Chapter 9: Africa

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Executive Summary

Africa is one of the most vulnerable continents to climate change and climate variability, a situation aggravated by the interaction of ‘multiple stresses’, occurring at various levels (very high confidence).

Africa’s major economic sectors are vulnerability to current climate sensitivity, with huge economic impacts, and this vulnerability is exacerbated by existing developmental challenges such as endemic poverty, poor governance and weak institutions, limited access to capital, including markets, infrastructure and technology, ecosystems degradation, and complex disasters and conflicts. These in turn have contributed to Africa’s weak adaptive capacity, increasing the continent’s vulnerability to projected climate change [9.2.2, 9.5, 9.6.1].

African farmers have developed several adaptation options to cope with current climate variability but such adaptations may not be sufficient for future changes of climate (very high confidence).

Human or societal adaptive capacity that was identified as being low for Africa in the Third Assessment Report is now better understood and supported by several case studies of both current and future adaptation options. Such advances in the science of adaptation to climate change and variability including, both contextual and outcome vulnerabilities to climate variability and climate change, however, show that these adaptations may be insufficient for future changes of climate [9.2, 9.4, 9.5, 9.6.2, Table 9.2].

Agricultural production and food security (including access to food) in many African countries and regions will likely be severely compromised by climate change and climate variability (very high confidence).

A number of countries in Africa already face semi-arid conditions that make agriculture challenging and climate change will likely reduce the length of growing season as well as force large regions of marginal agriculture in Africa out of production. Projected reductions in yield in some countries could be as much as 50% by 2020 and crop net revenues could fall by as much as 90% by 2100, with small scale farms being the most affected. This would adversely affect food security in the continent [9.2.1, 9.4.4, 9.6.1].

Climate change will aggravate the water stress currently faced by some countries while some countries that are not at risk will become at risk of water stress (very high confidence).

Climate change and variability will likely impose additional pressures on water availability, water accessibility and water demand in Africa. Even without climate change, several countries in Africa, particularly in northern Africa, will exceed the limits of their economically useable land-based water resources before 2025. About 25% (about 200 million) of Africa’s population currently experiences water stress. A 3°C temperature increase could lead to 0.4 – 1.8 billion more people at risk of water stress [9.2.1, 9.2.2, 9.4.1].

Changes in a variety of ecosystems are already being detected, particularly in southern African ecosystems, at a faster rate than anticipated (very high confidence).

Climate change, interacting with human drivers such as deforestation and forest fires are a threat to Africa’s forest ecosystem. Changes in grasslands and marine ecosystems are also noticeable. It is estimated that by the 2080s, parts of arid and semi-arid lands in Africa will likely increase by 5-8%. Climate change impacts on Africa’s ecosystem will likely have a negative effect on tourism as between 25 and 40% of animal species in national parks in sub-Saharan Africa will become endangered [9.2.2, 9.4.4, 9.4.5].

Climate variability and change could result in low-lying lands being inundated, with resultant
impacts on coastal settlements (high confidence).
Climate variability and change, coupled with human-induced changes, may also affect ecosystems
(mangroves and coral reefs), with additional consequences on fisheries and tourism. The projection
that sea level rise would increase flooding, particularly on the coasts of eastern Africa will have
implications for health. Sea level rise will likely increase the high socioeconomic and physical
vulnerability of coastal cities. The cost of adaptation to sea level rise could amount to at least 5-10% of GDP [9.4.3, 9.4.6, 9.5.2]

Human health, already compromised by a range of factors, could also be further negatively
impacted by climate change and climate variability (e.g. malaria in southern Africa and the
East African highlands) (high confidence).
It is likely that climate change may alter the ecology of some disease vectors in Africa and
consequently the spatial and temporal transmission of such diseases. Most assessments on health
have concentrated on malaria and still there are debates on the attribution of malaria resurgence in
some African areas. The need exists to examine the vulnerabilities and impacts of future climate
change on other infectious diseases such as dengue fever, meningitis, cholera, etc. [9.2.1.2, 9.4.3, 9.5.1]

9.1 Introduction

9.1.1 Summary of knowledge assessed in the Third Assessment Report
The Third Assessment Report (TAR) of the IPCC identified a range of impacts associated with
climate change and variability, including: decreases in grain yields; changes in runoff and water
availability in the Mediterranean and southern countries of Africa; increased stresses occasioned by
increased droughts and floods; and significant extinctions of plant and animal species and
associated livelihood impacts. Such factors were shown, moreover, to be aggravated by low
adaptive capacity (IPCC, 2001, Summary for Policy Makers). Many of these conclusions, as shown
below, remain valid for this Fourth Assessment Report.

9.1.2 New advances and approaches used in the Fourth Assessment Report
Recent enhanced scientific efforts, including a focus on both an impacts-led approach as well as a
vulnerability-led approach¹, have, enabled a more detailed assessment of the interacting roles of
climate and a range of other factors heightening change in Africa. This approach has been used to
frame much of what follows in this chapter and has enabled a greater sensitivity to, and a deeper
understanding of, the ‘role of multiple stresses’ in heightening vulnerability to climate stress.
Several of these stresses (outlined in 9.2.1., 9.2.2. and 9.4 below) are likely to be compounded by
climate change and climate variability in the future. Recent additional case studies on adaptation
have also been undertaken, providing new insights on adaptation (see 9.5, Table 9.2).

9.2 Current sensitivity/vulnerability

9.2.1 Current sensitivity to climate and weather

¹ Several sources. For a key source summarising these approaches see ‘New indicators of vulnerability and adaptive
capacity by Adger et al., 2004.
The climate of the continent is controlled by complex maritime and terrestrial interactions that produce a variety of climates across a range of regions, e.g. from the humid tropics to the hyper-arid Sahara (see IPCC, 2007, WG1, 11.2.). Climate exerts a significant control on the day-to-day economic development of Africa, particularly for the agricultural and water resources sectors, at regional, local, and household scales. Since the TAR, observed temperatures indicate a greater warming trend after the 1960s. Although these trends seem to be consistent over the continent, the changes are not always uniform. For instance, decadal warming rates of 0.29°C in the African tropical forests (Malhi and Wright, 2004) and 0.1 to 0.3°C in South Africa (Kruger and Shongwe, 2004) have been observed. In South Africa and Ethiopia, minimum temperatures have increased slightly faster than maximum or mean temperatures (Conway et al. 2004a; Kruger and Shongwe, 2004). Between 1961 and 2000, there was an increase in the number of warm spells over southern and West Africa, and a decrease in the number of extremely cold days (New et al., 2006). In eastern Africa, decreasing trends in temperature from weather stations located close to the coast or to major inland lakes have been noted (King’uyu et al., 2000).

For precipitation, the situation is more complicated. Rainfall exhibits notable spatial and temporal variability (e.g. Hulme et al., 2005). Interannual rainfall variability is large over most of Africa and, for some regions, multi-decadal variability is also substantial. In West Africa (4°-20°N; 20°W-40°E), a decline in annual rainfall has been observed since the end of the 1960s, with a decrease of 20 to 40% noted between 1931 and 1960 and 1968 to 1990 (Nicholson et al., 2000; Chappell and Agnew, 2004; Dai et al., 2004). In the tropical rainforest zone, a decline in mean annual precipitation of around 4% in West Africa, 3% in North Congo and 2% in South Congo for the period 1960-1998 have been noted (e.g. Mahli and Wright, 2004). A 10% increase in annual rainfall along the Guinean coast for the last 30 years has, however, also been noted (Nicholson et al., 2000). In other regions, such as southern Africa, no long-term trend has been noted. Increased interannual variability was, however, observed in the post-1970 period, with higher rainfall anomalies and more intense and widespread droughts noted (e.g. Fauchereau et al., 2003; Richard et al., 2001). In different parts of southern Africa (e.g. Angola, Namibia, Mozambique, Malawi, Zambia), a significant increase in heavy rainfall events has also been observed (Usman and Reason, 2004) including evidence for changes in seasonality and extremes (New et al., 2006; Tadross et al., 2005a). During the recent decades eastern Africa has been experiencing an intensifying dipole rainfall pattern on the decadal time scale. The dipole is characterised by increasing rainfall over the northern sector and declining amounts over the southern sector (Schreck and Semazzi, 2004).

Advances in understanding of the complex mechanisms responsible for rainfall variability have been made (see IPCC 2007, WG1, 11.3.2.1; 11.3.2.2 and 11.3.2.3; Warren et al., 2006; Reason et al., 2005; Washington and Preston, 2006). Understanding how possible climate regime changes (e.g. El Niño-Southern Oscillation (ENSO)) may influence future climate variability is critical in Africa and requires further research. The drying of the Sahel region since the 1970s has for example, been linked to a positive trend in the equatorial Indian Ocean sea surface temperatures, while the ENSO, is a significant control on rainfall at interannual scales (Giannini et al., 2003, see also IPCC, 2007, WG1, Chapter 11). In the same region, the intensity and localisation of the African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ) also influence rainfall variability (Nicholson and Grist, 2003) as well as the sea-surface temperatures in the Gulf of Guinea (Vizy and Cook, 2001), and a relation has been identified between the warm Mediterranean Sea and abundant rainfall (Rowell, 2003). The influence of the ENSO decadal variations has also been recognised in southwest Africa, influenced in part by the North Atlantic Oscillation (NAO) (Nicholson and Selato, 2000). Changes in these mechanisms have been identified in southern Africa, where severe droughts have been linked to regional atmospheric-oceanic anomalies before the 1970s then to ENSO (Fauchereau et al., 2003).
Several studies also have highlighted the importance of terrestrial vegetation cover and resultant dynamic feedbacks on the physical climate (see also IPCC 2007, WG1, Section 11, 11.2, 11.3.2.4.2). An increase in vegetation density, for example, has been noted to result in a year-round cooling of 0.8°C in the tropics, including tropical areas of Africa (Bounoua et al., 2000). Complex feedback mechanisms – mainly due to deforestation/land cover change and dust – also play a role in climate variability, particularly for the drought persistence in the Sahel and its surrounding areas (Nicholson, 2001; Semazzi and Song, 2001; Wang and Eltahir, 2000, 2002; Prospero and Lamb, 2003; Zeng, 2003). The complexity of the interactions precludes ‘simple interpretations’ – e.g. the role of human-induced factors (e.g. migration), together with climate, can contribute to changes in vegetation in the Sahel, that then feedback into the overall physical system in complex ways (see, for example, Eklundh, 2003; Held et al., 2005; Herrmann et al., 2005; Olsson et al., 2005). Mineral dust is the largest cause of uncertainty in the radiative forcing of the planet and the key role of the Sahara has long been emphasized. Better quantitative estimates of Saharan dust loadings and controls on emission have now emerged from both satellite and field campaigns (e.g. Washington and Todd, 2005; Washington et al., 2006).

Finally, research on the changes in extreme events, such as droughts and floods, have major implications for numerous Africans and requires further attention. Droughts, notwithstanding current limitations in modelling capabilities and understanding of atmospheric system complexity, have attracted much interest over the past 30 years (AMCEN/UNEP, 2002), particularly with reference to impacts on both ecological systems and on society. Droughts have long contributed to human migration, cultural separation, population dislocation and the collapse of prehistoric and early historic societies (Pandey et al., 2003). One third of the people in Africa live in drought-prone areas and are vulnerable to the impacts of droughts (World Water Forum, 2000). In Africa, for example, several millions regularly suffer impacts from droughts and floods. These impacts are often further exacerbated by other health problems, particularly diarrhoea, cholera and malaria (Few et al., 2004). During the mid-1980s, the economic losses from droughts totalled several hundred million US$ (Tarhule and Lamb, 2003). Droughts have mainly affected the Sahel, the Horn of Africa and southern Africa, particularly since the end of the 1960s (Richard et al., 2001; L’Hôte et al., 2002; Brooks, 2004; see this volume, Section 9.6.2 and IPCC 2007, WGI, section 3.3.4 and Chapter 11, 11.2.3.3). Floods are also critical and impact on African development. Recurrent floods in some countries are linked, in some cases, with ENSO events. When such events occur: important economic and human losses result (e.g. in Mozambique – e.g. www.wmo.ch/wcp/wcdmp/relatipubs/pdf/el_nino_in_brief.pdf; Obasi, 2005). Even countries located in dry areas (Algeria, Tunisia, Egypt, Somalia) have not been flood-safe (Kabat et al., 2002).

