9

Africa

Coordinating Lead Authors:

Michel Boko (Benin), Isabelle Niang (Senegal), Anthony Nyong (Nigeria), Coleen Vogel (South Africa)

Lead Authors:

Andrew Githeko (Kenya), Mahmoud Medany (Egypt), Balgis Osman-Elasha (Sudan), Ramadjita Tabo (Chad), Pius Yanda (Tanzania)

Contributing Authors:

Francis Adesina (Nigeria), Micheline Agoli-Agbo (Benin), Samar Attaher (Egypt), Lahouari Bounoua (USA), Nick Brooks (UK), Ghislain Dubois (France), Mukiri wa Githendu (Kenya), Karim Hilmi (Morocco), Alison Misselhorn (South Africa), John Morton (UK), Imoh Obioh (Nigeria), Anthony Ogbonna (UK), Hubert N'Djafa Ouaga (Chad), Katharine Vincent (UK), Richard Washington (South Africa), Gina Ziervogel (South Africa)

Review Editors:

Frederick Semmazzi (USA), Mohamed Senouci (Algeria)

This chapter should be cited as:

Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda, 2007: Africa. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge UK, 433-467.

Table of Contents

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, and low adaptive capacity (high confidence).
Africa's major economic sectors are vulnerable to current climate sensitivity, with huge economic impacts, and this vulnerability is exacerbated by existing developmental challenges such as endemic poverty, complex governance and institutional dimensions; limited access to capital, including markets, infrastructure and technology; ecosystem 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 (high confidence).
Human or societal adaptive capacity, identified as being low for Africa in the Third Assessment Report, is now better understood and this understanding is supported by several case studies of both current and future adaptation options. However, such advances in the science of adaptation to climate change and variability, including both contextual and outcome vulnerabilities to climate variability and climate change, show that these adaptations may be insufficient to cope with 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 are likely to be severely compromised by climate change and climate variability (high confidence).
A number of countries in Africa already face semi-arid conditions that make agriculture challenging, and climate change will be likely to reduce the length of growing season as well as force large regions of marginal agriculture 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 farmers 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 currently do not experience water stress will become at risk of water stress (very high confidence).
Climate change and variability are likely to 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 usable land-based water resources before 2025. About 25% of Africa's population (about 200 million people) currently experience high water stress. The population at risk of increased water stress in Africa is projected to be between 75-250 million and 350-600 million people by the 2020s and 2050s, respectively. [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 ecosystems. Changes in grasslands and marine ecosystems are also noticeable. It is estimated that, by the 2080s, the proportion of arid and semi-arid lands in Africa is likely to increase by 5-8%. Climate change impacts on Africa's ecosystems will probably have a negative effect on tourism as, according to one study, between 25 and 40% of mammal 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 e.g., mangroves and coral reefs, with additional consequences for fisheries and tourism. The projection that sea-level rise could increase flooding, particularly on the coasts of eastern Africa, will have implications for health. Sea-level rise will probably increase the high socio-economic and physical vulnerability of coastal cities. The cost of adaptation to sea-level rise could amount to at least 5-10% of gross domestic product. [9.4.3, 9.4.6, 9.5.2]

Human health, already compromised by a range of factors, could 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 will alter the ecology of some disease vectors in Africa, and consequently the spatial and temporal transmission of such diseases. Most assessments of health have concentrated on malaria and there are still 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 and cholera, among others. [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 resulting from increased droughts and floods; and significant plant and animal species extinctions and associated livelihood impacts. Such factors were shown, moreover, to be aggravated by low adaptive capacity (IPCC, 2001). Many of these conclusions, as shown below, remain valid for this Fourth Assessment Report[1].

9.1.2 New advances and approaches used in the Fourth Assessment Report

Recent scientific efforts, including a focus on both an *impacts-led* approach as well as a *vulnerability-led* approach (see Adger et al., 2004, for a summary), have enabled a more detailed assessment of the interacting roles of climate and a range of other factors driving 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 Sections 9.2.1, 9.2.2 and 9.4) 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 (see Section 9.5, Table 9.2).

9.2 Current sensitivity/vulnerability

9.2.1 Current sensitivity to climate and weather

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 Christensen et al., 2007). 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 have indicated a greater warming trend since 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., 2004; Kruger and Shongwe, 2004). Between 1961 and 2000, there was an increase in the number of warm spells over southern and western 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 observed (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 the periods 1931-1960 and 1968-1990 (Nicholson et al., 2000; Chappell and Agnew, 2004; Dai et al., 2004). In the tropical rain-forest zone, declines in mean annual precipitation of around 4% in West Africa, 3% in North Congo and 2% in South Congo for the period 1960 to 1998 have been noted (e.g., Malhi and Wright, 2004). A 10% increase in annual rainfall along the Guinean coast during the last 30 years has, however, also been observed (Nicholson et al., 2000). In other regions, such as southern Africa, no long-term trend has been noted. Increased interannual variability has, however, been observed in the post-1970 period, with higher rainfall anomalies and more intense and widespread droughts reported (e.g., Richard et al., 2001; Fauchereau et al., 2003). 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 weather extremes (Tadross et al., 2005a; New et al., 2006). During 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 our understanding of the complex mechanisms responsible for rainfall variability have been made (see Reason et al., 2005; Warren et al., 2006; Washington and Preston, 2006; Christensen et al., 2007). Understanding how possible climate-regime changes (e.g., in El Niño-Southern Oscillation (ENSO) events) 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 equatorial Indian Ocean sea-surface temperature (SST), while ENSO is a significant influence on rainfall at interannual scales (Giannini et al., 2003; Christensen et al., 2007). 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 SSTs in the Gulf of Guinea (Vizy and Cook, 2001), and a relationship has also been identified between the warm Mediterranean Sea and abundant rainfall (Rowell, 2003). The influence of ENSO decadal variations has also been recognised in south-west Africa, influenced in part by the North Atlantic Oscillation (NAO) (Nicholson and Selato, 2000). Changes in the ways these mechanisms influence regional weather patterns have been identified in southern Africa, where severe droughts have been linked to regional atmospheric-oceanic anomalies before the 1970s but to ENSO in more recent decades (Fauchereau et al., 2003).

Several studies also have highlighted the importance of terrestrial vegetation cover and the associated dynamic feedbacks on the physical climate (see Christensen et al., 2007). An increase in vegetation density, for example, has been suggested to result in a year-round cooling of 0.8°C in the

[1] Note that several authors (e.g., Agoumi, 2003; Legesse et al., 2003; Conway, 2005, Thornton et al., 2006) caution against over-interpretation of results owing to the limitations of some of the projections and models used.

tropics, including tropical areas of Africa (Bounoua et al., 2000). Complex feedback mechanisms, mainly due to deforestation/land-cover change and changes in atmospheric dust loadings, also play a role in climate variability, particularly for drought persistence in the Sahel and its surrounding areas (Wang and Eltahir, 2000, 2002; Nicholson, 2001; Semazzi and Song, 2001; Prospero and Lamb, 2003; Zeng, 2003). The complexity of the interactions precludes ‘simple interpretations’; for instance, the role of human-induced factors (e.g., migration), together with climate, can contribute to changes in vegetation in the Sahel that feed back into the overall physical system in complex ways (see, e.g., Eklundh and Olsson, 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 known. Better quantitative estimates of Saharan dust loadings and controls on emissions have now emerged from both satellite and field campaigns (e.g., Washington and Todd, 2005; Washington et al., 2006).

Finally, changes in extreme events, such as droughts and floods, have major implications for numerous Africans and require 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 million people regularly suffer impacts from droughts and floods. These impacts are often further exacerbated by health problems, particularly diarrhoea, cholera and malaria (Few et al., 2004). During the mid-1980s the economic losses from droughts totalled several hundred million U.S. dollars (Tarhule and Lamb, 2003). Droughts have mainly affected the Sahel, the Horn of Africa and southern Africa, particularly since the end of the 1960s (see Section 9.6.2; Richard et al., 2001; L’Hôte et al., 2002; Brooks, 2004; Christensen et al., 2007; Trenberth et al., 2007). 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 – see Mirza, 2003; Obasi, 2005). Even countries located in dry areas (Algeria, Tunisia, Egypt, Somalia) have not been flood-free (Kabat et al., 2002).

9.2.1.1 Sensitivity/vulnerability of the water sector

The water sector is strongly influenced by, and 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 since the 1960s, probably owing to periods of intense droughts followed by increases in rainfall and extreme rainfall events in late 1997 (e.g., in Lakes Tanganyika, Victoria and Turkana; see Riebeek, 2006). After the 1997 flood, Lake Victoria rose by about 1.7 m by 1998, Lake Tanganyika by about 2.1 m, and Lake Malawi by about 1.8 m, and very high river-flows were recorded in the Congo River at Kinshasha (Conway et al., 2005). The heavy rains and floods have been possibly 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 also include those observed for southern Africa (Schulze et al., 2001; 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 of impacts and vulnerabilities with regard to groundwater and climate interactions are available, and yet these are clearly of great concern for those dependent on groundwater for their water supply.

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 such as access to clean drinking water and sanitation, which effectively reduces the quantity of freshwater available for human use. Despite the considerable improvements in access to freshwater in the 1990s, only about 62% of the African population had access to improved water supplies in 2000 (WHO/UNICEF, 2000; Vörösmarty, 2005). As illustrated in Section 9.2.2, issues that affect access to water, including water governance, also need to be considered in any discussion of vulnerability to water stress 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 pinpoint the implications of the poor health status of many Africans 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 (see http://www.cdc.gov/malaria/; Patz and Olson, 2006). Incidences of malaria, including the recent resurgence in the highlands of 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; Patz et al., 2002; Abeku et al., 2004; Zhou et al., 2004; Patz and Olson, 2006). The economic burden of malaria is estimated as an average annual reduction in economic growth of 1.3% for those African countries with the highest burden (Gallup and Sachs, 2001).

The resurgence of malaria and links to climate and/or other causal ‘drivers’ of change in the highlands of East Africa has recently attracted much attention and debate (e.g., Hay et al., 2002a; Pascual et al., 2006). There are indications, for example, that in areas that have two rainy seasons – March to June (MAMJ) and September to November (SON) – more rain is falling in SON than previously experienced in the northern sector of East Africa (Schreck and Semazzi, 2004). The SON period is relatively warm, and higher rainfall is likely to increase malaria transmission because of a reduction in larval development duration. The spread of malaria into new areas (for

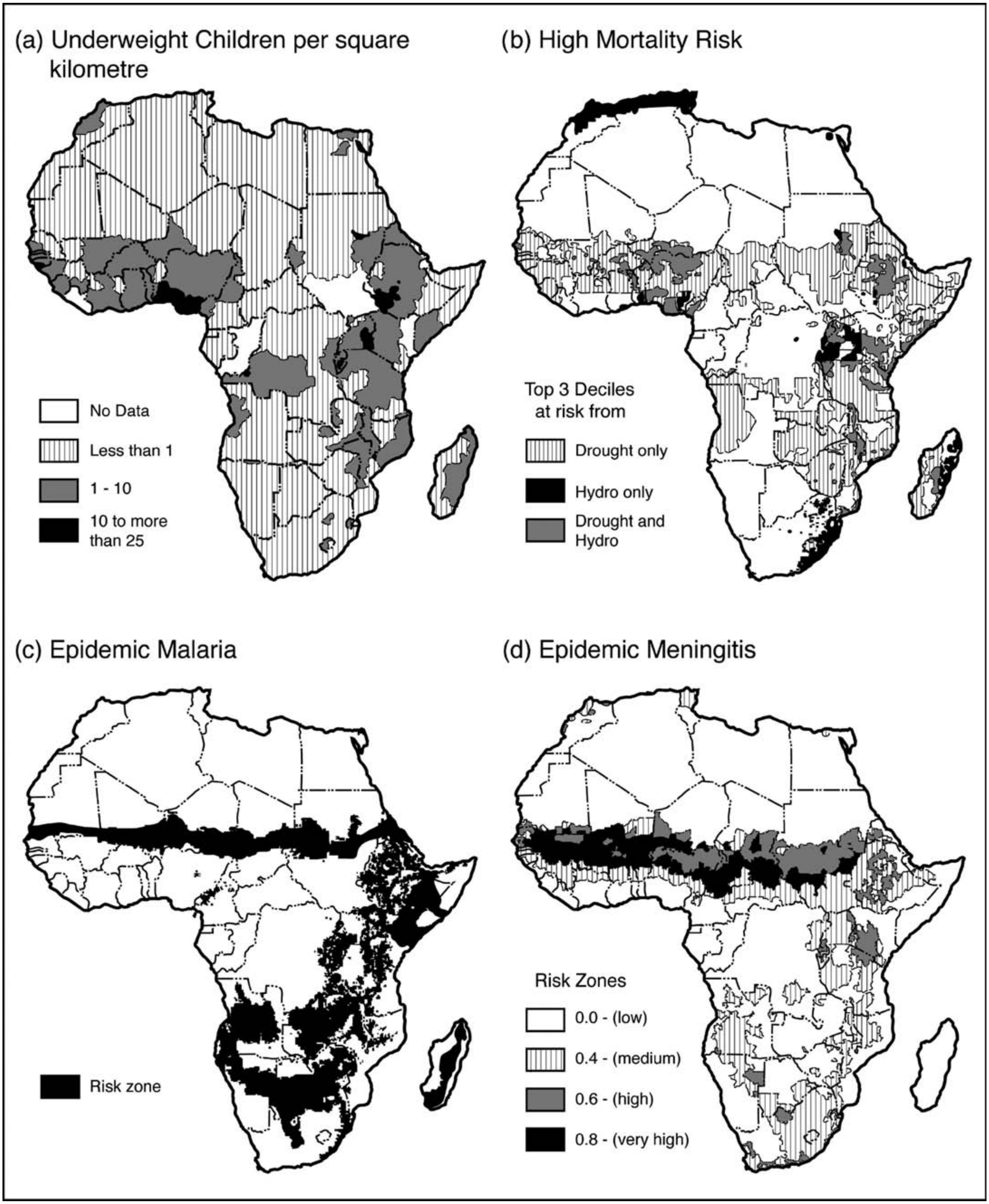


Figure 9.1. *Examples of current 'hotspots' or risk areas for Africa: (a) 'hunger'; (b) 'natural hazard-related disaster risks'; (c) regions prone to malaria derived from historical rainfall and temperature data (1950-1996); and (d) modelled distribution of districts where epidemics of meningococcal meningitis are likely to occur, based on epidemic experience, relative humidity (1961-1990) and land cover (adapted from IRI et al., 2006, p. 5; for further details see also Molesworth et al., 2003; Balk et al., 2005; Dilley et al., 2005; Center for International Earth Science Information Network, 2006; Connor et al., 2006).*

example, observations of malaria vector *Anopheles arabiensis* in the central highlands of Kenya, where no malaria vectors have previously been recorded) has also been documented (Chen et al., 2006). Recent work (e.g., Pascual et al., 2006) provides further new insights into the observed warming trends from the end of the 1970s onwards in four high-altitude sites in East Africa. Such trends may have significant biological implications for malaria vector populations.

New evidence regarding micro-climate change due to land-use changes, such as swamp reclamation for agricultural use and deforestation in the highlands of western Kenya, suggests that suitable conditions for the survival of *Anopheles gambiae* larvae are being created and therefore the risk of malaria is increasing (Munga et al., 2006). The average ambient temperature 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 10-month period (Afrane et al., 2005). Mosquito pupation rates and larval-to-pupal development have been observed to be significantly faster in farmland habitats than in swamp and forest habitats (Munga et al., 2006). Floods can also trigger malaria epidemics in arid and semi-arid areas (e.g., Thomson et al., 2006).

