IPCC WGII Fourth Assessment Report – Draft for Government and Expert Review

Chapter 9 – Africa

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Executive Summary

Africa is one of the most vulnerable continents to climate change and variability. Poverty is endemic in many areas of Africa and the number of Africans living below the poverty line has increased with sub-Saharan Africa being the only region in the world where, overall, poverty, livelihoods and food security continue to deteriorate. Environmental disasters (e.g. droughts and floods), 'creeping' social disasters (e.g. HIV/AIDS) and conflicts, further aggravate and threaten livelihoods, triggering new refugees and a host of knock-on impacts. In this chapter, the role of climate change and variability, as an *additional, but critical stressor*, to an already 'vulnerable' continent, is examined.

Knowledge assessment in the TAR and developments since the TAR

In previous IPCC climate assessments e.g. The Third Assessment Report (TAR)**,** Africa was shown to be highly vulnerable to climate change. Impacts of particular concern, included food production, human health, water resources, desertification, and coastal zones. Possible new development pathways, including a range of technological options were profiled as ways to possibly enhance African resilience to change, including climate change. Options included: improved cooperation and improvement in science, resource development and improved market access. Despite such suggestions and developments, the report concluded that the adaptive capacity to climate change was low.

Since the TAR, important scientific shifts, from a focus on an *impacts-led* approach to the inclusion of and effort to better understand climate change and variability from a *vulnerability-led* approach, have occurred (Adger *et al.*, 2004). The former focuses on the physical hazards associated with climate variability, with an emphasis on future modelling assessments and a range of projections including population changes. The latter attempts to better understand the underlying causes (e.g. socio-economic, institutional, cultural and other contextual factors) that may enhance vulnerability to climate risks and stresses. This shift in approach has been used to frame much of what follows in this chapter[1] and has arguably enabled a greater sensitivity to, and deeper understanding of, the 'role of multiple stresses' in heightening vulnerability to climate stress.

Current sensitivity/vulnerability: Warming through the twentieth century in Africa has been at the rate of between 0.26 and 0.50ºC/century. There has been an increase in precipitation in the semi-arid regions of West Africa, and an increasingly wetting trend in East Africa. Floods and droughts, which have caused major disruptions in the economy of many African countries, continue to aggravate vulnerability in the continent.

Various socio-economic, cultural and bio-physical factors and processes currently shape the contextual vulnerability of Africa to climate change and vulnerability. The natural environment and ecosystems, for example, are under stress from the combined pressures of habitat loss, over-harvesting of selected species and the spread of alien species. Notable changes in biophysical systems, such as the disintegration of the ice fields of Kilimanjaro (1962 – 2000), have been observed. Such changes are resulting in a range of 'knock-on impacts' (e.g. ice-sheet loss, exposing vegetation change, leading to changes in evaporation and to the overall water balance change). Human health, already compromised by a range of factors, could also be negatively impacted by climate change. It is estimated, for example, that the population currently at risk of malaria epidemics is 124 million resulting in an estimated 155,000- 310 000 deaths. Climate change, while disputed by some, could aggravate this situation as well as other health-related problems e.g. HIV/AIDS.

[1] The definition of vulnerability used in this chapter can be found in the SPM and the Glossary.

The role of climate variability is already exacerbating various other social ‘drivers’ of change and inequities, such as environmental management and governance at various levels in a number of sectors, including water, energy, health, agriculture, biodiversity and energy**.** Several countries are already facing energy and water crises including relatively developed countries such as South Africa. There are, however, large disparities in water stress across the continent with some areas not as severely water stressed as others. Increasing urban settlement (in an estimated 43 cities with more than one million inhabitants, a figure estimated to grow by 70 in 2015) will also place increasing pressure on over-strained and limited infrastructural resources, including shelter, water, sanitation and waste management that would be aggravated by periods of more frequent and intense droughts and floods. Inequity and lack of access to resources, including land, are also becoming major drivers of resource conflict and heightened vulnerability to a range of factors.

Agricultural production and food security (including access to food), for example, continue to be serious concerns in many African countries and regions. The agricultural sector in Africa is critical, contributing an average 21% of the GDP in many countries, ranging from 10-70%. A concern, for local livelihoods however, is the interplay of a range of multiple stresses compounding food insecurity, particularly in terms of *access* to food. *Production* of food *and access* to food, are constrained by a number of factors, including, legacies of structural adjustment policies and a lack of access to infrastructure and resources and international trade regimes. The pursuit of non-farm livelihoods and diversification of non-agrarian forms of activity to enhance livelihoods are, moreover, argued by some to be changing the rural face of Africa. Non-farming livelihoods, for example, may already account for as much as 40-45% of average household income in some areas. Trade, including the role of varying enterprises and markets (e.g. supermarkets), is adding to the range of factors changing rural, peri-urban and urban Africa. Such changes in community livelihood profiles may mean a range of different impacts associated with climate change and variability than has been previously assumed or investigated.

Assumptions of future trends: It is against this backdrop**,** that climate variability, for example, continues to aggravate and heighten many of the aforementioned stresses in several African countries and regions. Extreme dry and wet periods continue to persist. From 1970-2004, an estimated 14 African countries reported drought (lasting from 1 to 3 years) more than 10 times. Most were located in arid and semi-arid areas aggravating the livelihood security of farmers and pastoralists. Available evidence shows that temperatures continue to increase in Africa. Rainfall trends and projections are, however, more uncertain. Certain model projections, for example, show a drying, particularly in winter in parts of southern Africa, increases in rainfall in eastern Africa and drying along Africa’s Mediterranean coast.

Examples of some possible future impacts and vulnerabilities:
Despite the uncertainties and lack of ‘precision’ of the models used to generate ranges of scenarios (including future climate and socio-economic scenarios) a range of possible impacts are being postulated. Examples include:

- *Water*: IPCC's SRES emission scenarios for river-runoff projections for 2050, using HadCM3 climate models, indicate a significant decrease in runoff in the north and south of Africa, while the runoff in eastern Africa and parts of semi-arid sub-Saharan Africa is projected to increase by 2050. In addition, 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, using estimates based on the proportional changes in area, total population and proportion of water available (**9.4.1**) Such scenarios could be attenuated, however, by complex development and water management activities, particularly for large river basins e.g. The Nile River and Okavango River Basins and inland lakes e.g. Lakes Victoria and Tanganyika (**9.4.1**).

- *Health:* There is much debate about the role of climate and health impacts (e.g. malaria). Some assessments, however, show that by 2050 and continuing into 2080, large parts of the 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. Other health factors (e.g. HIV/AIDS) may compound periods of climate stress associated with climate change (**9.4.3**).
- *Agriculture*: Losses of potential agricultural land are shown for sub-Saharan Africa. Gains and losses in both agricultural potential land and crop production are also shown, using AEZ (agro-ecological models). These impacts are shown to be severe for many African countries, by the 2080s, further aggravating food security. Other sources of food e.g. from lakes could also be impacted, with reductions in primary productivity reducing fish yields of about 30% estimated for Lake Tanganyika and from coastal areas where increases in turbulence could reduce coastal fisheries by 50-60%.Various local level and household level impacts are not included here but would be critical for household food security (**9.4.4**).
- *Ecosystems:* Some expected key future vulnerabilities and impacts are (**9.4.5**): changes in aquatic ecosystem productivity of Lake Tanganyika, as indicated above; lake level fluctuations in Africa and possible impacts on fish species; environmental changes in North African wetland lakes; changes in extinction risks of known species and changes in desert environments. Preliminary assessments (using time thresholds of 2025, 2055, 2985) also show that over 5000 African plant habitats may undergo loss of species or shifts in habitat (between 81-97%) particularly for those in sub-Saharan Africa. Many species may shift to higher altitudes, and some (25-42%) are projected to lose their habitats by 2085. Two biomes, the fynbos and succulent Karoo in southern Africa are the most vulnerable to projected climate changes, whilst the savanna is argued to be more resilient. A loss of between 51% and 65% of the the Fynbos biome, for example, is projected by 2050 (**9.4.5**).
- *Coastal zones*: Land losses either due to coastal erosion or inundation could occur as a result of climate change. In the Mediterranean coastal zone of Egypt, using the SRES scenario, between 2,040 and 4,580 ha could be lost by 2100 due to sea level rise and land subsidence. In Cameroon, it has been estimated that by the year 2100 the length of the salt wedge in the Wouri estuary could decrease with a rainfall increase of 15% while it could increase in case of a rainfall decrease of 11%. 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 **(9.4.6**)

Adaptation

It is with these scenarios of possible change (see Summary Fig 9.5.) in mind that current adaptive capacity and adaptation options are considered for Africa. Much of the available data shows that many regions may be at risk from a range of stresses, many aggravated by climate change and variability. Sub-Saharan Africa emerges repeatedly as a ‘hot spot’ of vulnerability to climate change and other stresses. It is not, however, only climate change that may add to the burdens of Africans. Rather it is the net negative impact that could add to the existing vulnerabilities in the continent. Several regional plans and policies could, however, enhance adaptation including those linked to development. At the local level, several case studies, however, show the difficulty of designing a ‘one size fits all’ strategy. It is the interaction of the various ‘multiple stresses’ at various levels, including the composition of livelihoods, the role of social safety nets and other social factors that affect ‘contextual’ vulnerability and adaptive capacity (see the section on adaptation below), that require greater research and attention.

Implications for Development

Such multiple interactions therefore require creative multiple interventions at various levels.

Twinning adaptive capacity and development, as alerted to above, could be an option for Africa to enhance resilience to such multifarious changes. A range of factors including wealth, technology, education, information, skills, infrastructure, access to resources and management capabilities and political will may enhance adaptive capacity. Adaptive capacity, for example, is being shown to be ‘successful and sustainable’ when linked to effective governance systems, civil and political rights, and literacy.

Having provided a brief summary of some key vulnerabilities, possible future impacts and adaptation implications for development, the remainder of the chapter illustrates in further detail the issues outlined above.

9.1 Introduction and summary of knowledge assessed in the TAR

Africa is a continent vulnerable to a range of stressors including climate change and variability. Recent important scientific shifts, from a focus on an *impacts-led* approach to the inclusion of and effort to better understand climate change and variability from a *vulnerability-led* approach (Adger *et al.,* 2004), have occurred. The former focuses on the physical hazards associated with climate variability, with an emphasis on future modelling assessments and a range of projections including population changes. The latter attempts to better understand the underlying causes (e.g. socio-economic, institutional, cultural and other contextual factors) that may enhance vulnerability to climate risks and stresses. This shift in approach has been used to frame much of what follows in this chapter[2] and has arguably enabled a greater sensitivity to, and deeper understanding of, the ‘role of multiple stresses’ in heightening vulnerability to climate stress.

Prior assessments, (e.g. the TAR) 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 and central Africa. Projected future changes in mean seasonal rainfall under intermediate warming scenarios, show that by 2050 North Africa and the interior of southern Africa may experience decreases during the growing season. Major vulnerabilities and impacts highlighted in the report include: a reduction in soil moisture in sub-humid zones, a reduction in runoff of major river basins, droughts in some regions, critically low levels in lake storage and major dams, with consequent impacts on hydropower generation and industries; drastic shifts of biodiversity-rich biomes such as mountainous biomes, losses in other biomes e.g. mangrove vegetation along lagoons and shores. Food-importing countries are shown to be at greater risk of adverse climate change. Temperature rises and precipitation increase in some regions are also shown to extend the habitats of vector at high altitudes (e.g. malaria) and other diseases (e.g. cholera), particularly in areas where sanitary infrastructure is inadequate. Sea-level rise, coastal erosion, salt water intrusion, and flooding will have significant impacts on African communities and economies, mainly on mega cities lying in coastal low lands. Changes in spatial and temporal patterns in temperature, rainfall, solar radiation, and winds will enhance desertification process in arid, semi-arid, and dry sub-humid regions of Africa. The report concludes that the adaptive capacity of human systems in Africa is low because of lack of economic and financial resources and appropriate technologies, while its high vulnerability is a result of heavy reliance on rain-fed agriculture, high frequency of drought and floods in a context of widely spread poverty. The report stresses the low confidence in climate change projections and calls for the development and implementation of regional assessments of vulnerability, impacts and adaptation. Many of these conclusions, as shown below, still remain valid for this fourth assessment.

9.2 Current sensitivity/vulnerability

9.2.1 Current sensitivity to climate and weather

The continent, the second largest and comprising a land area of about 30 million km^2, exhibits large contrasts in its surface terrain and vegetation which may be important in modulating the global climate (AMCEN/UNEP, 2002). The climate of the continent is controlled by complex maritime and terrestrial interactions and experiences a wide range in climate from the humid tropics to the hyper-arid Sahara. Several sectors and ecosystems are vulnerable to these changes in climate, both in the short and the long term, as outlined below.

Climate exerts a control on the economic development of Africa, particularly the agricultural and

[2] The definition of vulnerability used in this chapter can be found in the SPM and the Glossary.

water resources section. Extreme events (like floods and droughts) are responsible for major disruptions in the economy of the countries (Benson and Clay, 2004; Washington *et al.*, 2004). Observations since the TAR, show that 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 more warming in the June-August (JJA) and September-November (SON) seasons (Hulme *et al.* , 2001, Malhi and Wright, 2004). In East Africa, a rising in minimum temperatures is observed since 1939 (King'uyu *et al.*, 2000; Conway *et al.*, 2004). For precipitation, there is a more complex regional differentiation, with a reduction in annual rainfall, for example, 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 in 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 (Hulme *et al.*, 2001). This variability depends on different teleconnections and is evident in some climate models (Vizy and Cook, 2001, McHugh and Rogers, 2001; Rowell, 2003; Cook *et al.* , 2004). These teleconnections are also linked to the El Niño-South Oscillation (ENSO), gradients of sea surface temperature between the northern and southern global oceans, especially the Atlantic, and the NAO (Dai and Wigley, 2000; Nicholson, 2001; Richard *et al.*, 2001; Nicholson and Grist, 2003; Gianini et al, 2003; Todd and Washington, 2004). The two regions in Africa with the most dominant ENSO influences are eastern equatorial Africa during the short October-November rainy season and south-eastern 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 and dust - may play a role in climate variability and change in the continent (Wang and Eltahir, 2002; 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 (Dia *et al.*, 2004), the Horn of Africa and Southern Africa particularly since the end of the 1960s (Brookes, 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). 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). The 'health' of the environment including ecosystems, agriculture, health as well as animal health and settlements is also strongly linked to climate and climate change. In the section that follows, some of the current sensitivities of ecosystems, agriculture, health and settlement to climate change and variability are shown.

Ecosystem sensitivity/vulnerability: Fluctuations in climate already exert a major influence on ecosystems, setting the spatial ranges of certain species and habitats. 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, however, under threat from climate change and other stresses. Africa's social and economic development is constrained by climate change, habitat loss, over harvesting of selected species, the spread of alien species, and illegal activities such as hunting and deforestation which threaten to undermine the integrity of the continent's rich but fragile ecosystems (UNEP, 2002; Huq *et al.* , 2003; Thomas *et al.* , 2004). Approximately half of the sub-humid and semi-arid parts of the southern African region, for example, are at moderate to high risk of desertification (e.g. Reich *et al.*, 2001; SAfMA, 2004).

Previous assessments of some changes in biodiversity associated with climate change, were those associated with coral bleaching and erosion of coastal environments. Different processes of mangrove degradation have been observed that can be due to changes in substrate (from mud to sand brought in by increased coastal erosion) or increases in salinity (Niang-Diop *et al*., 2005) but also to different anthropogenic activities such as deforestation and urban extension (Din *et al.* , 2001; Din and Blasco, 2003). The 1997-98 bleaching event, for example that affected most of the coral reefs in the Indian Ocean and Red Sea was associated with a strong ENSO event. The recovery has been strong in some areas but weak in others. Recent outbreaks of the 'crown-of-thorns' starfish, for example, have occurred in Egypt, Djibouti and western Somalia, along with some local bleaching (Kotb *et al.*, 2004). 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). Coral reefs are also, however, exposed to other local anthropogenic threats including land fills, dredging, sedimentation, shipping accidents, sewage discharge and effluents from desalination plants, mostly around towns, cities and tourist development sites.

Another suite of ecosystem changes that appear to be coupled to climate change are those observed on and around Mount Kilimanjaro. There is strong evidence that the ice fields in the Kilimanjaro Parks are being reduced by a range of factors, the most notable being climate change. The ice cap on Kilamanjaro has been decreased by about 55% between 1962 and 2000. The role of feedbacks and other multiple stresses (e.g. land use change and fire) also, however, play a critical role. The loss of 'cloud forests' through fire since 1976, has resulted in a 25% annual reduction of fog water (the equivalent of the annual drinking water of 1 million people living in Kilamanjaro) (Hemp, 2005; Agrawala, 2005). Kilimanjaro National Park is among the leading national parks in revenue collection (Bonine *et al.*, 2004) and the loss in glaciers could threaten the income generation capability of the National Park. Other 'knock-on' effects include implications for water in the surrounding areas. The ecosystem supplies water into the Pangani Basin through the Pangani river system. Water is used for irrigation on the densely populated slopes of the mountain, where traditional furrows are employed to irrigate coffee, bananas and other food crops (Ngana, 2001 & 2002). Further downslope, water from the mountain is used to irrigate large agricultural schemes (paddy rice and sugar). Along the Pangani River there are also some hydropower plants (e.g. Nyumba ya Mungu Dam – 8 MW, Hale – 21 MW, New Pangani Falls – 45 MW and Old Pangani Falls – 17.5 MW). All these rely mainly on water from the mountain. Electricity generated contributes about 17% of the hydropower produced in Tanzania (Ngula, 2002). There are other small-scale water users such as traditional irrigators, livestock keepers and fishermen whose numbers are also significant bearing in mind that the water passes through the semi arid area where water and green pastures during the dry season are scarce resources (Ngana, 2001 & 2002).

Agricultural sensitivity/vulnerability to climate and weather: The agricultural sector is also critical in Africa, contributing an average 21% and ranging from 10% to 70% of the GDP (Mendelsohn *et al.* , 2001), and is very sensitive to climate change and variability, particularly as much of Africa depends on rain-fed agriculture. African agriculture has the lowest record of productivity in the world (Mendelsohn *et al.* , 2001) and the lowest share of area planted with improved varieties in the world (Mendelsohn *et al.* , 2001, Sachs *et al.*, 2004). Per capita arable land in the continent has shrunk from 0.38 hectares to about 0.25 hectares over the past 20 years (Sachs *et al.*, 2004). In semi-arid regions of sub-Saharan Africa, farmers and pastoralists have to contend with extreme natural resource challenges (including limited water, poor soil fertility and a range of other resource constraints including inputs and improved seeds), situations that are usually aggravated by periods of prolonged droughts and floods often marked during El Nino situations (Benson and Clay, 2004; Vogel, 2005). Recent assessment, for example, show that African food production is significantly reduced if global climate changes towards more El Nino-like, conditions with maize production most strongly affected (Stige et al, 2006).

