme poverty and hunger (Goal 1)	Direct impacts; • Climate Change may be reduced poor people's livelihood assets, for example health, access to water, homes and infrastructure. • Climate change may alter the path and rate of Economic growth due to change in natural systems and resources, infrastructure and labour productivity. A reduction in economic growth directly impacts poverty through reduced income opportunities. • Climate change may alter regional food security. In particular in Africa, food security is expected to worsen.
Health related goals: • Combat major diseases	Direct Impacts: • Direct effects of climate change may include

• Reduce infant mortality Improve maternal health (Goals 4,5 & 6)	increase heat-related mortality and illness associated with heat waves (which may be balanced by less winter cold related deaths in some countries) • Climate change may increase the prevalence of some vector borne disease (e.g. malaria to dengue fever), and vulnerability to water, food or person to person borne diseases (e.g. cholera and dysentery). • Climate and pregnant women are particularly
	Susceptible to vector and water borne diseases. Anaemia – resulting from malaria – is responsible for a quarter of maternal mortality. Climate Change may also result in declining quantity and quality of drinking water, which is a prerequisite for good health and exacerbate malnutrition – an important source of ill health of among children – by reducing natural resource productivity and threatening food security, particularly in sub Saharan Africa.
Achieve universal primary education (Goal 2)	Indirect impacts: • Links to climate change are less direst but loss of livelihood assets (natural, health, financial and physical capital) may reduce opportunities for full time education in numerous ways. Natural disasters and drought reduce children's available time (which may be diverted to household tasks) while displacement and migration can reduce access to education opportunities.
Promote gender equality and empower women (Goal 3)	Indirect impacts: • Climate Change may exacerbate current gender inequalities. Depletion of natural resource and decreasing agricultural productivity may place additional burdens on women's health, and reduce time available to participate in decision-making processes and income generation activities. • Climate related disasters have been found to impact more severely female- headed households particularly where they have fewer assets to start with.
Ensure environmental sustainability (Goal 7)	Direct impacts: • Climate Change may alter the quality and productivity of natural resources and ecosystems, some of which may be irreversibly damaged, and these changes may also decrease biological diversity and compound existing environmental degradation
Global Partnerships (goal 8)	Direct impact: • Global climate change is a global issue and responses require global cooperation, especially to help developing countries adapt to adverse impacts of climate change.

9.7.1.3 Clean Development Mechanism

As is well documented, current emissions of greenhouse gases (GHGs) in Africa are practically negligible in global terms due to the low level of industrialisation. The entire continent is estimated to be responsible for less than seven per cent of global emissions, and only about four per cent of CO2 emissions. As a result, the options for mitigation in Africa are very limited. In fact the entire debate over emission reduction largely escapes the needs of this continent. The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

The Clean Development Mechanism (CDM) is the only Kyoto mechanism whereby developed countries invest in Southern, or developing countries .It is aimed to be a part of a program of sustainable development. . For some developing countries, this is important because of the possible attraction of foreign investment. Critics argue that rich countries can avoid responsibilities at home and that it will actually increase emissions because the credits earned will allow rich countries to emit more, while developing countries are not tied to reduction at this stage. According to Sokona *et al* 2002, the solution proposed in the Kyoto Protocol-participation in carbon trade via the Clean Development Mechanism (CDM) - is unlikely to benefit the poorest countries, which are unlikely to attract private sector in any case. However, in the African context a wide vision of the possibilities of mitigation must be taken. Strong interventions on behalf of the sustainable development of the continent will have the immediate effect of lowering the baseline of future emissions scenarios. Conceiving of the situation in these terms will allow for the fulfilment of the dual objectives of the CDM as well as stimulating private sector investment constructively.

Box 9.2: Funding climate change activities in Africa

Several bilateral and multilateral agencies are supporting the implementation of climate change programmes and projects in Africa. The UNFCCC secretariat collects and disseminates information on these sources and posts it in the UNFCCC website. Under the Convention, the GEF as the financial mechanism of the UNFCCC provides financing for the implementation of climate change activities – mitigation as well adaptation.