Other diseases are also important to consider with respect to climate variability and change, as links between variations in climate and other diseases, such as cholera and meningitis, have also been observed. About 162 million people in Africa live in areas with a risk of meningitis (Molesworth et al., 2003; Figure 9.1d). While factors that predispose populations to meningococcal meningitis are still poorly understood, dryness, very low humidity and dusty conditions are factors that need to be taken into account. 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, b; Devereux and Maxwell, 2001). The contribution of agriculture to GDP varies across countries but assessments suggest an average contribution of 21% (ranging from 10 to 70%) of GDP (Mendelsohn et al., 2000b). This sector is particularly sensitive to climate, including periods of climate variability (e.g., ENSO and extended dry spells; see 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, and a lack of access to inputs and improved seeds. These challenges are usually aggravated by periods of prolonged droughts and/or floods and are often particularly severe during El Niño events (Mendelsohn et al., 2000a, b; Biggs et al., 2004; International Institute of Rural Reconstruction, 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 (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 (see 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; Thomas et al., 2004).

Approximately half of the sub-humid and semi-arid parts of the southern African region 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 caused a 25-35 km southward shift of the Sahelian, Sudanese and Guinean ecological zones in the second half of the 20th century (Gonzalez, 2001). This has resulted in a loss of grassland and acacia, the loss of flora/fauna, and shifting sand-dunes in the Sahel (ECF and Potsdam Institute, 2004).

The 1997/1998 coral bleaching episode 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 resulted in reduced tourism in Mombasa and Zanzibar, and caused financial losses of about US$12-18 million (Payet and Obura, 2004). Coral reefs are also exposed to other local anthropogenic threats, including sedimentation, pollution and over-fishing, 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 have occurred in Egypt, Djibouti and western Somalia, along with some local bleaching (Kotb et al., 2004).

Observed changes in ecosystems are not solely 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). Sensitive mountain environments (e.g., Mt. Kilimanjaro, Mt. Ruwenzori) demonstrate the complex interlinkages between various atmospheric processes including solar radiation micro-scale processes, glacier-climate interactions, and the role of vegetation changes and climate interactions (Kaser et al., 2004). For example, the drop in atmospheric moisture at the end of the 19th century, and the drying conditions that then occurred, have been used to explain some of the observed glacier retreat on Kilimanjaro (Kaser et al., 2004). 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. Changes in the range of plant and animal species, for example, are already occurring because of forest fires on Kilimanjaro, and may place additional pressure on ecosystem services (Agrawala, 2005). The loss of 'cloud forests' through fire since 1976 has resulted in an estimated 25% annual reduction in 'fog water' (the equivalent of the annual drinking water demand of 1 million people living on Kilimanjaro) and is another critical impact in this region (see Chapter 4, Section 4.2; Box 9.1; Agrawala, 2005; Hemp, 2005).

9.2.1.5 Sensitivity/vulnerability of settlements and infrastructure

Impacts on settlements and infrastructure are well recorded for recent extreme climate events (e.g., the 2000 flooding event

Box 9.1. Environmental changes on Mt. Kilimanjaro

There is evidence that climate is modifying natural mountain ecosystems via complex interactions and feedbacks including, for example, solar radiation micro-scale processes on Mt. Kilimanjaro (Mölg and Hardy, 2004; Lemke et al., 2007). Other drivers of change are also modifying environments on the mountain, including fire, vegetation changes and human modifications (Hemp, 2005). During the 20th century, the areal extent of Mt. Kilimanjaro's ice fields decreased by about 80% (Figure 9.2). It has been suggested that if current climatological conditions persist, the remaining ice fields are likely to disappear between 2015 and 2020 (Thompson et al., 2002).

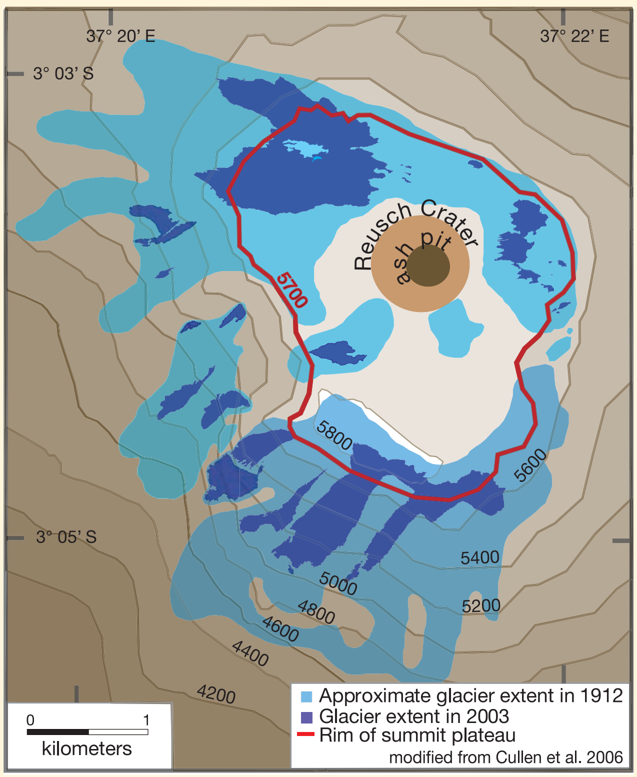


Figure 9.2. *Decrease in surface area of Mt. Kilimanjaro glaciers from 1912 to 2003 (modified from Cullen et al., 2006).*

in Mozambique – Christie and Hanlon, 2001; IFRCRCS, 2002; see also various infrastructural loss estimates from severe storm events in the western Cape, South Africa – http://www.egs.uct.ac.za/dimp/; and southern Africa – Reason and Keibel, 2004). Large numbers of people are currently at risk of floods (see, for example, UNDP, 2004; UNESCO-WWAP, 2006), particularly in coastal areas, where coastal erosion is already destroying infrastructure, housing and tourism facilities (e.g., in the residential region of Akpakpa in Benin (Niasse et al., 2004; see also Chapter 7, Section 7.2.).

9.2.2 Current sensitivity and vulnerability to other stresses

Complex combinations of socio-economic, political, environmental, cultural and structural factors act and interact to affect vulnerability to environmental change, including climate change and variability. Economic development in Africa has been variable (Ferguson, 2006). African economies have recently registered a significant overall increase in activity (growing by more than 5% in 2004 – OECD, 2004/2005; World Bank, 2006a, b). Sub-Saharan Africa, for example, has shown an increase of 1.2%/yr growth in average income since 2000 (UNDP, 2005). Despite this positive progress, boosted in part by increases in oil exports and high 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, e.g., Devereux and Maxwell, 2001; OECD, 2004/2005; Ferguson, 2006). Certain countries in sub-Saharan Africa suffer from deteriorating food security (Figure 9.1a) and declines in overall real wealth, with estimates that the average person in sub-Saharan Africa becomes poorer by a factor of two every 25 years (Arrow et al., 2004; Sachs, 2005). The interaction between economic stagnation and slow progress in education has been compounded by the spread of HIV/AIDS. In 2003, 2.2 million Africans died of the disease and an estimated 12 million children in sub-Saharan Africa lost one or both parents to HIV/AIDS (UNAIDS, 2004; Ferguson, 2006). This has produced a 'freefall' in the Human Development Index ranking, with southern African countries accounting for some of the steepest declines (UNDP, 2005). Indeed, some commentators have noted that sub-Saharan Africa is the only region in the world that has become poorer in this generation (Devereux and Maxwell, 2001; Chen and Ravallion, 2004).

A large amount of literature exists on the various factors that influence vulnerability to the changes taking place in Africa (e.g., to climate stress), and this section outlines some of the key issues (see, for example, Figure 9.1a-d). However, these factors do not operate in isolation, and usually interact in complex and 'messy' ways, frustrating attempts at 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 versus extensification, see Bryceson, 2004; Section 9.6.1). Structural adjustment accompanied by complex market reforms and market liberalisation (e.g., access to credit and subsidy arrangements) has aggravated the vulnerability of many in Africa, particularly those engaged in agriculture (see, e.g., Eriksen, 2004; Kherallah et al., 2004). Fertiliser prices, for example, have risen in response to subsidy removal, resulting in some mixed responses to agricultural reforms (Kherallah et al., 2004; Institute of Development Studies, 2005). Market-related and structural issues can thus serve to reduce people's agricultural productivity and reduce resilience to further agricultural stresses associated with climate change.

9.2.2.2 Governance and institutions

Complex institutional dimensions are often exposed during periods of climate stress. Public service delivery is hampered by poor policy environments in some sectors which provide critical obstacles to economic performance (Tiffen, 2003). Africa is also characterised by institutional and legal frameworks that are, in some cases, insufficient to deal with environmental degradation and disaster risks (Sokona and Denton, 2001; Beg et al., 2002). Various actors, structures and networks are therefore required to reconfigure innovation processes in Africa (e.g., in agriculture) to improve responses to climate variability and change in both rural and urban contexts (Tiffen, 2003; Scoones, 2005; Reid and Vogel, 2006; see also Section 9.5).

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) which 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 to the 1990s as a result of scientific breeding that produced high-yielding varieties (HYVs), combined with an increased use of fertilisers and irrigation. Africa's uptake of HYVs was the lowest in the developing world. The low levels of technological innovation and infrastructural development in Africa result in the extraction of natural resources for essential amenities such as 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-related stress. 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 in order 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 IFRCRCS, 2005) as well as hindering adaptation to climate stresses (see Section 9.5; 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 period 1950 to 2005, the urban population in Africa grew by an average annual rate of 4.3% from 33 million to 353 million (ECA, 2005; Yousif, 2005). Complex migration patterns, which are usually undertaken to ensure income via remittances (Schreider and Knerr, 2000) and which often occur in response to stress-induced movements linked to conflict and/or resource constraints, can further trigger a range of environmental and socio-economic changes. Migration is also associated with the spread of HIV/AIDS and other diseases. Several studies have shown that labour migrants tend to have higher HIV infection rates than non-migrants (UNFPA, 2003). Increases in population also exert stresses on natural resources. Agricultural intensification and/or expansion into marginal lands can trigger additional conflicts, cause crop failure, exacerbate environmental degradation (e.g., Olsson et al., 2005) and reduce biodiversity (Fiki and Lee, 2004), and this then, in turn, feeds 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 with variations in rainfall but are also linked to other socio-economic and cultural factors (see, for example, Little et al., 2001; Turner, 2003; Boone et al., 2004; Desta and Coppock, 2004; Thornton et al., 2004).

9.2.2.5 Water access and management

Water access and water resource management are highly variable across the continent (Ashton, 2002; van Jaarsveld et al., 2005; UNESCO-WWAP, 2006). The 17 countries in West Africa that share 25 transboundary rivers have notably 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 this situation, with urban populations in the southern African region achieving 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 water sources; the largest proportion being in Mozambique, followed by Angola, South Africa, Zambia and Malawi (Mutangadura et al., 2005). When water is available it is often of poor quality, thus contributing to a range of health problems including 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 environments, 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. The Water Exploitation Index[2] is high in several countries in the sub-region: >50% for Tunisia, Algeria, Morocco and Sudan, and

[2] Water Exploitation Index: total water abstraction per year as percentage of long-term freshwater resources.

>90% for Egypt and Libya (Gueye et al., 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 variations in climate is problematic. The complex interactions between over-fishing, industrial pollution and sedimentation, for example, are also degrading local water sources such as Lake Victoria (Odada et al., 2004), which impacts 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

In much the same way as 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 with regard to a range of stresses (Mano et al., 2003; USAID, 2003; Gommes et al., 2004). Maternal malaria, for example, has been shown to be associated with a twice as high HIV-1 viral concentration (ter Kuile et al., 2004) and infection rates are estimated to be 5.5% and 18.8% in populations with a HIV prevalence 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 also Section 9.6). While infectious diseases such as cholera are being eradicated in other parts of the world, they are re-emerging in Africa. A major challenge facing the continent is the relative weakness in disease surveillance and reporting systems, which hampers the detection and control of cholera epidemics, and, as a side effect, makes it difficult to obtain the long-term linked data sets on climate and disease that are necessary for the development of early warning systems (WHO, 2005).

9.2.2.7 Ecosystem 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, underwent deforestation at estimated rates of about 0.4% per year during the 1990s (Biggs et al., 2004). Further threats to Africa's forests are also posed by the high dependency on fuelwood and charcoal, major sources of energy in rural areas, that are estimated to contribute about 80 to 90% of the residential energy needs of low-income households in the majority of sub-Saharan countries (IEA, 2002). Moreoever, fire incidents represent a huge threat to tropical forests in Africa. An estimated 70% of detected forest fires occur in the tropics, with 50% of them being in Africa. More than half of all forested areas were estimated to have burned in Africa in 2000 (Dwyer et al., 2000; Kempeneers et al., 2002). Bush fires are a particular threat to woodlands, causing enormous destruction of both flora and fauna in eastern and southern Africa (for an extensive and detailed review on the role of fire in southern Africa, see SAFARI, 2004). The African continent also suffers 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 51% of urban populations and only about 8% of rural populations having access to electricity. This is compared with about 99% of urban populations and about 80% 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 the 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, p. 386; van Jaarsveld et al., 2005). Dependence on biomass can promote the 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 fuelwood, indoor pollution and other hazards (e.g., informal settlement fires - IEA, 2002). Further challenges from urbanisation, 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 between biophysical hazards (e.g., climate hazards - tropical cyclones, fire, insect plagues) is convincingly highlighted in the impacts and vulnerabilities to disaster risks and conflicts in several areas of the continent (see, for example, several reports of the International Federation of the Red Cross and Red Crescent Societies (IFRCRCS) of the past few years, available online at http://www.ifrc.org/; and several relevant documents such as those located on http://www.unisdr.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 illustrated 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 to 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 Section 9.6.1). Likewise, the floods in Mozambique in 2000 revealed a number of existing vulnerabilities that were heightened by the floods. These included: poverty (an estimated 40% of the population lives on less than US$1 per day and another 40% on less than US$2 per day); the debt problem, which is one of the biggest challenges facing the country; the fact that most of the floodwaters originated in cross-border shared basins; the poor disaster risk-reduction strategies with regard to dam design and management; and the poor communication networks (Christie and Hanlon, 2001; IFRCRCS, 2002; Mirza, 2003).

Conflicts, armed and otherwise, have recently occurred in the Greater Horn of Africa (Somalia, Ethiopia and Sudan) and the Great Lakes region (Burundi, Rwanda and the Democratic Republic of Congo) (Lind and Sturman, 2002; Nkomo et al., 2006). The 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 often a key driving force behind conflict (Lind and Sturman, 2002; Balint-Kurti, 2005; Ron, 2005). Climate change may become a contributing factor to conflicts in the future, particularly those concerning resource scarcity, for example, scarcity of water (Ashton, 2002; Fiki and Lee, 2004),).

It is against this background that an assessment of vulnerability to climate change and variability has to be contextualised. Although the commonly used indicators have limitations in capturing human well-being (Arrow et al., 2004), some aggregated proxies for national-level vulnerability to climate change for the countries in Africa have been developed (e.g., Vincent, 2004; Brooks et al., 2005). 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 affects vulnerability and adaptive capacity in Africa (see Section 9.5).