9.2.1.1 Sensitivity/vulnerability of the water sector

The water sector is strongly influenced by, and is sensitive to, changes in climate (including periods of prolonged climate variability). Evidence of interannual lake-level fluctuations and lake-level volatility, for example, has been observed between 1993 and 1997 probably owing to periods of intense droughts followed by increases in rainfall in late 1997 (e.g. in lakes Tanganyika, Victoria and Turkana) (see http://earthobservatory.nasa.gov/Study/Victoria/printall.php). After the 1997 flood, Lake Victoria rose by about 1.7m by 1998, Lake Tanganyika by about 2.1m, and Lake Malawi by about 1.8m, and very high river-flows were recorded in the Congo River at Kinshasha (Conway et al., 2004b). The heavy rains and floods have been attributed to large-scale atmosphere-ocean interactions in the Indian Ocean (Mercier et al., 2002).
Changes in runoff and hydrology linked to climate through complex interactions include those observed for southern Africa (Schulze et al., 2001 and New, 2002); South Central Ethiopia (Legesse et al., 2003); Kenya and Tanzania (Eriksen et al., 2005) and the wider continent (de Wit and Stankiewicz, 2006; Nkomo et al., 2006). Fewer assessments on impacts and vulnerabilities, as noted elsewhere in this chapter, on groundwater and climate interactions are available and yet this aspect is clearly of great concern for many depending on such water sources.

About 25% of the contemporary African population experiences high water stress. About 69% of the population lives under conditions of relative water abundance (Vörösmarty et al., 2005). However, this relative abundance does not take into account other equally important factors like access to clean drinking water and sanitation, which reduces the effective quantity of freshwater available for human use. Despite the considerable improvements in access in the 1990s, only about 62% of African population had access to improved water supply in 2000 (WHO/UNICEF, 2000). As illustrated below in section 9.2.2, issues that affect access to water, including issues of water governance, also need to be remembered in any discussion of vulnerability to water stresses in Africa.

9.2.1.2 Sensitivity/vulnerability of the health sector

Assessments of health in Africa show that many communities are already impacted by health stresses that are coupled to several causes including poor nutrition. These assessments repeatedly underscore the implications that poor health status of many in Africa has for future development (Figure 9.1a,d) (e.g. Sachs and Malaney, 2002; Sachs, 2005). An estimated 700,000 to 2.7 million people die of malaria each year and 75% of those are African children (www.cdc.gov/malaria; Patz and Olson, 2006). Incidences of malaria, including the recent resurgence in the highlands in East Africa, however, involve a range of multiple causal factors, including poor drug treatment implementation, drug resistance, land-use change, and various socio-demographic factors including poverty (Githeko and Ndegwa, 2001; Abeke et al., 2004; Zhou et al., 2004; Patz et al., 2002; Patz and Olson, 2006). The economic burden of malaria is estimated at an average annual reduction in economic growth of 1.3% for those African countries with the highest burden, with an estimated US$12 billion loss to the African continent’s GDP annually (Gallup and Sachs, 2001).

Recent interest in the resurgence of malaria and links to climate and/or other causal ‘drivers’ of change in the highlands of East Africa has spawned much attention and debate (e.g. Hay et al., 2002; Pascual et al., 2006). There are indications, for example, that in areas that have two rainy seasons, March to June (MAJ) and September to November (SON), more rain is being experienced in SON than before in the northern sector of East Africa (Schreck and Semazzi, 2004). The later period is relatively warmer and higher rainfall is likely to increase malaria transmission in the SON period because of a reduction in larval development duration. The spread of malaria into new areas, for example new records of malaria vector Anopheles arabiensis in the Central highlands of Kenya where no malaria vectors have previously been recorded, has also been noted (Chen et al., 2006). Recent work (e.g. Pascual et al., 2006), provides further new insights on observed warming trends from the end of the 1970s in four high-altitude sites in East Africa. Such trends are capable of contributing to significant biological implications in malaria vector populations.

New evidence from microclimate change due to land-use change such as swamp reclamation for agricultural use and deforestation in the highlands of western Kenya create suitable conditions for the survival of An. gambiae larvae and consequently increase risks of malaria (Munga et al., 2006). Average ambient temperatures in the deforested areas of Kakamega in the western Kenyan highlands, for example, was 0.5°C higher than that of the forested area over a ten-month period
Mosquito pupation rates and larval-to-pupal development have been observed to be significantly higher in farmland habitats than in swamp and forest habitats (Munga et al., 2006).

Other diseases are also important to consider with reference to climate variability and change, as links between variations in climate and other diseases such as cholera, heat stress and meningitis have also been observed. During the 1997-1998 El Niño event, for example, excessive flooding cases were associated with cholera epidemics in Dijibuti, Somalia, Kenya, Tanzania and Mozambique (Muriuki et al., 2005). Floods can also trigger malaria epidemics in arid and semi-arid areas (e.g. Thomson et al., 2006). About 162 million people in Africa, for example, live in areas with a risk of meningitis (Molesworth et al., 2003) (Figure 9.1c,d). While factors that predispose populations to meningococcal meningitis are still poorly understood, dryness, very low humidity, and dusty conditions are factors to consider. A recent study, for example, 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).
9.2.1.3 Sensitivity/vulnerability of the agricultural sector

The agricultural sector is a critical mainstay of local livelihoods and national GDP in some countries in Africa (Mendelsohn et al., 2000a and 2000b, Devereux and Maxwell, 2001).
Agriculture contributions to GDP vary across countries but assessments suggest an average contribution of 21% (ranging from 10% to 70%) to the GDP (Mendelsohn et al., 2000b). This sector is particularly sensitive to climate, including periods of climate variability (e.g. ENSO and extended dry spells - e.g. Usman and Reason, 2004). In many parts of Africa, farmers and pastoralists also have to contend with other extreme natural resource challenges and constraints such as poor soil fertility, pests, crop diseases, lack of access to inputs and improved seeds. These challenges are usually aggravated by periods of prolonged droughts and floods (Figure 9.1b) and are often marked during El Niño (Mendelsohn et al., 2000 a and b; International Institute for Rural Reconstruction, 2004; Biggs et al., 2004; Vogel, 2005; Stige et al., 2006).

9.2.1.4 Sensitivity/vulnerability of ecosystems

Ecosystems are critical in Africa, contributing significantly to biodiversity and human well-being (e.g. Biggs et al., 2004; Muriuki et al., 2005). The rich biodiversity in Africa, which occurs principally outside formally conserved areas, is under threat from climate variability and change and other stresses (e.g. see this volume, Chapter 4, Section 4.2). Africa’s social and economic development is constrained by climate change, habitat loss, over harvesting of selected species, the spread of alien species, and activities such as hunting and deforestation, which threaten to undermine the integrity of the continent’s rich but fragile ecosystems (UNEP/GRID-Arendal, 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; Biggs et al., 2004). In West Africa, the long-term decline in rainfall from the 1970s to the 1990s has caused a 25-35 kilometre shift of the Sahel, Sudan and Guinean ecological zones in the last half of the 20th century (Gonzalez, 2001). This has resulted in the loss of grassland and acacia, loss of flora/fauna, and shifting sand dunes in the Sahel that is already being observed (ECF, 2004). The 1997-1998 coral bleaching observed in the Indian Ocean and Red Sea was coupled to a strong ENSO. In the western Indian Ocean region, a 30% loss of corals reduced tourism in Mombasa and Zanzibar and resulted in financial losses of about USS 12-18 million (Payet and Obura, 2004). Coral reefs are also exposed to other local anthropogenic threats, including sedimentation, pollution, overfishing, particularly when they are close to important human settlements such as towns and tourist resorts (Nelleman and Corcoran, 2006). 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).

Observable changes in ecosystems are not only attributable to climate. Additional factors such as fire, invasive species and land-use change, interact and also produce change in several African locations (Muriuki et al., 2005). In Africa, sensitive mountain environments (e.g. Mt Kilimanjaro, Mt. Ruwenzori, etc.) illustrate the complex inter-linkages between atmospheric processes including solar radiation, glacier-climate interactions, climate variability and change, and the role of vegetation changes and climate interactions (Kaser et al., 2004). A drop in atmospheric moisture, for example, at the end of the 19th century and the drying conditions that then occurred, have been used to explain the observed glacier retreat on Kilimanjaro (Kaser et al., 2004). Others, however, consider the changes in the Kilimanjaro glaciers, and other tropical glaciers, to be more strongly associated with recent rising air temperatures. Ecosystem change, also induced by complex land-use/climate interactions, including the migration of species and the interaction with fire (e.g. Hemp, 2005), produces a number of feedbacks or ‘knock on impacts’. The downward migration of species of animals and plants, for example, is already observed to be occurring because of forest fires on Kilimanjaro and may place pressure on ecosystems (Agrawala, 2005). The loss of ‘cloud forests’
through fire since 1976 has resulted in 25% annual reduction of fog water (the equivalent of the
annual drinking water of one million people living in Kilimanjaro), is another critical impact in this
region (Agrawala, 2005; Hemp, 2005; see Box 9.1 and this volume, Chapter 4, Section 4.2).

Box 9.1: Environmental changes on Mt. Kilimanjaro.

There is evidence that climate change is modifying natural ecosystems via complex
interactions and feedbacks including solar
radiation on Mt Kilimanjaro (Molg and Hardy,
2004; see IPCC 2007, WG 1, chapter 4, Fig.
4.5.4). Other drivers of change are also modifying
environments on the mountain including fire,
vegetation changes and human modifications
(Hemp, 2005). Debate over past and current
climate change and ice cap coverage, however,
persists (see Thompson et al., 2002; Cullen et al.,
2006). Over the 20th century, the spatial extent of
Kilimanjaro’s ice fields has decreased by 80%
(Figure 9.2). It is suggested by some, that if
current climatological conditions persist, the
remaining ice fields are likely to disappear
between 2015 and 2020 (Thompson et al. 2002).

Figure 9.2 a+b: Snow and ice on Kilimanjaro
from

9.2.1.5 Sensitivity/vulnerability of settlement and infrastructure

Impacts on settlements and infrastructure are well recorded for recent extreme climate events (e.g.
the 2000 flooding event in Mozambique - Christie and Hanlon, 2001; International Federation of
the Red Cross and Red Crescent Societies, 2002; see also infrastructural loss estimates from severe
Large numbers of people are currently at risk of floods (see for example UNDP, 2004; and
UNESCO-WWAP, 2006), particularly in coastal areas, where coastal erosion is already destroying
infrastructure, houses, and tourism facilities (e.g. in the residential region of Akpakpa in Benin
(Niasse et al., 2004) (see also this volume Section 7, 7.2.).

9.2.2 Current sensitivity and vulnerability to other stresses

Complex socio-economic, political, environmental, cultural and structural factors configure
vulnerabilities to several changes, including climate change and variability. Economic development
in Africa has been variable, with some suggesting, in the 1990s that sub-Saharan Africa was
‘sliding off the world map’ (Ferguson, 2006). African economies have, however, recently registered
significant overall growth in the past decade (more than 5 % in 2004) (OECD, 2004/2005; World
Bank, 2006a and b). Sub-Saharan Africa, for example, has shown an increase of 1.2 % a year
growth in average income since 2000 (UNDP, 2005). Despite this positive progress, boosted in part
by increases in oil exports and good oil prices, several African economies, including informal and
local-scale economic activities and livelihoods, remain vulnerable to regional conflicts, the vagaries
of the weather and climate, volatile commodity prices and the various influences of globalisation
(see for example, Devereux and Maxwell, 2001; OECD, 2004/2005; Ferguson, 2006). Certain
countries in sub-Saharan Africa exhibit deteriorating food security (see Figure 9.1a) and declines in
overall genuine wealth, with estimates that the average person in sub-Saharan Africa becomes
poorer by a factor of two about every 25 years (Arrow et al., 2004; Sachs, 2005). The interaction of
economic stagnation and slow progress in education has been compounded by the spread of
HIV/AIDS. In 2003, some 2.2 million Africans died of the disease and an estimated 12 million
children in sub-Saharan Africa had lost one or both parents to HIV/AIDS (UNAIDS, 2004;
Ferguson, 2006). This has produced a ‘free fall’ in the Human Development Index ranking with
southern African countries accounting for some of the steepest declines (UNDP, 2005). Indeed
some note that sub-Saharan Africa is the only region in the world that has become poorer in this
generation (Devereux and Maxwell, 2001; Ravallion and Chen, 2004).