A) The GEF Trust Fund:

In the area of mitigation, the GEF Trust Fund finances projects that address the following:

- the removal of barriers to energy conservation and energy efficiency;
- the promotion of the adoption of renewable energy by removing barriers and reducing implementation costs; and
- the reduction of the long-term costs of low GHG gas -emitting energy technologies
- the promotion of environmentally sustainable transport

In the area of adaptation, the GEF Trust Fund has recently allocated resources in its present business plan to a strategic priority “Piloting an Operational Approach to Adaptation” (SPA) to support a portfolio of projects designed to provide lessons and experience and capacity building in the area of adaptation. Since its inception, the GEF has allocated more than $300 million for enabling activities and energy-related projects in African countries. These projects have attracted more than $1billion in co financing from other sources including bilateral support form Annex I Countries.

B) The special funds:

In addition to the Trust Fund, there are also two special funds established under the Convention, namely, the Special Climate Change Fund and the LDC Fund. The Adaptation Fund, established under the Kyoto Protocol, will be funded from proceeds of CDM activity in the future as well as from voluntary contributions. These funds have been entrusted to the GEF for its operation and management.

- The LDC Fund:

The Least Developed Countries Fund (LDC Fund) was established to support the preparation and implementation of the National Adaptation Programmes of Action - NAPAs - and other activities such as strengthening the institutional infrastructure as providing training and capacity building of negotiators to participate effectively in the climate change process. One of the main objectives of the NAPAs is to serve as a simplified and direct channel of communication for information relating to the urgent and immediate adaptation needs of the LDCs. As of April 2004, 12 donors had contributed US$16.5 million and the GEF Council had allocated $ 9.1 million. At the time, the GEF indicated that 26 African countries that had taken advantage of this Fund.

- The Special Climate Change Fund:

The Special Climate Change Fund was established to support the following areas: adaptation, transfer of technology, energy, transport, industry, agriculture, and economic diversification. At the recent Conference of the Parties in Milan in December of 2003, the GEF, which is responsible for administering the fund, was given some further guidance. Parties decided that adaptation activities to address impacts of climate change would have top priority for funding. Technology transfer and its associated capacity building activities were also agreed as essential areas for the Special Climate Change Fund to support. Guidance to the GEF on the other areas is expected at the Conference of the Parties in December of 2004.

9.8 Key uncertainties, confidence levels, unknowns, research gaps and priorities

9.8.1 Uncertainties, confidence levels and unknowns

- While climate models are consistent regarding the direction of warming in Africa, projected changes in precipitation are less consistent.
- The contribution of climate to food insecurity in Africa is still unknown. While drought may affect production in some years, climate variability does not explain the continuous decline of food production for three or four decades.

9.8.2 Research gaps and priorities

Climate

The climate of Africa is still not fully understood. Climate models developed from AOGCMs are very coarse and hide important regional variations in Africa's climate. There is also the need to develop regional climate models and sub-regional models at the scale that would be meaningful to decision-makers.

Water

A regional scale detailed researches of the impacts of climate change on the African rivers are still reacquired, and these researches should include a socioeconomic analysis of the watersheds and river basins. Water quality and its relation to water usage patterns is an important issue that needs to be incorporated into future projections.

Energy

There is very little information on the impacts of climate change on the energy sector in Africa. Therefore, conducting technical studies on the African energy sector under climate change is crucial considering the importance of energy to the development of the continent.

Ecosystem

There is a great need for a well established program of research and technology development in climate prediction to assess the risks and impacts of climate changes in wildlife species in Africa.

Tourism

There is a need to enhance practical researches regarding the impacts of climate change on tourism, as tourism is one of the important and highly promising economic activities in Africa.

Health

Most assessments have concentrated on malaria. It is needful to examine the impacts of future climate change on other diseases in Africa such as dengue fever, meningitis, etc.

Agriculture

Very little research has been conducted on the impacts of climate change on livestock. The livestock sector is a very important sector in Africa and is considered very vulnerable to climate change.