Sensitivity/vulnerability of the health sector to climate and weather: Climate-related diseases rank as high priority for their large global burden of disease and their high sensitivity to ecological change in the tropics in general. These diseases include malaria, schistosomiasis and lymphatic filariasis in cultivated and inland water systems in the tropics; dengue fever in tropical urban centres; leishmaniasis and Chagas disease in forest and dryland systems; meningitis in the Sahel; and cholera in coastal, freshwater and urban systems. In Africa, it has been estimated that the population currently at risk of epidemic malaria is 124.7 million resulting in 12.4 million cases of malaria and an estimated 155,000-310,000 deaths due to epidemics (Worrall *et al.*, 2004). An increase in malaria incidence and prevalence can be expected to increase with poverty, where a five-fold difference in the GDP between malarious and non-malarious countries has been noted (Sachs and Malaney, 2002). Understanding the links between climate and malaria is therefore critical.

Despite debates on the links between climate and malaria (e.g. Hay *et al.*, 2002) several examples of possible links have been highlighted. Areas with unstable malaria transmission are most sensitive to the impacts of climate variability and these are highlands and semi-arid areas. Thomson et al (2006), for example, have shown that malaria epidemics in semi-arid areas are highly correlated to anomalously high rainfall. Likewise Githeko and Ndegwa (2001), Abeku *et al.* (2004), Zhou *et al.* (2004) and Patz *et al.* (2002) have shown that malaria epidemics are associated with positively anomalously temperature and rainfall in the highlands of Eastern Africa. Hay et al 2002 have disputed these findings and offer drug resistance as an alternative explanation. Increases in malaria, rather than being attributed to climate are, argued by Hay *et al*. (2002) to be attributable to resistance to drugs, decreases in DDT spraying etc and collapse in vector control programmes (e.g. Hay *et al.*, 2002). When climate changes for a period 1911-1995, in the Eastern Highlands, were investigated, for example, no evidence for significant trends in climate were found.

Furthermore malaria epidemics are episodic in nature while drug resistance is incremental, and there is thus a mismatch between drug resistance and trends in malaria epidemics (Zhou *et al.* 2004). The historical records for Africa show warming of approximately 0.7°C over most of the continent during the 20th Century and an increase in the frequency and intensity of climate variability (IPCC 2001). Munga *et al.,* (2006) have shown that a 0.8°C increase in temperature resulted in a 10 day decrease in malaria vector larval developmental time. The impact of this is an increase in the numbers of mosquitoes per generation and increased malaria transmission.

There are indications that in areas that have two rainy 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. A second line of evidence linking climate change to malaria lies in the new records of malaria vector *Anopheles arabiensis* in the eastern highlands of Kenya 1700-1900 meters above sea level, (adjacent to Mount Kenya) where no malaria vectors have ever been recorded (Chen *et al.*, 2006).

A significant population 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 prevalence of 10% and 40%, respectively. It has been observed that 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.

New evidence from microclimate change due to land use change and spatial distribution of malaria transmitting mosquitoes adds an additional dimension to the debate and shows that such changes may impact on the intensity of malaria transmission in the African highlands. Swamp reclamation, for example, for agricultural use in the highlands of western Kenya, has been shown to increase mean maximum water temperature by 2.4^{o}C and the mean temperature by 0.8°C (e.g. Munga *et al.*, 2006).This process reduced the larval development time by 10 days thus increasing the numbers of mosquitoes emerging in a given time interval (e.g. in a month). Transmission of malaria is proportional to the size of the vector population. Deforestation in the highlands of western Kenya has also been linked to an increase in mean indoor temperature by 1.8^{o}C (Afrane *et al.*, 2005). The time taken to digest blood in mosquitoes is also a key additional consideration. The decreased time taken to digest blood in mosquitoes from 4.6 days to 2.9 days, implying that mosquitoes fed on people from once every five to once every three days, which would result in increased malaria transmission. Similar temperature changes have been observed during events such as the 1997/98 El Nino when severe malaria epidemics were observed in the Eastern African highlands.

Factors that predispose populations to meningococcal meningitis are still poorly understood but climatic conditions associated with the epidemics are dryness, very low humidity, and dusty 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). The projection that sea level rise would increase flooding particularly in the coasts of Eastern Africa (Nicholls, 2004) may also have implications for health. The potential for climate change to intensify or alter flood patterns may become a major additional driver of future health risks from flooding (Few *et al.*, 2004). Floods can also cause malaria epidemics in arid and semi-arid areas (e.g. Thompson *et al.,* 2006).

Sensitivity/vulnerability of the water sector: Observed responses to rainfall shifts are already being noted in several water situations. Evidence of interannual lake level fluctuations, for example, have been observed (1993-1997) probably owing to intense droughts and increases in lake levels (e.g. Lakes Tanganyika, Victoria and Turkana) occurring in 1997-1998, and linked to an excess in rainfall in late 1997. After the 1997 flood, the level of Lake Victoria rose by about 1.7m by 1998, Lake Tanganyika by about 2.1m and Labe Malawi by about 1.8m and very high river-flows were recorded in the Congo at Kinshasha (Conway *et al.*, 2004). The heavy rains and floods have been attributed to large scale perturbations in the Indian Ocean (Mercier, Cazenave and Maheu, 2002). The floods of 1997 brought both positive and negative socioeconomic impacts. Across Somalia, Kenya, Tanzania, Uganda and Ethiopia, agricultural impacts included areas with increased yield and beneficial effects on pastures due to surplus rainfall and localised crop losses during harvest and post-harvest activities. Other impacts included loss of lives and livestock due to widespread inundation, damage to housing and infrastructure and outbreak of Rift Valley Fever (Conway et al, 2004). Other changes in water and hydrology, linked to climate through complex interactions, include those for southern Africa (Schulze, Meigh and Horan, 2001), and South Central Ethiopia (e.g. Legasse, Valerie-coulomb and Gasse, 2003). Fewer assessments on groundwater and climate are available, and yet this aspect is clearly of great concern for many depending on such water sources.

Sensitivity/vulnerability of settlement and infrastructure: Changes in the ecosystem, possibly triggered by climate variability and climate change, may 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; Denton *et al.*, 2001; Karanja *et al.*, 2004; Davidson *et al*., 2003; Benson & Clay 2003). 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).

As livelihoods are threatened and habitats altered due to drought, inundation, floods, large-scale subsidence, erosion, desertification and other climate related events, Africa may face a new set of refugees: environmental refugees (Myers 2002; McLeman & Smit 2005) including those who move away from vulnerable regions. Fresh challenges will emerge for new settlement types, sizes and distributions, to cater for this population group (McLeman and Smit, 2004). A variety of migration patterns could emerge e.g. repetitive migrants (as part of ongoing adaptation to climate change), short-term shock migrants (responding to a particular climate stimulus), and large-scale migrants.

9.2.2 Current sensitivity and vulnerability to other stresses

Complex socio-economic, political, environmental, cultural and structural factors also configure vulnerabilities to several changes, including climate change and variability. African economies recently registered their highest overall growth in eight years (more than 5 per cent in 2004) (OECD, 2004/2005), with Sub-Saharan Africa showing an increase of 1.2 per cent a year since 2000 in average income (UNDP, 2005). Despite this positive progress, several African economies are still vulnerable to regional conflicts, the vagaries of the weather and climate and volatile commodity prices (OECD, 2004/2005). At the regional and country level, certain countries, for example, still face serious problems including those aggravated by conflicts and humanitarian collapses in Sudan, Zimbabwe and the parts of the Democratic Republic of Congo. Sub-Saharan Africa is one of the only regions in the world (see Table 9.1) where, overall, poverty, livelihoods and food security continue to deteriorate (Sachs, 2005).

Table 9.1: *Socio-economic indicators of regions in Africa (Source: World Bank "World Development Indicators 2003", copyright permission to be obtained).*

	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

	Sub-Saharan Africa	North Africa	South Africa	Developing Countries
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%

Human development

The Human Development Index (HDI) has been rising in developing regions in the world except for Sub-Saharan Africa, with twelve countries showing reversals in HDI. Such changes further impact on approximately 240 million people living in countries experiencing HDI reversals (UNDP, 2005). The interaction of economic stagnation, slow progress in education and the spread of HIV/AIDS has, moreover, produced a 'free fall' in HDI ranking with southern Africa accounting for some of the steepest declines (UNDP, 2005, 22). Child mortality further enhances the grim spectre, with the Sub-Saharan region accounting for 20% of births but 44% of deaths (UNDP, 2005). Africa's contribution to food shortages globally also continues to grow with several countries (e.g. 23 of 36 countries facing severe food shortages were African in February 2005, FAO, 2005). Many countries also face ongoing or chronic food crises (www.fao.org, see for example section 9.6)).

Trade, globalization and market reforms

Globalization, issues of trade and equity (e.g. with reference to agriculture see FAO, 2005; Schwind, 2005).), for example, are important processes that serve to heighten vulnerabilities in African countries (e.g. see also Sachs *et al.*, 2004, UNDP, 2005 and World Bank, 2006 for more detailed discussion). Space does not permit a full investigation here, but suffice it to say that the multifarious factors 'driving' and 'shaping' poverty and livelihoods in Africa (e.g. Hulme and Shepherd, 2003), changing face of rural Africa (Bryceson, 2004) and the various factors shaping the landscape (e.g.intensification vs extensification, see for example, Gray, 2004) cannot be ignored in an assessment of the possible role of climate change. Climate change in turn may also impact and aggravate the impacts from such processes. The role of structural adjustment, for example, accompanied by complex market reforms and market liberalization have arguable already aggravated the vulnerability of many in Africa, particularly those engaged in agriculture (e.g. large and small-scale farmers) (see for example Kherallah *et al.*, 2000). Fertiliser prices, for example, have risen in response to subsidy removal with declines in fertiliser use in many countries. The average rate of fertiliser use is 9kg per hectare of arable land compared to 107kg in most developing countries (Kherallah *et al.*, 2000; see also id21, April, 2006 and IDS, 2005). Access to credit has also declined in cases where state-sponsored credit systems have collapsed (e.g. Malawi and Tanzania) and access to agricultural extension has also been reduced with associated fiscal cuts in public expenditure. Population growth, which can trigger either intensification of agriculture or expansion into marginal lands, may also trigger conflicts, crop failure, environmental degradation and loss of biodiversity (Fiki and Lee, 2004). Inappropriate crop and land management practices also 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).

One area where these factors combine to heighten vulnerability is in food insecurity. It is estimated that 27% of Africans are undernourished, with some approximating those impacted to be about 210 million undernourished people (id21, 2006). Chronic food insecurity, heightened and triggered by climate, but enhanced by a range of factors, persists in Africa (id21, 2006; see also section 9.6 for more details). Chronic food insecurity, moreover, seriously threatens the attainment of the MDGs. 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). Evidence from sub-Saharan Africa, however, suggests that the sustainability of food aid is questionable, with the trend of food aid supplies in recent years dropping, not only as a percentage of all imports, but also in absolute tonnage imported (Stevens and Kennan, 2001).

Governance and institutions

The low level of food production in Africa and the persistent humanitarian situations (e.g. Southern Africa) are not only due to climatic variability or poor African soils, as sometimes suggested, but is also related to policy and institutional failure. Africa is characterized by insufficient institutional and legal frameworks to deal with environmental degradation (Sokona, 2001). There is now substantial evidence (Denton *et al.*, 2002) that institutional weakness in many African countries, mainly in terms of public service delivery, corruption and democratic governance is a critical obstacle to economic performance. Climate change and links to national development strategies are also still poorly co-ordinated in several African countries (e.g. Beg *et al.*, 2002; Denton, 2002), further compounding impacts and frustrating development. Various actors, locations and networks are required to reconfigure innovation processes in Africa (e.g. agriculture) (Scoones, 2005).

Access to markets and other infrastructure

There are also few technology options, and many 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, 2004) Sub-Saharan African countries have extremely low per capita densities of rail and road infrastructure. The existing transport systems were largely designed under colonial rule to transport natural resources from the interior to the nearest port. As a result, cross-country transport connections within Africa tend to be extremely poor and are in urgent need of extension, to reduce intraregional transport costs and promote cross-border trade (Sachs et al, 2004).

Science and technology

Most African countries also 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. Africa has been described as the world's great laggard in technological advance, particularly in agriculture, where Africa's uptake of High Yielding Varieties has been the lowest in the developing world (Sachs *et al.*, 2004). 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 also 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 also too weak to ensure proper management of scientific progress and technological innovation for developmental purposes.

Water access and management

In 2000, some 53% of Africa, representing about 60% of the total population, was classified as having water abundance. By 2025, this is likely to decrease to about 35% (Ashton, 2002). These estimates are based on assessments that compare the proportional changes in area, total population, and proportionof water available (Ashton, 2002). Countries characterised by water stress are located in eastern and southern Africa (Arnell, 2004). Water that is available is, moreover, often of poor quality. Lack of access to safe water contributes to illness and deaths and results in health problems (e.g. diarrhoea, intestinal worms, trachoma etc) particularly in children. Significant progress has been recorded in some parts of Africa. In southern Africa, for example, an increased majority of the urban population in the southern African region had access to improved water in 2004 (SAfMA, 2004).

Water access is also complicated by transboundary water management issues and several African countries share more than 50 major watersheds, river basins and lakes (Ashton, 2002). For instance, the 17 countries in West Africa (ECOWAS members, Chad and Mauritania) share 25 transboundary rivers and the majority of the West African countries have a water interdependency ratio of more than 40% (Niasse, 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, such as 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 for many current conflicts between African countries (Niasse, 2005), with possible heightened conflict expected with climate change impacts on water resources and water scarcity in Africa.

In larger water basins and watersheds, the interactions of climate and socio-economic conditions and policies influencing water supplies however frustrate simple attributions of the role of climate and water supply and access. There is high confidence, for example in the Nile Basin that temperatures will rise leading to losses in evaporation but there is less confidence in rainfall projections. Integrated analysis of climate change in Egypt together with population changes, land use changes and domestic growth strategies, show that changes in Nile flows may, moreover, be minor in relation to other non-climate changes (Conway, 2000; Yohe et al 2002; Conway, 2005).

The complex interplay of social and biophysical factors is also heightening the vulnerabilities and sensitivities of many lakes to a range of changes (including climate change). Overfishing, industrial pollution and sedimentation are degrading local water sources such as Lake Victoria (see for example Odada *et al.*, 2004), that impact on catches. The multispecies fishery of Lake Victoria has changed to only three species namely Nile perch, pelagic cyprinid-dagaa and tilapiine.

Health management

Much like water, the interaction of several 'human dimensions' e.g. service management, possible stigmatization associated with HIV/AIDS, is also stressing the health sector. Africa is in short supply of health workers, notably, doctors and nurses, where in addition many of the countries have a dilapidatory health infrastructure. The role of HIV/AIDS is contributing to a range of vulnerabilities (e.g. Gommes *et al.*, 2004, www.SARPN.org; Mano, Isaacson and Dardel, 2003; USAID, 2003). The deadly duo of HIV/AIDS and food insecurity in southern Africa (Gommes *et al.*, 2004, see other sources in food security case study 9.6 below) are now key drivers of the humanitarian crisis in the region.

Ecosystems degradation

Human 'drivers' are also shaping ecosystem services (see also SAfMA, 2005). Several areas, for example Zimbabwe, Malawi, eastern Zambia, central Mozambique as well as the Congo Basin rainforests in the Democratic Republic of Congo are undergoing deforestation with estimates of about 0.4% per year in the 1990s of humid tropical rain cover change (e.g. SAfMA, 2004). In Western and Central Africa loss and fragmentation of forest habitat and poaching of endangered species to meet the growing demand for bush meat is occurring. In Eastern Africa, encroachment of human settlements into protected areas and pastoral areas outside of reserves are priority concerns. In several areas, including 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. Alien invasive organisms are a widespread problem throughout the region, particularly in closed ecosystems including Lake Victoria and the Western Indian Ocean Islands (UNEP, 2002).

Energy

According to the World Energy Outlook (2002) four out of five people without electricity live in rural areas of the developing world, mainly in South Asia and sub-Saharan Africa. Extreme poverty and the lack of access to other fuels mean that 80% of the overall African population relies primarily on biomass to meet its residential needs (estimates suggest that only 23% of the population has electricity in sub-Saharan Africa and more than 500 million people without electricity in Africa (IEA, 2002). In Kenya, Tanzania, Mozambique and Zambia, nearly all rural households use wood for cooking, and over 90% of urban households use charcoal, (e.g. (IEA, 2002; SAfMA, 2004).. 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). With more than 500 million Africans without access to electricity, Africa is one of the least developed regions in term of electrification; in rural areas, over 83% of the population still lacks electricity. Biomass currently supplies about 85% of energy consumed in sub-Saharan Africa (Hall and Scrase, 2005). The number of people without electricity in this region has doubled in rural areas and tripled in urban areas in the last 30 years with some suggesting that biomass energy has increased roughly in proportion to population growth (Hall and Scrase, 2005). The absence of efficient and affordable energy services can severely damage the health of the poor. In rural sub-Saharan Africa, for example, many women carry 20 kilogrammes of fuel wood an average of five kilometres *every day*, and the lack of refrigeration means that food spoils rapidly. This in addition to constant exposure to carbon monoxide and other particulates from biomass fuel can have significant negative impacts on people's health (IEA, 2002).

Complex disasters and conflicts

The juxtaposition of many of the complex socio-economic factors outlined above and the interplay of biophysical stresses is well highlighted in the impacts and vulnerabilities to disaster risks and conflicts in several areas of the continent. Many disasters are a combination of a climate stressor (e.g. drought, flood), that occurs in conjunction with conflict, disease outbreaks etc (e.g. Benson and Clay, 2004).