9.3 Assumptions about future trends

9.3.1 Climate-change scenarios

In this section, the limits of the regions are those defined by Ruosteenoja et al. (2003). Very few regional to sub-regional climate change scenarios using regional climate models or empirical downscaling have been constructed in Africa mainly due to restricted computational facilities and lack of 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 emissions scenario (SRES A1B, see the Special Report on Emissions Scenarios: Nakićenović et al., 2000), used with 20 General Circulation Models (GCMs) for the period 2080-2099, annual mean surface air temperature is expected to increase between 3 and 4°C compared with the 1980-1999 period, with less warming in equatorial and coastal areas (Christensen et al., 2007). Other experiments (e.g., Ruosteenoja et al., 2003) indicate higher levels of warming with the A1FI emissions scenario and for the 2070-2099 period: up to 9°C for North Africa (Mediterranean coast) in June to August, and up to 7°C for southern Africa in September to November. Regional Climate Model (RCM) experiments generally give smaller temperature increases (Kamga et al., 2005). For southern Africa (from the equator to 45°S and from 5° to 55°E, which includes parts of the surrounding oceans), Hudson and Jones (2002), using the HadRM3H RCM with the A2 emissions scenario, found for the 2080s a 3.7°C increase in summer (December to February) mean surface air temperature and a 4°C increase in winter (June to August). As demonstrated by Bounoua et al. (2000), an increase in vegetation density, leading to a cooling of 0.8°C/yr 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). A stabilisation of the atmospheric CO_2 concentration at 550 ppm (by 2150) or 750 ppm (by 2250) could also delay the expected greenhouse gas-induced warming by 100 and 40 years, respectively, 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; Christensen et al., 2007).

Precipitation projections are generally less consistent with large inter-model ranges for seasonal mean rainfall responses. These inconsistencies are explained partly by the inability of GCMs to reproduce the mechanisms responsible for precipitation including, for example, the hydrological cycle (Lebel et al., 2000), or to account for orography (Hudson and Jones, 2002). They are also explained partly by model limitations in simulating the different teleconnections and feedback mechanisms which are responsible for rainfall variability in Africa. Other factors that complicate African climatology include dust aerosol concentrations and sea-surface temperature anomalies, which are particularly important in the Sahel region (Hulme et al., 2001; Prospero and Lamb, 2003) 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 rainfall have been undertaken.

With the SRES A1B emissions scenario and for 2080-2099, mean annual rainfall is very likely to decrease along the Mediterranean coast (by 20%), extending into the northern Sahara and along the west coast to 15°N, but is likely increase in tropical and eastern Africa (around +7%), while austral winter (June to August) rainfall will very probably decrease in much of southern Africa, especially in the extreme west (up to 40%) (Christensen et al., 2007). In southern Africa, the largest changes in rainfall occur during the 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 (December to February) rainfall, and those located south of 10°S, which 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 (October to December) rainfall and an increase in late summer (January to March) rainfall over the eastern parts of southern Africa.

For the western Sahel (10 to 18°N, 17.5°W to 20°E), there are still discrepancies between the models: some projecting a significant drying (e.g., Hulme et al., 2001; Jenkins et al., 2005) and others 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 of easterly jets and squall lines is also critical for predicting 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 available on extreme events (Christensen et al., 2007), despite frequent reporting of such events, including their impacts (see Section 9.2.1). A recent study using four 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 present century (Huntingford et al., 2005). Modelling of global drought projections for the 21st century, based on the SRES A2 emissions scenario, shows drying for northern Africa that appears consistent with the 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 (Christensen et al., 2007). There could very probably be an increase of between 10 and 20% in cyclone intensity with a 2-4°C SST rise (e.g., Lal, 2001), but this observation is further complicated by the fact that SST does not account for all the changes in tropical storms (McDonald et al., 2005).

9.3.2 Socio-economic scenarios

The SRES scenarios adopt four storylines or 'scenario families' that describe how the world populations, economies and political structures may evolve over the next few decades (Nakićenović 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' scenarios assume more regionalisation. While some authors have criticised the population and economic details included in the SRES scenarios, the scenarios still provide a useful baseline for studying 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. For example, 24 countries in sub-Saharan Africa are 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). The sub-Saharan share of the global total of those earning below US$1/day is also estimated to 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.

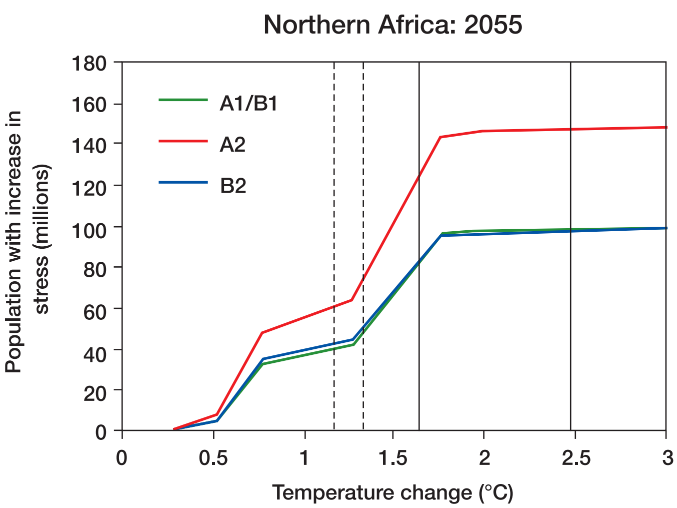
9.4 Expected key future impacts and vulnerabilities, and their spatial variation

Having provided some background on 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. Note that several authors (e.g., Agoumi, 2003; Legesse et al., 2003; Conway, 2005, Thornton et al., 2006) warn against the over-interpretation of results, owing to the limitations of some of the projections and models used. 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 availability, water accessibility and water demand in Africa. Even in the absence of climate change (see Section 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, p. 236). In some assessments, the population at risk of increased water stress in Africa, for the full range of SRES scenarios, is projected to be 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. An analysis of six climate models (HadCM3, ECHAM4-OPYC, CSIRO-Mk2, CGCM2, GFDL_r30 and CCSR/NIES2) and the SRES scenarios (Arnell, 2004) shows a likely increase in the number of people who could experience water stress by 2055 in northern and southern Africa (Figure 9.3). In contrast, more people in eastern and western Africa will be likely to experience a reduction rather than an increase in water stress (Arnell, 2006a).

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 0 and 10% show that the Ouergha watershed in Morocco is likely to undergo changes for the period 2000-2020. A 1°C increase in temperature could change runoff by of the order of 10%, assuming that the precipitation levels remain constant. If such an annual decrease in runoff were to occur in other watersheds, the impacts in such areas could be equivalent to the loss of one large dam per year (Agoumi, 2003). Further interactions between climate and other factors influencing water resources have also been well highlighted for Egypt (Box 9.2).



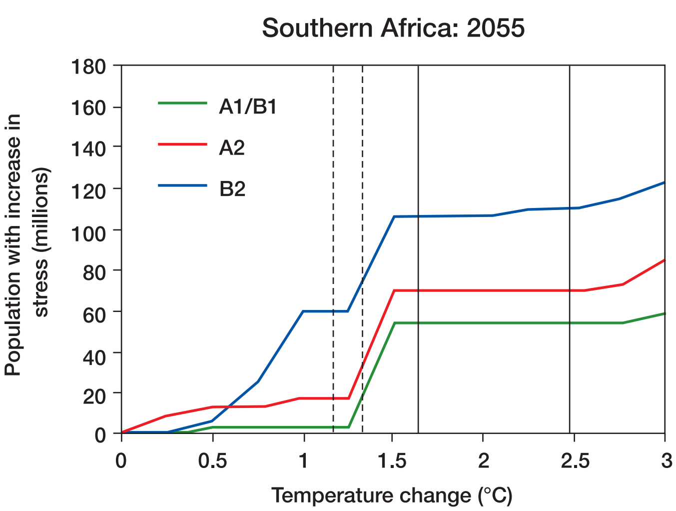


Figure 9.3. *Number of people (millions) with an increase in water stress (Arnell, 2006b). Scenarios are all derived from HadCM3 and the red, green and blue lines relate to different population projections.*

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 70 km^3 which is already far in excess of the available resources (Gueye et al., 2005). A major challenge is to close the rapidly increasing gap between the limited water availability and the escalating demand for water from various economic sectors. The rate of water utilisation has already reached its maximum for Egypt, and climate change will exacerbate this vulnerability.

Agriculture consumes about 85% of the annual total water resource and plays a significant role in the Egyptian national economy, contributing about 20% of GDP. More than 70% of the cultivated area depends on low-efficiency surface irrigation systems, which cause high water losses, a decline in land productivity, waterlogging and salinity problems (El-Gindy et al., 2001. Moreover, unsustainable agricultural practices and improper irrigation management affect the quality of the country's water resources. Reductions in irrigation water quality have, in their 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 (EPIQ, 2002; ICID, 2005):

- improving water sanitation coverage for urban and rural areas;
- wastewater management;
- optimising use of water resources by improving irrigation efficiency and agriculture drainage-water reuse.

However, with climate change, an array of serious threats is apparent.

- Sea-level rise could impact on the Nile Delta and on people living in the delta and other coastal areas (Wahab, 2005).
- Temperature rises will be likely to reduce the productivity of major crops and increase their water requirements, thereby directly decreasing crop water-use efficiency (Abou-Hadid, 2006; Eid et al., 2006).
- There will probably be a general increase in irrigation demand (Attaher et al., 2006).
- There will also be a high degree of uncertainty about the flow of the Nile.
- Based on SRES scenarios, Egypt will be likely to 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 capacity 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, the 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% in streamflow 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 probably experience a significant reduction in streamflow. Even for South Africa, the increases under the high emissions scenarios are modest at under 10% (Strzepek and McCluskey, 2006).

Additional assessments of climate change impacts on hydrology, based on six GCMs 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 Stankiewicz, 2006). A critical 'unstable' area is identified for some parts, for example, the east-west band from Senegal to Sudan, separating the dry Sahara from wet Central Africa. Parts of southern Africa are projected to experience significant losses of runoff, with some areas being particularly impacted (e.g., parts of South Africa) (New, 2002; de Wit and Stankiewicz, 2006). Other regional assessments report emerging changes in the hydrology of some of the major water systems (e.g., the Okavango River basin) which could be negatively impacted by changes in climate; impacts that could possibly be greater than those associated with human activity (Biggs et al., 2004; Anderssen et al., 2006).

Assessments of impacts on water resources, as already indicated, currently do not fully capture multiple future water uses and water stress and must be approached with caution (see, e.g., Agoumi, 2003; Conway, 2005). Conway (2005) 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 structures. 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 (see 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; Stern, 2007).

9.4.2 Energy

There are remarkably few studies available that examine the impacts of climate change on energy use in Africa (but see a recent regional assessment by Warren et al., 2006). However, even in the absence of climate change, 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 emissions 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 microclimates and hydrology and will possibly exacerbate the scope and scale of climate-change impacts.

9.4.3 Health

Vigorous debate among those working in the health sector has improved our understanding of the links between climate variability (including extreme weather events) and infectious diseases (van Lieshout et al., 2004; Epstein and Mills, 2005; McMichael et al., 2006; Pascual et al., 2006; Patz and Olson, 2006). Despite various contentious issues (see Section 9.2.1.2), new assessments of the role of climate change impacts on health have emerged since the TAR. Results from the "Mapping Malaria Risk in Africa" project (MARA/ARMA) show a possible expansion and contraction, depending on location, of climatically suitable areas for malaria by 2020, 2050 and 2080 (Thomas et al., 2004). By 2050 and continuing into 2080, for example, a large part of the 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 geographical 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 probably continue into South Africa.

Using parasite survey data in conjunction with results from the 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 incursions of malaria by the 2050s, with conditions for transmission becoming highly suitable by the 2080s. By this period, areas currently with low rates of malaria transmission in central Somalia and the Angolan highlands could also become highly suitable. Among all scenarios, the highlands of eastern Africa and areas of southern Africa are likely to 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 the lack of protective genetic modifications 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 costs of malaria are also huge and include considerable costs to individuals and households as well as high costs at community and national levels (Holding and Snow, 2001; Utzinger et al., 2001; Malaney et al., 2004).

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 of 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 probability that sea-level rise could 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 possible future changes in animal health arising from climate variability and change have been undertaken. The demographic impacts on trypanosomiasis, for example, can arise through modification of the habitats suitable for the tsetse fly. These modifications can be further exacerbated by climate variability and climate change. Climate change is also expected to 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 all 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 events. Finally, heat stress and drought are likely to have further negative impacts 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 various assessments of impacts of climate change on agriculture based on various climate models and SRES emissions scenarios indicate certain agricultural areas that may undergo negative changes. It is estimated that, by 2100, parts of the Sahara are likely to emerge as the most vulnerable, showing likely agricultural losses of between 2 and 7% of GDP. Western 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 to 1.3% (Mendelsohn et al., 2000b).

More recent assessments combining global- and regional-scale analysis, impacts of climate change on growing periods and 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 GCMs agree on areas of change in the coastal systems of southern and eastern Africa (Figure 9.4). Under both the A1 and B1 scenarios, mixed rain-fed semi-arid systems are shown to be affected in the Sahel, as well as 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., semi-arid lands) become more marginal, with moderate impacts on coastal systems (Thornton et al., 2006; see Chapter 5, Section 5.4.2). Such changes in the growing period are important, especially when viewed against

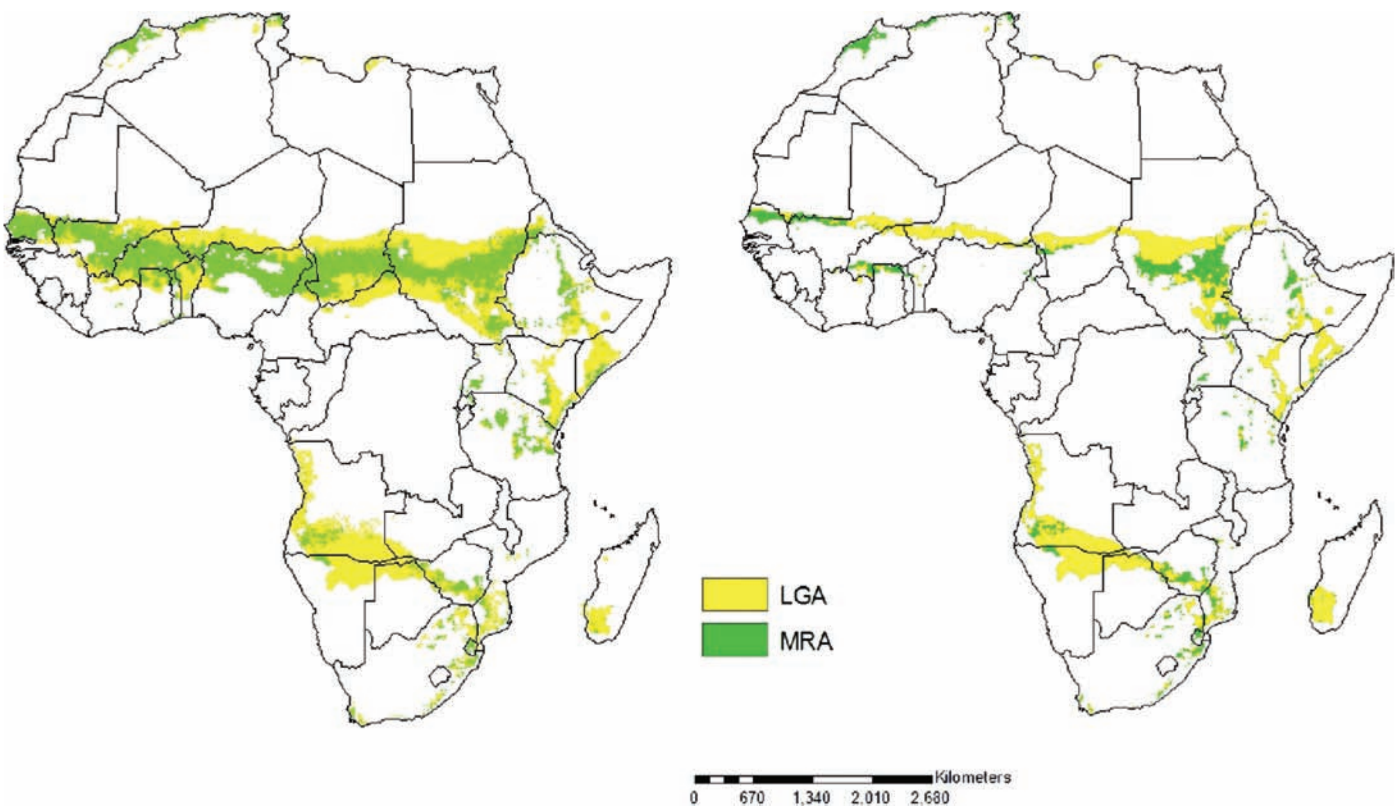


Figure 9.4. *Agricultural areas within the livestock-only systems (LGA) in arid and semi-arid areas, and rain-fed mixed crop/livestock systems (MRA) in semi-arid areas, are projected by the HadCM3 GCM to undergo >20% reduction in length of growing period to 2050, SRES A1 (left) and B1 (right) emissions scenarios, after Thornton et al. (2006).*

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.