A large literature exists on the various factors that configure vulnerability to changes in Africa (e.g.
to climate stress), and this section outlines the key issues (see for example Figures 9.1 a-d). These
factors do not operate in isolation and usually interact in complex and ‘messy’ ways, frustrating
appropriate interventions to increase resilience to change.

9.2.2.1 Globalisation, trade and market reforms

There are important macro-level processes that serve to heighten vulnerability to climate variability
and change across a range of scales in Africa (Sachs et al., 2004; UNDP, 2005; Ferguson, 2006).
Issues of particular importance include globalisation, trade and equity (with reference to agriculture
see FAO, 2005; Schwind, 2005) and modernity and social justice (e.g. Ferguson, 2006). Numerous
‘structural’ factors are ‘driving’ and ‘shaping’ poverty and livelihoods (Hulme and Shepherd, 2003)
and changing the face of rural Africa (e.g. intensification vs. extensification; see Bryceson, 2004
and see also 9.6.1 below). Structural adjustment, for example, accompanied by complex market
reforms and market liberalisation (e.g. access to credit and subsidy arrangements) has already
aggravated the vulnerability of many in Africa, particularly of those engaged in agriculture (see for
example, Kherallah et al., 2004; Eriksen and Silva, 2003; Eriksen, 2004). Fertiliser prices have risen
in response to subsidy removal, resulting in declines in fertiliser use in many countries, and often
subsequent reductions in agricultural outputs (Kherallah et al., 2004; Institute of Development
Studies, 2005). Such market related and structural issues can thus serve to reduce people’s
agricultural productivity and reduce their resilience to further agricultural stresses associated with
climate change.

9.2.2.2 Governance and institutions

There is substantial evidence for institutional weakness in many African countries, which is often
exposed during periods of climate stress. Public service delivery is hampered by institutional
weaknesses, which provide critical obstacles to economic performance (Beg et al., 2002; Tiffen,
2003). Africa is also characterised by institutional and legal frameworks that are insufficient for
dealing with environmental degradation and disaster risks (Sokona and Denton, 2001; Tiffen,
2003). Various actors, locations and networks are therefore required to reconfigure innovation
processes in Africa (e.g. in agriculture) to improve responses to climate variability and change (see
Tiffen, 2003; Scoones, 2005; Reid and Vogel, 2006; see also 9.5 below).
9.2.2.3 Access to capital, including markets, infrastructure and technology

Constraints in technological options, limited infrastructure, skills, information and links to markets further heighten vulnerability to climate stresses. In the agricultural sector, for example, many African countries depend on inefficient irrigation systems (UNEP, 2004) that heighten vulnerability to climate variability and change. Africa has been described as the world’s great laggard in technological advance in the area of agriculture (Sachs et al., 2004). For instance, most of the developing world experienced a Green Revolution—a surge in crop yields in the 1970s through the 1990s as a result of scientific breeding that produced high-yield varieties (HYVs), combined with increased use of fertilizers and irrigation. Africa’s uptake of HYVs was the lowest in the developing world. The low levels of technological innovations and infrastructural developments in Africa result in extraction of natural resources for essential amenities like clean water, food, transportation, energy and shelter (Sokona and Denton, 2001). Such activities degrade the environment and compound vulnerability to a range of stresses, including climate. Sub-Saharan African countries also have extremely low per capita densities of rail and road infrastructure (Sachs, 2005). As a result, cross-country transport connections within Africa tend to be extremely poor and are in urgent need of extension, to reduce intra-regional transport costs and promote cross-border trade (Sachs, 2005). Such situations often exacerbate drought and flood impacts (see for example the role of information access in International Federation of the Red Cross and Red Crescent Societies, 2005) as well as adaptation to climate stresses (see Section 9.5 and this volume, Chapter 17, Section 17.3.2).

9.2.2.4 Population and environment interactions

Notwithstanding the range of uncertainties related to the accuracy of census data, the African continent is witnessing some of the most rapid population growth, particularly in urban areas (Tiffen, 2003). During the years 1950 to 2005, the urban population in Africa grew by an average rate of 4.3% from 3.3 million to 353 million (ECA, 2005). Complex migration patterns, that are usually undertaken to ensure income via remittances (Schreider and Knerr, 2000), and often occur in response to stress-induced movements linked to conflict and/or resource constraints, can further trigger a range of environmental and socioeconomic changes. International migration has led to significant haemorrhaging of national skills in critical development sectors such as education and health (New York Times, 2004). Migration is also associated with the spread of HIV/AIDS and other diseases. Several cases have shown that labour migrants tend to have higher HIV infection rates than non-migrants (UNFPA, 2003). Increases in population exert stresses on natural resources. Agricultural intensification and/or expansion into marginal lands can trigger additional conflicts, crop failures, and exacerbate environmental degradation (e.g. Olsson et al., 2005) and reduce biodiversity (Fiki and Lee, 2004) that then in turn feed-back, via complex pathways, into the biophysical system. Variations in climate, both short and long term, usually aggravate such interactions. Changes in rain-fed livestock numbers in Africa, a sector often noted for exerting noticeable pressure on the environment, are already strongly coupled to variations in rainfall but are also linked to other socio-economic and cultural factors (see for example, Little et al., 2001; Desta and Coppock, 2003; Turner, 2003; Boone et al., 2004; Thornton et al., 2004).

9.2.2.5 Water access and management

Water access and water resource management is highly variable across the continent (e.g. Ashton, 2002; van Jaarsveld et al., 2005; UNESCO-WWAP, 2006). The 17 countries in West Africa
(ECOWAS members, Chad and Mauritania) that share 25 transboundary rivers have notable high water interdependency (Niasse, 2005). Eastern and southern African countries are also characterised by water stress brought about by climate variability and wider governance issues (Ashton, 2002; UNESCO-WWAP, 2006). Significant progress has, however, been recorded in some parts of Africa to improve these situations, with urban populations in the southern African region having improved water access over recent years (Van Jaarsveld et al., 2005). Despite this progress about 35 million people in the region are still using unimproved sources, the largest proportion being in Mozambique followed by Angola, South Africa, Zambia and Malawi (ECA, 2005). When water is available it is, moreover, often of poor quality contributing to a range of health problems such as diarrhoea, intestinal worms and trachoma. Much of the suffering from lack of access to safe drinking water and sanitation is borne by the poor, those who live in degraded environment and overwhelmingly by women and children. The relevance of the problem of water scarcity is evident in North Africa considering that estimates for the average annual growth of the population are the world’s highest: 2.9% for the period 1990-2002. Water resources exploitation index is high in several countries in the sub-region - > 50% for Tunisia, Algeria, Morocco and Sudan, and > 90% for Egypt and Libya (ECA, 2005). Until recently, these countries have adopted a supply-oriented approach to managing their water resources. However, managing the supply of water cannot in itself ensure that the needs of a country can be met in a sustainable way.

Attributing sensitivity and vulnerability in the water sector solely to the vagaries of climate, is problematic. The complex interactions of overfishing, industrial pollution and sedimentation, for example, are also degrading local water sources such as Lake Victoria (Odada et al., 2004), that impact on catches. Integrated analyses of climate change in Egypt, moreover, show that population changes, land-use changes and domestic growth strategies, may be more important in water management decision making than a single focus on climate change (Conway, 2005).

9.2.2.6 Health management

Much like the aforementioned sectors, the health sector is affected by the interaction of several ‘human dimensions’ e.g. inadequate service management, poor infrastructure, the stigma attached to HIV/AIDS, and the ‘brain drain’. HIV/AIDS is contributing to vulnerability to a range of stresses (Gommes et al., 2004; Mano et al. 2003; USAID, 2003). Maternal malaria, for example, has been shown to be associated with a two-fold higher HIV-1 viral concentration (Ter Kuile et al., 2004) and is estimated to be 5.5% and 18.8% in populations with HIV prevalences of 10% and 40%, respectively. The deadly duo of HIV/AIDS and food insecurity in southern Africa are key drivers of the humanitarian crisis (Gommes et al., 2004, see 9.6). While infectious diseases such as cholera are being eradicated in other parts of the world, it is re-emerging in Africa. A major challenge facing the continent is the relative weakness in disease surveillance and reporting systems, which hamper the detection and control of cholera epidemics, and as a side effect, make it difficult to obtain the long-term linked datasets on climate and disease that are necessary to develop early warning systems (WHO, 2005).

9.2.2.7 Ecosystems degradation

Human ‘drivers’ are also shaping ecosystem services that impact on human well being (e.g. Muriuki et al., 2005; van Jaarsveld et al., 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 (Biggs et al., 2004). Further threats to Africa’s forest are also posed by the high dependency on fuelwood - a
major source of energy in rural areas - representing about 70% of total energy consumption in the continent (FAO, 2004a). Moreover, fire incidents represent a huge threat to tropical forest in Africa. An estimated 70% of the detected fires occur in the tropics, with 50% of them in Africa. More than half of forested areas were estimated to have burned in Africa in 2000 (Kempeneers et al., 2002). Bush fires are a particular threat to the woodlands, causing enormous destruction to both flora and fauna in eastern and southern Africa (for extensive and detailed review on the role of fire in southern Africa, see SAFARI, 2004). The African continent suffers the most from the impacts of desertification. At present, almost half (46%) of Africa’s land area is vulnerable to desertification (Granich, 2006).

9.2.2.8 Energy

Access to energy is severely constrained in sub-Saharan Africa, with an estimated 53% of urban populations and only 8% of rural populations having access to electricity. This is compared to 99% of urban populations and 88% of rural populations who have access in Northern Africa (IEA, 2002). Other exceptions also include South Africa, Ghana and Mauritius. 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, with this fuel source supplying more than 80% of energy consumed in sub-Saharan Africa (Hall and Scrase, 2005). In Kenya, Tanzania, Mozambique and Zambia, for example, nearly all rural households use wood for cooking, and over 90% of urban households use charcoal, (e.g. IEA, 2002; van Jaarsveld et al., 2005). Dependence on biomass can promote removal of vegetation. The absence of efficient and affordable energy services can also result in a number of other impacts including health impacts associated with the carrying of fuel wood, indoor pollution and other hazards (e.g. informal settlement fires) (IEA, 2002). Further challenges from urbanisation and rising energy demands and volatile oil prices further compound energy issues in Africa (ESMAP, 2005).

9.2.2.9 Complex disasters and conflicts

The juxtaposition of many of the complex socio-economic factors outlined above and the interplay of biophysical hazards (e.g. climate hazards - tropical cyclones, fire, insect plagues) is well highlighted in the impacts and vulnerabilities to disaster risks and conflicts in several areas of the continent (see for example several IFRC and Red Crescent Societies Reports of the past few years, www.ifrc.org; and several relevant documents such as those located on www.idsdrg.org) (see Figure 9.1b). Many disasters are caused by a combination of a climate stressor (e.g. drought, flood) and other factors, such as conflict, disease outbreaks and other ‘creeping’ factors (e.g. economic degradation over time) (Benson and Clay, 2004; Reason and Keibel, 2004; Eriksen et al., 2005). The role of these multiple interactions is well highlighted in the case of Malawi and Mozambique. In 2000 in Malawi, agriculture 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) (for more details on structural causes and drought interactions and impacts e.g. food security, see 9.6 case study below). Likewise, the floods in Mozambique, in 2000, revealed a number of existing vulnerabilities that were heightened by the floods. These included: poverty (40 % of the population lives on less than US1$ per day and another 40 % on less than US2$ per day); the debt problem, which is one of the biggest challenges facing the country; the fact that most of the floodwaters originate in cross-border basins; the poor disaster risk-reduction strategies with regards to dam design and management; and the poor communication networks (Christie and Hanlon, 2001; International Federation of the Red Cross and
Conflicts, armed and otherwise, have occurred 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, see also Nkomo et al., 2006). Causes of such conflicts include structural inequalities, resource mismanagement and predatory states. Elsewhere, land distribution and land scarcity have promoted conflict (e.g. Darfur, Sudan; see for example, Abdalla, 2006), often exacerbated by environmental degradation. Ethnicity is also a key driving force behind conflict (Lind and Sturman, 2002; see also Balint-Kurti, 2005; James, 2005). Climate change may become a contributing factor to conflicts in the future, particularly concerning water (Ashton, 2002) and resource scarcity (Fiki and Lee, 2004).