The role of multiple interactions, linking climate to a range of other stresses, is further well highlighted in the case of Malawi and Mozambique. In Malawi, agriculture in 2000 accounted for about 40% of the GDP, a drop of about 4% from 1980. The real annual fluctuations in agricultural, non-agricultural and total GDP for 1980-2001 show that losses during droughts (e.g. as occurred in the mid-1990s) were more severe than disaster losses during the floods in 2001 (Benson and Clay, 2004). Despite these differences, food security threats during the locally erratic rains of 2001/02 were also observable. The combination of unsustainable agricultural practices, structural changes in agriculture, institutional weaknesses in agriculture, political instability, short-term variability in external aid levels and the effects of HIV/AIDs on human resources, when coupled to changes in climate are some of the complex mix of factors that shape impacts in many countries of Africa as this case shows (See also food security section 9.6.1 below) (Benson and Clay, 2004). The floods in Mozambique in 2000 also revealed a number of persistent and chronic vulnerabilities that were heightened by the floods. These included: 1) poverty (40 % of the population lives on less than US1$ per day) and another 40 % on less than US2$ per day; 2) the debt problem is one of the biggest challenges facing the country; 3) most of the floodwaters originate in cross-border basins; 4) there is poor disaster risk-reduction with regards to dam design and management; 5) communication networks are poor etc (Mirza, 2003).

Armed conflicts, that have become so frequent in Africa, also aggravate environments at risk and threaten livelihoods. The impacts of such disasters can also contribute to rural-urban migration, generating new types of refugees as described earlier. Structural inequalities, resource mismanagement and predatory states have been shown to be some of the key factors driving conflict in the Greater Horn of Africa (Somalia, Ethiopia and Sudan) and the Great Lakes (Burundi, Rwanda and the Democratic Republic of Congo) (Lind and Sturman, 2002). Land distribution and land scarcity also trigger conflicts, usually viewed as conflicts of enthnicity (Lind and Sturman, 2002; see also Balin-Kurti,, 2005; James, 2005). Climate change may become an additional driver for conflict such as water conflict (Ashton, 2002) and resource-scarcity conflicts (Fiki and Lee, 2004).

It is against this background that an assessment of vulnerability to climate change and variability has to be contextualised. Some proxies for national-level vulnerability to climate change, including economy, health and nutrition, education, infrastructure, governance, geography and demography, agriculture, energy and technology, for example, have been used to give some indications of vulnerability to climate change for Africa. The majority of vulnerable countries in an assessment using such proxies (e.g. Brookes, Adger and Kelly, 2005) were situated in sub-Saharan Africa (33 of the 50 assessed were sub-Saharan African countries). At the local level, several case studies similarly show that it is the interaction of such 'multiple stresses', including the resilience composition of livelihoods, the role of social safety nets and other social protection measures that affect vulnerability and adaptive capacity (see section on adaptation below). Climate change and periods of climate variability (Davidson, *et al.*, 2003) thus severely aggravate such situations by enhancing vulnerabilities and impacts as well as strictly limiting the adaptive capacity of people across the continent.

9.3 Assumptions about future trends

9.3.1 Climate change scenarios

Having provided some background above that sets the scene for an assessment of the possible role of climate variability and climate change for Africa, attention now shifts to outline some of the scenarios that have been used to derive consequences and vulnerabilities associated with climate change. Although uncertainties in the models and scenarios are still present, there is growing consensus that Africa is warming, with relatively less clarity about precipitation. What remains uncertain, however, is the spatial scale and magnitude of impacts associated with changes since most of the scenarios are based on global scales.

Very limited experiments of regional to sub-regional climate change scenarios using regional climate models or empirical downscaling have been conducted in Africa mainly due to restricted computational facilities and human resources (Hudson and Jones, 2002; Swart *et al.*, 2002) as well as problems of insufficient climate data (Jenkins *et al.*, 2002). The first results, however, seem promising and better adapted (in both geographical and temporal scales) to the needs of vulnerability analyses.

Under the medium-high emission scenario (A1B) used with an ensemble of 20 GCMs and for the years 2079-2099, annual mean surface air temperature is expected to increase between 3 and 4°C compared with the 1979-1999 period with smaller values in equatorial and coastal areas (chap.11, WGI). Other experiments using a full range of SRES emission scenarios indicate higher levels of warming with the A1F1 emission scenario for Northern and Southern Africa up to 9^{o}C in June-August and 7°C in September-November respectively for the 2070-2099 period (Ruosteenoja *et al.*, 2003). Regional Climate Models experiments give generally smaller values of temperature increase (Kamga *et al., 2004).* For southern Africa (equator to 45°S and 5° to 55°E) Hudson and Jones (2002) using the HadRM3H regional climate model with the A2 SRES emission scenario found for the 2080s a 3.7°C increase in summer (December to February) mean surface air temperature and a 4°C increase in winter (June to August).

Precipitation projections are generally less consistent with large intermodel ranges in seasonal mean rainfall responses. This is explained partly by difficulties of global circulation models to reproduce the mechanisms responsible for precipitations including, for example, the hydrological cycle (Lebel *et al.*, 2000) or the orography (Hudson and Jones, 2002) but also by some limitations to simulate the different teleconnections and feedback mechanisms which are responsible for rainfall variability, including factors such as dust aerosols concentrations or sea surface temperature anomalies, which are particularly important in the Sahel region (Prospero and Lamb, 2003; Hulme *et al.*, 2001) and southern Africa (Reason, 2002); deforestation in the equatorial region (Semazzi and Song, 2001); or soil moisture in southern Africa (New *et al.*, 2005). 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).

With the A1B scenario and for the years 2079-2099, the mean annual rainfall is very likely expected to decrease in Northern Africa (by about 13%) and northern Sahara, but may likely increase in Eastern Africa (by 7%) while winter (JJA) rainfall will decrease in much of Southern Africa (up to 40%) (very likely) (WGI, Chapter 11). In the latter region, Hudson and Jones (2002) also found the largest changes in rainfall during austral winter, with a 30% decrease under the A2 scenario, even though there is very little rain during this season. However, there are differences between the equatorial regions (north of 10°S and particularly east of 20°E) which show an increase in summer (DJF) rainfall due to enhanced convection and a decrease south of 10°S especially over the western and central land areas, associated with a decrease in the number of rain-days and in the average intensity of rainfall. Recent downscaling experiments made for South Africa indicate increased summer rainfall over the convective region of the central and eastern plateau and the Drakensberg Mountains (Hewitson and Crane, 2006).

For Western Sahel (10-18°N, 17.5°W-20°E), there are still controversies between the global circulation models. While some models project a significant drying (Hulme *et al.*, 2001; Jenkins *et al.*, 2005), others simulate a progressive wetting of the Sahel (Maynard *et al.*, 2002; Wang *et al.*, 2004; Haarsma *et al.*, 2005; Kamga *et al.*, 2005; Hoerling *et al.*, 2005). However, Kamga *et al.* (2005) stressed that land use changes and degradation, which are not simulated by their model, could induce drier conditions. The behaviour of easterly jets and squall lines is also critical to predict the impacts of climate change in the sub-region (Jenkins *et al.*, 2002).

Globally, tropical cyclones could decrease by around 30% with the exception of the North Atlantic (for further details WGI, chap 10). This is accompanied by a 10% increase in maximum wind speeds. However, McDonald *et al.* (2005) found a 6% global decrease in the number of tropical storms but with fewer in the North Atlantic and more in the Indian ocean. Lal (2001) considered very likely a 10 to 20% increase in cyclone intensity for a 2-4°C sea surface temperature rise. Regarding sea level rise, the projected contributions of glaciers and ice caps could be less than what was indicated in the TAR while the Antarctica ice sheet is still negatively contributing to future sea level rise (WGI, Chapter 10).

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 annual mean temperatures are respectively 2.9° and 2.1°C (compared to the 1961-1990 mean). 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).

These recent assessments of the mean response to an increase in atmospheric greenhouse gases concentrations suggests a large-scale warming associated with changes in precipitation rates, amounts and regional distribution. There is also evidence that these climate changes are occurring at a rate that may exceed the capacity of many terrestrial plants to adapt under water availability and high temperature stresses. Several studies have highlighted the importance of terrestrial vegetation cover and its dynamic on the physical climate (eg: Bounoua *et al.*, (2000)). The climate system is sensitive to the energy exchange at the land-atmosphere interface through change in albedo, roughness length and soil moisture, all of which are altered by vegetation. Bounoua *et al.* (2000) show that an increase in vegetation density resulted in a year round cooling of 0.8C in the tropics including Africa which could partially compensate for parallel increase in greenhouse warming.

Climate change projected over the same time horizon as that used by the IPCC in assessing the response of climate to greenhouse gases - next fifty to one hundred years - has shown that land use change plays a central role in modulating climate. Historically in Africa, large-scale anthropogenic degradation of the landscape has converted large areas of forest to wooded grassland and cropland; and wooded grasslands to cropland and resulted in warming (Bounoua *et al.*, 2002). This warming is a result of combination of morphological changes in vegetation offset by physiological changes that reduce latent heat flux of existing compared with undisturbed vegetation. When water efficient, tropical C4 grasses replaced C3 vegetation, latent heat flux was further reduced exacerbating thus the warming. In a subsequent study, Defries *et al.*, (2002) further suggest that unlike the past, most of landscape modification in the future is likely to occur in tropical and sub-tropical regions with the largest impact in Africa. They suggest that tropical warming could be up to 1.5^{o}C greater than that induced by decadal-scale variation in vegetation density and is associated with a decrease and evapotranspiration and an increase in runoff.

9.3.2 Socioeconomic scenarios

There are several socioeconomic scenarios that describe journeys to possible futures. The IPCC SRES scenarios, for example, adopts four story lines, producing four ‘scenario families’ that describe how the world population, economies and political structure may evolve over the next few decades (IPCC, 2000), Details of the SRES scenarios can be found in IPCC (2000) The ‘A’ scenarios focus on economic growth, the ‘B’ scenarios on environmental protection, the ‘1’ scenarios assume more globalisation and the ‘2’ assume more regionalisation. While some have criticised the population and economic details in the SRES scenarios they still provide a useful "baseline" on impacts related to greenhouse gas emissions (Tol *et al.*, 2005).

The projected GDP per Capita for the different regions in Africa under the various SRES scenarios are presented in Fig. 9.1. In all cases, average income is likely to rise throughout the century, though West and Central Africa consistently perform poorer than the other regions. Most of the scenarios assume a continued growth population projections, with the Western Indian Ocean Islands having the lowest growth rates (Fig 9.2). 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. Nevertheless, these estimates did not consider likely impacts of HIV/AIDS on population, and therefore must be treated with necessary caution. 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, 2004).

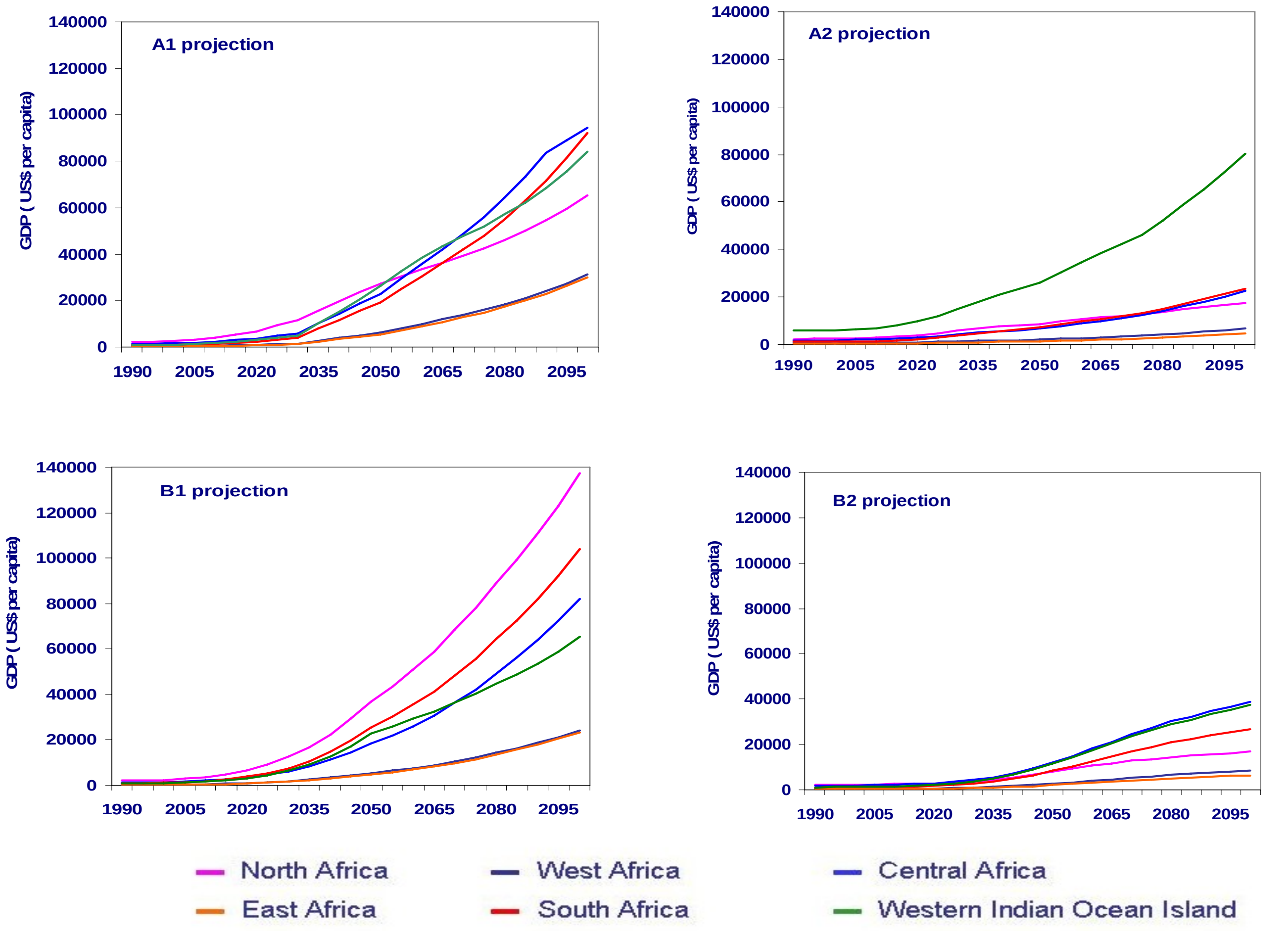


Fig. 9.1: *Downscaled GDP for Africa adapted from SRES Scenarios (Data Distribution Centre, IPCC.*

More recently, the UNDP has provided various scenarios that are linked to the MDG'S up to 21015 (UNDP, 2005, see report as well as methods and caveats to the report). The situation for the already vulnerable region of Sub-Saharan Africa still appears bleak; twenty-four countries in Sub Saharan Africa are, for example, projected to be unable to meet several of the MDGs, and not one Sub-Saharan country with a significant population is on track to meet the target with respect to child and maternal health (UNDP, 2005, 41). Sub-Saharan' share of below $1 a day poverty will also rise sharply from 24% today to 41% by 2015 (UNDP, 2005).

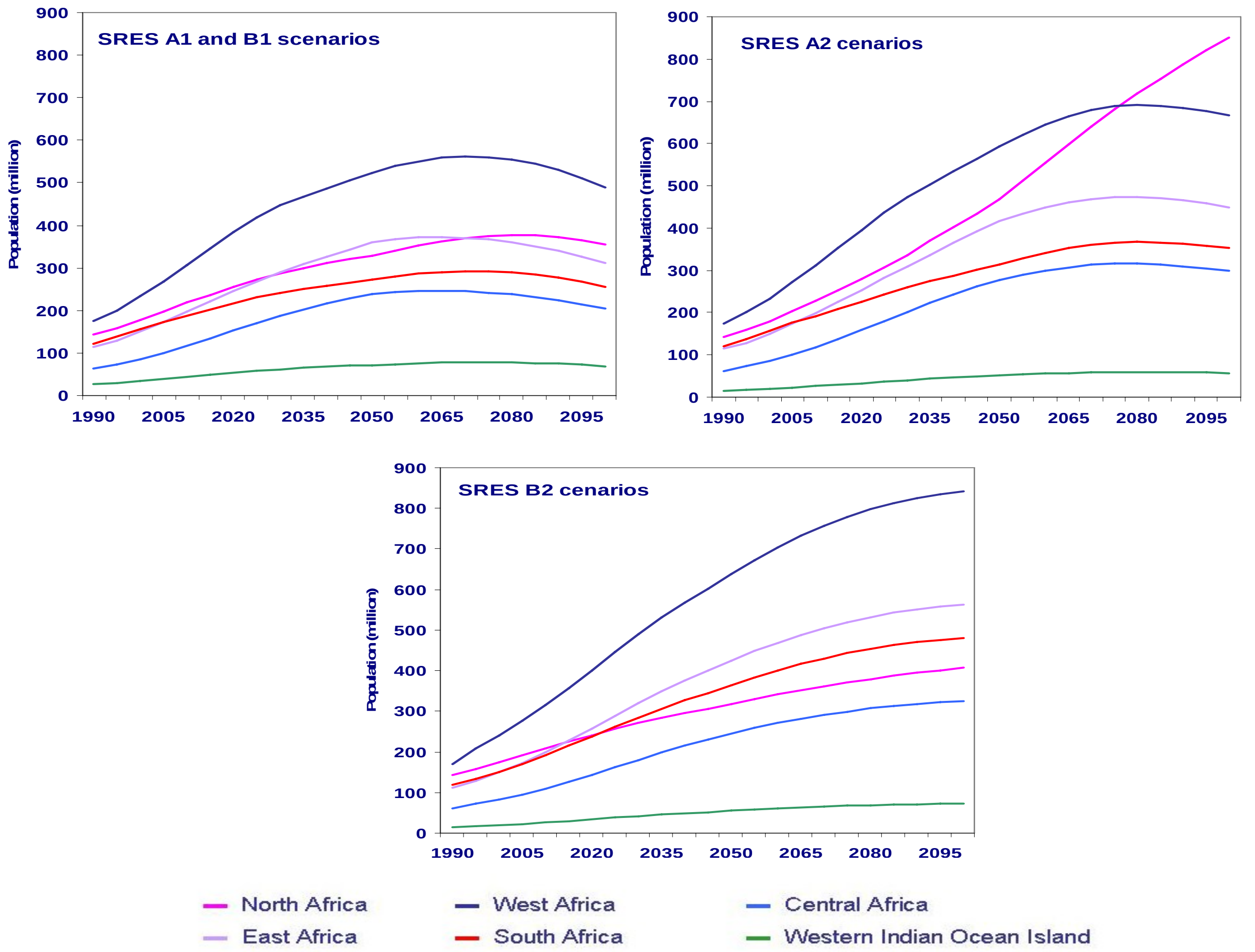


Fig. 9.2: *Downscaled regional Population Projection adapted from SRES A1/A2, B1 and B2 Marker Scenario (Downscaled GDP for Africa adapted from SRES Scenarios (Data Distribution Centre, IPCC).*

Other outlooks include those linked to population and urbanisation. Due to a 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, may 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 through the development of 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 a decline of real incomes in rural areas, which are compounded by lack of investment in agriculture and overexploitation of ecosystem services to deepen vulnerability (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 crops 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, 2004)

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

Having provided some background on the scenarios and model capabilities being used, this chapter now focuses on trying to tease out some of the impacts and vulnerabilities that may arise using the various scenarios and model projections as guides.