Other recent assessments using the FAO/IIASA Agro-Ecological Zones model (AEZ) in conjunction with IIASA's world food system or Basic Linked System (BSL), as well as climate variables from five different GCMs under four SRES emissions scenarios, show further agricultural impacts such as changes in agricultural potential by the 2080s (Fischer et al., 2005). By the 2080s, a significant decrease in suitable rain-fed land extent and production potential for cereals is estimated under climate change. Furthermore, for the same projections, for the same time horizon the area of arid and semi-arid land in Africa could increase by 5-8% (60-90 million hectares). The study shows that wheat production is likely to disappear from Africa by the 2080s. On a more local scale, assessments have shown a range of impacts. Southern Africa would be likely to experience notable reductions in maize production under possible increased ENSO conditions (Stige et al., 2006).

In other countries, additional risks that could be exacerbated by climate change include greater erosion, deficiencies in yields from rain-fed agriculture of up to 50% during the 2000-2020 period, and reductions in crop growth period (Agoumi, 2003). A recent study on South African agricultural impacts, based on three scenarios, indicates that crop net revenues will be likely to fall by as much as 90% by 2100, with small-scale farmers being the most severely 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 2050 compared with their production under current climate conditions (Eid et al., 2006). Other agricultural activities could also be affected 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 Chapter 5).

However, not all changes in climate and climate variability will be negative, as agriculture and the growing seasons in certain areas (for example, parts of the Ethiopian highlands and parts of southern Africa such as Mozambique), may lengthen under climate change, due to a combination of increased temperature and rainfall changes (Thornton et al., 2006). Mild climate scenarios project further benefits across African croplands for irrigated and, especially, dryland farms. However, it is worth noting that, even under these favourable scenarios, populated regions of the Mediterranean coastline, central, western and southern Africa are expected to be adversely affected (Kurukulasuriya and Mendelsohn, 2006a).

Fisheries are another important source of revenue, employment and proteins. They contribute over 6% of Namibia's and Senegal's GDP (Njaya and Howard, 2006). Climate-change impacts on this sector, however, need to 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 annual global temperature (e.g. of the order of 1.5 to 2.0°C) fisheries in North West Africa and the East African lakes are shown to be impacted (see ECF and Potsdam Institute, 2004; Warren et al., 2006). In coastal regions that have major lagoons or lake systems, changes in freshwater flows and a greater intrusion of salt water into lagoons will affect the 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 upwelling; with those that are dependent on the first two 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 probably bring about a 10% decline in productivity in the spawning grounds and an increase of 3% in the main feeding grounds (Clark et al., 2003).

The impact of climate change on livestock farming in Africa was examined by Seo and Mendelsohn (2006a, b). They showed that a warming of 2.5°C could increase the income of small livestock farms by 26% (+US$1.4 billion). This increase is projected to come from stock expansion. Further increases in temperature would then lead to a gradual fall in net revenue per animal. A warming of 5°C would probably increase the income of small livestock farms by about 58% (+US$3.2 billion), largely as a result of stock increases. By contrast, a warming of 2.5°C would be likely to decrease the income of large livestock farms by 22% (–US$13 billion) and a warming of 5°C would probably reduce income by as much as 35% (–US$20 billion). This reduction in income for large livestock farms would probably result both from a decline in the number of stock and a reduction in the net revenue per animal. Increased precipitation of 14% would be likely to reduce the income of small livestock farms by 10% (–US$ 0.6 billion), mostly due to a reduction in the number of animals kept. The same reduction in precipitation would be likely to reduce the income of large livestock farms by about 9% (–US$5 billion), due to a reduction both in stock numbers and in net revenue per animal.

The study by Seo and Mendelsohn (2006a) further shows that higher temperatures are beneficial for small farms that keep goats and sheep because it is easy to 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 also a shift from livestock to crops.

Assessing future trends in agricultural production in Africa, even without climate change, remains exceedingly difficult (e.g., contributions to GDP and impacts on GDP because of climate variability and other factors - see, for example, Mendelsohn et al., 2000b; Tiffen, 2003; Arrow et al., 2004; Desta and Coppock, 2004; Ferguson, 2006). While agriculture is a key source of livelihood in Africa, there is evidence that off-farm incomes are also increasing in some areas - up to 60 to 80% of total incomes in some cases (Bryceson, 2002). Urbanisation and off-farm increases in income 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, especially 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 Chapter 4; Nkomo et al., 2006; Warren et al., 2006).

Mountain ecosystems appear to be undergoing significant observed changes (see Section 9.2.1.4), aspects of which are likely to be linked to complex climate-land interactions and which may continue under climate change (e.g., IPCC, 2007a). By 2020, for example, indications are that the ice cap on Mt. Kilimanjaro could disappear for the first time in 11,000 years (Thompson et al., 2002). Changes induced by climate change are also likely to result in species range shifts, as well as in changes in tree productivity, adding further stress to forest ecosystems (UNEP, 2004). Changes in other ecosystems, such as grasslands, are also likely (for more detail, see assessments by Muriuki et al., 2005; Levy, 2006).

Mangroves and coral reefs, the main coastal ecosystems in Africa, will probably be affected by climate change (see Chapter 4, Box 4.4; Chapter 6, Section 6.4.1, Box 6.1). Endangered species associated with these ecosystems, including manatees and marine turtles, could also be at risk, along with migratory birds (Government of Seychelles, 2000; Republic of Ghana, 2000; République Démocratique du Congo, 2000). Mangroves could also colonise coastal lagoons because of sea-level rise (République du Congo, 2001; Rocha et al., 2005).

The coral bleaching following the 1997/1998 extreme El Niño, as mentioned in Section 9.2.1, is an indication of the potential impact of climate change-induced ocean warming on coral reefs (Lough, 2000; Muhando, 2001; Obura, 2001); disappearance of low-lying corals and losses of biodiversity could also be expected (République de Djibouti, 2001; Payet and Obura, 2004). The proliferation of algae and dinoflagellates during these warming events could increase the number of people affected by toxins (such as ciguatera) due to the consumption of marine food sources (Union des Comores, 2002; see also Chapter 16, Section 16.4.5). In the long term, all these impacts will have negative effects on fisheries and tourism (see also Chapter 5, Box 5.4). In South Africa, changes in estuaries are expected mainly as a result of reductions in river runoff and the inundation of salt marshes following sea-level rise (Clark, 2006).

The species sensitivity of African mammals in 141 national parks in sub-Saharan Africa was assessed using two climate-change scenarios (SRES A2 and B2 emissions scenarios with the HadCM3 GCM, for 2050 and 2080), applying a simple IUCN Red List assessment of potential range loss (Thuiller et al., 2006). Assuming no migration of species, 10-15% of the species were projected to fall within the IUCN Critically Endangered or Extinct categories by 2050, increasing to 25-40% of species by 2080. Assuming unlimited species migration, the results were less extreme, with these proportions dropping to approximately 10-20% by 2080. Spatial patterns of loss and gain showed contrasting latitudinal patterns, with a westward range shift of species around the species-rich equatorial transition zone in central Africa, and an eastward shift in southern Africa; shifts which appear to be related mainly to the latitudinal aridity gradients across these ecological transition zones

Table 9.1. *Significant ecosystem responses estimated in relation to climate change in Africa. These estimations are based on a variety of scenarios (for further details on models used and impacts see Chapter 4, Section 4.4 and Table 4.1).*

Ecosystem impacts	Area affected	Scenario used and source
About 5,000 African plant species impacted: substantial reductions in areas of suitable climate for 81-97% of the 5,197 African plants examined, 25-42% lose all area by 2085.	Africa	HadCM3 for years 2025, 2055, 2085, plus other models – shifts in climate suitability examined (McClean et al., 2005)
Fynbos and succulent Karoo biomes: losses of between 51 and 61%.	South Africa	Projected losses by 2050, see details of scenarios (Midgley et al., 2002; see Chapter 4, Section 4.4, Table 4.1)
Critically endangered taxa (e.g. Proteaceae): losses increase, and up to 2% of the 227 taxa become extinct.	Low-lying coastal areas	4 land use and 4 climate change scenarios (HadCM2 IS92aGGa) (Bomhard et al., 2005)
Losses of nyala and zebra: Kruger Park study estimates 66% of species lost.	Malawi South Africa (Kruger Park)	(Dixon et al., 2003) Hadley Centre Unified Model, no sulphates (Erasmus et al., 2002; see Chapter 4, Section 4.4.3)
Loss of bird species ranges: (restriction of movements). An estimated 6 species could lose substantial portions of their range.	Southern African bird species (Nama-Karoo area)	Projected losses of over 50% for some species by 2050 using the HadCM3 GCM with an A2 emissions scenario (Simmons et al., 2004; see Chapter 4, Section 4.4.8)
Sand-dune mobilisation: enhanced dune activity.	Southern Kalahari basin – northern South Africa, Angola and Zambia. For details in Sahel, see Section 9.6.2 and Chapter 4, Section 4.3.	Scenarios: HadCM3 GCM, SRES A2, B2 and A1fa, IS92a. By 2099 all dune fields shown to be highly dynamic (Thomas et al., 2005; see Chapter 4, Section 4.4.2)
Lake ecosystems, wetlands	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; see Chapter 4, Section 4.4.8)
Grasslands	Complex impacts on grasslands including the role of fire (southern Africa)	See detailed discussion Chapter 4, Section 4.4.3

9.4.6 Coastal zones

In Africa, highly productive ecosystems (mangroves, estuaries, deltas, coral reefs), which form the basis for important economic activities such as tourism and fisheries, are located in the coastal zone. Forty percent 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 on these coastal megacities because of the concentration of poor populations in potentially hazardous areas that may be especially vulnerable to such changes (Klein et al., 2002; Nicholls, 2004). Cities such as Lagos and Alexandria will probably be impacted. In very recent assessments of the 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 of the world are those located in Africa: North Africa, West Africa and southern Africa (see Nicholls and Tol, 2006; for more detailed assessments, see 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 2100 would be likely to decrease the penetration of salt water in the Wouri estuary (République de Côte d'Ivoire, 2000). Alternatively, with an 11% decrease in rainfall, 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 km^2 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 great 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 (World Tourism Organization, 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 (World Tourism Organization, 2005). However, very few assessments of projected impacts on tourism and climate change are available, particularly those using scenarios and GCM 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 places of interest to tourists, including wildlife areas and parks, may also attract fewer tourists under marked climate changes. Climate change could, for example, lead to a poleward shift of centres of tourist activity and a shift from lowland to highland tourism (Hamilton et al., 2005).

9.4.8 Settlements, industry and infrastructure

Climate variability, including extreme events such as storms, floods and sustained droughts, already has marked impacts on settlements and infrastructure (Freeman and Warner, 2001; Mirza, 2003; Niasse et al., 2004; Reason and Keibel, 2004). Indeed, for urban planners, the biggest threats to localised population concentrations posed by climate variability and change are often expected to be from little-characterised and unpredictable rapid-onset disasters such as storm surges, flash floods and tropical cyclones (Freeman, 2003). Negative impacts of climate change could create a new set of refugees, who 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). However, few detailed assessments of such impacts using climate as a driving factor have been undertaken for Africa.

In summary, a range of possible impacts of climate change has been discussed in this section (for other summaries, see Epstein and Mills, 2005; Nkomo et al., 2006). The roles of some other stresses that may compound climate-induced changes have also been considered. Clearly, several areas require much more detailed 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.

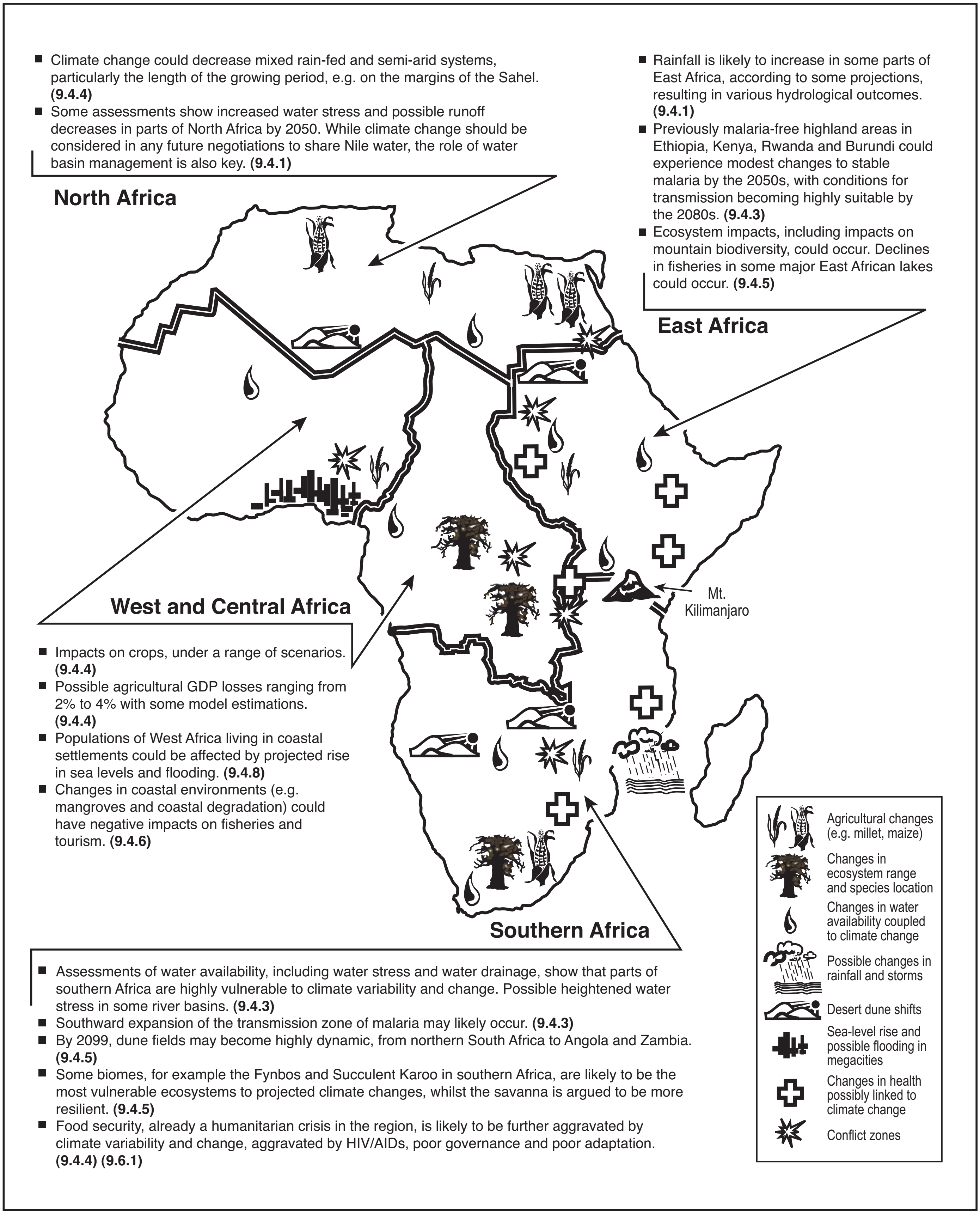


Figure 9.5. *Examples of current and possible future impacts and vulnerabilities associated with climate variability and climate change for Africa (for details see sections highlighted in bold). Note that these are indications of possible change and are based on models that currently have recognised limitations.*

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 necessity (e.g., Thornton et al., 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 Chapter 18). Owing to constraints of space, not all cases nor all details can be provided here. 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; Adger and Vincent, 2005; Brooks et al., 2005; Grothmann and Patt, 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 Section 9.6.1) and the move towards off- or non-farm livelihood incomes in parts of Africa repeatedly surface as key adaptation options (e.g., Bryceson, 2004; Benhin, 2006; Osman-Elasha et al., 2006). As indicated in Section 9.2.1, reducing risks with regard to possible future events will depend on the building of stronger livelihoods to ensure resilience to future shocks (IFRCRCS, 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 but is also driven by a range of other possible factors (see, for example, Section 9.2.2.9). 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).