It is against this background that an assessment of vulnerability to climate change and variability has to be contextualised. Although indicators have limitations in capturing human well-being (Arrow et al., 2004), some aggregated proxies for national-level vulnerability to climate change for countries in Africa have been developed (e.g. Brooks et al., 2005; Vincent, 2004). These indicators include elements of economy, health and nutrition, education, infrastructure, governance, demography, agriculture, energy and technology. The majority of countries classified as vulnerable in an assessment using such proxies were situated in sub-Saharan Africa (33 of the 50 assessed by Brooks et al., 2005 were sub-Saharan African countries). At the local level, several case studies similarly show that it is the interaction of such ‘multiple stresses’, including composition of livelihoods, the role of social safety nets and other social protection measures that affect vulnerability and adaptive capacity in Africa (see 9.5 below).

9.3 Assumptions about future trends

9.3.1 Climate change scenarios

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). Under the medium-high emission scenario (A1B) used with 20 Global Circulation Models (GCMs) and for the years 2080-2099, annual mean surface air temperature is expected to increase between 3 and 4°C compared with the 1980-1999 period with smaller warming in equatorial and coastal areas (see IPCC 2007, WGI, 11.3.2.4.1). Other experiments (e.g. Ruosteenoja et al., 2003) indicate higher levels of warming with the A1FI emission scenario and for the 2070-2099 period: up to 9°C for North Africa (Mediterranean coast) in June-August and up to 7°C for southern Africa in September-November. Regional Climate Models (RCMs) experiments give generally smaller temperature increases (Kamga et al., 2005). For southern Africa (equator to 45oS and 5° to 55°E, which includes parts of surrounding oceans), Hudson and Jones (2002) using the HadRM3H regional climate model with the A2 SRES (Special Report on Emission Scenarios) 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). As demonstrated by Bounoua et al. (2000), an increase in vegetation density, leading to a cooling of 0.8°C per year in the tropics, including Africa, could partially compensate for greenhouse warming but the reverse effect is simulated in the case of land cover conversion which will probably increase in the next 50 years (Defries et al., 2002; see also FAO, 2004b for the role of

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2 In this section, the limits of the regions are those defined by Ruosteenoja et al. (2003)
land-use change and carbon sequestration). A stabilisation of the atmospheric CO₂ concentration at
550 ppm (by 2150) or 750 ppm (by 2250) could also delay the expected greenhouse gas induced
warming respectively by 100 years and 40 years across Africa (Arnell et al., 2002). For the same
stabilisation levels in the Sahel (10°-20°N, 20°W-40°E) the expected annual mean air temperature
in 2071-2100 (5°C) will be reduced respectively by 58% (2.1°C) and 42% (2.9°C) (Mitchell et al.,
2000; see also IPCC 2007, WG1, 11.3.2).

Precipitation projections are generally less consistent with large inter-model ranges in seasonal
mean rainfall responses. These inconstancies are explained partly by difficulties of global
circulation models to reproduce the mechanisms responsible for precipitation including, for
example, the hydrological cycle (Lebel et al., 2000) or the orography (Hudson and Jones, 2002).
They are also explained partly by model limitations to simulate the different teleconnections and
feedback mechanisms, which are responsible for rainfall variability in Africa. Other factors that
complicate African climatology include: dust aerosol 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; Bounoua et al., 2002); and soil moisture in southern Africa (New et al., 2006).

These uncertainties make it difficult to provide 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). Nonetheless, estimations of projected future climate
scenarios have been undertaken.

With the A1B SRES scenario and for the years 2080-2099, the mean annual rainfall is very likely
expected to decrease along the Mediterranean coast (by 20%) extending into northern Sahara and
along the west coast to 15°N, but may likely increase in tropical and East Africa (around +7%) while austral winter (JJA - June-August) rainfall will very likely decrease in much of southern
Africa especially in the extreme West (up to 40%) (See IPCC, 2007, WGI, 11.3.2.4.2; Table 11.2
and 11.3.3.3.3.). In southern Africa, the largest changes in rainfall occur during austral winter, with
a 30% decrease under the A2 scenario, even though there is very little rain during this season
(Hudson and Jones, 2002). There are, however, differences between the equatorial regions (north of
10°S and east of 20°E) which show an increase in summer (DJF - December to March) rainfall and those located south of 10°S that show a decrease in rainfall associated with a decrease in the number of rain days and in the average intensity of rainfall. Recent downscaling experiments 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). Using RCMs, Tadross
et al. (2005b), found a decrease in early summer (OND - October to December) rainfall and an
increase in late summer (JFM - January to March) rainfall over the eastern parts of southern Africa.

For the western Sahel (10-18°N, 17.5°W-20°E), there are still controversies between the models,
some projecting a significant drying (e.g. Hulme et al., 2001; Jenkins et al., 2005) and those
simulating a progressive wetting with an expansion of vegetation into the Sahara (Brovkin, 2002;
Maynard et al., 2002; Claussen et al., 2003; Wang et al., 2004; Haarsma et al., 2005; Kamga et al.,
2005; Hoerling et al., 2006). Land-use changes and degradation, which are not simulated by some
models, could induce drier conditions (Huntingford et al., 2005; Kamga et al., 2005). The behaviour
easterly jets and squall lines is also critical to predict the impacts of climate change on the sub-
region given the potential links between such phenomena and the development of the rainy season
(Jenkins et al., 2002; Nicholson and Grist, 2003).

Finally, there is still limited information on extreme events (see IPCC, 2007, WGI, Table 11.3),
despite noticeable reporting of such events, including their impacts (see 9.2.1 above). A recent
study using 4 GCMs for the Sahel region (3.75 to 21.25° N; 16.88 W to 35.63°E) showed that the number of extremely dry and wet years will increase during the next century (2081-2099) (Huntingford et al., 2005). Modelling of global drought projections for the 21st century, using the Palmer Drought Severity Index, evaporation estimates based on the A2 SRES scenarios show drying for northern Africa that appears consistent with rainfall scenarios outlined above, and wetting over central Africa (Burke et al., 2006). On a global basis, droughts were also estimated to be slightly more frequent and of much longer duration by the second half of the 21st century relative to the present day. Other experiments indicate that in a warmer world, and by the end of the century (2080-2100), there could also be more frequent and intense tropical storms in the southern Indian Ocean (e.g. McDonald et al., 2005). Tropical cyclones are likely to originate over the Seychelles from October to June due to the southward displacement of the Near Equatorial Trough (WGI, 11.3.9.1.2). There could very likely be an increase of between 10 to 20% in cyclone intensity with a 2-4°C sea surface temperature rise (e.g. Lal, 2001) but this observation is further complicated by the fact that sea-surface temperature does not account for all the changes in tropical storms (McDonald et al., 2005).

9.3.2 Socioeconomic scenarios

The IPCC SRES scenarios adopt four story lines or ‘scenario families’ that describe how the world populations, economies and political structures may evolve over the next few decades (Nakicenovic et al., 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 authors have criticised the population and economic details in the SRES scenarios, the scenarios still provide a useful baseline on impacts related to greenhouse gas emissions (Tol et al., 2005). The situation for the already vulnerable region of sub-Saharan Africa still appears bleak, even in the absence of climate change and variability. Twenty-four countries in sub-Saharan Africa are, for example, projected to be unable to meet several of the Millennium Development Goals (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). Sub-Saharan’s share of those earning below one US dollar a day is estimated to also rise sharply from 24% today to 41% by 2015 (UNDP, 2005). It is within this context, coupled with the multiple stresses presented in section 9.2.2., that the following summary of key future impacts and vulnerabilities associated with possible climate change and variability needs to be assessed.

9.4 Expected key future impacts and vulnerabilities, and their spatial variation

Having provided some background on some existing sensitivities/vulnerabilities generated by a range of factors, including climate stress, some of the impacts and vulnerabilities that may arise under a changing climate in Africa, using the various scenarios and model projections as guides, are presented for various sectors. For other assessments see also Biggs et al., 2004; Muriuki, et al., 2005, and Nkomo et al., 2006.

9.4.1 Water

Climate change and variability have the potential to impose additional pressures on water

Note, that several authors (e.g. Agoumi, 2003; Legesse et al., 2003; Conway, 2005, Thornton et al., 2006) caution about over interpreting results owing to the limitations of some of the projections and models used.
availability, water accessibility, and water demand in Africa. Even in the absence of climate change (see 9.2.2), present population trends and patterns of water use indicate that more African countries will exceed the limits of their ‘economically usable, land-based water resources before 2025’ (Ashton, 2002). The population at risk of increased water stress in Africa, for the full range of SRES scenarios, is projected to be between 75-250 million and 350-600 million people by the 2020s and 2050s, respectively (Arnell, 2004). However, the impact of climate change on water resources across the continent is not uniform. Based on six climate models (HadCM3, ECHAM4-OPYC, CSIRO-Mk2, CGCM2, GFDL_r30 and CCSR/NIES2) and the SRES scenarios shows a likely increase in the number of people that could experience water stress by 2055 in Northern Africa and southern Africa (See Figure 9.3) (Arnell, 2004). On the other hand, more people in eastern Africa and western Africa will likely experience a reduction than an increase in water stress (Arnell, 2006).

![Northern Africa: 2055](image1)

![Southern Africa: 2055](image2)

**Figure 9.3:** Number of people (millions) with increase in water stress (Arnell, 2005). Scenarios are all derived from HadCM3 and the red, green and red lines relate to different population projections.

Clearly these estimations are at macro-scales and may mask a range of complex hydrological interactions and local-scale differences (for other assessments on southern Africa where some of these interacting scalar issues have been addressed, see Schulze et al., 2001). Detailed assessments in northern Africa based on temperature increases of 1-4°C and reductions in precipitation of between 1-10% show that the Ouergha watershed in Morocco is likely to undergo changes for the period 2000-2020. A 1°C degree increase in temperature could change runoff in the order of 10%. If such an annual decrease in runoff were to occur in other watersheds the impacts in such areas could be in the order of one large dam being lost per year (Agoumi, 2003). Further interactions between climate and other factors influencing water sharing are well highlighted for Egypt (Box 9.2).

**Box 9.2: Climate, water availability and agriculture in Egypt.**

Egypt is one of the African countries that could be vulnerable to water stress under climate change. The water used in 2000 was estimated at about 70km³ which is already far in excess of the available resources (ECA, 2005). A major challenge is to close the rapidly increasing gap between the limited water availability and the escalating demand for water that various economic sectors needs. The rate...
of water utilization of water resources has already reached its maximum for Egypt and climate change will exacerbate this vulnerability (ECA, 2005).

Agriculture consumes about 85% of the annual total water resources and plays a significant role in the Egyptian national economy, contributing about 20% of GDP. More than 70% of the cultivated areas depend on low-efficiency surface irrigation systems, which cause high water losses, decline in land productivity, water-logging, and salinity problems. Moreover, unsustainable agricultural practices, and improper irrigation management affect the quality of the country’s water resources. Reduction in irrigation water quality has in its turn harmful effects on irrigated soils and crops.

Institutional water bodies in Egypt are working to achieve the following targets by 2017 through the National Improvement Plan:

- 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.

But with climate change, an array of serious threats is apparent:

- Sea level rise will likely reduce areas of the Nile delta, and 12-15% of the existing agricultural land in the delta is projected to be lost; in addition to losses of huge urban and economic centres in costal cities;
- Temperature rises will likely reduce the productivity of the major crops, and increase their water requirements thereby directly decreasing crop water use efficiency;
- There will likely be a general increase in irrigation demands;
- There will also be a high degree of uncertainty about the flow of the Nile;
- Based on SRES scenarios, Egypt will likely experience an increase in water stress, with a projected decline in precipitation and a projected population of between 115 and 179 million by 2050. 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).

Using ten scenarios derived by using five climate models (CSIRO2, HadCM3, CGCM2, ECHAM and PCM) in conjunction with two different emissions scenarios, Strzepek and McCluskey (2006) arrived at the following conclusions regarding impacts of climate change on streamflow in Africa. First, possible range of Africa-wide climate change impacts on streamflow increases significantly between 2050 and 2100. The range in 2050 is from a decrease of 15% to an increase of 5% above the 1961-1990 baseline. For 2100, the range is from a decrease of 19% to an increase of 14%.