9.4.1 Water

In the absence of climate change the water situation for many in Africa is already precarious. By 2025, nine countries, for example, 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.

Climate change and variability have the potential to impose additional pressures on water availability and accessibility on both the supply and demand sides in Africa. Arnell (2003 and 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 southern Africa, while the runoff in eastern Africa and parts of arid Saharan Africa is projected to increase by 2050. Although Arnell's work is based on a global-level analysis and on six climate models driven by SRES scenarios (see Arnell, 2004), it gives a general view about the situation of runoff from African rivers under climate change conditions. Arnell’s results are consistent with those of Smith and Lazo (2001) and Huq *et al.* (2003). Further, these results also indicate that the number of the years with runoff below current drought runoff is likely to increase by about 30% across much of southern Africa by the 2050s (Arnell, 2004) (for details about southern Africa see also Schulze, Meigh & Horan, 2001 and Shulze 2005).

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 Fig. 9.3

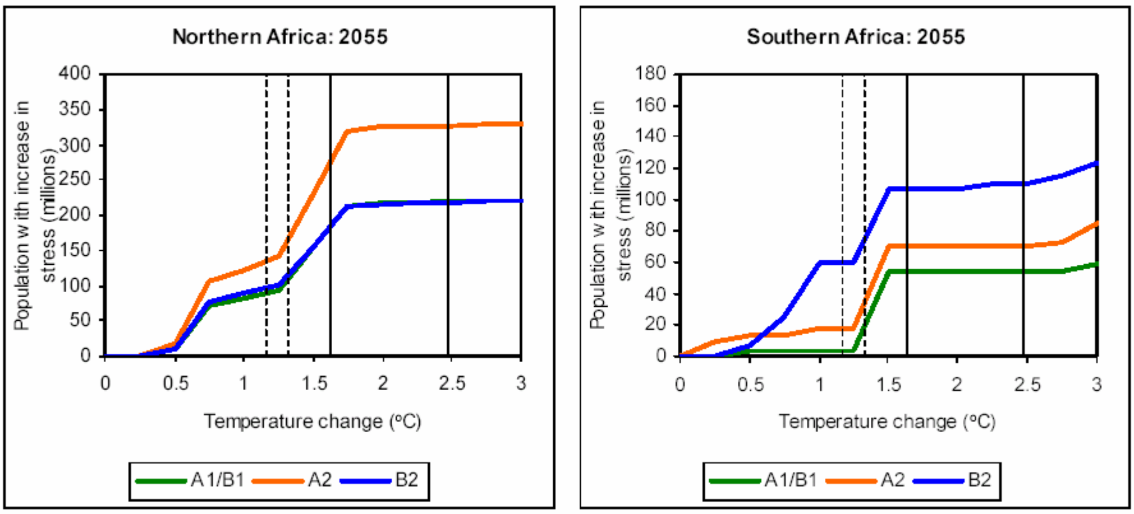


Fig. 9.3: *Number of people (millions) with increase in water stress (Arnell, 2005).*

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). The interaction between climate and other factors influencing water sharing and use are well highlighted for Egypt (Box 9.1).

Box 9.1: Climate, water availability and agriculture 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).

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 in its turn harmful effects on irrigated soils and crops.

Agricultural 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:

- Sea level rise (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 their water requirements thereby directly decreasing crop water use efficiency;
- General increase of irrigation demands;
- High degree of uncertainty about 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;
- Ongoing expansion of irrigated areas will reduce the headroom of Egypt to cope with future fluctuation in flow (Conway, 2005).

Institutional water bodies 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.

Based on the inputs from six GCM models, with downscaled estimations and composite ensembles for the period 2070-2090, drainage impacts across Africa suggest that parts of southern Africa are projected to experience significant losses of what little drainage Africa has. Some areas are particularly impacted (e.g. parts of South Africa).(de Wit and Stankiewicz, 2006). Increases of drainage are estimated for East Africa with increases in rainfall generated in the models. A third critical 'unstable' area is the east-west band from Senegal to Sudan separating the dry Sahara from west Central Africa. Conway (2005), however, is more cautious and argues that there is no clear indication of how Nile flow will be affected, because of the uncertainty about rainfall patterns in the basin, and over water management.

Other assessments for the southern African region (e.g. SAfMA, 2004; Murray-Hudson, Wolski, and Rongrose, 2006; Anderson *et al.*, 2006) show that changes in the hydrology of some of the major water systems (e.g. Okavango River Basin) could also be negatively impacted by changes in climate change, in fact substantially more so than changes associated with human activity (e.g. water abstraction, damming etc). Despite the uncertainties associated with model outputs (e.g. HadCM3, CCC and GLFD GCM scenarios) for periods 2020-2050 and 2050-2080, evidence for the Okavango river basin shows that there is a clear indication of reduced flow from 2050 onwards "…with implications that the mean future river regime may be similar to the most extreme conditions observed from historical records" (Anderson, *et al.*, 2006, 27).

Observed responses to rainfall shifts are already being noted in other terrestrial water sources that could be considered possible indicators of current and future water stress linked to climate change and variability. Evidence of interannual lake level fluctuations, for example, have been observed (1993-1997), and probably result from intense droughts and increases in lake levels (e.g. Lakes Tanganyika, Victoria and Turkana) occurring in 1997-1998, and have been linked to an excess in rainfall in late 1997 coupled to large scale perturbations in the Indian Ocean (Mercier, Cazenave and Maheu, 2002). The role of other complex multiple-stresses e.g. overfishing, pollution, eutrophication and sedimentation also impact on these lakes and influence management and adaptation options to various changes (Odada, *et al.*, 2004).

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 south-western 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, see also further details of a range of possible impacts associated with the Western Cape, Provincial Government of the Western Cape *et al.*, 2005).

A number of other 'drivers' of change, however, may heighten the stresses of climate change in the water sector, such as water policy, water abstraction, impacts of water pressure etc. The role of water management and water governance in the future will also be key in the water sector. Future access to water in rural areas, that depend on low-order streams for surface supply, need to be seriously addressed by countries which share river basins (e.g. De Wit and Stankiewicz, 2006). In a similar vein, Conway (2005) stresses that climate change should be considered in any future negotiations to share Nile water, which should include proportional shares rather than fixed volumes and called for an update of the volumes used in the 1959 Nile Waters Agreement.

9.4.2 Energy

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 exacerbating the scope and scale of climate change impacts. The numbers depending on biomass fuels are expected to increase from an estimated 580 million in year 2000 to 820 million in 2030. Charcoal is being increasingly used as an energy source in many urban cases. This dependency has a great impact on the vegetation cover, forest trees and biodiversity in general (GEO, 2004).

Concerning some futuristic perspectives in the energy sector in Africa**,** biomass is expected to continue to be widely used, projected to account for 80% of residential energy use in 2030 (EIA, 2002). Other projections (e.g. IEA, 2002) suggest that by 2030 most of the people in sub-Saharan Africa will still be without electricity although by 2025 this should stabilize as many seek livelihoods in cities where access to electricity may be possible. Options for exploitation of alternative sources of energy are being explored in both Southern and Northern Africa (GEO, 2003). South Africa is one of the most energy consuming countries in Africa, its energy sector contributing about 15% of the total GDP, and its economy being heavily energy dependant. It is intended in this case, to achieve 5% renewable energy share of electricity production by 2010, when the potential of imported cleaner energy sources (gas and hydro) is considered (Davidson *et al.*, 2002). Electricity supply will increase at a rate of 2.8% per annum. Most of the people without access to electricity in 2030 will, however, be found in sub-Saharan Africa (650 million) (IEA, 2002). The contribution of hydropower's contribution of the total energy resources could decrease from 4.34% in 2001 to 3.39% in 2025 (de Villers *et al*., 2000).

It is estimated that Africa will double its population over the next 50 years, which means that the growth in energy demand would show little signs of slowing down through 2050, increasing by over 300% with respect to 2000. The region would continue to rely significantly on oil and gas, which it has in abundance, 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). Since fossil energy and biomass sources are not sustainable, some countries have initiated energy policies which consist in developing renewable energy sources such as co-generation using sugar bagasse, ethanol programme, small scale bio-energy technologies (Karekezi, 2001). A development project in Sudan integrated the use of energy efficient stoves at the household-level with other natural resources conservation activities. This has largely contributed to energy conservation as well as to improving condition of the vegetation cover (Osman, 2006). A key issue will also be trying to understand more fully the complex mix of fuel uses that people employ, since it is a misconception that electricity simply replaces biomass usage (IEA, 2002) and which electrification projects are feasible given inability to pay for services and other development constraints (IEA, 2002).

9.4.3 Health

In this section future impacts and possible vulnerabilities induced by climate change on both humans and animals are highlighted. Despite the controversy on the links between climate and malaria highlighted above, an area clearly requiring more research and debate, links between climate (including extreme weather events) have impacts on infectious diseases (e.g. Patz *et al.*, 2005; MacMichael, Woodruff and Hales, 2006). Thomas, Davies & Dunn (2004) using the MARA/ARMA models for suitability of malaria in Africa and GCM projections, for example, show that there could be both 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 estimating a 5-7% potential increase (mainly altitudinal) in malaria distribution with little increase in the latitudinal extent of the disease by 2100. Hartman *et al.* (2002) using sixteen climate scenarios show 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 and 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.

An important criterion indicating the effects of climate change and variability is also the altitudinal shift in vector breeding and incidence of disease. Chen et al (2006) observed the presence of malaria vector *Anopheles arabiensis* in the eastern highlands of Kenya where no vectors have been observed before. Cases of malaria have also been reported in the area and these are considered as new records.

The above observations strongly suggest that climate variability and change will increase malaria transmission in the highlands of Eastern Africa where currently transmission is marginal. Currently 16% of the African population is living in the highlands.

Impacts of climate change on health, for example incidence of malaria, also have to be weighed up with reference to existing vulnerabilities and possible adaptations. 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 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) The social and economic cost of malaria is huge and span costs to individuals and households to costs at community and national levels (Malaney *et al.*, 2004; Utzinger *et al.*, 2001; Holding and Snow, 2001).

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 this sickle cell genotype was 26% in a malaria-holoendemic lowland area compared with 3% in a neighboring 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.

The role of other health impacts and 'drivers' of change (e.g. HIV/AIDS and cholera etc) may also be linked to climate change and climate variability and a range of other factors (Harrus and Baneth, 2005). The links between weather and climate and diseases is, however, complex with the role of food security and a range of other multiple stresses compounding and resulting in a range of consequences (see section 9.6). Climate change and variability, for example, may compound existing stresses (e.g. conflict) that may trigger population movement that may then further compound health problems (e.g. Gommes *et al.* 2004). The case in Rwanda, during 1994, is informative (Gommes *et al.*, 2004). With changes in population linked to genocide in 1994, there have also been notable changes in food crops grown (e.g. roots and tubers and cassava) as people try to optimise food production in degraded and reduced availability of land after the war and the household impacts of HIV/AIDS (for other research on the links between agriculture and HIV/AIDS, see for example, du

Guerny 2002a and b). Such food crops (e.g. cassava) that are starch-based and low in protein may further aggravate health problems. Rainfall changes during the time and the outbreak of cholera epidemic (killing over 40 000 people in 1994) further aggravated the tragedy of the Rwandan people. The complex mix of factors of health and a range of stresses therefore requires innovative and urgent research and development 'thinking'.

Having examined some of the possible links between climate change and health, attention now turns to examine changes that could be expected in relation to animals. Livestock in Africa is an important economic activity, and 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 (Baylis and Githeko 2005). Thornton *et al.* (2006a) has observed that the demographic impacts on *trypanosomiasis* rise through modifying habitat suitability for the tsetse fly are likely to be considerable and these impacts may be exacerbated by climate change.

Climate change is expected to affect both pathogen and vector habitat suitability through changes in moisture and temperature (Baylis 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. Rift Valley Fever epidemics are associated with flooding and could increase with a higher frequency of El Nino events. Heat stress and drought are likely to have a further negative impact on animal health, production of dairy products, meat and reproduction as already observed in the USA (St-Pierre *et al*., 2003).

9.4.4 Agriculture (see also section 9.6. on food security below)

The agricultural sector in Africa, as highlighted in the executive summary above, is critical, in some African countries contributing an average 21% of the GDP, and ranging from 10-70% of GDP (Mendelsohn *et al*., 2001). Using previous levels of carbon dioxide and their projected impacts on GDP, the Sahel and IGAD 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*., 2000b).

Scenarios and estimates of change for African agriculture have been undertaken. Using the FAO/IIASA agro-ecological zone model (AEZ) in conjunction with IIASAa global food system model and using climate variables from five different general circulation models under four socioeconomic scenarios (e.g., HadCM3-A1FI 2080s scenario). Fischer *et al.* (2002, 2005) show that for both suitable rain-fed land extent and production potential of cereals, a significant decrease in Northern and Southern Africa could result. Substantial losses of potential agricultural land (AEZ, for example, projects up to an additional 11% of land area of 265 million hectares to be constrained for crop agriculture in southern Africa, Fischer et al, 2005). By the 2080s, AEZ further estimates and increase of 5-8% (60-90 million hectares) of arid and semi-arid land in Africa. Developing countries consistently face a substantial decrease of wheat-production potential, according to all scenarios for the 2080s (in the order of 15-45%); wheat is virtually disappearing from Africa. In Northern Africa, three-quarters of suitable rain-fed land is lost as compared to reference climate conditions.

The case for sub-Saharan Africa is not positive and will surely aggravate the various other suite of stresses already constraining development in the region. Simulations with AEZ suggest that there will be decreases of constraint-free prime land for crop cultivation, there will be an increase of moisture stress and constraints of between 30-60 million hectares in addition to the 1.5 million hectares already unfit for agriculture under current climate (Fischer *et al.*, 2005, 2074).

Individual country results are also a reason for concern. For example, in the results of the HadCM3 scenarios, 20-40 poor and food-insecure countries, with a projected total population in 2080 in the range of 1-3 billion, may lose on average 10-20% of their cereal-production potential due to climate change. With the exception of the results for the NCAR-PCM model, Sudan, Nigeria, Senegal, Mali, Burkina Faso, Somalia, Ethiopia, Zimbabwe, Chad, Sierra Leone, Angola, Mozambique, and Niger lose cereal-production potential in the 2080s for three climate models, across all the emission scenarios. These countries currently have 87 million undernourished people, equivalent to 45 % of the total undernourished population in sub-Saharan Africa (Fischer *et al.*, 2005). By contrast, Zaire, Tanzania, Kenya, Uganda, Madagascar, Cote d' Ivoire, Benin, Togo, Ghana and Guinea all gain cereal-production potential in the 2080s. These eight countries, that gain in cereal production, currently have 73 million undernourished, equivalent to 38% of the undernourished population in sub-Saharan Africa (Fischer *et al.*, 2005). Eid and EL-Marsafawy (2002), reported that climate change could decrease national production of many crops in Egypt (ranging from -11% for rice to -28% for soybeans) by the year 2050 compared to their production under current Egyptian conditions.

Further detailed assessment, combining global and regional-scale analysis (e.g. Jones and Thornton, 2003) show three major types of response of the maize crop to climate change which indicate that: i) crop yields decrease (10 % decrease as result of rainfall changes and temperature changes, but to an extent that can be readily handled by breeding and agronomy; ii) crop benefits from climate change, as is the case in the Ethiopian highlands where substantial localized yield increases are predicted, sometimes up to 100 %; and iii) maize yields decline so drastically, all other things being equal, that major changes may have to be made to the agricultural system, or even human population may be displaced. However, the authors while noting changes in maize production for Africa under various model scenarios also caution that such aggregate results hide several local variations (e.g. yield reductions of more than 1 ton/ha could be devastating for local communities). Furthermore, projected changes in the length of the growing (LGP) period from downscaled HADCM3 GCM scenarios (Fig. 9.4) show that some of the larger losses and gains are located in areas with LGP less than 60 days i.e. in marginal areas for cropping. Also many parts of sub-Saharan Africa are likely to experience a decrease in the length of the growing period. Other areas could experience an increase in the growing season particularly around highland areas (Thorton *et al.*, 2006).

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 may be possible to grow more temperate crops e.g. apples, pears, barley, wheat, etc on the adjoining elevations (Parry et. al., 2004).