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, also needs to be better understood (e.g., Reid and Vogel, 2006)

Other opportunities for adaptation that can be created include many linked to technology. The role of seasonal forecasts, and their production, dissemination, uptake and integration in model-based decision-making support systems, has been fairly extensively examined in several African contexts (Table 9.2). Significant constraints, however, include the limited support for climate risk management in agriculture and therefore a limited demand 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 existing rain-fed farming systems (Rockström, 2003), such as water-harvesting systems to supplement irrigation practices in semi-arid farming systems ('more crop per drop' strategies, see 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 Ndegwa, 2001; as discussed in Section 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 2 and 6 months before the onset of an 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 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 the weather becomes warmer, farmers tend to shift towards more heat-tolerant crops. Depending upon whether precipitation increases or decreases, farmers will shift towards water-loving or drought-tolerant 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 with disaster risk-reduction strategies (see several references on http://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 and school feeding schemes (for a detailed discussion, see Devereux, 2003).

Table 9.2. *Some examples of complex adaptations already observed in Africa in response to climate and other stresses (adapted from the initial categorisation of Rockström, 2003).*

Theme	Emerging characteristics of adaptation	Authors
	Social resilience	
Social networks and 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; Eriksen et al., 2005; Grothmann and Patt, 2005.
Institutions	• Role and architecture of institutional design and function is critical for understanding and better informing policies/measures for enhanced resilience to climate change. • Interventions linked to governance at various levels (state, region and local levels) either enhance or constrain adaptive capacity.	Batterbury and Warren, 2001; Ellis and Mdoe, 2003; Owuor et al., 2005; Osman-Elasha et al., 2006; Reid and Vogel, 2006.
	Economic resilience	
Equity	• Issues of equity need to be viewed on several scales • ***Local scale***: (within and between communities) - Interventions to enhance community resilience can be hampered by inaccessibility of centres for obtaining assistance (aid/finance) • ***Global scale***: see IPCC, 2007b, re CDMS etc.	Sokona and Denton, 2001; AfDB et al., 2002; Thomas and Twyman, 2005.
Diversification of livelihoods	• Diversification has been shown to be a very strong and necessary economic strategy to increase resilience to stresses. • Agricultural intensification, for example based on increased livestock densities, the use of natural fertilisers, soil and water conservation, can be useful adaptation mechanisms.	Ellis, 2000; Toulmin et al., 2000; Block and Webb, 2001; Mortimore and Adams, 2001; Ellis, 2003; Ellis and Mdoe, 2003; Eriksen and Silva, 2003; Bryceson, 2004; Chigwada, 2005.
Technology	• Seasonal forecasts, their production, dissemination, uptake and integration in model-based decision-making support systems have been examined in several African contexts (see examples given). • Enhanced resilience to future periods of drought stress may also be supported by improvements in present rain-fed farming systems through: - water-harvesting systems; - dam building; - water conservation and agricultural practices; - drip irrigation; - development of drought-resistant and early-maturing crop varieties and alternative crop and hybrid varieties.	Patt, 2001; Phillips et al., 2001; Roncoli et al., 2001; Hay et al., 2002b; Monyo, 2002; Patt and Gwata, 2002; Archer, 2003; Rockström, 2003; Ziervogel and Calder, 2003; Gabre-Madhin and Haggblade, 2004; Malaney et al., 2004; Ziervogel, 2004; Ziervogel and Downing, 2004; Chigwada, 2005; Orindi and Ochieng, 2005; Patt et al., 2005; Matondo et al., 2005; Seck et al., 2005; Van Drunen et al., 2005; Ziervogel et al., 2005; Abou-Hadid, 2006; Osman-Elasha et al., 2006.
Infrastructure	• Improvements in the physical infrastructure may improve adaptive capacity. • Improved communication and road networks for better exchange of knowledge and information. • General deterioration in infrastructure threatens the supply of water during droughts and floods.	Sokona and Denton, 2001.

9.5.2 Adaptation costs, constraints and opportunities

Many of the options outlined above come with a range of costs and constraints, including large transaction costs. However, deriving quantitative estimates of the potential costs of the impacts of climate change (or those associated with climate variability, such as droughts and floods) and costs without adaptation (Yohe and Schlesinger, 2002) is 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 (e.g., Mirza, 2003). 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). However, if no adaptation is undertaken, then the losses due to climate change could be 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 the costs of including flexible and efficient approaches to adapting to climate change into management options (see Stern, 2007).

Despite some successes (see examples 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., Rockström, 2003). The interaction of both social (e.g., access to food) and biophysical (e.g., drought) stresses thus combine to aggravate critical stress periods (e.g., during and after ENSO events). Traditional coping strategies (see Section 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, e.g., Washington et al., 2004, 2006).

As shown in several sections 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 Section 9.2.2). The full implications of climate change for development are, however, currently not clearly understood. For example, factors heightening vulnerability to climate change and affecting national-level adaptation have 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 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. 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 (e.g., short-term responses, unco-ordinated processes, isolated projects) are only one type of solution (Sachs, 2005). Other solutions that could be considered include mainstreaming adaptation into national development processes (Huq and Reid, 2004; Dougherty and Osman, 2005). There may be several opportunities to link disaster risk reduction, poverty and development (see, for example, several calls and plans for such action such as the Hyogo Declaration - http://www.unisdr.org/wcdr/intergover/official-doc/L-docs/Hyo-go-declaration-english.pdf). 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 governments, humanitarian and development agencies to collaborate in order 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 - http://www.sarpn.org/ - for several case studies and examples; see also Table 9.2 for other possible adaptation options).

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 causes of poverty (both structural and other) 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. Some of the complex interactions of such drivers and climate are further illustrated in the two case studies below.

9.6 Case studies

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

It has long been recognised that climate variability and change have an impact on food production, (e.g., Mendelsohn et al., 2000a, b; Devereux and Maxwell, 2001; Fischer et al., 2002; Kurukulasuriya and Rosenthal, 2003), although the extent and nature of this impact is as yet uncertain. Broadly speaking, food security is less seen in terms of sufficient global and national agricultural food production, and more in terms of livelihoods that are sufficient to provide enough food for individuals and households (Devereux and Maxwell, 2001; Devereux, 2003; Gregory et al., 2005). 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: these include household income, human health, government policy, conflict, globalisation, market failures, as well as environmental issues (Devereux and Maxwell, 2001; Marsland, 2004; Misselhorn, 2005).

Building on this recognition, three principal components of food security may be identified:

i. the *availability* of food (through the market and through own production);
ii. adequate purchasing and/or relational power to acquire or *access* food;
iii. the acquisition of sufficient nutrients from the available food, which is influenced by the ability to digest and absorb *nutrients* necessary for 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; 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 runs counter to the assumption that people's food security in Africa derives solely (or even primarily) from their own

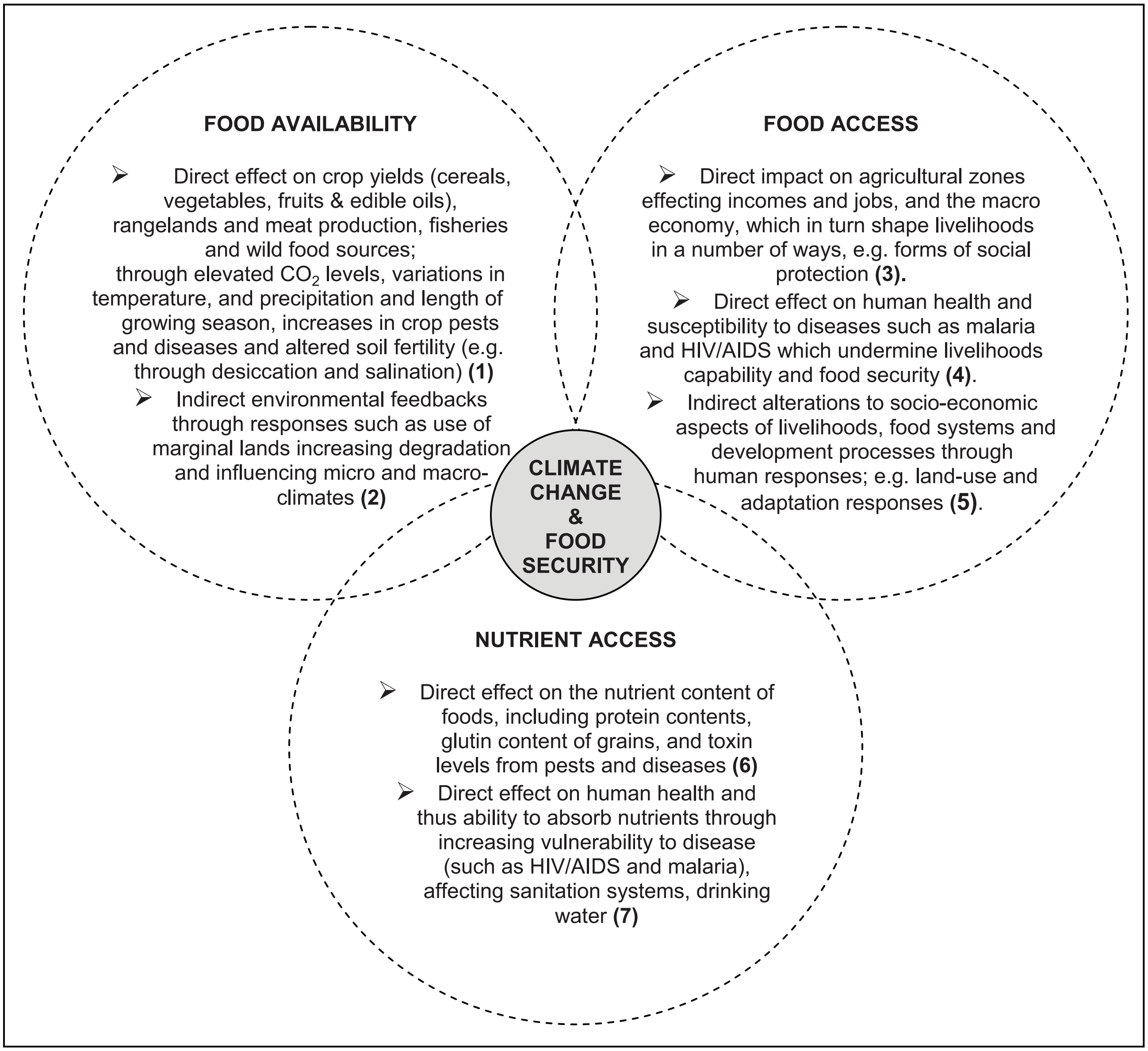


Figure 9.6. *Linkages identified between climate change in Africa and three major components of food security. Adapted from inputs of (1) Swaminathan, 2000; Fischer et al., 2002; Turpie et al., 2002; Rosegrant and Cline, 2003; Slingo et al., 2005. (2) Fischer et al., 2002; Slingo et al., 2005. (3) Turpie et al., 2002; African Union, 2005. (4) Piot and Pinstrup-Anderson, 2002; Turpie et al., 2002; Mano et al., 2003; USAID, 2003; Gommes et al., 2004; van Lieshout et al., 2004. (5) Adger and Vincent, 2005; Brooks et al., 2005; Gregory et al., 2005; Thomas and Twyman, 2005; O'Brien, 2006. (6) Slingo et al., 2005. (7) Swaminathan, 2000; Schulze et al., 2001; Gommes et al., 2004.*

agricultural production (Bryceson, 2000, 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% 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 both 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 foods 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 the infrastructure, such as roads, which can be damaged during climate events (e.g., Abdulai and Crolerees, 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 also 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; Adger and Vincent, 2005; Brooks et al., 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 household and community levels, as well as though 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). 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 remains unclear.

While exploring the local-level dynamics of people's vulnerability to climate change, of which adaptive capacity is a key component, it is important 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, 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 forecasting

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, thunderstorms, windstorms, harmattan (a dry dusty wind that blows along the north-west coast of Africa) and sunshine to prepare for future weather (Ajibade and Shokemi, 2003). Indigenous methods of weather forecasting are known to complement farmers' 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 to 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 the 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 in conjunction with and compared with 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; using tall grasses such as *Andropogon gayanus* for fixing soil surface nutrients washed away by runoff; erosion-control bunding to reduce significantly the effects of runoff; restoring lands by using green manure; constructing stone dykes; managing low-lying lands and protecting river banks (AGRHYMET, 2004).

Adaptation strategies that are applied by pastoralists in times of drought include the use of emergency fodder, culling of weak livestock for food, and multi-species composition of herds to survive climate extremes. During drought periods, pastoralists and agro-pastoralists change from cattle to sheep and goat husbandry, as the feed requirements of the latter are lower (Seo and Mendelsohn, 2006b). The pastoralists' nomadic mobility reduces the pressure on low-capacity grazing areas through their cyclic movements from the dry northern areas to the wetter southern areas of the Sahel.

African women are particularly known to possess indigenous knowledge which helps to maintain household food security, particularly in times of drought 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 (Ramphele, 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 range 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 (see Section 9.2.1). These struggles, however, are increasingly waged alongside a range of other stresses, such as HIV/AIDS, conflict and land struggles (see Section 9.2.2). Despite good economic growth in some countries and sectors in Africa (OECD, 2004/2005), large inequalities still persist, and some sources suggest that hopes of reaching the MDGs by 2015 are slipping (UNDP, 2005). While climate change may not have featured directly in the setting of the MDGs, it is clear from the evidence presented here that climate change and variability may be an additional impediment to achieving them (Table 9.3; 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 associated increased disaster risks, will seriously hamper future development. On an annual basis, for example, developing countries have already absorbed US$35 billion in direct losses from natural disasters (Mirza, 2003). However, these figures 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).

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 of droughts and floods and possible future climate change. While drought may affect production in some years, climate variability alone does not explain the limits of food production in Africa. Better models and methods to improve understanding of 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 contention, some shown here, also exist, with particular reference to health, the water sector and certain ecosystem responses, e.g., in 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 poorly researched, particularly for local assessments and for groundwater 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. Preliminary investigations give some indications of these interactions, but further analysis is required.