Second, for southern Africa, almost all countries except South Africa will likely experience significant reduction in streamflow. Even for South Africa, the increases under the high scenarios are modest at under 10%.

Assessments of the role of climate change on hydrology based on six GCM models and a composite ensemble of African precipitation models for the period 2070-2099 derived from 21 fully coupled ocean-atmosphere GCMs, show various drainage impacts across Africa (de Wit and Stankewitz, 2006). A critical 'unstable' area is also identified for other parts of Africa, for example, the east-west band from Senegal to Sudan, separating the dry Sahara from west Central Africa. Parts of southern Africa are projected to experience significant losses in water drainage, with some areas being particularly impacted (e.g. parts of South Africa) (New, 2002; de Wit and Stankiewicz, 2006). Other regional assessments note emerging changes in the hydrology of some of the major water
systems (e.g. the Okavango River Basin) that could 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) (Biggs et al., 2004).

Assessments of water impacts, as indicated before, do not currently fully capture multiple future water uses and stress and must be approached with caution (e.g. Agoumi, 2003; Conway, 2005). Conway (2005), for example, argues that there is no clear indication of how Nile flow will be affected by climate change because of the uncertainty about rainfall patterns in the basin, and the influence of complex water management and water governance. Clearly, more detailed research on water hydrology, drainage and climate change is required. Future access to water in rural areas, drawn from low-order surface water streams, also needs to be addressed by countries sharing river basins (e.g. De Wit and Stankiewicz, 2006). Climate change should therefore be considered among a range of other water governance issues in any future negotiations to share Nile water (Conway, 2005; see also Stern, 2006).

9.4.2 Energy

There are remarkably few studies available that examine the impacts of climate change on energy use in Africa (see, however, a recent regional assessment by Warren et al., 2006). Even in the absence of climate change, however, a number of changes are expected in the energy sector. Africa’s recent and rapid urban growth (UNEP, 2005) 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/GRID-Arendal, 2002; du Plessis et al. 2003). These changes will alter existing surface microclimate and hydrology and will possibly exacerbate the scope and scale of climate change impacts.

9.4.3 Health

Vigorous debate amongst those working in the health sector has improved the understanding of the links between climate variability (including extreme weather events) and infectious diseases (van Lieshout et al., 2004; Patz and Olson, 2006; Epstein and Mills, 2005; Pascual et al., 2006, McMichael, et al., 2006). Despite the contested issues (see 9.2.1 above), new assessments of the role of climate change on health have emerged since the TAR. Results from the Mapping Malaria Risk in Africa Project (MARA/ARMA) show a possible expansion and contraction of climate suitable areas for malaria are indicated by 2020, 2050 and 2080 (Thomas et al., 2004). By 2050 and continuing into 2080, for example, a large part of western Sahel and much of southern-central Africa is shown to be likely to become unsuitable for malaria transmission. Other assessments (e.g. Hartmann et al., 2002), using 16 climate change 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. Strong southward expansion of the transmission zone will likely continue into South Africa.

Using parasite survey data in conjunction with HadCM3 GCM, projected scenarios estimate a 5-7% potential increase (mainly altitudinal) in malaria distribution, with little increase in the latitudinal extent of the disease by 2100 (Tanser et al., 2003). Previously malaria-free highland areas in Ethiopia, Kenya, Rwanda and Burundi could also 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 become highly suitable. Among all scenarios, the highlands of eastern and areas of southern Africa will likely become more suitable for transmission (Hartmann et al., 2002).

As the rate of malaria transmission increases in the highlands the likelihood of epidemics may increase due to lack of protective polymorphism in the newly affected populations. 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, for example, 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 also huge and includes sizeable costs to individuals and households as well as costs at community and national levels (Holding and Snow, 2001; Utzinger et al., 2001; Malaney et al., 2004). Based on HadCM3 and B1, A2a and A1FI scenarios, it is estimated that by the 2080s an additional 80 million people will likely be at risk of malaria (Warren et al., 2006).

Climate variability may also interact with other background stresses and additional vulnerabilities such as immunocompromised populations (HIV/AIDS) and conflict and war (Harrus and Baneth, 2005) in the future, resulting in increased susceptibility and risk to other infectious diseases (e.g. cholera) and malnutrition. 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). The projection that sea-level rise would increase flooding, particularly on the coasts of eastern Africa (Nicholls, 2004), may also have implications for health (McMichael et al., 2006).

Relatively fewer assessments of the possible future changes in animal health arising from climate variability and change have been undertaken. The demographic impacts on trypanosomiasis, for example, can rise through modification of the habitats suitable for tsetse fly. These modifications can be further exacerbated by climate variability and climate change. Climate change is expected to also affect both pathogen and vector habitat suitability through changes in moisture and temperature (Baylis and Githeko, 2006). Changes in disease distribution, range, prevalence, incidence and seasonality can be expected. However, there is low certainty about the degree of change. Rift Valley Fever epidemics, evident during the 1997/98 El Niño event in East Africa and associated with flooding, could increase with a higher frequency of El Niño. Finally, heat stress and drought are likely to have a further negative impact on animal health and production of dairy products as already observed in the USA (St-Pierre et al., 2003; see also Warren et al., 2006).

9.4.4 Agriculture

Results from assessments of inputs of climate change on agriculture based on various climate models and SRES scenarios indicate certain agricultural areas that may undergo negative change under climate change. It is estimated that by 2100, parts of the Sahara will likely emerge as the most vulnerable, showing likely agricultural losses of between 2 and 7% of the GDP. West Africa and central Africa are also vulnerable, with impacts ranging from 2 to 4%. Northern and southern Africa, however, are expected to have losses of 0.4%-1.3% (Mendelsohn et al., 2000b).

Combining global- and regional-scale analysis, impacts of climate change on growing periods and on agricultural systems and possible livelihood implications have also been examined (Jones and Thornton, 2003; Huntingford et al., 2005; Thornton et al., 2006). Based on the A1FI scenario, both the HadCM3 and ECHam4 models agree on areas of change in the coastal systems of southern and eastern Africa (Figure 9.4). Under both the A1 and B1 scenarios, for example, mixed rain-fed semi-
arid systems are shown to be affected in the Sahel, and mixed rain-fed and highland perennial systems in the Great Lakes region and in other parts of East Africa. In the B1 world, marginal areas (e.g. the semi-arid systems) become more marginal, with moderate impacts on coastal systems (see Thornton et al., 2006; see this volume, Section 5, 5.4.2). Such changes in growing period are important especially when viewed against possible changes in seasonality of rainfall, onset of rain days and intensity of rainfall as indicated in sections 9.2.1. and 9.3.1. above.

**Figure 9.4:** Areas within the LGA (Livestock only systems, arid-semiarid) and MRA (rainfed, mixed crop/livestock systems, arid-semi-arid) projected to undergo >20% reduction in LGP (Length of Growing Period to 2050: HadCM3, A1 (left) and HadCM3, B1 (right), after ILRI, TERI and ACTS, 2006.

Recent assessments using the FAO/IIASA Agro-Ecological zone model (AEZ) in conjunction with IIASA’s global food system model, as well as climate variables from five different GCMs under four SRES show further agricultural impacts such as changes in agricultural potential by 2080s (Fischer et al., 2005). By the 2080s, a significant decrease in suitable rain-fed land extent and production potential of cereals are estimated under climate change. Furthermore, for the same time horizon and using various climate change scenarios arid and semi-arid land in Africa could increase by 5-8% (60-90 million hectares). The study shows that wheat production may likely disappear from Africa by the 2080s. On a more local scale, assessments have shown a range of impacts. Southern Africa would likely experience notable reductions in maize production under possible increased ENSO conditions (Stige et al., 2006). In other countries in the region, risks that could be exacerbated by climate change include greater erosion, deficiencies in yields from rain-based agriculture of up to 50% during the 2000-2020 period and reductions in crop growth (Agoumi, 2003). A recent study based on three scenarios indicates that crop net revenues will likely fall by as much as 90% by 2100, with small-scale farms being the most affected. However, there is the possibility that adaptation could reduce these negative effects (Benhin, 2006). In Egypt, for example, climate change could decrease national production of many crops (ranging from -11% for rice to -28% for soybeans) by the year 2050 compared to their production under current climate conditions (Eid and El-Marsafway, 2002). Other agricultural activities could also be impacted by
climate change and variability, including changes in the onset of rain days and the variability of dry spells (e.g. Reason et al., 2005; see also this volume, Section 5).

Not all changes in climate and climate variability will, however, be negative for agriculture and the growing seasons in certain areas, such as around the Ethiopian highlands, may lengthen under climate change. A combination of increased temperatures and rainfall changes may lead to the extension of the growing season, for example in some of the highland areas (Thornton et al., 2006).

As a result of a reduction in frost on the alpine zones of Mt. Kenya and Mt. Kilimanjaro, for example, it may be possible to grow more temperate crops, e.g. apples, pears, barley, wheat, etc., on the adjoining elevations (Parry et al., 2004; see also this volume, Section 5, 5.4.2). Mild climate scenarios predict further benefits across African cropland for irrigated and especially dryland farms. However, it is noted that even in these favourable scenarios, regions in the Mediterranean, central, western and southern Africa that are currently produce stand to be adversely affected (Kurukulasuriya and Mendelsohn, 2006a).

Fisheries are another important source of revenues, employment, and proteins. It constitutes over six percent of Namibia’s and Senegal’s GDP (Njaya and Howard, 2006). Climate change impacts on this sector have to, however, be viewed together with other human activities including impacts that may arise from governance of fresh and marine waters (AMCEN/UNEP, 2002). Fisheries could be affected by different biophysical impacts of climate change, depending on the resources on which they are based (Niang-Diop, 2005; Clark, 2006). With a rise in temperature (e.g. 1.4 and 1.9°C annual global mean rise in temperature) fisheries in North West and the East African lakes are shown to be impacted (see ECF, 2004; see also Warren et al., 2006). 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 that are the basis of inland fisheries or aquaculture (République de Côte d’Ivoire, 2000; République du Congo, 2001; Cury and Shannon, 2004). In South Africa, fisheries could be affected by changes in estuaries, coral reefs and upwellings, those being dependent on the two first ecosystems being the most vulnerable (Clark, 2006). Recent simulations based on the NCAR GCM under a doubling of carbon dioxide indicate that extreme wind and turbulence could decrease productivity by 50-60%, while turbulence will likely bring about a 10% decline in productivity on the spawning ground and an increase of 3% on the main feeding grounds (Clark et al., 2003).

The impact of climate change on livestock in Africa has been examined (Seo and Mendelsohn, 2006a). A warming of 2.5°C will likely increase small farm livestock income by 26% (+US$1.4 billion). This increase is projected to come from an expansion of the stock. Further increases in temperature would lead to gradual fall in net revenues per animal. A warming of 5°C could likely increase small farm livestock by income by about 58% (+US$3.2 billion), largely as a result of stock increase. By contrast, a warming of 2.5°C will likely decrease large farm livestock by 22% (-US$13 billion) and a warming of 5°C will likely reduce it by as much as 35% (-US$20 billion). This reduction of large farm livestock income would likely result from both a shrinking of the stock and a reduction in net revenue per animal owned. Increased precipitation of 14% would likely reduce small farm livestock income by 10% (-US$ 0.6 billion), mostly due to a shrinking of the stock. The same reduction in precipitation would likely reduce large farm livestock income by about 9% (-US$5 billion) due to a reduction in both the stock and the net revenue per animal owned.

The study by Seo and Mendelsohn (2006a) further shows that higher temperatures are good for small farms that keep goats and sheep because they could easily substitute animals that are heat tolerant. By contrast, large farms are more dependent on species such as cattle, which are not heat tolerant. Increased precipitation is likely to be harmful to grazing animals because it implies a shift
from grassland to forests and an increase in harmful disease vectors and a shift from livestock to crops.

Assessing future trends in agricultural production in Africa, even without climate variability and change, however, remains exceedingly difficult (e.g., contributions to GDP and loss contributions because of climate variability and other factors - see for example Mendelsohn, et al., 2000b; Tiffen, 2003; Arrow et al., 2004; Desta and Coppock, 2003; Fergusson, 2006). While agriculture is a key source of livelihood in Africa there is evidence that off-farm incomes, for example, are also increasing in some areas - up to 60 to 80% of incomes in some cases (Bryceson, 2002).