Other agricultural activities could also be impacted by climate change. Changes in rain-fed livestock numbers in Africa are already strongly coupled to changes in rainfall and linked to other socio-economic and cultural factors (e.g. Little, Mahmoud and Layne Coppock, 2001; Turner, 2003; Burnsilver, Boone and Galvin, 2003), Several factors, including climate variability and change, constrain pastoral mobility and decision-making in changing environments and these should be carefully considered when assessing impacts and vulnerabilities to climate stress (see Little, Mahmoud and Coppock, 2001; Burnsilver, Boone and Galvin, 2003; Turner, 2003; Boone *et al.*, 2004; Thornton *et al.*, 2004). The impacts of drought on animal survival and productivity, and on peoples' livelihoods and management systems will also, however, depend largely on socio-economic

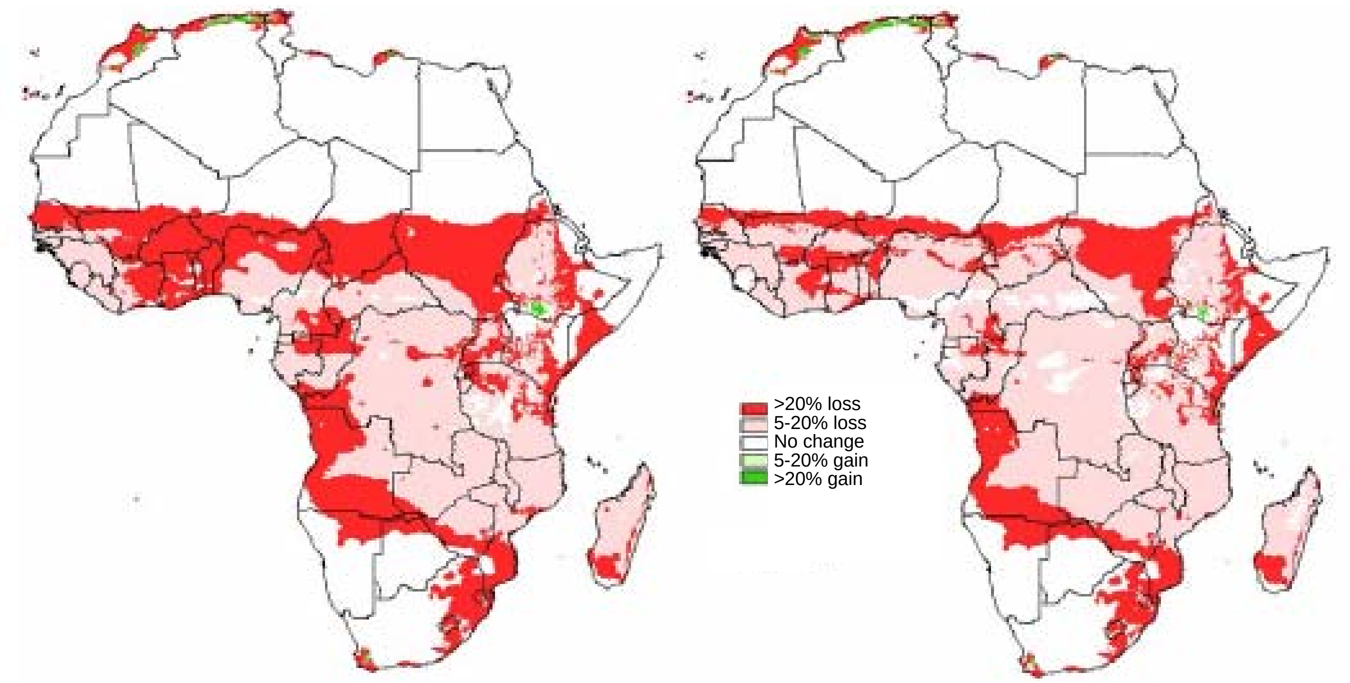


***Fig. 9.4:** Percentage change in length of growing period to 2050, HadCM3 and scenarios A1F1 and A2 (copyright to be obtained) (Thornton et al., 2006b)*

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 are also important sources of revenues, employment and proteins, but are also responsible for overexploitation of some fish stocks (AMCEN/UNEP, 2002). They could be affected by different biophysical impacts of climate change depending on the resources on which they are based (Niang-Diop, 2005). In coastal regions that have major lagoons or lake systems, changes in freshwater flows, and more intrusion of salt waters in the lagoons, will affect species which are the basis of inland fisheries or aquaculture (Republique de Cote d' Ivoire, 2000; Republique du Congo, 2001, Cury and Shannon, 2004). In South Africa, fisheries could be affected by changes in estuaries, coral reefs and upwellings, those being dependant on the two first ecosystems being the most vulnerable (Clark, 2006). 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).

Africa is already experiencing a major deficit in food production in several regions (see food security case study, 9.6 below), and potential declines in soil moisture will aggravate the current agricultural vulnerabilities (Parry *et al.*, 2004). Climatic variability, particularly the changes in the frequency and intensity of extreme meteorological events such as droughts and floods already contributes to crop losses (Jagtap and Chan, 2000). Widespread malnutrition, a recurrent need for emergency food aid, and increasing dependency on food grown outside the region are all current chronic vulnerabilities driven by a range of factors often 'triggered by climate variability' (see 9.6) . Questions still remain on the uncertainty associated with the projections shown above including the role of scale (studies are often too global and mask local level dynamics e.g. the role of gender in food access) and the role of multiple stresses and other factors (e.g. trade, governance, culture, land claims etc). Jones and Thornton (2003), while noting changes in maize production for Africa under various model scenarios, caution that such aggregate results hide several local variations (e.g. yield reductions of more than 1 ton/ha could be devastating for local communities). Given the length of time needed for effective agricultural research cycles, we need to urgently identify much more clearly what the system-level impacts of climate change on poor households might be, and if these are far-reaching, then we need to start work on adaptive and ameliorative options as a matter of urgency (Jones and Thornton, 2003) (see more details in adaptation section and food security case study, 9.6, below).

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 may be threatened. Several key ecosystems are presented here including an introduction to terrestrial and aquatic ecosystems followed by a more detailed focus on components of these e.g. lake, mountain, desert and coastal ecosystems

Terrestrial and aquatic ecosystems

Climate change and variability may result in species losses, extinctions and also constrain the 'climate spaces' and ranges of many plants and animals. Preliminary assessments of over 5000 African plant species show possible shifts in climatically suitable areas for African plant species when using the Hadley Centre third generation coupled ocean-atmosphere climate model for 2025, 2055 and 2085 (McClean *et al*., 2005). Areas of suitable climate for 81-97% of the 5197 plant species examined are projected to decrease in size or shift location (McClean *et al.,* 2005). In South Africa, for example, isolated plant communities, particularly at high altitudes will be affected by temperature rise. Two biomes, the fynbos and succulent Karoo in southern Africa, are predicted to be the most vulnerable to projected climate changes, whilst the savannah is argued to be the most resilient (Van Maltitz and Scholes, 2005). Changes in the seasonal distribution of rainfall could affect fire regimes and plant phonological cues, especially in the southern Cape (Tyson *et al.*, 2002). Assessments also indicate that in South Africa, the savannah and the Nama-Karoo biomes will advance at the expense of the grasslands. In the Kruger National Park, for example, modelling of climate change shows possible losses of up to 66% of species (Erasmus, *et al.*, 2002). Other impacts for other parts of South Africa include those species on the Red List status of the Proteacea in the Cape Floristic region. A loss of area of the Fynbos biome, for example, of between 51% and 65% is projected by 2050 (Midgley *et al.*, 2002). With increasing severity of climate, using eight different land use and climate change scenarios for 2080, the proportion of Critically Endangered taxa increases from about 1-7%, and almost 2% of the 227 Proteaceae taxa could become extinct because of climate change. Most of the threatened taxa occur in low lying coastal areas (Bomhard *et al.* , 2005).

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).

Available climate 'space' for bird species may also change. Among the potential impacts on southern

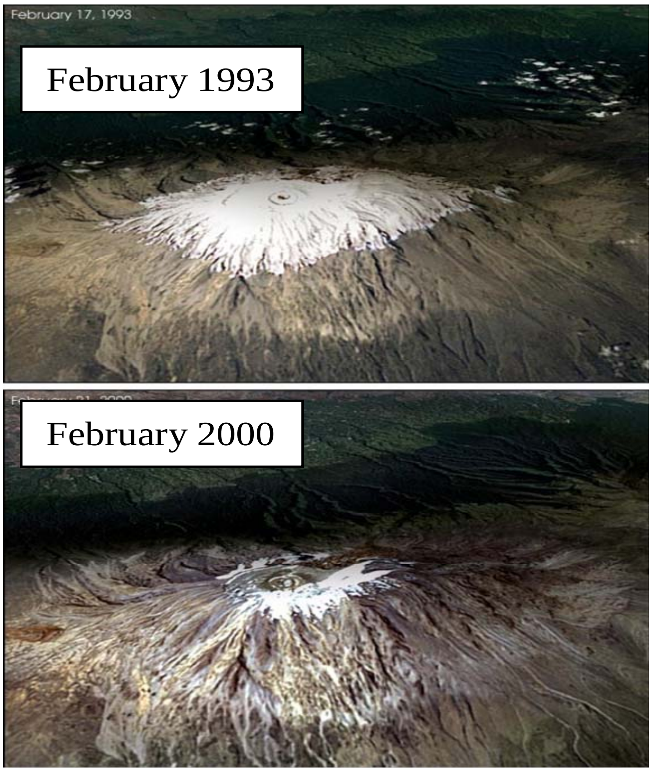
African birds, those with small ranges and restricted to mountain slopes, mountain tops or islands and those occurring mainly at the southern or western extremes of these biomes are ranked highest at risk. By 2050 an estimated six species will lose substantial portions of their range (Simmons, *et al.*, 2004). Despite the uncertainty in current rainfall projections, recent assessments for woody savannah plants, show despite plant hardiness it may be affected by rainfall declines or increases in periodic fluctuations Tews and Jeitsch, 2004). Such changes may spawn conflicts between conservation and other land uses.

Mountain ecosystems

Mountain ecosystems, including, Mt. Kilimanjaro are also vulnerable to future climate change**.** By 2020 indications are that the ice cap could disappear for the first time in 11 000 years. With rising temperature one outcome could be upward migration of vegetation zones. Another cause of ice-cap wasting could lie in increased forest fires as a result of drier and warmer conditions, causing a *down-ward* rather than *upward* migration of species and animals. Downward migration of species of animals and plants are already observed to be occurring because of climate-change forest fires on Kilimanjaro (satellite images from book by Arawala, 2005). Here global warming is not causing upward migration of species but the opposite (Hemp, 2005). Further, the loss of ‘cloud forests’ through fire since 1976 has resulted in 25% annual reductions of fog water (the equivalent of the annual drinking water of 1 million people living in Kilamanjaro) (Hemp, 2005; Agrawala, 2005). (See Box 9.2.)

Box 9.2: Climate change impacts, Mt. Kilimanjaro.

There is clear evidence that climate change is modifying natural ecosystems such as Mt. Kilimanjaro. Six ice cores from Kilimanjaro provide an 11.7 thousand-year record of Holocene climate and environmental variability for eastern equatorial Africa, including three periods of abrupt climate change: 8.3, 5.2, and 4 thousand years ago (ka). Also, over the 20th century, the spatial extent of Kilimanjaro’s ice fields has decreased by 80%, and if current climatological conditions persist, the remaining ice fields are likely to disappear between 2015 and 2020 (Thomson *et al.* 2002).



Source and credit: http://earthobservatory.nasa.gov/ Newsroom/NewImages/images.php3?img_id=10856 Accessed 09 Mav 2006.

Disappearance of the ice cap will substantially reduce goods and services currently offered by the Mount Kilimanjaro Ecosystem. For example, Tanzania Government, through Tanzania National Parks gets revenues through tourism. Kilimanjaro National Park is among the leading national parks in revenue collection (Bonine *et al.*, 2004). Also, the ecosystem supplies water into the Pangani Basin through the Pangani river system. The water is used in many ways. For example, it is used for irrigation on the densely populated slopes of the mountain where traditional furrows are employed to irrigate coffee, bananas and other food crops (Ngana, 2001

& 2002). Further downslopes of the mountain water from the mountain is used to irrigate large schemes (paddy rice and sugar). Along the Pangani River there are three hydropower plants (Nyumba ya Mungu Dam – 8 MW, Hale – 21 MW, New Pangani Falls – 45 MW and Old Pangani Falls – 17.5 MW). All these rely mainly on water from the mountain. Electricity generated contribute about 17% of the ydropower produced in Tanzania (Ngula, 2002). There are other small scale water users such as traditional irrigators, livestock keepers and fishermen whose numbers are also significant bearing in mind that the water pass through the semi arid area where water and green pastures during the dry season are scarce resources (Ngana, 2001 & 2002).

Lake ecosystems

Other ecosystems that could be impacted by climate changes include aquatic ecosystems, particularly large lakes. For example, warming has been shown to have contributed to a rise in surface-water temperature in Lake Tanganyika, which as in turn increased the stability of the water column. Also, a regional decrease in wind velocity has contributed to reduced mixing, decreasing deep-water nutrient upwelling and entrainment into surface waters. Carbon isotope records in sediment cores suggest that primary productivity of the aquatic ecosystem of Lake Tanganyika may have decreased by about 20%, implying a roughly 30% decrease in fish yields (O'Reilly, et. al., 2003). Predicted future climate change may further reduce the Lake's productivity.

Desert ecosystems and land degradation

Sand dune mobilization has also been shown to be linked to climate change. Regardless of the emission scenario used, significantly enhanced dune activity is simulated in desert dune fields in the southern Kalahari basin in the future. By 2099 all dune fields are highly dynamic from northern South Africa to Angola and Zambia (e.g. Thomas, Knight and Wiggs, 2005). Future climate change may also impact land degradation. For example, Meadows & Hoffman (2003) show that former "homeland states" in South Africa are likely to become more susceptible to degradation under predicted climate scenarios.

Coastal and marine ecosystems

The main coastal ecosystems in Africa are mangroves and coral reefs and chapter 6 describes their main potential responses to climate change drivers. With climate change, endangered species associated with these ecosystems, like manatees and marine turtles, could be at risk, along with migratory birds (Government of Seychelles, 2000; Republic of Ghana, 2000; République Démocratique du Congo, 2000). In other countries colonization of lagoons by mangroves is expected due to a better connection with the ocean (République du Congo, 2001).

The important coral bleaching following the 1997-98 extreme El Niño event in the Indian Ocean and the Red Sea is considered to be an indication of the potential impact of climate change induced ocean warming on coral reefs (Lough, 2000; Muhando, 2001; Obura, 2001). Such events could increase the number of people affected by intoxications (such as 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. In the long term, all these impacts will have negative effects on fisheries and tourism. In South Africa, changes in estuaries are expected mainly due to reductions in rivers run off and to drowning or inundation of salt marshes following sea level rise (Clark, 2006). The observed increase in the number of tropical species in the Mngazana estuary is considered to be a potential indication of climate change (Mbande *et al.*, 2005).

Any changes in primary production would propagate into the marine food web and, consequently, will have impacts on the productivity of whole marine ecosystems (Hitz and Smith, 2004). These changes could induce “regime shifts” , in which large marine ecosystems that are climate-dependent change their state (at large spatial scales and at different trophic levels) over a 10–30 year period (Caddy and Garibaldi, 2000), inducing changes in the dynamics of fish and other marine biota (de Young *et al.* , 2004; Polovina, 2004). As pointed out by Cury 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, as well as ecological and behavioural changes (Cury *et al.* , 2003). A noted expression of such regime shifts is 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, like the Benguela systems, where anchovy and sardine co-exist, there has been alternation between regimes of high sardine and high anchovy abundance. Recent colonization of the Canary islands by *Gnatholepis thompsoni* is interpreted as an indication of ocean warming allowing the invasion of Indo-Pacific coral reef gobies belonging to the same genus (Rocha *et al.*, 2005).

9.4.6. Coastal zones

As can be seen above, coastal zones are particularly sensitive to climate. 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. Forty percent 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, coastal megacities with at least 8 million people will be 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.

The first generation of vulnerability and adaptation studies only considered the direct impacts of sea level rise, and few of them used socio-economic scenarios (Niang-Diop *et al.*, 2005). Land losses - either due to coastal erosion or inundation - represent between less than 0.1 to 3% of the total area of each country. In the Mediterranean coastal zone of Egypt and using SRES scenario, between 2,040 and 4,580 ha could be lost by the year 2100 due to sea level rise and land subsidence (Abd El Wahab, 2005). 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). In Cameroon, it was estimated that by the year 2100 the length of the salt wedge in the Wouri estuary would almost disappear with an increase of 15 % increase in rainfall. It substantially icnrease by about 70 km in case of a 11% decrease in rainfall.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 (République 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 potential changes in the frequency and intensity of ENSO events and coral bleaching (Klein *et al.*, 2002).

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). 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, two thirds of the population live in coastal areas and 90% of the country's tourism infrastructures are situated along the coastline.

Population at risk in the coastal zones represents between 0.5 and 17% of the total population but these are conservative values since population growth rates were generally not considered. Economic values at risk are generally actual values but they always represent a high percentage of the national GDP (between 5.8 and 542%) (Niang-Diop, 2005). 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 Dollars for a 1.0 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 Guinée, 2002). In Eritrea, a 0.5-1.0 m rise in sea level will cause damage of about $256.83 million due to the submergence of infrastructure and other economic installations in Massawa, one of the country's two port cities (State of Eritrea, 2001). These results confirm previous studies stressing the high vulnerability of the socio-economic system of African coastal states due to their low economic development. The less affected countries (Mauritius for example) are those with a relatively high GDP.

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) in such environments. According to 2004 statistics, Europe earned a little 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). These benefits may however change with climate change. 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, mangrove vegetation degradation and reduced fresh water supply (water pollution, cholera epidemics, FRITSCH, 2006). However, while some locations may see a diminution of demand from the leisure traveller, others - currently less important as tourism destinations - may see an increase.

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. Although scientific evidence is still lacking, it is probable that flood risks and water-pollution related diseases in low lying regions (coastal areas) and coral reefs bleaching could impact negatively on tourism (Barry and McLeman, 2004). African tourist places and sites, which are currently warm, may attract fewer tourists than currently cool places: Climate change could, for example, lead to a poleward shift and a shift from lowland to highland tourism (Hamilton and al, 2005).

Despite the current paucity of research on the impacts of tourism and climate change for Africa, which could be substantial, available evidence shows some possible impacts:

- excessive heat that could lead to unsuitable conditions for tourism, especially in already warm areas, such as North Africa, the Sahara and the Mediterranean Coast: an increase by 4-5 degrees Celsius on the Mediterranean coast (in A2 scenario for 2100) (GIEC 2001, p.69) could discourage tourists from frequenting coastal resorts during the summer, the peak tourist period (Hamilton et al, 2005);

- sea level rise could increase coastal erosion in Mediterranean popular mass tourism destinations, and threaten tourist accommodation and facilities built along the shoreline. Erosion is already reported in some areas of Tunisia. A simulation for the Rosetta area in Egypt (El-Raey *et al.* 1997) for example, has shown, that for a sea level rise of 0,5 m by 2100, 32% or urban clusters and 52% of historical monuments would be lost;

- an increase in desertification could threaten already stressed oasis ecosystems and endanger oasis tourism, currently developing in Morocco, Tunisia, Libya, Mauritania, and more generally in the Saharan region (INRA 2005);

- other tourist attractions in parts of Africa could also be impacted. For example, melting snow in areas such as Kilimanjaro (already observed), alteration of rainforest and reduced water discharge of Victoria Falls (depending on climate change impacts on rainfalls), and changes in wetlands such as the Okavango Delta (Watson *et al.*, 1997);

Wildlife watching, which is a basis for tourism and an important source of funding for nature conservation, especially in Southern Africa, could be affected. Climate change could create an additional stress to some already altered and fragmented ecosystems of Africa (populations of elephants or Rhinoceros) and necessitate a new delineation of protected areas. Diminution of grasslands replaced either by Savannah or by dry forests could impact on tourist destinations in southern Africa. A fifth (e.g. 15 to 20%) of nature reserves could experience changes in their biomes (refer section 9.4.5. above).