Table 9.3. *Potential impacts of climate change on the Millennium Development Goals (after AfDB et al., 2002; Thornton et al., 2006).*

Millennium Development Goals: climate change as a cross-cutting issue	
Potential impacts	***Millennium Development Goal****
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 changes 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 (see Sections 9.4.1, 9.4.3, 9.4.4 and 9.4.8).	Eradicate extreme poverty and hunger (**Goal 1**)
Climate change is likely to directly impact children and pregnant women because they are particularly susceptible to vector- and water-borne diseases, e.g., malaria is currently responsible for a quarter of maternal mortality. Other expected impacts include: • increased heat-related mortality and illness associated with heatwaves (which may be balanced by less winter-cold-related deaths in some countries); • increased prevalence of some vector-borne diseases (e.g., malaria, dengue fever), and vulnerability to water, food or person-to-person diseases (e.g. cholera, dysentery) (see Section 9.4.3); • declining quantity and quality of drinking water, which worsens malnutrition, since it is a prerequisite for good health; • reduced natural resource productivity and threatened food security, particularly in sub-Saharan Africa (see Sections 9.4.3, 9.4.3, 9.4.4, 9.6.1).	Health-related goals: • reduce infant mortality (**Goal 4**); • improve maternal health (**Goal 5**); • combat major diseases (**Goal 6**).
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 (see Section 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 (see Section 9.4, Table 9.1 and Chapter 4).	Ensure environmental sustainability (**Goal 7**)
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 (see Sections 9.2.1 and 9.2.2).	Achieve universal primary education (**Goal 2**)
One of the expected impacts of climate change is that it could exacerbate current gender inequalities, through impacting on the 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 (see Section 9.7.1, Table 9.2).	Promote gender equality and empower women (**Goal 3**)
Global climate change is a global issue, and responses require global co-operation, especially to help developing countries adapt to the adverse impacts of climate change.	Global partnerships (**Goal 8**)

* The order in which the Millennium Development Goals are listed here places the goals that could be directly impacted first, followed by those that are indirectly impacted.

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 in order to understand and show the interactions between vulnerability and adaptation to climate change and 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, see Christensen et al., 2007), the climate of many parts of Africa is still not fully understood. Climate scenarios developed from GCMs are very coarse and do not usually adequately capture important regional variations in Africa's climate. The need exists to further develop regional climate models and sub-regional models at a scale that would be meaningful to decision-makers and to 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 groundwater 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 specific 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, economic 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).

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 on 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 as 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 most 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 there are still debates on the attribution of malaria resurgence in some African areas. The need exists to examine the impacts of future climate change on other health problems, e.g., dengue fever, meningitis, etc, and their associated vulnerabilities. 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 relationship between CO_2-enrichment and future production of agricultural crops in Africa, salt-tolerant plants, and other trees and plants in coastal zones. Very little research has been conducted on the impacts of climate change on livestock, plant pests and diseases. The livestock sector is very important 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 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 the 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). However, this chapter has 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, both public and 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 between 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 an 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.

References

Abdalla, A.A., 2006: Environmental degradation and conflict in Darfur: experiences and development options. *Environmental Degradation as a Cause for Conflict in Darfur: Conference Proceedings*, Khartoum, Sudan, December 2004, University for Peace, Addis Ababa, 112 pp. http://www.unsudanig.org/darfur-jam/trackII/data/cluster/development/Environmental%20Degradation%20as%20a%20cause%20of%20conflict%20in%20Darfur%20(.pdf.

Abdulai, A. and A. Crolerees, 2001: Determinants of income diversification amongst rural households in Southern Mali. *Food Policy*, **26**, 437-452.

Abeku, T.A., S.J. De Vlas, G. Borsboom, A. Tadege, Y. Gebreyesus, H. Gebreyohannes, D. Alamirew, A. Seifu and Co-authors, 2004: Effects of meteorological factors on epidemic malaria in Ethiopia: a statistical modelling approach based on theoretical reasoning. *Parasitology*, **128**, 585-593.

Abou-Hadid, A.F., 2006: Assessment of impacts, adaptation and vulnerability to climate change in North Africa: food production and water resources. AIACC Final Report (AF 90), Washington, District of Columbia, 148 pp.

Adger, N. and K. Vincent, 2005: Uncertainty in adaptive capacity. *C. R. Geosci.*, **337**, 399-410.

Adger, N., N. Brooks, M. Kelly, G. Bentham, M. Agnew and S. Eriksen, 2004: New indicators of vulnerability and adaptive capacity. Technical Report 7, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 128 pp.

AfDB (African Development Bank), Asian Development Bank, UK DFID, Netherlands DGIS, European Commission DG for Development, German BMZ, OECD, UNDP, UNEP and World Bank, 2002: *Poverty and Climate Change: Reducing Vulnerability of the Poor Through Adaptation*, UNEP, 56 pp. http://povertymap.net/publications/doc/PovertyAndClimateChange_WorldBank.pdf.

Afrane, Y.A., B.W. Lawson, A.K. Githeko and G. Yan, 2005: Effects of microclimatic changes caused by land use and land cover on duration of gonotrophic cycles of *Anopheles gambiae* (Diptera: Culicidae) in western Kenya highlands. *J. Med. Entomol.*, **42**, 974-980.

African Union, 2005: Status of food security and prospects for agricultural development in Africa: 2005. AU Ministerial Conference of Ministers of Agriculture, Addis Ababa, 26 pp.

Agoumi, A., 2003: Vulnerability of North African countries to climatic changes: adaptation and implementation strategies for climatic change. Developing Perspectives on Climate Change: Issues and Analysis from Developing Countries and Countries with Economies in Transition. IISD/Climate Change Knowledge Network, 14 pp. http://www.cckn.net//pdf/north_africa.pdf.

Agrawala, S., Ed., 2005: *Bridge over Troubled Waters: Linking Climate Change and Development*. OECD, Paris, 154 pp.

AGRHYMET, 2004: Rapport synthèse de l'enquête générale sur les itinéraires d'adaptation des populations locales à la variabilité et aux changements climatiques conduite sur les projets pilotes par AGRHYMET et l'UQAM, par Hubert N'Djafa Ouaga, 13 pp.

Ajibade, L.T., 2003: A methodology for the collection and evaluation of farmers' indigenous environmental knowledge in developing countries. *Indilinga: African Journal of Indigenous Knowledge Systems*, **2**, 99-113.

Ajibade, L.T. and O. Shokemi, 2003: Indigenous approaches to weather forecasting in Asa L.G.A., Kwara State, Nigeria. *Indilinga: African Journal of Indigenous Knowledge Systems*, **2**, 37-44.

AMCEN/UNEP, 2002: *Africa Environment Outlook: Past, Present and Future Perspectives*. Earthprint, Stevenage, 410 pp.

Anderssen, L., J. Wilk, M.C. Todd, D.A. Hughes, A. Earle, D. Kniveton, R. Layberry, H.H.G. Savenije, 2006: Impact of climate change and development scenarios on flow patterns in the Okavango River, *J. Hydrol.*, **331**, 43-57.

Archer, E.R.M., 2003: Identifying underserved end-user groups in the provision of climate information. *B. Am. Meteorol. Soc.*, **84**, 1525-1532.

Armah, K.A., G. Wiafe and D.G. Kpelle, 2005: Sea-level rise and coastal biodiversity in West Africa: a case study from Ghana. *Climate Change and Africa*, P.S. Low, Ed., Cambridge University Press, Cambridge, 204-217.

Arnell, N.W., 2004: Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environ. Chang.*, **14**, 31-52.

Arnell, N.W., 2006a: Global impacts of abrupt climate change: an initial assessment. Working Paper 99, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 37 pp.

Arnell, N.W., 2006b: Climate change and water resources: a global perspective. *Avoiding Dangerous Climate Change*, H.J. Schellnhuber, W. Cramer, N. Nakićenović, T. Wigley and G. Yohe, Eds., Cambridge University Press, Cambridge, 167-175.

Arnell, N.W., M.G.R. Cannell, M. Hulme, R.S. Kovats, J.F.B. Mitchell, R.J. Nicholls, M.L. Parry, M.T.J. Livermore and A. White, 2002: The consequences of CO_2 stabilisation for the impacts of climate change. *Climatic Change*, **53**, 413-446.

Arrow, K., P. Dasgupta, L. Goulder, G. Daily, P. Ehrlich, G. Heal, S. Levin, K.-G. Mäler and Co-authors, 2004: Are we consuming too much? *J. Econ. Perspect.*, **18**, 147-172.

Ashton, P.J., 2002: Avoiding conflicts over Africa's water resources. *Ambio*, **31**, 236-242.

Attaher, S., M.A. Medany, A.A. Abdel Aziz and A. El-Gindy, 2006: Irrigation-water demands under current and future climate conditions in Egypt. *Misr. Journal of Agricultural Engineering*, **23**, 1077-1089.

Balint-Kurti, D., 2005: Tin trade fuels Congo War. *News24*, 07/03/2005. http://www.news24.com/News24/Africa/Features/0,,2-11-37_1672558,00.html.

Balk, D., A. Storeygard, M. Levy, J. Gaskell, M. Sharma and R. Flor, 2005: Child hunger in the developing world: an analysis of environmental and social correlates. *Food Policy*, **30**, 584-611.

Batterbury, S. and A. Warren, 2001: The African Sahel 25 years after the great drought: assessing progress and moving towards new agendas and approaches. *Global Environ. Chang.*, **11**, 1-8.

Baylis, M. and A.K. Githeko, 2006: The effects of climate change on infectious diseases of animals. UK Foresight Project, Infectious Diseases: Preparing for the Future. Office of Science and Innovation, London, 35 pp.

Beg, N., J. Corfee Morlot, O. Davidson, Y. Afrane-Okesse, L. Tyani, F. Denton, Y. Sokona, J.P. Thomas and Co-authors, 2002: Linkages between climate change and sustainable development. *Clim. Policy*, **2**, 129-144.

Benhin, J.K.A., 2006: Climate change and South African agriculture: impacts and adaptation options. CEEPA Discussion Paper No. 21, Special Series on Climate Change and Agriculture in Africa. Centre for Environmental Economics and Policy in Africa, University of Pretoria, Pretoria, 78 pp.

Benson, C. and E.J. Clay, 2004: *Understanding the Economic and Financial Impacts of Natural Disasters*. Disaster Risk Management Series No. 4. World Bank Publications, Washington, District of Columbia, 130 pp.

Biggs, R., E. Bohensky, P.V. Desanker, C. Fabricius, T. Lynam, A.A. Misselhorn, C. Musvoto, M. Mutale and Co-authors, 2004: *Nature Supporting People: The Southern African Millennium Ecosystem Assessment Integrated Report*. Millennium Ecosystem Assessment, Council for Scientific and Industrial Research, Pretoria, 68 pp.

Block, S. and P. Webb, 2001: The dynamics of livelihood diversification in post-famine Ethiopia. *Food Policy*, **26**, 333-350.

Bomhard, B., D.M. Richardson, J.S. Donaldson, G.O. Hughes, G.F. Midgley, D.C. Raimondo, A.G. Rebelo, M. Rouget and W. Thuiller, 2005: Potential impacts of future land use and climate change on the Red List status of the Proteaceae in the Cape Floristic Region, South Africa. *Glob. Change Biol.*, **11**, 1452-1468.

Bounoua, L., G.J. Collatz, S.O. Los, P.J. Sellers, D.A. Dazlich, C.J. Tucker and D.A. Randall, 2000: Sensitivity of climate to changes in NDVI. *J. Climate*, **13**, 2277-2292.

Bounoua, L., R. DeFries, G.J. Collatz, P. Sellers and H. Khan, 2002: Effects of land cover conversion on surface climate. *Climatic Change*, **52**, 29-64.

Brooks, N., 2004: Drought in the African Sahel: long-term perspectives and future prospects. Working Paper 61, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 31 pp.

Brooks, N., W.N. Adger and P.M. Kelly, 2005: The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environ. Chang*., **15**, 151-163.

Brovkin, V., 2002: Climate-vegetation interaction. *J. Phys. IV*, **12**, 57-72.

Bryceson, D., 2000: Rural Africa at the crossroads: livelihood practices and policies. *Natural Resource Perspectives*, **52**, http://www.odi.org.uk/nrp/52.pdf.

Bryceson, D.F., 2002: The scramble in Africa: reorienting rural livelihoods. *World Dev.*, **30**, 725-739.

Bryceson, D.F., 2004: Agrarian vista or vortex: African rural livelihood policies. *Review of African Political Economy*, **31**, 617-629.

Bryceson, D.F. and J. Fonseca, 2006: Risking death for survival: peasant responses to hunger and HIV/AIDS in Malawi. *World Dev.*, **34**, 1654-1666.

Burke, E.J., S.J. Brown and N. Christidis, 2006: Modelling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *J. Hydrometeorol*., **7**, 1113-1125.

Center for International Earth Science Information Network, 2006: *Where the Poor Are: An Atlas of Poverty*. Columbia University, New York, 57 pp. http://www.ciesin.org/povmap/downloads/maps/atlas/atlas.pdf.

Chappell, A. and C.T. Agnew, 2004: Modelling climate change in West African Sahel rainfall (1931-90) as an artifact of changing station locations. *Int. J. Climatol*., **24**, 547-554.

Chen, H., A.K. Githeko, G. Zhou, J.I. Githure and G. Yan, 2006: New records of *Anopheles arabiensis* breeding on the Mount Kenya Highlands indicate indigenous malaria transmission. *Malaria J*., **5**, 17.

Chen, S. and M. Ravallion, 2004: How have the world's poorest fared since the early 1980s? *The World Bank Research Observer*, **19**, 141-169.

Chigwada, J., 2005: Climate proofing infrastructure and diversifying livelihoods in Zimbabwe. *IDS Bull*., **36**, S103-S116.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Koli, W.-T. Kwon, R. Laprise, V.M. Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional climate projections. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 847-940.

Christie, F. and J. Hanlon, 2001: *Mozambique and the Great Flood of 2000*. Indiana University Press, Indiana, 176 pp.

Clark, B.M., 2006: Climate change: a looming challenge for fisheries management in southern Africa. *Mar. Policy*, **30**, 84-95.

Clark, B.M., S. Young and A. Richardson, 2003: Likely effects of global climate change on the purse seine fishery for Cape anchovy *Engraulis capensis* off the west coast of Southern Africa (SE Atlantic). http://swfsc.noaa.gov/uploadedFiles/Education/lasker_events.doc.

Claussen, M., V. Brovkin, A. Ganopolski, C. Kubatzki and V. Petoukhov, 2003: Climate change in northern Africa: the past is not the future. *Climatic Change*, **57**, 99-118.

Connor, S.J., P. Ceccato, T. Dinku, J. Omumbo, E.K. Grover-Kopec and M.C. Thomson, 2006: Using climate information for improved health in Africa: relevance, constraints and opportunities. *Geospatial Health*, **1**, 17-31.

Conway, D., 2005: From headwater tributaries to international river: observing and adapting to climate variability and change in the Nile Basin. *Global Environ. Chang*., **15**, 99-114.

Conway, D., C. Mould and W. Bewket, 2004: Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia. *Int. J. Climatol*., **24**, 77-91.

Conway, D., E. Allison, R. Felstead and M. Goulden, 2005: Rainfall variability in East Africa: implications for natural resources management and livelihoods. *Philos. T. Roy. Soc. A*, **363**, 49-54.

Coughenour, J. Hudson, P. Weisberg, C. Vogel and J.E. Ellis, 2004: Ecosystem modeling adds value to South African climate forecasts. *Climatic Change*, **64**, 317-340.

Cullen, N.J., T. Mölg, G. Kaser, K. Hussein, K. Steffen and D.R. Hardy, 2006: Kilimanjaro glaciers: recent areal extent from satellite data and new interpretation of observed 20th century retreat rates. *Geophys. Res. Lett*., **33**, L16502, doi:10.1029/2006GL027084.

Cury, P. and L. Shannon, 2004: Regime shifts in upwelling ecosystems: observed changes and possible mechanisms in the northern and southern Benguela. *Prog. Oceanogr.*, **60**, 223-243.

Dai, A., P.J. Lamb, K.E. Trenberth, M. Hulme, P.D. Jones and P. Xie, 2004: The recent Sahel drought is real. *Int. J. Climatol*., **24**, 1323-1331.