Urbanisation and off-farm increases in incomes also seem to be contributing to reduced farm sizes. Future scenarios and projections may thus need to include such changes, as well as relevant population estimates allowing for the impact of HIV/AIDS, and the impacts of HIV/AIDS on farm labour productivity (Thornton et al., 2006).

### 9.4.5 Ecosystems

A range of impacts on terrestrial and aquatic ecosystems has been suggested under climate change (see for example, Leemans and Eickhout, 2004), some of which are summarised in Table 9.1. (For further details see this volume, Section 4; Nkomo et al., 2006; Warren et al., 2006.)

<table>
<thead>
<tr>
<th>ECOSYSTEM IMPACTS</th>
<th>AREA AFFECTED</th>
<th>SCENARIO USED AND SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated 5000 plants impacted, substantial reductions in areas of suitable climate for 81-97% of the 5197 African plants examined, 25-42% lose all area by 2085.</td>
<td>Africa</td>
<td>HadCM3 for years 2025, 2055, 2085, plus other models – shifts in climate suitability examined</td>
</tr>
<tr>
<td>Fynbos and succulent Karoo biomes e.g. losses of between 51% and 61% (4.4).</td>
<td>e.g. South Africa</td>
<td>Projected losses by 2050, see details of scenarios (Table 4.2 and this volume, Chapter 4, Section 4.4) e.g. Midgley et al., 2002.</td>
</tr>
<tr>
<td>Critically endangered taxa (e.g. Proteaceae) losses increase, and up to 2% of the 227 taxa become extinct (4.4).</td>
<td>e.g. Low-lying coastal areas</td>
<td>Scenarios - 4 land use and 4 climate change scenarios (HadCM2 IS92aGGa), Bomhard et al., 2005.</td>
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<tr>
<td>Losses of nyala and zebra</td>
<td>e.g. Malawi</td>
<td>(Dixon et al., 2003)</td>
</tr>
<tr>
<td>Losses of greater than 50% of some species estimated, particularly in Kruger Park estimate 66% of species lost (4.4.3 and 4.4).</td>
<td>e.g. South Africa (Kruger Park)</td>
<td>Hadley Centre Unified Model, no sulfates, (Erasmus et al., 2002).</td>
</tr>
<tr>
<td>Losses of bird species range (restriction of movements). An estimated 6 species could lose substantial portions of their range (4.4.8).</td>
<td>e.g. Southern African bird species (e.g. Nama-Karoo area).</td>
<td>Projected losses of over 50% for some species by 2050 using the HadCM3 A2 scenario (Simmons et al., 2004).</td>
</tr>
<tr>
<td>Sand dune mobilisation – enhanced dune activity (4.4.2).</td>
<td>e.g. Southern Kalahari basin – Northern South</td>
<td>Scenarios - HadCM3, SRES A2, B2 and A1fa, IS92a. By 2099 all dune fields</td>
</tr>
</tbody>
</table>
Africa, Angola and Zambia. For details in Sahel (see 9.6.2 and 4.3).

**Lake ecosystems, wetlands**

- For details in Sahel (see 9.6.2 and 4.3).
- e.g. Lake Tanganyika
- Carbon isotope data show aquatic losses of about 20% with a 30% decrease in fish yields. It is estimated that climate change may further reduce lake productivity (O’Reilly et al., 2003).

**Grasslands (4.4.3)**

- Complex impacts on grasslands including the role of fire (southern Africa).
- (See detailed discussion this volume, Chapter 4, Section 4, 4.4.3).
In Africa, highly productive ecosystems (mangroves, estuaries, deltas, coral reefs), which constitute the basis for important economic activities, such as tourism and fisheries, are located in the coastal zone. Forty per cent of the population of West Africa live in coastal cities and it is expected that the 500 km of coastline between Accra and the Niger delta will become a continuous urban megalopolis of more than 50 million inhabitants by 2020 (Hewawasam, 2002). By 2015, three coastal megacities of at least 8 million inhabitants will be located in Africa (Klein et al., 2002; Armah et al., 2005; Gommes et al., 2005). The projected rise in sea level will have significant impacts in these coastal megacities because of the concentration of poor populations in potentially hazardous areas that may be more vulnerable to such changes (Klein et al., 2002; Nicholls, 2004). Cities like Lagos and Alexandria will likely be impacted. In very recent assessments of potential flood risks that may arise by 2080 across a range of SRES scenarios and climate change projections, three of the five regions shown to be at risk of flooding in coastal and deltaic areas are those located in Africa: North Africa, West Africa, and southern Africa (e.g. Nicholls and Tol, 2006; Warren et al., 2006).

Other possible direct impacts of sea-level rise have been examined (Niang-Diop et al., 2005). In Cameroon, for example, indications are that a 15% increase in rainfall by the year 2100 would likely decrease the penetration of salt water in the Wouri estuary (République de Côte d’Ivoire, 2000). Alternatively, with an 11% decrease in rainfall, the salt water could extend up to about 70 km upstream. In the Gulf of Guinea, sea-level rise could induce overtopping and even destruction of the low barrier beaches that limit the coastal lagoons, while changes in precipitation could affect the discharges of rivers feeding them. These changes could also affect lagoonal fisheries and aquaculture (République de Côte d’Ivoire, 2000). Indian Ocean islands could also 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). Coastal agriculture (e.g. plantations of palm oil and coconuts in Benin and Côte d’Ivoire, shallots in Ghana) could be at risk of inundation and soil salinisation. In Kenya, losses for three crops (mangoes, cashew nuts and coconuts) could cost almost US$500 million for a 1 m sea-level rise (Republic of Kenya, 2002). In Guinea, between 130 and 235 km² of rice fields (17% and 30% of the existing rice field area) could be lost as a result of permanent flooding, depending on the inundation level considered (between 5 and 6 m) by 2050 (République de Guinée, 2002). In Eritrea, a 1 m rise in sea level is estimated to cause damage of over US$250 million as a result of 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 socio-economic and physical vulnerability of settlements located in marginal areas.

9.4.7 Tourism

Climate change could also place tourism at risk, particularly in coastal zones and mountain regions. Important market changes could also result from climate change (WTO, 2003) in such environments. The economic benefits of tourism in Africa, which according to 2004 statistics accounts for 3% of worldwide tourism, may change with climate change (WTO, 2005). Very few assessments of projected impacts on tourism and climate change are, however, available, particularly those using scenarios and climate model outputs. Modelling climate changes as well as human behaviour including personal preferences, choices and other factors is exceedingly complex. Although scientific evidence is still lacking, it is probable that flood risks and water pollution-related diseases in low-lying regions (coastal areas) as well as coral reef bleaching as a result of climate change could impact negatively on tourism (McLeman and Smit, 2004). African tourist...
places of interest, including wild life areas and parks, may also attract fewer tourists under marked climate changes. Climate change could, for example, lead to a pole ward shift of centres of tourist activity and a shift from lowland to highland tourism (Hamilton et al., 2005).

9.4.8 Settlement, industry and infrastructure

Climate variability, including extreme events such as storms, floods and sustained droughts, already has marked impacts on settlement and infrastructure (Reason and Keibel, 2004; Freeman and Warner 2001; Mirza, 2003; Niasse et al., 2004). Indeed, for urban planners, the bigger threats of climate variability and change to infrastructure are often expected to be from the little characterised and unpredictable rapid-onset disasters like storm surges, flash floods and tropical cyclones, coupled with localised population concentrations (Freeman, 2003). Negative impacts of climate change could create a new set of refugees, for example, may migrate into new settlements, seek new livelihoods and place additional demands on infrastructure (Myers, 2002; McLeman and Smit, 2005). A variety of migration patterns could thus emerge, e.g. repetitive migrants (as part of ongoing adaptation to climate change) and short-term shock migrants (responding to a particular climate event). Few detailed assessments of such impacts using climate as a driving factor have, however, been undertaken for Africa.

In summary, a range of possible impacts of climate change has been provided above (for other summaries, see also Nkomo et al., 2006 and The Centre for Health and the Global Environment, Harvard Medical School et al., 2005). The roles of some other stresses that may compound climate-induced changes have also been included. Clearly, several areas require much further investigation (particularly in the energy, tourism, settlement and infrastructure sectors). Despite the uncertainty of the science and the huge complexity of the range of issues outlined, initial assessments show that several regions in Africa may be affected by different impacts of climate change (Figure 9.5). 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 on the continent.
Figure 9.5: Examples of current and possible future impacts and vulnerabilities associated with climate variability and climate change for Africa (for details see sections highlighted in bold) (Sources various). Please note these are indications of possible change and are based on models that currently have limitations but that provide current available assessments.
9.5. Adaptation constraints and opportunities

The covariant mix of climate stresses and other factors in Africa means that for many in Africa, adaptation is not an option, but a necessary compulsion (see Kelkar, 2006). A growing cohort of studies is thus emerging on adaptation to climate variability and change in Africa, examples of which are given below (see also this volume, Section 18). A range of factors including wealth, technology, education, information, skills, infrastructure, access to resources, and various psychological factors and management capabilities can modify adaptive capacity (e.g. Block and Webb, 2001; Ellis and Mdoe, 2003; Brooks et al., 2005; Grothman and Patt, 2005; Adger and Vincent, 2005). Adaptation is shown to be successful and sustainable when linked to effective governance systems, civil and political rights, and literacy (Brooks et al., 2005).

9.5.1 Adaptation practices

Of the emerging range of livelihood adaptation practices being observed (Table 9.2), diversification of livelihood activities, institutional architecture (including rules and norms of governance), adjustments in farming operations, income-generation projects and selling of labour (e.g. migrating to earn an income - see also 9.6.1 below) and the move toward off- or non-farm livelihood incomes in parts of Africa repeatedly surface as key adaptation options (e.g. Bryceson, 2004; Osman et al., 2006; Benhin, 2006). As indicated in 9.2.1 above, reducing risks to possible future events will depend on the building of stronger livelihoods to ensure resilience to future shocks (International Federation of the Red Cross and Red Crescent Societies, 2002). The role of migration as an adaptive measure, particularly as a response to drought and flood, is also well known. Recent evidence, however, shows that such migration is not only driven by periods of climate stress (e.g. drought) (Eriksen and Silva, 2003). Migration is a dominant mode of labour (seasonal migration) providing a critical livelihood source. The role of remittances derived from migration provides a key coping mechanism in drought and non-drought years but is one that can be dramatically affected by periods of climate shock, when adjustments to basic goods such as food prices are impacted by food aid and other interventions (Devereux and Maxwell, 2001).

Table 9.2: Some examples of complex adaptations already observed in Africa in response to climate and other stresses (Source: adapted from initial categorization of Rockstrom, 2003).