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 throughout the continent (e.g. 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 9.2)

Precipitation and wind events: More intense and variable precipitation events with increased mean and peak precipitation intensities for tropical cyclones leading to increased runoffs and flash floods

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 (Copyright to be obtained).

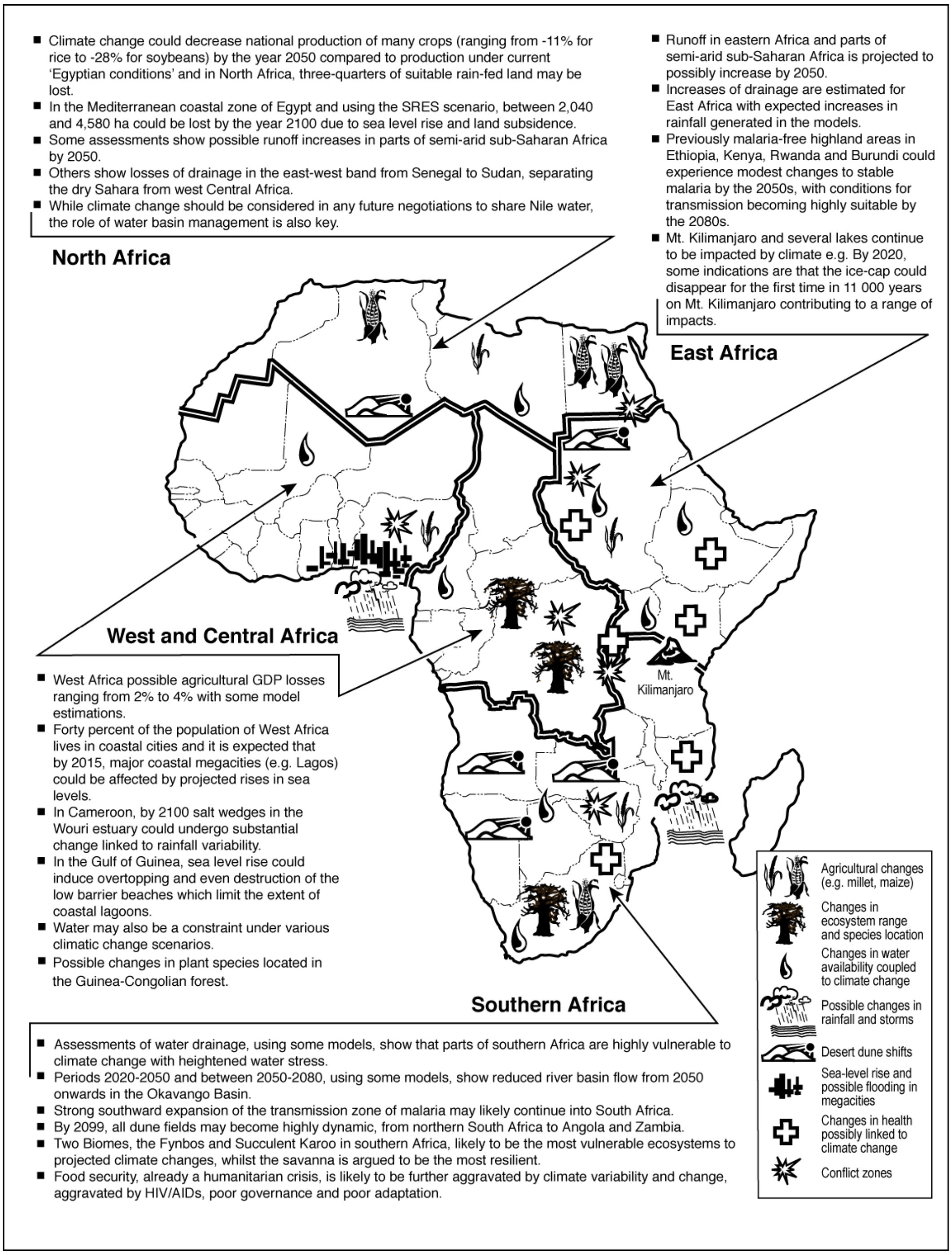


Fig. 9.5: *Summary of Future Impacts linked to climate change as indicated by various scenarios and projections (Fig. Under construction, suggestions welcome)*

are expected in areas within the continent (Denton *et al.* 2001). 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 (Niasse & Afoudou, 2003). At the same time, in Ghana, floods over the White Volta River region claimed lives and caused extensive damage to buildings (Niasse & Afoudou, 2003). 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 and displacement of over 35,000 people (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 (e.g. Washington, Harrison and Conway, 2004). 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 trends, 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 (see water section above (9.4.1). Water reduction and hydrological changes in some parts of Africa (e.g. southern Africa) may result in a number of settlement implications. These may impact adversely on hydropower plants, irrigation schemes, and industrial and domestic water supply. 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).

In summary, a range of possible impacts to climate change have been provided above. The roles of some other stresses, that may compound these have also been included, although clearly thee areas require much further investigation. Despite the uncertainty of the science and the huge complexity of the range of issues, initial assessments show that several regions may be impacted by climate change (Fig. 9.8). Such impacts, it is argued here, may further constrain development and the attainment of the MDGs in Africa. Adaptive capacity and adaptation thus emerge as critical areas for consideration.

9.5. Adaptation: practices, strategies and constraints

The costs of impacts and adaptation to climate change and variability are additional demands being placed on already over-burdened African countries, albeit strained by a range of stresses including poor governance, land tensions, conflicts etc. Despite these problems, Africans are resilient to many stresses and have demonstrated their adaptive capacity and adaptation in the face of climate risks in a number of ways.

9.5.1. Adaptive capacity practices

Adaptive capacity is increasingly being shown to be linked to economic resources and wealth, both in certain international contexts and at more local levels (e.g. Block and Webb, 2001; Ellis and Mdoe, 2003). A range of factors including wealth, technology, education, information, skills, infrastructure, access to resources and management capabilities and political could thus enhance adaptive capacity (e.g. Brooks, Adger and Kelly, 2005). Adaptive capacity, is for example being shown to be 'successful and sustainable' when linked to effective governance systems, civil and political rights, and literacy (Brooks *et al.*, 2004).

Adaptive capacity and practices are, however, a part of a broad and expanding field (Table 9.3) several themes emerging (e.g. social resilience, ecological resilience, economic resilience) that are used to focus the discussion below.

1 ***Table 9.3:*** *Examples of strategies that may build resilience and enhance adaptive capacity.*

SOCIAL RESILIENCE		
Theme	**Emerging characteristics of adaptation**	**Authors**
Social Networks & Social Capital	• Perceptions of risks by rural communities are important in shaping how a problem is perceived (e.g. climate risk). Such perceptions can shape the variety of adaptive actions taken. • Networks of community groups are important ways to cope and adapt to times of climate and other stresses in Africa. • E.g: Local savings schemes, many of them based on regular membership fees are useful financial 'stores' drawn down during times of stress.	• Quinn *et al.*, 2003 • Block & Webb, 2001 • Grothmann & Patt, 2005 • Ellis & Bahiigwa, 2003
Institutions	• **Role & architecture of institutional design & function is critical to understand and better inform policies/measures for enhanced resilience to climate change** • Interventions linked to governance at various levels (state, region & local) either enhance or constrain adaptive capacity. - Egs: 1) The Sahel – CILSS Grouping (Permanent Interstate Committee for the Fight against Drought in Sahelian countries founded in 1973)2) Kwa Zulu-Natal, South Africa, Kenya & Tanzania • The role of policies & institutions in relation to adaptation is an important factor contributing to the sustainability of most coping strategies practised by local communities	• Batterbury and Warren, 2001 • Osman, 2006 • Ellis and Mdoe, 2003 • Owuor et al, 2005 • Reid and Vogel, 2006
ECONOMIC RESILIENCE		
Theme	**Characteristics**	**Authors**
Equity	• **Issues of equity need to be viewed on several scales** • <u>Local scale</u>: within & between community equity results in 'winners & losers' & widens existing inequity in a community or household - Interventions to enhance community resilience can be hampered by inaccessibility of centres to obtain assistance (aid/finance). This results in the relatively well-off gaining access to such schemes, while further exacerbating & constraining the poor's capacity to diversify. • <u>Global scale:</u> Developing countries, should be recognised as possibly having to have 'survival emissions' necessary for the sustainable lives of people in developing countries as they proceed along development trajectories inevitably calling for future emissions growth - The role of CDM's & their impact on a range of factors require more detailed investigation. - While possibly of benefit, these initiatives may place additional pressures on African governments already struggling to contribute to a range of pressures, not least negotiations on climate change.	• UNDP *et al.*, 2003; Beder, 2000 • ADB, 2003 • Vordzorgbe, 2002 • Thomas & Twyman, 2005 • Mortimore & Adams, 2001 • Sonkona & Denton, 2001 • Spalding – Fecher & Simmonds, 2005 • Leach and Leach, 2004; • Mushove & Vogel, 2005
Diversification of Livelihoods	• **Diversification has been shown to be a very strong and necessary economic strategy to increase resilience to stresses** • Eg: agricultural intensification based on increased livestock densities, the use of natural fertiliser, soil and water conservation, and crop and income diversification in Nigeria & Niger. Local markets have also played a crucial role in supporting agricultural innovation. • There is a move in many African rural contexts toward off- or non-farm livelihood incomes • The poor, however, often cannot diversify and have very limited diversification options available to them. Micro-financing & other social safety nets may enhance adaptation	• Toulmin *et al.*, 2000 • Block & Webb, 2001 • Ellis 2000 • Mortimore & Adams, 2001 • Nyong *et al.*, 2006 • Bryceson, 2004 • Ellis & Mdoe, 2003 • Ellis, 2003 • Chigwada, 2005

	if supported by long-term sustainable institutional arrangements.	
Technology	• **Seasonal forecasts, their production, dissemination, uptake and integration in model-based decision-making support systems has been examined in several African contexts**: - Constraints: the lack of limited support for climate risk management in agriculture, the lack of appropriate institutional structures and institutions for such products and the limited understanding of the cultural and local knowledge systems and practices already in use to manage climate risks and the wider constraints to agriculture and other livelihood activities. • **Enhanced resilience to future periods of drought stress may also be supported by improvements in present rain-fed farming systems through**: - water harvesting systems; dam building; water conservation and agricultural practices that can be used to increase resilience in times of drought stress; drip irrigation; development of drought resistant and early maturing crop varieties and alternative crop and hybrid varieties • 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 • Multiple and flexible agricultural management tools and systems are also showing some positive results in enhancing agricultural yields	• UNCTAD, 2003 • Vogel and O'Brien 2001; • Patt, 2001; • Phillips, Makuadze and Unganai, 2001 • Patt and Gwata, 2002; • Archer, 2003 • Roncoli, Ingram and Kirshen, 2001 • Ziervogel, 2004 • Ziervogel and Calder, 2003 • Ziervogel and Downing, 2004 • Ziervogel *et al.*, 2005 • Osman et al, 2006 • Rockstrom, 2003 • Chigwada, 2005 • Seck *et al.*, 2005 • Orindi and Ochieng, 2005 • Matondo, Peter and Msibi, 2005 • Gandah et al, 2000 • Monyo 2002 • Gabre-Madhin and Haggblade, 2004 • Hay et al, 2003 • Malaney et al, 2004 • Van Drunen, 2005 • ECA 2002 • WARDA Annual Report, 1999 • Abou Hadid, 2006 • Benjaminsen, 2001 • Brink et al, 1998
Infrastructure	• **Improvements in the physical infrastructure may improve adaptive capacity.** • Eg: improved communication and road networks provide better access and improved exchange of knowledge and information. • Yet general deterioration in infrastructure threatens the supply of water during droughts • In the absence of any real infrastructural or institutional capacity, most people in sub-Saharan Africa will be at particular risk	• Burton, 2001 • Sokona and Denton, 2001

(*Source: adapted from initial categorization of Rockstrom, 2003, 871*).

9.5.1.1 Social resilience

Social networks and social capital

Social networks and capital are emerging as key adaptive strategies but still require further articulation and understanding (see various examples Table 9.3).

Institutions

The role and architecture of institutional design and function is critical to understand, particularly to better inform policies and measures for enhanced resilience to climate change and to counter other factors e.g. reduce the impacts of poverty etc (Table 9.3). At the continent-wide level, CAADP framework (Comprehensive Africa Agriculture Development Programme), for example, may improve food security through improved sustainable land management efforts, market access being increased etc (NEPAD, 2002). The role of institutions at more local scales, both formal and informal insitutions, however, also need to be better understood (see examples Table 9.3).

9.5.1.2 Economic Resilience

Equity

Increasingly, assessments at the local scale (e.g. see examples Table 9.3) and at the global scale are emerging as areas of increased attention (Leichenko & O'Brien, 2002). The issue of equity and adaptation relates also to the critical factor of past emissions and responsibilities, producers and polluters, who indeed should pay and the introduction of climate change mitigation mechanisms (e.g. CDMs etc). Developing countries, it is argued (e.g. Sokona and Denton, 2001) should be recognised as possibly having to have 'survival emissions' (Mwandosya Mark, 2000 cited in Sonkona and Denton, 2001) necessary for the sustainable lives of people in developing countries as they proceed along development trajectories inevitably calling for future emissions growth (Sonkona and Denton, 2001). The role of CDMS and development (see Spalding – Fecher and Simmonds, 2005) and their impacts on a range of factors (e.g. sustainable development in Africa and local livelihoods, see for example Leach and Leach, 2004) also requires more detailed investigation (e.g. the range of institutional requirements that may be needed). While possibly of benefit, these initiatives may place additional pressures on African governments already struggling to contribute to a range of pressures, not least negotiations on climate change (Spalding-Fecher and Simmonds, 2005) and thus require careful and 'creative thinking' particularly if they are to benefit local livelihoods and communities dependant on 'carbon sink' areas for a range of livelihood and other multiple functions (e.g. Leach and Leach, 2004; Mushove and Vogel, 2005).

Diversification of livelihoods

Diversification has been shown to be a very strong and necessary economic strategy to increase resilience to stresses (see several examples Table 9.3). Diversification strategies, including income-generation projects and selling of labour (e.g. migrating to earn an income (Nyong *et al.*, 2006) is reflecting the move in many African rural contexts, toward off- or non-farm livelihood incomes (e.g. Bryceson, 2004). The poor, however, often cannot diversify and have very limited diversification options available to them (e.g. Block and Webb, 2001; Ellis and Mdoe, 2003). Micro-financing (e.g. Chigwada, 2005) and other social safety nets, as a means to enhance adaptation to current and future shocks and stresses, may also be successful if supported by local institutional arrangements on a long-term sustainable basis (Ellis, 2003).

Technology

Many of the climate change adaptive strategies already identified directly or indirectly involve technology (e.g. warning systems, crop varieties and hybrids, irrigation, settlement and relocation or redesign of communities or infrastructure, flood control measures etc) (See several examples Table 9.3). The role of *seasonal forecasts, their production, dissemination, uptake and integration in model-based decision-making* support systems has been examined in several African contexts showing a number of possibilities and constraints to forecasts as adaptive tools (see examples Table 9.3).

Enhanced resilience to future periods of drought stress may also be supported by improvements in present rain-fed farming systems (Rockstrom, 2003) e.g. water harvesting systems to supplement irrigation practices in semi-arid farming systems ('more crop per drop strategies') (see several other examples Table 9.3).

Recent advances in biotechnology are argued by many to be a possible source of safely harnessing and producing foods that have greater yields, resist pests and diseases and offer other positive nutritional, health and environmental attributes (Brink et al, 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). 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) and 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 which is 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. Another simulation study examined wheat grain yield cultivated under current and future climate conditions (+1.5 ^{O}C and +3.6 ^{O}C) in Egypt, to elaborate a number of adaptation measures under irrigated agriculture system (e.g. Abou Hadid, forthcoming, 2006).

Infrastructure

Improvements in the physical infrastructure may improve the adaptive capacity to periods of climate stress e.g. improved communication and road networks to provide better access and improved exchange of knowledge and information. The opposite is true, however, in most urban centres in Africa, where the general deterioration in infrastructure threatens 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).

9.5.2 Adaptation: costs, constraints and opportunities

Impact and Adaptation costs

Although it is recognized that adaptation has a pivotal role in reducing the costs of climate change, many studies pay little attention to it (DeCanio, 2000).As shown in this chapter, 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 and adaptation (Yohe & Schlesinger, 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.

Despite these problems some economic loss inventories and estimations have been undertaken. The devastating floods, for example, in Mozambique, as result of tropical cyclones reduced the annual growth in Mozambique from 8% to 2% (Washington, Harrison & Conway 2004). The drought, still persisting at the time of writing this chapter, in East Africa, had previously in 2000, reduced Kenya's hydroelectric power resulting in an US$72 million emergency loan form the World Bank (Washington, Harrison and Conway, 2004). In other cases the combined impacts of climate events and other stresses has been marked. In Malawi, for example, a land-locked country with agriculture making up almost half of the GDP (40 percent GDP in 2000), is one of the poorest countries and is also cited as one of the most severely impacted by the scourge of HIV/AIDS. Benson and Clay (2004, 14) list six factors that have increased the economic sensitivity of Malawi to shocks and stress such as droughts and floods including: unsustainable agricultural practices; structural change in agriculture; institutional weaknesses in agriculture; political instability; short-term variability in external aid levels; and the effects of HIV/AIDS.

The costs of impacts and adaptation are heightened by compound and co-occurring stresses. Many countries in Africa have been impacted and responded to compound disasters including droughts and floods in the past few years (e.g. Benson and Clay, 2004). Conflicts, HIV/AIDS, problems of governance and the legacies of structural adjustment and other ongoing problems e.g. (trade regimes debates) all, however, undermine capacity to respond to potential risks (e.g. Benson and Clay, 2004; Vogel and Smith, 2002).