Davidson, O., K. Halsnaes, S. Huq, M. Kok, B. Metz, Y. Sokona and J. Verhagen, 2003: The development and climate nexus: the case of sub-Saharan Africa. *Clim. Policy*, **3**, 97-113.

de Wit, M. and J. Stankiewicz, 2006: Changes in water supply across Africa with predicted climate change. *Science*, **311**, 1917-1921.

Dea, D. and I. Scoones, 2003: Networks of knowledge: how farmers and scientists understand soils and their fertility: a case study from Ethiopia. *Oxford Development Studies*, **31**, 461-478.

DeFries, R.S., L. Bounoua and G.J. Collatz, 2002: Human modification of the landscape and surface climate in the next fifty years. *Glob. Change Biol*., **8**, 438-458.

Desta, S. and L. Coppock, 2004: Pastoralism under pressure: tracking system change in southern Ethiopia. *Hum. Ecol*., **32**, 465-486.

Devereux, S., 2003: Policy options for increasing the contribution of social protection to food security. Forum for Food Security in Southern Africa, Overseas Development Institute, London, 35 pp.

Devereux, S. and S. Maxwell, Eds., 2001: *Food Security in Sub-Saharan Africa*. ITDG Publishing, Pietermaritzburg, 361 pp.

DFID (Department for International Development), 2004: The impact of climate change on the vulnerability of the poor. Policy Division, Global Environmental Assets, Key sheet 3, 6 pp. http://www.dfid.gov.uk/pubs/files/climatechange/3vulnerability.pdf.

Dilley, M., R.S. Chen, U. Deichmann, A.L. Lerner-Lam, M. Arnold, J. Agwe, P. Buys, O. Kjekstad and Co-authors, 2005: *Natural Disaster Hotspots: A Global Risk Analysis*. Disaster Risk Management Series No. 5. The World Bank, Washington, District of Columbia, 148 pp. http://www.proventionconsortium.org/themes/default/pdfs/Hotspots.pdf.

Dixon, R.K., J. Smith and S. Guill, 2003: Life on the edge: vulnerability and adaptation of African ecosystems to global climate change. *Mitigation and Adaptation Strategies for Global Change*, **8**, 93-113.

Dougherty, W. and B. Osman, 2005: Mainstreaming adaptation into national development plans. *AIACC Second Regional Workshop for Africa and Indian Ocean Islands*, Dakar, Senegal. http://www.aiaccproject.org/meetings/meetings.html.

du Plessis C, D.K. Irurah and R.J. Scholes, 2003: The built environment and climate change in South Africa. *Build. Res. Inf*., **31**, 240–256.

Dwyer, E.S., S. Pinnock, J.M. Gregoire and J.M.C. Pereira, 2000: Global spatial and temporal distribution of vegetation fire as determined from satellite observations. *Int. J. Remote Sensing*, **21**, 1289-1302.

Easton, P. and M. Roland, 2000: Seeds of life: women and agricultural biodiversity in Africa. IK Notes 23. World Bank, Washington, District of Columbia, 4 pp.

ECA (Economic Commission for Africa), 2002: Harnessing technologies for sustainable development. Economic Commission for Africa Policy Research Report, Addis Ababa, 178 pp.

ECA (Economic Commission for Africa), 2005: Assessing sustainable development in Africa. Africa's Sustainable Development Bulletin. Economic Commission for Africa, Addis Ababa, 59 pp.

ECF (European Climate Forum) and Potsdam Institute, 2004: What is dangerous climate change? *Initial Results of a Symposium on Key Vulnerable Regions, Climate Change and Article 2 of the UNFCCC*, Buenos Aires. Beijing, 39 pp. http://www.european-climate-forum.net/.

2006: Assessing the impacts of climate change on agriculture in Egypt: a ricardian approach. Centre for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No. 16, Special Series on Climate Change and Agriculture in Africa, University of Pretoria, Pretoria, 1-33.

Eklundh, L. and L. Olsson, 2003: Vegetation trends for the African Sahel 1982–1999. *Geophys. Res. Lett*., **30**, 1430, doi:10.1029/2002GL016772.

El-Gindy, A., A.A. Abdel Azziz and E.A. El-Sahaar, 2001: Design of irrigation and drainage networks. Faculty of Agriculture lectures, Ain Shams University, 28 pp. (in Arabic).

Ellis, F., 2000: *Rural Livelihoods and Diversity in Developing Countries*. Oxford University Press, Oxford, 296 pp.

Ellis, F., 2003: Human vulnerability and food insecurity: policy implications. Forum for Food Security in Southern Africa, Overseas Development Group, University of East Anglia, Norwich, 47 pp.

Ellis, F. and G. Bahiigwa, 2003: Livelihoods and rural poverty reduction in Uganda. *World Dev.*, **31**, 997-1013.
Ellis, F. and N. Mdoe, 2003: Livelihoods and rural poverty reduction in Tanzania. *World Dev.*, **31**, 1367-1384.
EPIQ (Environmental Policy and Institutional Strengthening Indefinite Quantity, Water Policy Reform Activity, Agricultural Policy Reform Programme and Market-Based Incentives Team), 2002: Economic Instruments for Improved Water Resources Management in Egypt, Prepared for the United States Agency for International Development/Egypt, No. PCE-I-00-96-00002-00, 173 pp.
Epstein, P.R. and E. Mills, Eds., 2005: *Climate Change Futures: Health, Ecological and Economic Dimensions*. Center for Health and the Global Environment, Harvard Medical School, Boston, Massachusetts, 142 pp.
Erasmus, B.F.N., A.S. van Jaarsveld, S.L. Chown, M. Kshatriya and K.J. Wessels, 2002: Vulnerability of South Africa animal taxa to climate change. *Glob. Change Biol.*, **8**, 679-693.
Eriksen, S., 2004: Building adaptive capacity in a 'glocal' world: examples from Norway and Africa. *ESS Bulletin*, **2**, 18-26.
Eriksen, S., 2005: The role of indigenous plants in household adaptation to climate change: the Kenyan experience. *Climate Change and Africa*, P.S Low, Ed., Cambridge University Press, Cambridge, 248-259.
Eriksen, S.H. and J. Silva, 2003: The impact of economic liberalisation on climate vulnerability among farmers in Mozambique. IHDP Open Meeting, 16–18 October 2003, Montreal, 15 pp.
Eriksen, S.H., K. Brown and P.M. Kelly, 2005: The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. *Geogr. J.*, **171**, 287-305.
ESMAP (Energy Sector Management Assistance Program), 2005: The vulnerability of African countries to oil price shocks: major factors and policy options – the case of oil importing countries. World Bank Report 308/5, Washington, District of Columbia, 76 pp.
FAO, 2004: Locust crisis to hit northwest Africa again: situation deteriorating in the Sahel. FAO News Release, 17 September 2004. http://www.fao.org/newsroom/en/news/2004/50609/.
FAO, 2005: *The State of Food and Agriculture*. Food and Agriculture Organization of the United Nations, Rome, 211 pp.
Fauchereau, N., S. Trzaska, Y. Richard, P. Roucou and P. Camberlin, 2003: Sea-surface temperature co-variability in the southern Atlantic and Indian Oceans and its connections with the atmospheric circulation in the southern hemisphere. *Int. J. Climatol.,* **23**, 663-677.
Fekete, B.M., C.J. Vörösmarty, J.O. Roads and C.J. Willmott, 2004: Uncertainties in precipitation and their impact on runoff estimates. *J. Climate*, **17**, 294-304.
Ferguson, J., 2006: *Global Shadows: Africa in the Neoliberal World Order*. Duke University Press, Durham and London, 257 pp.
Few R., M. Ahern, F. Matthies and S. Kovats, 2004: Floods, health and climate change: a strategic review. Working Paper 63, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 138 pp.
Fiki, O.C. and B. Lee, 2004: Conflict generation, conflict management and self-organizing capabilities in drought-prone rural communities in north eastern Nigeria: a case study. *Journal of Social Development in Africa*, **19**, 25-48.
Fischer, G., M. Shah and H. van Velthuizen, 2002: *Climate Change and Agricultural Vulnerability*. International Institute for Applied Systems Analysis, Laxenberg, 152 pp.
Fischer, G., M. Shah, F.N. Tubiello and H. van Velthuizen, 2005: Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. *Philos. T. Roy. Soc. B*, **360**, 2067-2083.
Freeman, P.K., 2003: Natural hazard risk and privatization. *Building Safer Cities: The Future of Disaster Risk*, A. Kreimer, M. Arnold and A. Carlin, Eds., World Bank Disaster Management Facility, Washington, District of Columbia, 33-44.
Freeman, P. and K. Warner, 2001: Vulnerability of infrastructure to climate variability: how does this affect infrastructure lending policies? Report commissioned by the Disaster Management Facility of the World Bank and the ProVention Consortium, Washington, District of Columbia, 42 pp.
Frenken, K., Ed., 2005: Irrigation in Africa in figures – AQUASTAT Survey – 2005. Food and Agricultural Organisation of the United Nations, Rome, 89 pp.
Gabre-Madhin, E.Z. and S. Haggblade, 2004: Successes in African agriculture: results of an expert survey. *World Dev.*, **32**, 745-766.
Gallup, J.L. and J.D. Sachs, 2001: The economic burden of malaria. *Am. J. Trop. Med. Hyg.*, **64**, 85-96.
Gana, F.S., 2003: The usage of indigenous plant materials among small-scale farmers in Niger state agricultural development project: Nigeria. *Indilinga: African Journal of Indigenous Knowledge Systems*, **2**, 53-60.
Giannini, A., R. Saravanan and P. Chang, 2003: Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. *Science*, **302**, 1027-1030.
Githeko, A.K. and W. Ndegwa, 2001: Predicting malaria epidemics in Kenyan highlands using climate data: a tool for decision makers. *Global Change and Human Health*, **2**, 54-63.
Gommes, R., J. du Guerny, M.H. Glantz, L.-N. Hsu and J. White, 2004: Climate and HIV/AIDS: a hotspots analysis for early warning rapid response systems. UNDP, NCAR and FAO, Bangkok, 36 pp.
Gommes, R., J. du Guerny, F.O. Nachtergalle and R. Brinkman, 2005: Potential impacts of sea-level rise on populations and agriculture. *Climate Change and Africa*, P.S Low, Ed., Cambridge University Press, Cambridge, 191-203.
Gonzalez, P., 2001: Desertification and a shift of forest species in the West African Sahel. *Climate Res.*, **17**, 217-228.
Government of Seychelles, 2000: Initial National Communication under the United Nations Framework Convention on Climate Change (UNFCCC), Ministry of Environment and Transport, 145 pp. http://unfccc.int/resource/docs /natc/seync1.pdf.
Granich, S., 2006: Deserts and desertification. *Tiempo*, **59**, 8-11.
Gregory, P.J., J.S.I. Ingram and M. Brklacich, 2005: Climate change and food security. *Philos. T. Roy. Soc. B*, **360**, 2139-2148.
Grothmann, T. and A. Patt, 2005: Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Global Environ. Chang.*, **15**, 199-213.
Gueye, L., M. Bzioul and O. Johnson, 2005: Water and sustainable development in the countries of Northern Africa: coping with challenges and scarcity. *Assessing sustainable development in Africa*, Africa's Sustainable Development Bulletin, Economic Commission for Africa, Addis Ababa, 24-28.
Haarsma, R.J., F.M. Selten, S.L. Weber and M. Kliphuis, 2005: Sahel rainfall variability and response to greenhouse warming. *Geophys. Res. Lett.*, **32**, L17702, doi:10.1029/2005GL023232.
Haddad, B.M., 2005: Ranking the adaptive capacity of nations to climate change when socio-political goals are explicit. *Global Environ. Chang.*, **15**, 165-176.
Hall, D.O. and J.I. Scrase, 2005: Biomass energy in sub-Saharan Africa. *Climate Change and Africa*, P.S Low, Ed., Cambridge University Press, Cambridge, 107-112.
Hamilton, J.M., D.J. Maddison and R.S.J. Tol, 2005: Effects of climate change on international tourism. *Climate Res.*, **29**, 245-254.
Hammerich, A., O.M.R. Campbell and D. Chandramohan, 2002: Unstable malaria transmission and maternal mortality: experiences from Rwanda. *Trop. Med. Int. Health*, **7**, 573-576.
Harrus, S. and G. Baneth, 2005: Drivers for the emergence and re-emergence of vector-borne protozoal and bacterial diseases. *Int. J. Parasitol.*, **35**, 1309-1318.
Hartmann, J., K. Ebi, J. McConnell, N. Chan and J.P. Weyant, 2002: Climate suitability: for stable malaria transmission in Zimbabwe under different climate change scenarios. *Global Change and Human Health*, **3**, 42-54.
Hay, S.I., J. Cox, D.J. Rogers, S.E. Randolph, D.I. Stern, G.D. Shanks, M.F. Myers and R.W. Snow, 2002a: Climate change and the resurgence of malaria in the East African Highlands. *Nature*, **415**, 905-909.
Hay, S.I., D.J. Rogers, S.E. Randolph, D.I. Stern, J. Cox, G.D. Shanks and R.W. Snow, 2002b: Hot topic or hot air? Climate change and malaria resurgence in East African highlands. *Trends in Parasitology*, **18**, 530-534.
Held, I.M., T.L. Delworth, J. Lu, K.L. Findell and T.R. Knuston, 2005: Simulation of Sahel drought in the 20th and 21st centuries. *P. Natl. Acad. Sci. USA*, **102**, 17891-17896.
Hemp, A., 2005: Climate change-driven forest fires marginalize the impact of ice cap wasting on Kilimanjaro. *Glob. Change Biol.*, **11**, 1013-1023.
Herrmann, S.M., A. Anyamba and C.J. Tucker, 2005: Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environ. Chang.*, **15**, 394-404.
Hewawasam, I., 2002: Managing the marine and coastal environment of sub-Saharan Africa: strategic directions for sustainable development. World Bank, Washington, District of Columbia, 57 pp.
Hewitson, B.C. and R.G. Crane, 2006: Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. *Int. J. Climatol.*, **26**, 1315-1337.
Hoerling, M., J. Hurrell, J. Eischeid and A. Phillips, 2006: Detection and attribution of twentieth-century northern and southern African rainfall change. *J. Climate*, **19**, 3989-4008.

Holding, P.A. and R.W. Snow, 2001: Impact of *Plasmodium falciparum* malaria on performance and learning: review of the evidence. *Am. J. Trop. Med. Hyg.*, **64**, 68-75.

Hudson, D.A. and R.G. Jones, 2002: Regional climate model simulations of present day and future climates of Southern Africa. Technical Note 39, Hadley Centre, Bracknell, 42 pp.

Hugon, P. and P.X. Nanterre, 2003: Food insecurity and famine in southern Africa, an economic debate: lack of availabilities, market failures, inequities of rights, effects of shocks or systemic risks? Preprints, *SARPN Meeting: Food Security in Southern Africa*, 18 March 2003, Pretoria.

Hulme, D. and A. Shepherd, 2003: Conceptualizing chronic poverty. *World Dev.*, **31**, 403-423.

Hulme, M., R.M. Doherty, T. Ngara, M.G. New and D. Lister, 2001: African climate change: 1900–2100. *Climate Res.*, **17**, 145-168.

Hulme, M., R. Doherty, T. Ngara and M. New, 2005: Global warming and African climate change. *Climate Change and Africa*, P.S Low, Ed., Cambridge University Press, Cambridge, 29-40.

Huntingford, C., F.H. Lambert, J.H.C. Gash, C.M. Taylor and A.J. Challinor, 2005: Aspects of climate change prediction relevant to crop productivity. *Philos. T. Roy. Soc. B*, **360**, 1999-2009.