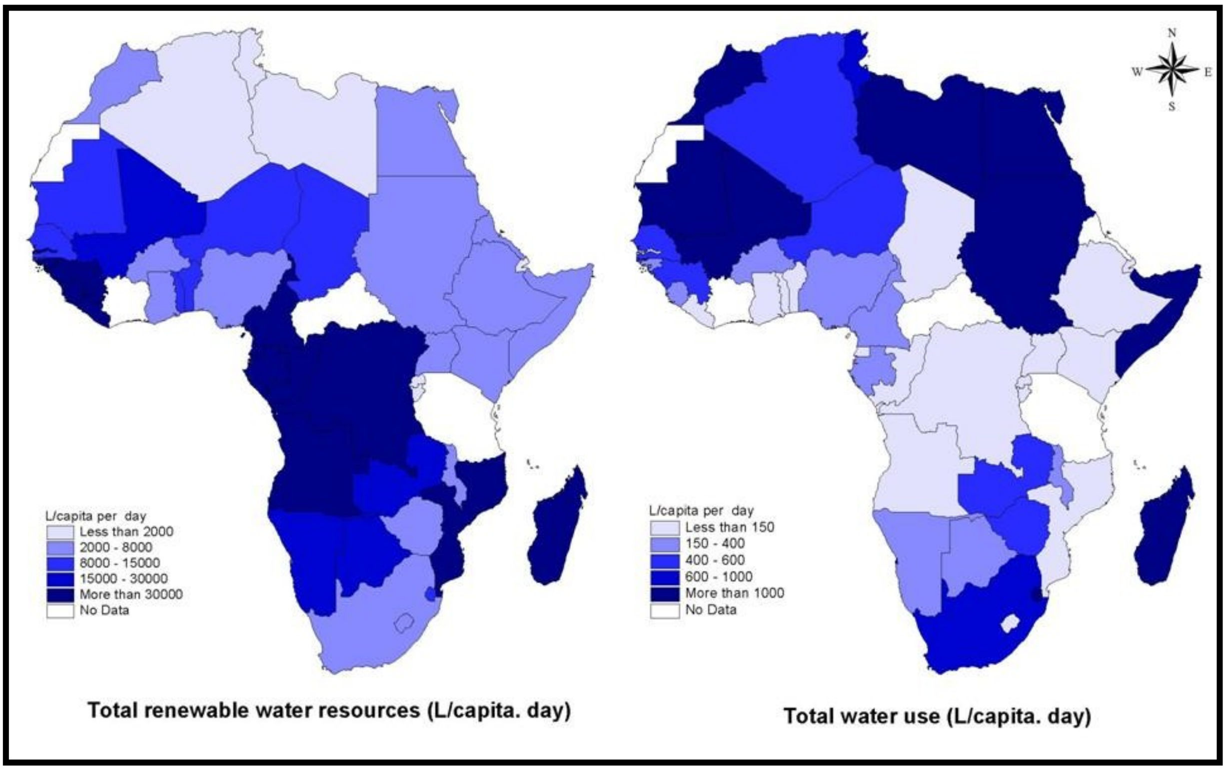
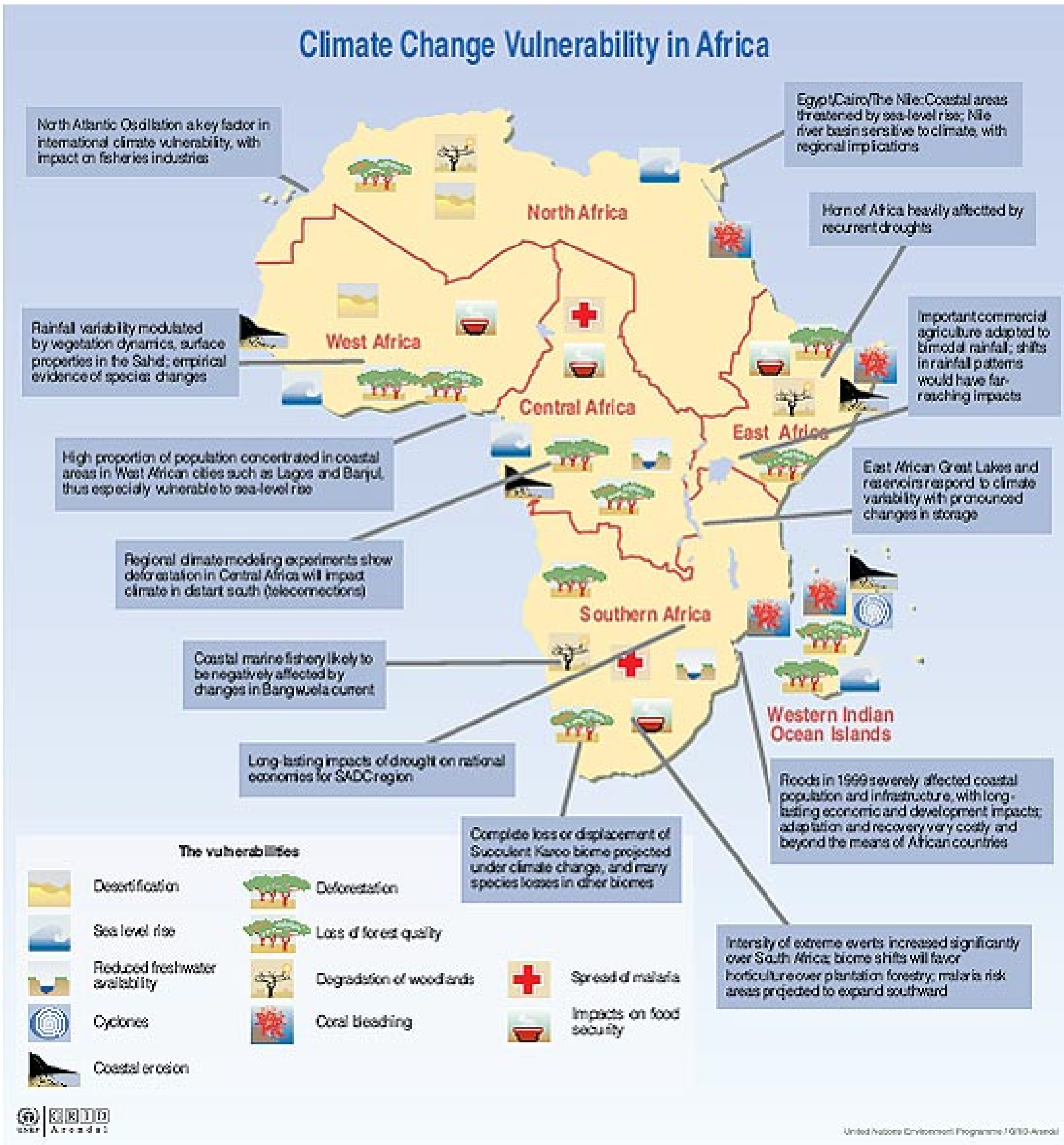