Attempts to quantify adaptation cost in Africa including the evaluation of a set of adaptation measures implemented in some African countries are cited in (Van Drunen, 2005). Examples from Egypt and Senegal are shown in Table 9.4 below:

Table 9.4*: Examples of adaptation costs for Egypt and Senegal.*

	Potential risk	Cost without adaptation	Cost with adaptation
Impact of climate change on the low lying lands of northern fringes of the Delta in Egypt	5.4 million people would be at risk of loosing their homes to flooding in 0.5 m SLR scenario by 2050	US$2.5 billion (at 1992 prices), in addition to a loss of up to 14% of GNP	The cost of protection (adaptation measures) was estimated at 5-10% of GNP
Sand dune encroachment in Senegal	area at risk equal to 948 km2 (.5% of the total area of the country	risk without adaptation goes up to US$ 490 million in 2050	cost of protecting and replanting the dune areas was estimated at US$250 for 40 CM SLR in 2050 with 3% discount rate

Adapted from (Van Drunen, 2005).

Opportunities and constraints

The design of proactive rather than reactive strategies can also enhance adaptation. Pro-active, *ex-ante* interventions, for example in drought interventions [e.g. agricultural capital stock and extension advice in Zimbabwe (Owens, Hoddinott & Kinsey, 2003)] can raise household welfare and heighten resilience in non-drought years. Capital and extension services can increase net crop incomes without crowding out net private transfers. Re-allocating funds from an *ex-post* response to shocks can reduce poverty and increases income in non-drought years and the build up of stocks. Other factors that could be investigated to enhance resilience to shocks, including climate change and variability, include: national grain reserves, grain futures markets, weather insurance, the role of food price subsidies, cash transfers, school feeding schemes etc (for detailed discussion on these Devereux, 2003).

Improved Early Warning systems may also be used to reduce vulnerability to future risks associated with climate variability and change. In malaria research, some show that while epidemics in the highlands have been associated with positive anomalies in temperature and rainfall (Githeko & Ndegwa 2001), those in the semi arid areas are mainly associated with excessive rainfall (Thomson *et al.*, 2006). Using such information it has been argued that climate driven malaria epidemics can be predicted with lead times of 2-6 months before the onset of the event. Such lead times provide opportunities for putting interventions in place in good time to prevent excessive morbidity and mortality.

With regard to energy future 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). Additional 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 (Mansur *et al.,* 2005).

Despite some success stories cited above there is also evidence of an erosion of coping and adaptive strategies as a result of varying land use changes as well as socio-political and cultural stresses in some cases. Such losses in adaptive capacity can trigger agrarian crises and may occur in the future. In areas where there was originally shifting cultivation and livestock movement, for example, permanent settlements have become dominant and the vegetation cover has become reduced, resulting in the loss of long fallows to replenish soils. Continuous cultivation, at the expense of soil replenishment, can result in real 'agrarian dramas' (e.g. Rockstrom, 2003). The interaction of both social and biophysical stresses thus combine to lead to critical stress periods. In Southern Africa, a potentially large disaster and humanitarian crisis is caused "…not by a very serious drought, but rather a small environmental shock, acting on extremely vulnerable societies" (Rockstrom, 2003).

In many communities in Africa, traditional ways are also 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).

Adaptation opportunity –mainstreaming adaptation into development policies

As shown in several cases in this chapter, the low adaptive capacity of Africa is due in large part to the extreme poverty of many Africans, frequent natural disasters such as droughts and floods and agriculture heavily dependent on rainfall as well as a range of macro and micro-structural problems (e.g. impacts of structural adjustment policies, neo-liberalisation, problems of local governance etc). The implications of climate change on development are not fully understood. Factors heightening vulnerability to climate change and affecting national level adaptation have, for example, been shown to include issues of governance, civil and political rights and literacy (e.g. Brookes, Adger and Kelly, 2005). The most vulnerable nations in this assessment (using climate outcomes represented by mortality from climate-related disasters as an indication of climate outcomes), were those situated in sub-Saharan Africa and those that have recently experienced conflict. Reductions in mortality it is suggested may be achieved through increasing government effectiveness and accountability, civil and political rights and literacy (Brookes, Adger and Kelly, 2005).

Considering that climate change is evident Africa, needs to focus on increasing adaptive capacity over the long term, *ad hoc* responses (short-term responses, uncoordinated processes, isolated projects, etc.) are, however, not a solution. One of the solutions that could considered is to mainstream adaptation into national development processes (Huq and Reid, 2005; Dougherty and Osman, 2005) as well as integrate adaptation into all relevant strategies, policies, programs and projects. Such options should not, however, be seen as an abdication of developed countries of their responsibilities in the wider climate change agenda.

There may, for example, be several opportunities of linking disaster risk reduction, poverty and development. Where communities live with various risks, risk-reduction and development can possibly become reinforcing strategies (e.g. Yahmin, Rahman and Huq, 2005). There are early signs of relative success in southern Africa and Ethiopia, with unprecedented efforts by humanitarian and development agencies to collaborate to find ways to move away from reliance on short-term emergency responses to food insecurity to longer-term development-oriented strategies that involve closer partnerships with governments (see Food security case study below and SARPN, www.sarpn.org for several case studies and examples), possible adaptation options already suggested (e.g. Mirza, 2003; Yahmin, Rahman and Huq, 2005 etc). In addition, issues of mitigation, and the range of trade-offs, including those linked to energy usage, and mitigation options (e.g. the design of possible equitable mitigation commitments, see for example, Beg *et al.*, 2002; Adger *et al.*, 2003) cannot be ignored.

The recent formulation of various Poverty Reduction Strategies Papers (PRSPs), could also be used as vehicles to help mainstreaming process, using a combination of ‘Top Down’ and ‘Bottom up’ approaches. According to the World Bank Environment Strategy “integrating environmental considerations into the new Poverty Reduction Strategy Papers” is an urgent task (World Bank, 2000). Moreover, 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. In addition to that, many LDCs are in the process of formulating their National Adaptaton Plans 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).

Notwithstanding these efforts and suggestions, the context and the realities of the causes of vulnerability to a range of stresses, not least climate change and variability, must be kept centre stage. “Uncovering the structural causes of poverty at international, national and local levels must be centre-stage in formulation of poverty-alleviating strategies” (Bryceson, 2004, 623). Despite some optimistic views that some ‘… are likely to absorb and build on ideas that are now flowing in from the outside (in this case the Sahelian region, e.g. Batterbury and Warren, 2001), others (e.g. Bryceson, 2004) caution that various notions of rural capacity and efforts to enhance sustainable livelihoods in Africa cannot ignore the impact of neo-liberal policies and current world market conditions that leave avenues for ‘achieving poverty reduction disturbingly vague’ (Bryceson, 2004, 632). The causes, impacts and legacies of various strategies including liberalisation policies, decades of SAP structural adjustment programmes and market conditions cannot be ignored in discussions on poverty alleviation and adaptation to stresses (including climate change), areas that require much more intensive investigation.

9.6 Case Studies

9.6.1 Food insecurity in Africa

Although the extent and nature of climate change impact on food production are yet uncertain, it has long been recognised that climate variability and change have an impact on food production, as outlined above (e.g. Mendelsohn *et al.* , 2000a and b; Fischer *et al.* , 2002; see also Kurukulasuriya and Rosenthal, 2003; Devereux and Maxwell, 2003; IRI, 2004). Food security is, however, no longer defined solely in terms of the food-production components of food systems (Gregory, Ingram and Brklacich, 2005). Broadly speaking, food security is less seen as *sufficient global and national* *agricultural food production*, than as *livelihoods that are sufficient to provide enough food for individuals and households* (Maxwell, 2001; Devereux and Maxwell 2003; Devereux, 2004). The key recognition in this shifting focus is that there are multiple factors, at all scales, that impact on an individual or household's ability to *access* sufficient food, such as household income, human health, government policy, conflict, globalisation, and market failures (HSRC, 2003; Misselhorn, 2004; FIVIMS SA, 2005; Marsland, 2004; Gommes *et al.*, 2004; SARP, 2004; Maxwell and Devereux, 2003). 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, they were more complex than before, being precipitated b 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, 2001)

Building on the recognition that there are numerous factors affecting food access, three principle components of people's food security may be identified: the *availability* of food (through the market and through own production); adequate purchasing and/or relational power to acquire or *access* food; and the acquisition of sufficient *nutrients* from food acquired, which is influenced by the ability to digest and absorb nutrients due to human health, access to safe drinking water, environmental hygiene and the food nutritional content itself (Swaminathan, 2000; Hugon and Nanterre 2003; Young, 2001; Gommes *et al.* , 2004). The importance of this more nuanced understanding of food security in relation to climate change is that climate change may, either directly or indirectly, profoundly impact on all three of these components in shaping food security (Fig. 9.6).

The potential impacts of climate change on *food access* in Fig. 9.6. may, for example, be better understood in the light of changes in Africa's livelihoods landscape, in which a trajectory of diversification out of agricultural-based activities - 'deagrarianisation'- has been found in the livelihoods of rural people in many parts of sub-Saharan Africa (Bryceson, 2002; 2004). The assumption that people's food security in Africa derives solely (or even primarily) from agricultural production is thus now a contested area (Adger and Vincent, 2005). At the same time, for the continent as a whole, the agriculture sector, which is highly dependent on precipitation, is estimated to account for approximately 60 per cent of total employment, indicating its crucial role in livelihoods and food security derived through food access (The Royal Society 2005). A further illustrative climate-change impact on livelihoods is its possible negative impacts on the tourism sector, caused by temperature, precipitation and sea-level changes which in turn will have an impact on people's livelihoods and ability to secure food (e.g. Hamilton, Maddison and Tol, 2005).

The key issues, therefore, in relation to the potential impacts of climate change on food security in Africa encompass not only a narrow understanding of the impacts of climate change on food production, but a wider understanding of how climate change might interact with other environmental, social, economic and political factors that determine the vulnerability of households, communities and countries, as well as their capacity to adapt (Swaminathan, 2000; Brookes, Adger and Kelly, 2005; Adger and Vincent, 2005); the impact of climate change on food security cannot be considered independently of the broader issue of human security (O'Brien, 2006). The inclusion of climate change in understanding human vulnerability and adaptation is being increasingly explored at the household and community levels, as well as though regional agro-climatalogical studies in Africa, and a number of studies 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 the face of climate change and variability. Scenario analyses of climate change in the West African Sahel, for example, suggest an increasingly high-risk environment for agriculture, including a southward shift of arid and semi-arid zones, a shift in the onset of the growing season, and lower yields (Verhagen, Dietz and Rubin, 2001). The impact on food security, however, is mediated by farmer's adaptation capacity and choices which are based on a variety of driving or causal mechanisms, including previous climate experiences which given impetus to new response strategies which have enhanced their capacity to adapt to future events (Verhagen, Dietz and Rubin, 2001). Livelihood diversification, a key coping and adaptive mechanism to periods of changing rainfall and other pressures, has been found to be further enabled in the Sahel with increased mobility as people become more urbanised (Mortimore and Adams, 2001). The importance of an integrated 'systems' view of linkages between climate change, food security and livelihoods is further highlighted in research in Southern Mali, in which Abdulai and CroleRees (2001) show results resonating with other investigations (e.g. Ellis, 2003 and others), that poorer households some

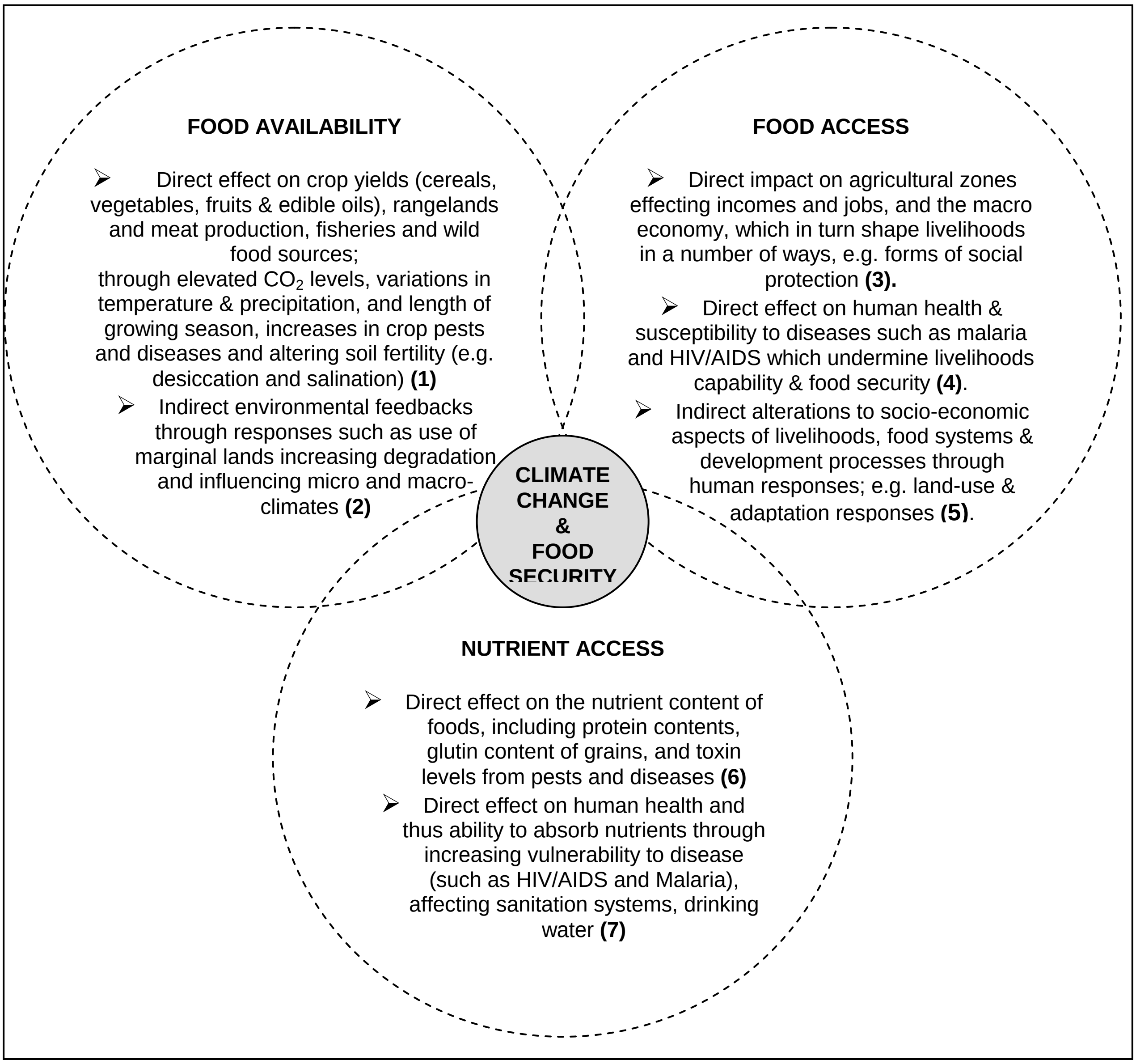


Fig. 9.6: *Linkages identified between climate change in Africa and three major components of food security. [References: (1) Swaminathan, 2000; Turpie et al., 2002; Fischer, Shah and Velthuizen, 2002; Rosegrant and Cline, 2003; AIACC, 2004; The Royal Society, 2005. (2) Fischer, Shah and Velthuizen, 2002; The Royal Society, 2005. (3) Turpie et al., 2002; African Union, 2006. (4) Piot and Pinstrup-Anderson, 2002; Turpie et al., 2002; Mano, Isaacson and Dardel, 2003; USAID, 2003; Gommes et al., 2004; Van Lieshout et al., 2004. (5) AIACC, 2004; Brooks, Adger and Kelly, (in press); Adger and Vincent, 2005; Gregory, Ingram and Brklacich, 2005; Thomas and Twyman, 2005; O'Brien, 2006. (6) The Royal Society, 2005. (7) Swaminathan, 2000; Gommes et al., 2004; Schulze, Meigh and Horan, 2001.]*

distance from local markets have fewer opportunities in non-cropping activities than their counterparts closer to local markets. Research elsewhere in the world indicates that elements of social capital (such as associations, networks and levels of trust) are important determinants of social vulnerability to climate change, but how these develop and are used in mitigating vulnerability remain unclear (Adger, 1999).

While exploring the local level dynamics of people's vulnerability to climate change - of which adaptive capacity is a key component - is critical in developing an understanding of the future of food security in Africa, such understandings cannot simply be aggregated to reflect national or regional vulnerability (Brookes, Adger and Kelly, in press). A number of recent studies are beginning to probe the enormous challenges of developing scenarios of adaptive capacity at multiple scales, and a complex range of factors, including behavioural economics (Grothmann and Patt, 2005), national aspirations and socio-political goals (Haddad, 2005), governance, civil and political rights and literacy (Brookes, Adger and Kelly, in press), economic well-being and stability, demographic structure, global interconnectivity, institutional stability and well-being, and natural resource dependence (Adger and Vincent, 2005), are all emerging as powerful determinants of vulnerability and the capacity to adapt to climate change. Such determinants permeate through food 'systems' to impact on food security at various levels. Attainment of the Millennium Development Goals, including the first goal which is to eradicate extreme poverty and hunger, in the face of climate change will therefore require science that specifically considers food insecurity as an integral element of human vulnerability within the context of complex social, economic, political and biophysical systems, and that is able to offer usable findings for decision makers at all scales.

9.6.2 Drought in the Sahel

The semi-arid Sahel, constituting the transition zone between the arid Sahara and humid tropical Africa, has exhibited considerable rainfall variability on both inter-annual and decadal timescales throughout the twentieth century, while paleo-environmental and historical data also indicate significant rainfall variability on centennial and millennial scales (Brookes, 2004). A number of historical sources record periods of serious drought; Tarhule and Woo (1997) 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 consequent socio-economic challenges have attracted diverse international interest groups emphasizing the need to understand the complex causes of droughts in the Sahel (Batterbury and Warren, 2001; Foley *et al.*, 2003; Dia *et al.*, 2004).

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 (Brookes, 2004). 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 (Foley *et al.* , 2003; Lioubimtseva and Adams, 2004). Emerging hypotheses on the current Sahel climate regime include the role of changing SSTs, land cover changes and land degradation that act 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 drivers push 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 provides us with examples of both recent climate changes, complex interacting drivers of change and of cases of coping and adaptation to change. The Sahelian 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 where 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 (Fiki and Lee, 2004).

Farmers and pastoralists 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 (Brookes, 2004). This process also transforms the nature of societies and communities and thus requires greater understanding of the complex drivers of change in the region.