<table>
<thead>
<tr>
<th>Theme</th>
<th>Emerging characteristics of adaptation</th>
<th>Authors</th>
</tr>
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</table>
| Social Networks & Social Capital | • Perceptions of risks by rural communities are important in configuring the problem (e.g. climate risk). Perceptions can shape the variety of adaptive actions taken.  
• Networks of community groups are also important.  
• Local savings schemes, many of them based on regular membership fees, are useful financial ‘stores’ drawn down during times of stress. | • Ellis and Bahiigwa, 2003; Quinn et al., 2003; Grothmann and Patt, 2005; Eriksen et al., 2005. |
| Institutions                  | • Role and architecture of institutional design and 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 levels) either enhance or constrain adaptive capacity. | • Battersbury and Warren, 2001; Ellis and Mdoe, 2003; Owuor et al, 2005; Osman, et al., 2006; Reid and Vogel, 2006. |

5 Owing to constraints in chapter length, neither all cases nor all details can be provided here.
### ECONOMIC RESILIENCE

<table>
<thead>
<tr>
<th>Theme</th>
<th>Characteristics</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equity</strong></td>
<td>• Issues of equity need to be viewed on several scales</td>
<td>Sokona and Denton, 2001; AFDB, 2002; Thomas and Twyman, 2005.</td>
</tr>
<tr>
<td></td>
<td>• Local scale: (within &amp; between community)</td>
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<td></td>
<td>- Interventions to enhance community resilience can be</td>
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<td></td>
<td>hampered by inaccessibility of centres to obtain</td>
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<td></td>
<td>assistance (aid/finance).</td>
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<td></td>
<td>- Global scale see IPCC WG 3 re: CDMS etc.</td>
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<tr>
<td><strong>Diversification of Livelihoods</strong></td>
<td>• Diversification has been shown to be a very strong and necessary economic strategy to increase resilience to stresses</td>
<td>Ellis, 2000; Toulmin et al., 2000; Block and Webb, 2001; Eriksen and Silva, 2003; Mortimore and Adams, 2001; Nyong et al., 2006; Bryceson, 2004; Ellis and Mdoe, 2003; Ellis, 2003; Chigwada, 2005.</td>
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<tr>
<td></td>
<td>• Agricultural intensification, for example, based on increased livestock</td>
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<td>densities, the use of natural fertiliser, soil and water conservation can</td>
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<tr>
<td></td>
<td>be useful adaptation mechanisms.</td>
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<tr>
<td><strong>Technology</strong></td>
<td>• Seasonal forecasts, their production, dissemination, uptake and</td>
<td>Patt, 2001; Patt et al., 2005 Phillips et al., 2001; Monyo, 2002; Patt and Gwata, 2002; Archer, 2003; Hay et al., 2003; Rockstrom, 2003; Roncoli et al., 2001; Ziervogel and Calder, 2003; Gabre-Madhin and Haagblade, 2004; Malaney et al., 2004; Ziervogel, 2004; Ziervogel and Downing, 2004; Chigwada, 2005; Orindi and Ochieng, 2005; Matondo et al., 2005; Seck et al., 2005; Ziervogel et al., 2005; Osman et al., 2006; Van Drunen et al., 2005; Abou Hadid, 2006.</td>
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<td></td>
<td>integration in model-based decision-making support systems has been</td>
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<tr>
<td></td>
<td>examined in several African contexts (see examples given).</td>
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<tr>
<td></td>
<td>• Enhanced resilience to future periods of drought stress may also be</td>
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<td></td>
<td>supported by improvements in present rain-fed farming systems through:</td>
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<td></td>
<td>- water harvesting systems; dam building; water</td>
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<td></td>
<td>conservation and agricultural practices; drip irrigation; development of</td>
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<td></td>
<td>drought resistant and early maturing crop varieties and alternative crop</td>
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</tr>
<tr>
<td></td>
<td>and hybrid varieties.</td>
<td></td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td>• Improvements in the physical infrastructure may improve adaptive capacity.</td>
<td>Sokona and Denton, 2001.</td>
</tr>
<tr>
<td></td>
<td>• Improved communication and road networks for better exchange of</td>
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<tr>
<td></td>
<td>knowledge and information.</td>
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</tr>
<tr>
<td></td>
<td>• General deterioration in infrastructure threatens the supply of water during</td>
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<td></td>
<td>droughts and floods.</td>
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Institutions and their effective functioning play a critical role in successful adaptation; it is therefore important to understand the design and functioning of such institutions (Table 9.2). The role of institutions at more local scales, both formal and informal institutions, however, also needs to be better understood (e.g. Reid and Vogel, 2006). (See other examples in Table 9.2.)

Other opportunities for adaptation that can be created include many linked to technology. The role of seasonal forecasts, their production, dissemination, uptake and integration in model-based decision-making support systems has been fairly extensively examined in several African contexts (see Table 9.2). Noticeable constraints, however, include the limited support for climate risk management in agriculture, for such seasonal forecast products (e.g. O’Brien and Vogel, 2003).

Enhanced resilience to future periods of drought stress may also be supported by improvements in present rain-fed farming systems (Rockstrom, 2003), such as water harvesting systems to supplement irrigation practices in semi-arid farming systems (‘more crop per drop strategies’, Table 9.2). Improved early warning systems and their application may also reduce vulnerability to future risks associated with climate variability and change. In malaria research, for example, it has been shown that while epidemics in the highlands have been associated with positive anomalies in temperature and rainfall (Githeko and Ndewga 2001; as discussed above in 9.4.3); those in the semi-arid areas are mainly associated with excessive rainfall (Thomson et al., 2006). Using such climate information it may be possible to give outlooks with lead times of between two and six months before the onset of the event (Thomson et al., 2006). Such lead times provide opportunities...
for putting interventions in place and for preventing excessive morbidity and mortality during malaria epidemics.

In Africa, biotechnology research could also 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). Wheat grain yield cultivated under current and future climate conditions (for example, increases of 1.5 °C and 3.6 °C) in Egypt highlight a number of adaptation measures, including various technological options that may be required under an irrigated agriculture system (e.g. Abou Hadid, 2006). A detailed study of current crop selection as an adaptation strategy to climate change in Africa (Kurukulasuriya and Mendelsohn, 2006b) shows that farmers select sorghum and maize-millet in the cooler regions of Africa, maize-beans, maize-groundnut, and maize in moderately warm regions, and cowpea, cowpea-sorghum, and millet-groundnut in hot regions. The study further shows that farmers choose sorghum and millet groundnut when conditions are dry, cowpea, cowpea-sorghum, maize-millet, and maize when medium wet and maize-beans and maize-groundnut when very wet. As temperatures warm, farmers tend to shift towards more heat tolerant crops. Depending upon whether precipitation increases or decreases, farmers will shift towards drought tolerant or water loving crops respectively.

The design and use of proactive rather than reactive strategies can also enhance adaptation. Proactive, ex-ante interventions, such as agricultural capital stock and extension advice in Zimbabwe (Owens et al., 2003), can raise household welfare and heighten resilience during non-drought years. In many cases these interventions can also be coupled to disaster-risk reduction strategies (see several references on www.unisdr.org.) Capital and extension services can also increase net crop incomes without crowding out net private transfers. Other factors that could be investigated to enhance resilience to shocks such as droughts, include: national grain reserves, grain future markets, weather insurance, the role of food price subsidies, cash transfers, school feeding schemes, etc. (for detailed discussion on these, see Devereux, 2003.)

9.5.2 Adaptation costs, constraints and opportunities

Many of the options outlined above come, however, with a range of costs and constraints, including large transaction costs. Deriving quantitative estimates of the potential costs of the impacts of climate change (indeed even those associated with climate variability - droughts and floods) and costs without adaptation (Yohe & Schlesinger, 2002) is, however, difficult. Limited availability of data and a variety of uncertainties relating to future changes in climate, social and economic conditions, and the responses that will be made to address those changes, frustrate precise cost and economic-loss inventories. Despite these problems, some economic loss inventories and estimations have been undertaken. In some cases (e.g. Egypt and Senegal) assessments have attempted to measure costs that may arise with and without adaptation to climate change impacts. Large populations are estimated to be at risk of impacts linked to possible climate change. Assessments of the impacts of sea-level rise in coastal countries show that costs of adaptation could amount to at least 5-10% of GDP (Niang-Diop, 2005). If no adaptation is included then costs increase losses of up to 14% GDP (Van Drunen et al., 2005). In South Africa, initial assessments of the costs of adaptation in the Berg River Basin also show that the costs of not adapting to climate change can be much greater than costs that may arise if flexible and efficient approaches are not included into management options (see Stern, 2006).

Despite some success stories (see example in Table 9.2), there is also evidence of an erosion of coping and adaptive strategies as a result of varying land-use changes and socio-political and cultural stresses. Continuous cultivation, for example, at the expense of soil replenishment, can
result in real ‘agrarian dramas’ (e.g. Rockstrom, 2003). The interaction of both social (e.g. access to food) and biophysical stresses (e.g. drought) thus combine to aggravate critical stress periods (e.g. during and after ENSO events). Traditional coping strategies (see 9.6.2) may not be sufficient in this context, either currently or in the future, and may lead to unsustainable responses in the longer term. Erosion of traditional coping responses not only reduces resilience to the next climatic shock but also to the full range of shocks and stresses to which the poor are exposed (DFID, 2004).

Limited scientific capacity and other scientific resources are also factors that frustrate adaptation. (See, for example, Washington et al., 2004; Washington et al., 2006.)

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; agriculture that is heavily dependent on rainfall; as well as a range of macro- and micro-structural problems (see 9.2.2). The implications of climate change on development are, however, currently not fully understood. Factors heightening vulnerability to climate change and affecting national level adaptation have, for example, been shown to include issues of local and national governance, civil and political rights, and literacy (e.g. Brooks et al., 2005). The most vulnerable nations in the assessment undertaken by Brooks et al. (2005) (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 (Brooks et al., 2005). At the more local level, the poor often cannot adopt diversification as an adaptive strategy and often have very limited diversification options available to them (e.g. Block and Webb, 2001; Ellis and Mdoe, 2003). Micro-financing and other social safety nets and social welfare grants, as a means to enhance adaptation to current and future shocks and stresses, may be successful in overcoming such constraints if supported by local institutional arrangements on a long-term sustainable basis (Ellis, 2003; Chigwada, 2005).

Africa needs to focus on increasing adaptive capacity to climate variability and climate change over the long term. Ad hoc responses, for example, short-term responses, uncoordinated processes, isolated projects, etc., are only one type of solution (Sachs, 2005). Other solutions that could be considered include mainstreaming adaptation into national development processes (e.g. Huq and Reid, 2005; Dougherty and Osman, 2005). There may, for example, be several opportunities to link disaster risk reduction, poverty and development (see, for example, several calls and plans for such action; e.g. Hyogo declaration, www.unisdr.org). Where communities live with various risks, coupling risk reduction and development activities can provide additional adaptation benefits (e.g. Yamin et al., 2005). Unprecedented efforts by government, 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, are also increasing. [(See food insecurity case study below and SARPN, www.sarpn.org, for several case studies and examples; see also other possible adaptation options already suggested (e.g. Table 9.2).]

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 at the forefront, including a deeper and further examination of the structural causes of poverty at international, national and local levels (Bryceson, 2004). The causes, impacts and legacies of various strategies - including liberalisation policies, decades of structural adjustment programmes (SAP) and market conditions - cannot be ignored in discussions on poverty alleviation and adaptation to stresses (including climate change). The interaction of such drivers and climate are illustrated further in two case studies below.
9.6 Case Studies

9.6.1 Food insecurity – the role of climate variability, change and other stressors

Although the extent and nature of climate change impact on food production are as yet uncertain, it has long been recognised that climate variability and change have an impact on food production, e.g. Mendelsohn et al., 2000a and b; Devereux and Maxwell, 2001; Fischer et al., 2002; Kurukulasuriya and Rosenthal, 2003). 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 (Gregory et al., 2005; Devereux and Maxwell, 2001; Devereux, 2003). 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, market failures, as well as environmental issues (Devereux and Maxwell, 2001; Marsland, 2004; Misselhorn, 2004).

Building on this recognition, 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 nutritional content of the food itself (Swaminathan, 2000; Hugon and Nanterre 2003). Climate variability, such as periods of drought and flood as well as longer-term change may, either directly or indirectly, profoundly impact on all these three components in shaping food security (Ziervogel et al., 2006, see Figure 9.6).

The potential impacts of climate change on food access in Figure 9.6 may, for example, be better understood in the light of changes in Africa’s livelihoods landscape. 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. Less reliance on food production as a primary source of people’s food security contests the assumption that people’s food security in Africa derives solely (or even primarily) from their own agricultural production (Bryceson, 2003, 2004; Bryceson and Fonseca, 2006). At the same time, however, 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 through purchase (Slingo et al., 2005).
There are a number of other illustrative impacts that climate variability and change have on livelihoods and food access, many of which also impact on food availability and nutrient access aspects of food security. These include impacts on the tourism sector (e.g. Hamilton et al., 2005), and on market access, which affect the ability of farmers to obtain agricultural inputs, sell surplus crops, and purchase alternative foods. These impacts affect food security through altering or restraining livelihood strategies, while also affecting the variety of food available and nutritional intake (Kelly et al., 2003). Market access is influenced not only by broader socio-economic and political factors, but also by distance from markets and the condition of infrastructure, such as roads, which can be damaged during climate events (e.g. Abdulai and Crole-Rees, 2001; Ellis, 2003).