Figure 9.5: *Water availability and use in Africa*



Source: Anna Ballance, 2002

Figure 9.6: *Climate change vulnerability in Africa*

Annex 1: African Numbers

	Sub-Saharan Africa	North Africa	South Africa	Developing Countries
% Urban population	33.6	59.0	58.6	41.2
Urban population growth rate % (1992-2002)	4.7	2.9	3.1	3.1
Rural population growth rate (1992-2002)	1.7	0.2	-0.4	0.8
Population density 2001 pop/ha	0.3	0.2	0.4	0.6
Population growth rate 1992-2002	2.6	1.7	1.5	1.7
Fertility rate (births per women) 2001	5.0	3.0	3.0	3.0
Life expectancy at birth (years) 2001	46.0	68.0	47.0	64.0
Mortality rate, infant (per 1,000 live births) 2001	105.0	36.0	56.0	61.0
Cereal production per capita in Kg (2002)	120.4	110.6	287.0	242.0
Cereal production per cap growth rate (1992-2002)	-0.2	-2.4	8.2	-0.7
Irrigated agriculture, ha per 1000 pop (2001)	8.4	32.5	33.7	42.4
GDP per capita, PPP (current $)	1826.0	4314.0	11290.0	3918.0
GDP per capita growth rate (1991-2001) 1995$	-0.1	1.9	0.2	1.8
External debt, per capita (DOD, current $) 2001	301.2	673.8	556.2	450.8
ODA per capita (current $) 2001	20.7	14.9	9.9	11.1
School enrolment, primary (% gross) 2000	86.0	107.8	111.0	…
Vehicles (per 1,000 people) 1996	23.0	74.0	142.0	39.0
Total renewable water resource per capita (m3)	5769.3	3116.1 *		6004.3
Water withdrawal as % of Renewable Resources	3%	51% *		8%

Source: World Bank "World Development Indicators 2003"

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