Climatic future of the Sahel

The climatic future of the Sahel remains uncertain. Since 2001, a number of published studies have suggested that increases in atmospheric CO_2 will lead to an enhanced West African Monsoon, wetter conditions in parts of the Sahel, and an expansion of vegetation into the Sahara (Brovkin, 2002; Claussen *et al.* , 2003; Maynard *et al.* , 2002). A study by Wang and Eltahir (2002) suggests that the Sahelian “biosphere-atmosphere system … is more resilient to drought-inducing external forcing” at 350 than 300 ppm of CO_2 and they forecast more prolonged humid periods and shorter dry episodes in the Sahel in the future. While a wetter Sahel might improve the prospects for agriculture and pastoralism, such a change would also be associated with risks. For instance, heavy rains in the 1950s led to crop failure and famine (Grolle, 1997), while in recent years wet conditions have allowed locust swarms to flourish in the Sahel, increasing food insecurity (FAO, 2004). Wetter conditions would also be associated with an increased incidence of flash flooding, and might also affect the distribution of water-borne diseases transmitted via surface water or the movement of human and animal populations.

While anthropogenic global warming may lead to a more robust rainfall regime in the short term, a continued rise in CO_2 concentrations may cause an increase in regional aridity in the latter part of the twentieth century. Wang and Eltahir (2002) suggest that vegetation changes associated with a shift to a wetter and more robust rainfall regime are partly the result of an enhanced CO_2 fertilisation effect which is unlikely to be sustained at higher CO_2 concentrations. Furthermore, a modelling study by Mitchell *et al.* (2000) suggests that stabilising atmospheric CO_2 concentrations at 550 and 750 ppm by the end of the twenty first century will result in a warming of the southern hemisphere oceans and northern Indian Ocean relative to the remaining northern hemisphere oceans, a pattern that is associated with dry conditions in the Sahel.

The response of the African Monsoon to increased CO_2 concentrations is thus likely to be highly non-linear, and the Sahel is likely to continue to experience a high degree of climatic variability on a range of timescales for the foreseeable future. Sahelian societies may be confronted by hazards associated with both increased and decreased rainfall over the course of the twenty first century. Any strategies to exploit newly productive areas resulting from increased rainfall must consider the prospects of a return to aridity, and avoid the mistakes of the 1950s and 1960s which led to an exacerbation of vulnerability.

9.6.3 Indigenous Knowledge Systems

Concept of indigenous knowledge

Until recently, the indigenous knowledge of local communities has not been considered in formal planning and development initiatives. Indigenous knowledge has been defined as institutionalized local knowledge that has been built upon and passed on from one generation to the other by word of mouth The term indigenous knowledge is best used to distinguish between knowledge systems developed by a community and scientific knowledge system which are generally referred to as 'western' or "modern' knowledge (Ajibade, 2003). It is the basis for local-level decision-making in many rural communities. Indigenous knowledge has value not only for the culture in which it evolves, but also for scientists and planners striving to improve conditions in rural localities.

In recent times, the importance of indigenous knowledge has been realized in the design and implementation of sustainable development projects. However, little has been done to incorporate this into formal climate change mitigation and adaptation strategies. Climate change cannot be divorced from sustainable development as sustainable development may be the most effective way to frame the mitigation question and a crucial dimension of climate change adaptation and impacts (Swart *et al.* 2003). Incorporating indigenous knowledge into climate change policies can lead to the development of effective adaptation strategies that are cost-effective, participatory, and sustainable (Robinson and Herbert 2001). This case study highlights examples of indigenous knowledge related to climate variability and change in Africa.

Indigenous Knowledge in Reducing Vulnerability to climate variability and change

Local communities and farmers in Africa have developed intricate systems of gathering, predicting, interpreting and decision-making in relation to weather. A study in Nigeria (Ajibade and Shokemi, 2003) identified five weather systems, which local communities and farmers were capable of forecasting using accumulated experiences. These include rainfall, thunderstorm, windstorm, harmattan and sunshine. The occurrence of some of these as observed could also be modified (induced or prevented). The study concluded that indigenous methods of weather forecasting could compliment rather than contradict western-based methods. A similar study in Burkin Faso showed that farmers' forecasting knowledge encompasses shared and selective repertoires. Experienced (mostly elderly male) farmers formulate hypotheses about seasonal rainfall by observing natural phenomena, while cultural and ritual specialists draw predictions from divination, visions, or dreams (Roncoli *et al.*, 2001). The most widely relied upon indicators are the timing, intensity, and duration of cold temperatures during the early part of the dry season (November–January). Other forecasting indicators include the production of fruit by certain local trees, the water level in streams and ponds, the nesting of small quail-like birds, insect behaviour in rubbish heaps outside compound walls. After exploring ways in which local knowledge converges with western scientific knowledge and how they diverge, the study concludes that western scientific knowledge, the study calls for the integration of both knowledge systems in the provision of information to improve the local production system and encourage sustainable development. To a great extent, these systems of climate forecasts have been very helpful to local farmers and pastoralists in managing their vulnerability. Farmers are known to make decisions on cropping patterns based on local predictions of climate, and decisions on planting dates, based on complex cultural models of weather.

Indigenous knowledge in Adaptation

Lack of adaptive capacity is often cited as one of the constraints to reducing Africa's vulnerability to climate change. Be that as it may, one should not assume a vacuum in knowledge regarding adaptation. African communities and farmers have always coped with changing environments. They do not only have knowledge about practices, they also have knowledge of how to adapt to adverse environments and shocks. The enhancement of indigenous capacity is a key to the empowerment of local communities and their effective participation in the development process (Leautier, 2004). People are better able to adopt new ideas when they can be seen in the context of existing practices and ways of doing. Several projects have demonstrated that capacity building that considers the perspectives of local communities and builds on existing capabilities (available knowledge and institutions) helps create increased ownership, sustainability, and relevance of capacity enhancing measures.

Local farmers in several parts of Africa have been known to conserve carbon in soils through the use of zero tilling practices in cultivation, mulching and other soil management techniques (Osunade 1994). Natural mulches moderate soil temperatures and extremes, suppress diseases and harmful pests, and conserve soil moisture. Before the advent of chemical fertilizers, local farmers largely depended on organic farming, which can also reduce greenhouse gas emissions. The use of natural plants as agrochemicals have also been reported (Gana, 2003). The study found wide-spread use among small-scale farmers of indigenous plant materials to combat pests that normally attack their food crops. Because plant materials are natural, they have been found to be non-toxic, readily available, and less expensive compared to synthetic and very often poisonous substances found in the open markets. Other indigenous strategies that are adopted by local farmers include controlled bush clearing, revegetating bunds or using tall grass such as *Andropogon gayanus* for fixing soil surface nutrients washed off by runoffs, mulching, using erosion control bounding, namely contour stone bund and tree-trunks to reduce significantly the effects of runoffs, restoring lands by using green manure, constructing stone dikes, managing Low-lands and protecting river banks (AGRHYMET, 2004).

Adaptation strategies that are applied among the pastoralists include the use of emergency fodder in times of droughts, multi-species composition of herds to survive climate extremes, and culling of weak livestock for food during periods of drought. During drought periods, pastoralists and agro-pastoralists change from cattle to sheep and goat husbandry as the feed requirements of the later is less than the former (Oba 1997). Pastoralists' nomadic mobility reduces the pressure on low carrying capacity grazing areas through the circular movement from the dry northern areas to the wetter southern areas of the Sahel. This system of seasonal movement represents a local type of traditional ranching management system of range resources.

African women are particularly known to possess indigenous knowledge to maintain household food security particularly in times of droughts and famine. They often rely on minor crops or semi-domesticated plants, more tolerant to droughts and pests, providing a reserve for extended periods of economic hardship (Ramphele, 2004). In southern Sudan, women are directly responsible for the selection of all sorghum seeds saved for planting each year. They cull seeds and preserve a spread of varieties that will ensure resistance to the variety of conditions that may arise in any given growing season (Easton and Roland, 2000).

Not only is local knowledge being called on to enhance the understanding of adaptive capacity but such knowledge is also being used to inform the existing science of global environmental change and to challenge some of the myths that feed certain notions of environmental change in Africa (e.g. Davis, 2005 building on much earlier work by Ellis and Swift, 1988, among others). Existing data, and indigenous ecological knowledge, for example, drawn from Morroccan range managers, is contesting notions of increased desertification due to overgrazing or other pastoral activities with Davis (2005) arguing for a careful examination of ‘privileged knowledge’ vs ‘suppressed knowledge’ in global environmental change in Africa (e.g. Davis, 2005, 13). Such interrogations of ‘drivers’ of land-use change may become of increasing relevance particularly as land use changes are being seen to be strong contributing factors ‘driving’ the climate system in parts of Africa (see section 9.3.1. above). In other cases, it is argued that current patterns of adaptation, in the face of a range of stresses including climate stress, can build on traditional and historical cases of success. “If these rich local traditions have been so adaptable in the past, as they certainly have been, they are likely o be able to absorb and build on ideas that are flowing in rapidly form the outside” (Batterbury and Warren, 2001).

9.7 Conclusions

9.7.1 Links between climate change and sustainable development

Climate has always been something that those living in Africa have had to contend with. The difference, however, for many Africans is that their ability to respond is already burdened by other demands and stresses e.g. HIV/AIDS, conflict, land struggles etc. Despite good economic growth in some countries and sectors in Africa [e.g. in 2003 the economic growth rate of Africa was 3.6. per cent – a four-year high (OECD, 2003/2004)] large inequalities still persist and hopes of reaching the MDGs by 2015 are slipping (e.g. OECD, 2003/2004).

Although future climate change seems to be a marginal issue when compared to the current pressing issues of development and the existing challenges of poverty (Davidson *et al.*, 2003), it is clear in some cases that climate change and variability, and increased disaster risks, may hamper development. On an annual basis, for example, developing countries have absorbed US $35 billion in damages from natural disasters (Mirza, 2003). A challenge therefore is to shape and manage development while at the same time building resilience to shocks, including those related to climate change and variability (Davidson *et al.*, 2003), in the context of competing sustainable development objectives at various scales and at various levels (Adger *et al.*, 2003).

9.7.1.1 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 (MDGs), in particular to halve by 2015 the proportion of people who live in poverty. While climate change may not have featured directly in the goals it is clear from evidence here that climate change and variability may be an additional impediment to achieving them (Table 9.5).

Table 9.5: *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	Potential Impacts
• Eradicate extreme poverty and hunger (Goal 1)	Climate Change may reduce poor people's livelihood assets, for example health, access to water, homes and infrastructure. It may also alter the path and rate of development **(09.5)** 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, placing possible additional strains on regional and local food security **(09.6.1).**
• Health related goals: Combat major diseases • Reduce infant mortality Improve maternal health (Goals 4,5 & 6)	Climate change is likely to directly impact children and pregnant women because they are particularly susceptible to vector and water borne diseases e.g. anaemia – resulting from malaria which is currently responsible for a quarter of maternal mortality. Other expected impacts include: • Increase heat-related mortality and illness associated with heat waves (which may be balanced by less winter cold related deaths in some countries) sections • 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). **(09.4.3).** • Declining quantity and quality of drinking water, which exacerbate malnutrition, since it is a prerequisite for good health . • Reducing natural resource productivity and threatening food security, particularly in sub Saharan Africa? (**09.4.5; 09.6.1**)
• 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 **(09.4.5; 09.4.6).** - Climate change would alter the ecosystem-human interfaces and interactions that may lead to loss of biodiversity and hence erode the basic support systems for the livelihood of many people in Africa. **(09.4.5; 09.6.1).**
• Achieve universal primary education (Goal 2)	**Indirect impacts**: Links to climate change include: • 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. **(09.2.2).**

Millennium Development Goals: Climate Change as a cross-cutting issue	
Millennium Development Goal	Potential Impacts
• Promote gender equality and empower women (Goal 3)	**One of the expected impacts** of climate change is that it could exacerbate current gender inequalities, through impacting natural resource base leading to decreasing agricultural productivity. This may place additional burdens on women's health, and reduce time available to participate in decision-making and for practicing 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. **(09.5.1-09.5.3; 09.7.1).**
• Global Partnerships (goal 8)	Global climate change is a global issue and responses require global cooperation, especially to help developing countries adapt to adverse impacts of climate change

**The order of the MDGs Goals as listed here represents the goals that could be directly impacted first, followed by those that are indirectly impacted.*

9.7.1.2. Relationships between mitigation policies and development

Limiting climate change to 'safe' levels in the long term is likely to require not only focussing on poverty, climate change and adaptation but also focussing on climate change mitigation priorities and strategies to enhance development (Beg *et al.*, 2002). GHG emissions are, for example, insignificant across with the major emissions in these areas estimated to be coming from land use and deforestation. At the same time, however, the region is one of the most vulnerable to the impacts of climate stress and possible climate change. Therefore several 'ancillary benefits' of GHG mitigation and development could be achieved e.g. avoiding loss of life through illness due to air pollution (e.g. Beg *et al.*, 2002) with some indications of the net ancillary benefits being estimated (e.g. OECD *et al.*, 2000). It is critical, however, for developing countries to ensure that these policies are not implemented at the cost of reduced economic development (Beg *et al.*, 2002), and it is here that the synergies and tradeoffs of such policies require much closer investigation.

The Clean Development Mechanism (CDM) is the only Kyoto mechanism whereby developed countries invest in Southern, or developing countries, and it is aimed at being part of a program of sustainable development. For some developing countries, this is important because of the possible attraction of foreign investment. However, in the African context a wide vision of the possibilities of mitigation must be taken (e.g. Leach and Leach, 2004; (Spalding-Fech and Simmonds, 2005, see also the recent World Bank Climate Plan, Mekay, 2006).

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

9.8.1 Uncertainties, confidence levels and unknowns

- While climate models are generally consistent regarding the direction of warming in Africa, projected changes in precipitation are less consistent.
- The role of land-use and cover change seems to emerge as a key theme, although the links of land use changes, climate stress and possible feedbacks, are not yet clearly understood.
- The contribution of climate to food insecurity in Africa is still not fully understood, particularly the role of multiples stresses. While drought may affect production in some years, climate variability does not explain the continuous decline of food production for three or four decades in Africa. Better models and methods to better understand 'multiple stresses', particularly at a

range of scales e.g. global, regional and local, are required.

- Several areas of debate also exist, particularly with reference to health, frustrating attempts to attribute, with confidence, cause to single 'drivers' of change (e.g. the role of climate in influencing malaria). The impact of climate change on other health problems and major diseases is also, despite a few cases, still speculative.
- Impacts in the water sector, while addressed by global and regional scale model assessments, are still relatively thin for local assessments, particularly examining ground water impacts.
- Several of the impacts and vulnerabilities presented here are derived from global models which mask local level situations. Developing and improving local-level climate models and scenarios could improve the confidence attached to the various projections.
- Finally, there is still much uncertainty of attributing the role of climate change in complex systems, shaped by various interacting multiple stressors, with degrees of confidence. Preliminary investigations do give some indications of possible changes, but these require more analysis.

9.8.2 Research gaps and priorities

As shown at the outset of this chapter, there has been a substantial shift from an impacts-led approach in climate change science to a vulnerability-led approach. Despite this shift, much of the research remains focussed on impacts. For Africa, as this chapter has attempted to show, however, a great deal more needs to be done to understand and show the links between vulnerability, impacts and adaptation to climate change and variability. Some research gaps are identified below:

Climate
The climate of Africa is still not fully understood. Climate models developed from GCMs 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. A further need is an improved understanding of climate variability, periods of climate extremes, and links to climate change.

Water
Detailed, regional-scale research of the impact of, and vulnerability to, climate variability and change with reference to water is needed e.g. for African watersheds and river basins including the complex interactions of water governance in these areas. Water quality and its relation to water usage patterns is also an important issue that needs to be incorporated into future projections.

Energy
There is very little detailed information on the impacts and vulnerabilities of the energy sector in Africa to climate change and variability. There is also a need to identify and assess the barriers (technical, economical and social) to the transfer and adoption of alternative and renewable energy sources specifically solar energy as well as the design, implications, impacts and possible benefits of current mitigation options (e.g. CDMs).

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 ecosystems including wildlife species in Africa. Assessment of the impacts of climate variability and change on important, sensitive and unique ecosystems in Africa (hotspots) e.g. Rainforest of Congo Basin, Mountainous biodiversity (e.g. Mara mountain in Sudan, Kenya and Kilimanjaro) still require further research.

Tourism

There is a need to enhance practical research regarding the vulnerability and impacts of climate change on tourism, as tourism is one of the important and highly promising economic activities in Africa. There seem to be large gaps in research on energy and tourism implications and impacts of climate change.

Health

Most assessments have concentrated on malaria. There is a need to examine the vulnerabilities and impacts of future climate change to and for other diseases in Africa such as dengue fever, meningitis, etc. as well as seriously beginning a dialogue and research effort on the heightened vulnerabilities associated with HIV/AIDS and periods of climate stress and climate change. There have been, arguably, few attempts to really explore this area of research in Africa.

Agriculture

More regional and local research is still required to study the relation between CO_2 enrichment and future production of agricultural crops in Africa. Very little research has been conducted on the impacts of climate change on livestock, plant pests and diseases. The livestock sector is a very important sector in Africa and is considered very vulnerable to climate change.

Adaptation:

There is need to improve our understanding of the role of complex socio-economic, socio-cultural and biophysical systems, including a re-examination of possible myths of environmental change and links between climate change, adaptation and development in Africa. Such investigations arguably underpin much of the emerging discourse on adaptation. There is also a need to assess the current and expected future impacts and vulnerabilities that may arise from the interaction of multiple stressors on the coping capacities of African communities.

There is also a need to improve and continue to assess the means (including the institutional design and requirements) by which scientific knowledge and advanced technological products e.g. (early warning, seasonal forecasts) could be used to enhance resilience of vulnerable communities in Africa in order to improve their coping capacity to current and future climate variability and change. There is also the need for recognised ‘hubs’ or centres of excellence that need to be established in Africa where African scientific capacity can be developed by African scientists, enhancing institutional ‘absorptive capacity’ in the various regions to improve research in fields of climate change impacts, vulnerability and adaptation.

Finally, despite the shift in focus from ‘impacts-led’ research to ‘vulnerability-led’ research there are still few studies that clearly show the interaction of multiple stresses and adaptation to such stresses in Africa. The role of land use and cover change is one area that could be further explored to enhance the understanding of the complex system. Likewise, while there is evidence of researchers grappling with various paradigms of research e.g. disaster risk reduction and climate change, there are still few detailed and rich compendia of studies on ‘human dimensions’ interactions, adaptation and climate change (both of a historical, current and future scenarios nature). The need for better understanding, methods and meta- and detailed local-level analysis of the role of ‘multiple stressors’ in the African context, is clearly evident from much of this chapter.

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