The key issues, therefore, in relation to the potential impacts of climate variability and change on food security in Africa encompass not only a narrow understanding of such impacts on food production, but a wider understanding of how such changes and impacts 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; Brooks et al., 2005; Adger and Vincent, 2005). The impact of climate variability and change on food security therefore cannot be considered independently of the broader issue of human security (O’Brien, 2006). The inclusion of climate variability and change in understanding human vulnerability and adaptation is being increasingly explored at the household and community levels, as well as through regional agro-climatological studies in Africa (e.g. Verhagen et al., 2001).

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 (see also Table 9.2 above). Adaptive capacity and choices, however, are based on a variety of complex causal mechanisms. Crop choices, for example, are not based purely on resistance to drought or disease but on factors such as cultural preferences, palatability, and seed storage capacity (Scoones et al., 2005). Research elsewhere in the world also indicates that elements of social capital (such as associations, networks and levels of trust) are important determinants of social resilience and responses to climate change, but how these develop and are used in mitigating vulnerability remain unclear.

While exploring the local-level dynamics of people’s vulnerability to climate change, of which adaptive capacity is a key component, is important there is a need to find ways to embed such findings into wider scales of assessment (e.g. country and regional scales) (Brooks et al., 2005). A number of recent studies are beginning to probe the enormous challenges of developing scenarios of adaptive capacity at multiple scales. From these studies, 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, 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 (MDGs) particularly the first goal of eradicating 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 Indigenous knowledge systems
The term ‘indigenous knowledge’ is used to describe the knowledge systems developed by a community as opposed to the scientific knowledge that is generally referred to as ‘modern’ knowledge (Ajibade, 2003). Indigenous knowledge is the basis for local-level decision making in many rural communities. It has value not only for the culture in which it evolves, but also for scientists and planners striving to improve conditions in rural localities. 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).

9.6.2.1 Indigenous knowledge in weather forecasts

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, for example, shows that farmers are able to use knowledge of weather systems such as rainfall, thunderstorm, windstorm, harmattan (a dry dusty wind that blows along the northwest coast of Africa) and sunshine to prepare for future weather (Ajibade and Shokemi, 2003). Indigenous methods of weather forecasting are known to complement farmer’s planning activities in Nigeria. A similar study in Burkina Faso showed that farmers’ forecasting knowledge encompasses shared and selective experiences. 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 timing of fruiting by certain local trees, the water level in streams and ponds, the nesting behaviour of small quail-like birds, and insect behaviour in rubbish heaps outside compound walls (Roncoli et al., 2001).

9.6.2.2 Indigenous knowledge in mitigation and adaptation

African communities and farmers have always coped with changing environments. They have knowledge and practices to cope with 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 these can be seen in the context of existing practices. A study in Zimbabwe observed that farmers’ willingness to use seasonal climate forecasts increased when the forecasts were presented with and compared to the local indigenous climate forecasts (Patt and Gwata, 2002).

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 (Dea and Scoones, 2003). Natural mulches moderate soil temperatures and extremes, suppress diseases and harmful pests, and conserve soil moisture. The widespread use of indigenous plant materials, such as agrochemicals to combat pests that normally attack food crops, has also been reported among small-scale farmers (Gana, 2003). It is likely that climate change will alter the ecology of disease vectors and such indigenous practices of pest management would be useful adaptation strategies. 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; erosion control bunding 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 latter
are less than those of the former (Seo and Mendelsohn, 2006b). Pastoralists’ nomadic mobility
reduces the pressure on low-carrying-capacity grazing areas through the cyclic movement from the
dry northern areas to the wetter southern areas of the Sahel.

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 indigenous plants
that are more tolerant to droughts and pests, providing a reserve for extended periods of economic
hardship (Ramphela, 2004; Eriksen, 2005). In southern Sudan, for example, women are directly
responsible for the selection of all sorghum seeds saved for planting each year. They preserve a
spread of varieties of seeds that will ensure resistance to the variety of conditions that may arise in
any given growing season (Easton and Roland, 2000).

9.7 Conclusion: links between climate change and sustainable development

African people and the environment have always battled the vagaries of weather and climate
(9.2.1). These struggles, however, are increasingly waged alongside a range of other stresses, such
as HIV/AIDS, conflict, land struggles etc (see 9.2.2 above). Despite good economic growth in some
countries and sectors in Africa, large inequalities still persist, and some sources suggest
(OECD/IEA, 2004/2005) that hopes of reaching the MDGs by 2015 are slipping. While climate
change may not have featured directly in the setting of the MDGs it is clear from evidence here that
climate change and variability may be an additional impediment to achieving them (Table 9.3;
Kelkar in Thornton et al., 2006).

Although future climate change seems to be marginally important when compared to other
development issues (Davidson et al., 2003), it is clear that climate change and variability and
increased disaster risks associated with variations and changes in climate, may hamper future
development. On an annual basis, for example, developing countries have already absorbed US$35
billion in damages from natural disasters (Mirza, 2003). These figures, however, do not include
livelihood assets and losses and overall emotional and other stresses that are often more difficult to
assess. A challenge therefore is to shape and manage development that also builds resilience to
shocks, including those related to climate change and variability (Davidson et al., 2003; Adger et
al., 2004).

Table 9.3: Potential Impacts of Climate Change on the Millennium Development Goals (modified
after AfDB et al., 2002 and Kelkar, 2006).

<table>
<thead>
<tr>
<th>Millennium Development Goal*</th>
<th>Potential Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eradicate extreme poverty and hunger (Goal 1)</td>
<td>Climate Change (CC) 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 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. In addition to CC expected impacts on regional food security, are likely particularly in Africa where food security is expected to worsen (sections 9.4.1, 9.4.3, 9.4.4 and 9.4.8).</td>
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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:

- Increased heat-related mortality and illness associated with heat waves (which may be balanced by less winter cold related deaths in some countries) sections
- Increased prevalence of some vector borne diseases (e.g. malaria to dengue fever), and vulnerability to water, food or person-to-person diseases (e.g. cholera and dysentery) (9.4.3)
- Declining quantity and quality of drinking water, which exacerbate malnutrition, since it is a prerequisite for good health.
- Reduced natural resource productivity and threatened food security, particularly in sub Saharan Africa (9.4.3, 9.4.3, 9.4.4, 9.6.1).

### 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 (9.4.4)

- 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. (9.4, Table 9.1 and this volume, section 4).

### 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 (9.2.1 and 9.2.2)

### 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 female-headed households particularly where they have fewer assets (9.7.1, Table 9.2).

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.

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

While much is being discovered about climate variability and change, the impacts and possible
responses to such changes result in significant areas that require more concerted effort and learning.

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 land-cover change (i.e. land architecture in various guises) emerges as a key theme. The links between 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 other multiple stresses that enhance impacts to droughts and floods and possible future climate change. While drought may affect production in some years, climate variability alone does not explain limits of food production in Africa. Better models and methods to better understand multiple stresses, particularly at a range of scales e.g. global, regional and local and including the role of climate change and variability, are therefore required.
- Several areas of debate and contestation, some shown here, also exist, with particular reference to health, the water sector and certain ecosystem responses e.g. mountain environments. More research on such areas is clearly needed.
- Impacts in the water sector, while addressed by global- and regional-scale model assessments, are still relatively few, particularly for local assessments, including a focus on ground water impacts. Detailed ‘systems’ assessments including hydrological systems assessments also need to be expanded upon.
- Several of the impacts and vulnerabilities presented here derived from global models do not currently resolve local-level changes and impacts. Developing and improving regional and local-level climate models and scenarios could improve the confidence attached to the various projections.
- Local-scale assessments of various sorts, including adaptation studies, are still focused on understanding current vulnerabilities and adaptation strategies. Few comprehensive, comparable studies are available within regions, particularly those focusing on future options and pathways for adaptation.
- Finally, there is still much uncertainty in assessing the role of climate change in complex systems that are shaped by interacting multiple stressors, with a degree of confidence. Preliminary investigations 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 to a vulnerability-led approach in climate change science. Despite this shift, much of the climate change research remains focused on impacts. For Africa, however, as this chapter has attempted to show, a great deal more needs to be done to understand and show the interactions between vulnerability and adaptation to climate change variability and the consequences of climate variability and change both in the short and long term.

9.8.2.1 Climate

Notwithstanding the marked progress made in recent years, particularly with model assessments
(e.g. in parts of Africa, as evident in WG1, section 11), the climate of many parts of Africa is still not fully understood. Climate models developed from GCMs are very coarse and do not adequately capture important regional variations in Africa’s climate. The need exists to develop regional climate models and sub-regional models at a scale that would be meaningful to decision makers and include stakeholders in framing some of the issues that may require more investigation. A further need is an improved understanding of climate variability, including an adequate representation of the climate system and the role of regional oceans and diverse feedback mechanisms.

9.8.2.2 Water

Detailed, regional-scale research on the impact of, and vulnerability to, climate change and variability 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 are also important issues that need to be incorporated into future projections. Further research on the impacts of climate variability and change on ground water is also needed.

9.8.2.3 Energy

There is very little detailed information on the impacts and vulnerabilities of the energy sector in Africa specifically to climate change and variability, particularly using and applying SRES scenarios and GCMs outputs. 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. Clean Development Mechanisms (CDMs), including carbon sequestration etc.].

9.8.2.4 Ecosystems

There is a great need for a well-established programme of research and technology development in climate prediction, which could assess the risks and impacts of climate change in ecosystems. Assessment of the impacts of climate variability and change on important, sensitive and unique ecosystems in Africa (hotspots), on the rainforests of the Congo Basin, on other areas of mountain biodiversity as well inland and on marine fish stocks, still requires further research.

9.8.2.5 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. Large gaps appear to exist in research on the impacts of climate variability and change on tourism and related matters, such as the impacts of climate change on coral reefs and how these impacts might affect ecotourism.

9.8.2.6 Health

Most assessments on health have concentrated on malaria and still there are debates on the attribution of malaria resurgence in some African areas. The need exists to examine the...
vulnerabilities and impacts of future climate change on dengue fever, meningitis, etc. There is also an urgent need to begin a dialogue and research effort on the heightened vulnerabilities associated with HIV/AIDS and periods of climate stress and climate change.

9.8.2.7 Agriculture

More regional and local research is still required on a range of issues, such as the study of the relation between CO₂ enrichment and future production of agricultural crops in Africa, salt tolerant plants, and other trees and plants in coastal zones. Very little research has also 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 variability and change. Research on the links between agriculture, land use, and carbon sequestration and agricultural use in biofuels also needs to be expanded.

9.8.2.8 Adaptation

There is a 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 of the 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 and the future adaptation options and pathways that may arise from the interaction of multiple stressors on the coping capacities of African communities.

9.8.2.9 Vulnerability and risk reduction

While there are some joint activities that involve those trying to enhance risk-reduction activities, there is still little active engagement between communities that are essentially researching similar themes. The need exists, therefore, to enhance efforts on the coupling and drawing together of disaster-risk-reduction activities, vulnerability assessments, and climate change and variability assessments. 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 systems, seasonal forecasts) could be used to enhance the resilience of vulnerable communities in Africa in order to improve their capacity to cope with current and future climate variability and change.

9.8.2.10 Enhancing African capacity

A need exists for African recognised ‘hubs’ or centres of excellence established by Africans and developed by African scientists. There is the need to also enhance institutional ‘absorptive capacity’ in the various regions, providing opportunities for young scientists to improve research in fields of climate change impacts, vulnerability and adaptation.

9.8.2.11 Knowledge for action

Much of the research on climate has been driven by the atmospheric sciences community including,
more recently, greater interaction with biophysical scientists (e.g. global change programmes including IGBP/WCRP). This chapter has, however, shown that there is much to be gained from a more nuanced approach, which includes those working in the sociological and economic sciences (e.g. IHDP and a range of others). Moreover, the growing interest in partnerships, public/private, as well as the inclusion of large corporations, formal and informal business and wider civic society requires more inclusive processes and activities. Such activities, however, may not be sufficient, particularly if change is rapid. For this reason, more ‘urgent’ and ‘creative’ interactions (e.g. greater interactions between users and producers of science, stakeholder interactions, communication, institutional design etc) will be required. Much could also be gained by greater interactions between those from the disaster-risk-reduction-, development- and climate-science communities.

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 land-cover change is one area that could be further explored to enhance such understanding. 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 (of both a historical, current, and future-scenarios nature). The need for more detailed local-level analyses of the role of multiple interacting factors, including development activities and climate risk-reduction in the African context, is evident from much of this chapter.
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