Huq, S. and H. Reid, 2004: Mainstreaming adaptation in development. *IDS Bull.*, **35**, 15-21.

ICID (International Commission on Irrigation and Drainage, New Delhi), 2005: Water Policy Issues of Egypt, Country Policy Support Programme, 36 pp.

IEA (International Energy Association), 2002: *World Energy Outlook 2002*. International Energy Agency, Paris, 533 pp. http://www.iea.org/textbase/nppdf/free/2000/weo2002.pdf.

IFRCRCS (International Federation of Red Cross and Red Crescent Societies), 2002: *World Disasters Report: Focusing on Reducing Risk*. Geneva, 240 pp.

IFRCRCS (International Federation of Red Cross and Red Crescent Societies), 2005: *World Disasters Report: Focus on Information in Disasters*. Geneva, 251 pp.

Institute of Development Studies, 2005: *New Directions for African Agriculture,* I. Scoones, A. deGrassi, S. Devereux and L. Haddad, Eds., *IDS Bull.*, **36**, 160 pp.

International Institute of Rural Reconstruction, 2004: *Drought Cycle Management: A Toolkit for the Drylands of the Greater Horn*. Cordiad and Acacia Consultants, Nairobi, 253 pp.

IPCC, 2001: *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White, Eds., Cambridge University Press, Cambridge, 1032 pp.

IPCC, 2007a: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 996 pp.

IPCC, 2007b: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, B. Metz, O. Davidson, P. Bosch, R. Dave and L. Meyer, Eds., Cambridge University Press, Cambridge, UK.

IRI, GCOS, DfID and ECA, 2006: A gap analysis for the implementation of the Global Climate Observing System programme in Africa, IRI (International Research Institute for Climate and Society) Technical Report, IRI-TR/06/1, 52 pp.

Jenkins, G.S., G. Adamou and S. Fongang, 2002: The challenges of modelling climate variability and change in West Africa. *Climatic Change*, **52**, 263-286.

Jenkins, G.S., A.T. Gaye and B. Sylla, 2005: Late 20th century attribution of drying trends in the Sahel from the Regional Climate Model (RegCM3). *Geophys. Res. Lett.*, **32**, L22705, doi:10.1029/2005GL024225.

Jones, P.G. and P.K. Thornton, 2003: The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environ. Chang.*, **13**, 51-59.

Kabat, P., R.E. Schulze, M.E. Hellmuth and J.A. Veraart, Eds., 2002: Coping with impacts of climate variability and climate change in water management: a scoping paper. DWC-Report No. DWCSSO-01 (2002). Dialogue on Water and Climate, Wageningen, 114 pp.

Kamga, A.F., G.S. Jenkins, A.T. Gaye, A. Garba, A. Sarr and A. Adedoyin, 2005: Evaluating the National Center for Atmospheric Research climate system model over West Africa: present-day and the 21st century A1 scenario. *J. Geophys. Res.–Atmos.*, **110**, D03106, doi:10.1029/2004JD004689.

Kaser, G., D.R. Hardy, T. Mölg, R.S. Bradley and T.M. Hyera, 2004: Modern glacier retreat on Kilimanjaro as evidence of climate change: observations and facts. *Int. J. Climatol.*, **24**, 329-339.

Kelly, V., A.A. Adesina and A. Gordon, 2003: Expanding access to agricultural inputs in Africa: a review of recent market development experience. *Food Policy*, **28**, 379-404.

Kempeneers, P., E. Swinnen and F. Fierens, 2002: GLOBSCAR Final Report, TAP/N7904/FF/FR-001 Version 1.2, VITO, Belgium, 25 pp. http://geofront.vgt.vito.be/geosuccess/documents/Final%20Report.pdf;jsessionid=668127C51913A12DB357A8569F4FE74F.

Kherallah, M., C. Delgado, E. Gabre-Madhin, N. Minot and M. Johnson, 2004: The road half travelled: agricultural market reform in Sub-Saharan Africa. Policy Report, International Food Policy Research Institute, Washington, District of Columbia, 4 pp.

King'uyu, S.M., L.A. Ogallo and E.K. Anyamba, 2000: Recent trends of minimum and maximum surface temperatures over Eastern Africa. *J. Climate*, **13**, 2876-2886.

Klein, R.J.T., R.J. Nicholls and F. Thomalla, 2002: The resilience of coastal megacities to weather-related hazards. *Building Safer Cities: The Future of Disaster Risk*, A. Kreimer, M. Arnold and A. Carlin, Eds., The World Bank Disaster Management Facility, Washington, District of Columbia, 101-120.

Kotb, M., M. Abdulaziz, Z. Al-Agwan, K. Al-Shaikh, H. Al-Yami, A. Banajah, L. DeVantier, M. Eisinger and Co-authors, 2004: Status of coral reefs in the Red Sea and Gulf of Aden in 2004. *Status of Coral Reefs of the World: 2004*, C. Wilkinson, Ed., Volume 1, Australian Institute of Marine Science, Townsville, 137-154.

Kruger, A.C. and S. Shongwe, 2004: Temperature trends in South Africa: 1960–2003. *Int. J. Climatol.*, **24**, 1929-1945.

Kurukulasuriya, P. and S. Rosenthal, 2003: Climate change and agriculture: a review of impacts and adaptations. Climate Change Series Paper 91, World Bank, Washington, District of Columbia, 106 pp.

Kurukulasuriya, P. and R. Mendelsohn, 2006a: A Ricardian analysis of the impact of climate change on African cropland. Centre for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No. 8. University of Pretoria, Pretoria, 58 pp.

Kurukulasuriya, P. and R. Mendelsohn, 2006b: Crop selection: adapting to climate change in Africa. Centre for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No. 26. University of Pretoria, Pretoria, 28 pp.

Lal, M., 2001: Tropical cyclones in a warmer world. *Current Sci.*, **80**, 1103-1104.

Leautier, F., 2004: Indigenous capacity enhancement: developing community knowledge. *Indigenous Knowledge: Local Pathways to Global Development*. The World Bank, Washington, District of Columbia, 4-8.

Lebel, T., F. Delclaux, L. Le Barbe and J. Polcher, 2000: From GCM scales to hydrological scales: rainfall variability in West Africa. *Stoch. Env. Res. Risk A.*, **14**, 275-295.

Leemans, R. and B. Eickhout, 2004: Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. *Global Environ. Chang.*, **14**, 219-228.

Legesse, D., C. Vallet-Coulomb and F. Gasse, 2003: Hydrological response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. *J. Hydrol.*, **275**, 67-85.

Lemke, P., J. Ren, R.B. Alley, I. Allison, J. Carrasco, G. Flato, Y. Fujii, G. Kaser, P. Mote, R.H. Thomas and T. Zhang, 2007: Observations: Changes in snow, ice and frozen ground. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 337-384.

Levy, P., 2006: Regional climate change impacts on global vegetation. *Understanding the Regional Impacts of Climate Change: Research Report prepared for the Stern Review on the Economics of Climate Change*, R. Warren, N. Arnell, R. Nicholls, P. Levy and J. Price, Eds., Working Paper 90, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 99-108.

L'Hôte, Y., G. Mahé, B. Some and J.P. Triboulet, 2002: Analysis of a Sahelian annual rainfall index from 1896 to 2000: the drought continues. *Hydrolog. Sci. J.*, **47**, 563-572.

Lind, J. and K. Sturman, Eds., 2002: *Scarcity and Surfeit: The Ecology of Africa's Conflicts*. Institute for Security Studies, Pretoria, 388 pp.

Little, P.D., H. Mahmoud and D.L. Coppock, 2001: When deserts flood: risk management and climate processes among East African pastoralists. *Climate Res*., **19**, 149-159.

Lough, J.M., 2000: 1997-98: Unprecedented thermal stress to coral reefs? *Geophys. Res. Lett*., **27**, 3901-3904.

Malaney, P., A. Spielman and J. Sachs, 2004: The malaria gap. *Am. J. Trop. Med. Hyg*., **71**, 141-146.

Malhi, Y. and J. Wright, 2004: Spatial patterns and recent trends in the climate of tropical rainforest regions. *Philos. T. Roy. Soc. B*, **359**, 311-329.

Mano, R., B. Isaacson and P. Dardel, 2003: Identifying policy determinants of food security response and recovery in the SADC region: the case of the 2002 food emergency. FANRPAN Policy Paper, 31 pp. http://www.reliefweb.int/library/documents/2003/fews-sad-13may.pdf .

Marsland, N., 2004: Development of food security and vulnerability information systems in Southern Africa: the experience of Save the Children UK. Save the Children, 64 pp.

Matondo, J.I., G. Peter and K.M. Msibi, 2005: Managing water under climate change for peace and prosperity in Swaziland. *Phys. Chem. Earth*, **30**, 943-949.

Maynard, K., J.-F. Royer and F. Chauvin, 2002: Impact of greenhouse warming on the West African summer monsoon. *Clim. Dynam*., **19**, 499-514.

McClean, C.J., J.C. Lovett, W. Küper, L. Hannah, J.H. Sommer, W. Barthlott, M. Termansen, G.F. Smith and Co-authors, 2005: African plant diversity and climate change. *Ann. Mo. Bot. Gard*., **92**, 139-152.

McDonald, R.E., D.G. Bleaken, D.R. Cresswell, V.D. Pope and C.A. Senior, 2005: Tropical storms: representation and diagnosis in climate models and the impacts of climate change. *Clim. Dynam*., **25**, 19-36.

McLeman, R. and B. Smit, 2004: Climate change, migration and security. Canadian Security Intelligence Service, Commentary No. 86. http://www.csis-scrs.gc.ca/en/publications/commentary/com86.asp.

McLeman, R. and B. Smit, 2005: Assessing the security implications of climate change-related migration. Preprint, *Human Security and Climate Change: An International Workshop*, Oslo, 20 pp.

McMichael, A.J., R.E. Woodruff and S. Hales, 2006: Climate change and human health: present and future risks. *Lancet*, **367**, 859-869.

Mendelsohn, R., W. Morrison, M.E. Schlesinger and N.G. Andronova, 2000a: Country-specific market impacts from climate change. *Climatic Change*, **45**, 553-569.

Mendelsohn, R., A. Dinar and A. Dalfelt, 2000b: Climate change impacts on African agriculture. Preliminary analysis prepared for the World Bank, Washington, District of Columbia, 25 pp.

Mercier, F., A. Cazenave and C. Maheu, 2002: Interannual lake level fluctuations (1993–1999) in Africa from Topex/Poseidon: connections with ocean-atmosphere interactions over the Indian Ocean. *Global Planet. Change*, **32**, 141-163.

Midgley, G.F., L. Hannah, D. Millar, M.C. Rutherford and L.W. Powrie, 2002: Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecol. Biogeogr*., **11**, 445-451.

Mirza, M.M.Q., 2003: Climate change and extreme weather events: can developing countries adapt? *Clim. Policy*, **3**, 233-248.

Misselhorn, A.A., 2005: What drives food insecurity in Southern Africa? A meta-analysis of household economy studies. *Global Environ. Chang*., **15**, 33-43.

Mitchell, J.F.B., T.C. Johns, W.J. Ingram and J.A. Lowe, 2000: The effect of stabilising the atmospheric carbon dioxide concentrations on global and regional climate change. *Geophys. Res. Lett*., **27**, 2977-2980.

Molesworth A.M., L.E. Cuevas, S.J. Connor, A.P. Morse and M.C. Thomson, 2003: Environmental risk and meningitis epidemics in Africa. *Emerg. Infect. Dis*., **9**, 1287-1293.

Mölg, T. and D.R. Hardy, 2004: Ablation and associated energy balance of a horizontal glacier surface on Kilimanjaro. *J. Geophys. Res*., **109**, D16104, doi:10.1029/2003JD004338.

Monyo, E.S., 2002: Pearl millet cultivars released in the SADC region. ICRISAT, Bulawayo, 40 pp.

Mortimore, M.J. and W.M. Adams, 2001: Farmer adaptation, change and 'crisis' in the Sahel. *Global Environ. Chang*., **11**, 49-57.

Muhando, C.A., 2001: The 1998 coral bleaching and mortality event in Tanzania: implications for coral reef research and management. *Marine Science Development in Tanzania and Eastern Africa: Proc. 20th Anniversary Conference on Advances in Marine Science in Tanzania*, M.D. Richmond and J. Francis, Eds., Institute of Marine Science/Western Indian Ocean Marine Science Association, Zanzibar, 329-342.

Munga, S., N. Minakawa, G. Zhou, E. Mushinzimana, O.O.J. Barrack, A.K. Githeko and G. Yan, 2006: Association between land cover and habitat productivity of malaria vectors in western Kenyan highlands. *Am. J. Trop. Med. Hyg*., **74**, 69-75.

Muriuki, G.W., T.J. Njoka, R.S. Reid and D.M. Nyariki, 2005: Tsetse control and land-use change in Lambwe valley, south-western Kenya. *Agr. Ecosyst. Environ*., **106**, 99-107.

Mutangadura, G., S. Ivens and S.M. Donkor, 2005: Assessing the progress made by southern Africa in implementing the MDG target on drinking water and sanitation. *Assessing sustainable development in Africa*, Africa's Sustainable Development Bulletin, Economic Commission for Africa, Addis Ababa, 19-23.

Myers, N., 2002: Environmental refugees: a growing phenomenon of the 21st century. *Philos. T. Roy. Soc. B*, **357**, 609-613.

Nakićenović, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E. Lebre la Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H.H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor and Z. Dadi, Eds., 2000: *Emissions Scenarios: A Special Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press, Cambridge, 509 pp.

Nelleman, C. and E. Corcoran, Eds., 2006: Our precious coasts: marine pollution, climate change and the resilience of coastal ecosystems. United Nations Environment Programme, GRID- Arendal, Norway, 40 pp.

New, M., 2002: Climate change and water resources in the southwestern Cape, South Africa. *S. Afr. J. Sci*., **98**, 369-373.

New, M., B. Hewitson, D.B. Stephenson, A. Tsiga, A. Kruger, A. Manhique, B. Gomez, C.A.S. Coelho and Co-authors, 2006: Evidence of trends in daily climate extremes over southern and west Africa. *J. Geophys. Res.–Atmos*., **111**, D14102, doi:10.1029/2005JD006289.

Niang-Diop, I., 2005: Impacts of climate change on the coastal zones of Africa. *Coastal Zones in Sub-Saharan Africa: A Scientific Review of the Priority Issues Influencing Sustainability and Vulnerability in Coastal Communities*, IOC, Ed., IOC Workshop Report No. 186. ICAM Dossier No. 4, 27-33.

Niang-Diop, I., M. Dansokho, A.T. Diaw, S. Faye, A. Guisse, I. Ly, F. Matty, A. Sene and Co-authors, 2005: Senegal. *Climate Change in Developing Countries: An Overview of Study Results from the Netherlands Climate Change Studies Assistance Programme*, M.A. van Drunen, R. Lasage and C. Dorland, Eds., IVM, Amsterdam, 101-109.

Niasse, M., 2005: Climate-induced water conflict risks in West Africa: recognizing and coping with increasing climate impacts on shared watercourses. Preprint, *Human Security and Climate Change: An International Workshop*, Oslo, 15 pp.

Niasse, M., A. Afouda and A. Amani, Eds., 2004: *Reducing West Africa's Vulnerability to Climate Impacts on Water Resources, Wetlands and Desertification: Elements for a Regional Strategy for Preparedness and Adaptation*. International Union for Conservation of Nature and Resources (IUCN), Cambridge, 84 pp.

Nicholls, R.J., 2004: Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios. *Global Environ. Chang*., **14**, 69-86.

Nicholls, R.J. and R.S.J. Tol, 2006: Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. *Philos. T. Roy. Soc. A*, **364**, 1073-1095.

Nicholson, S.E., 2001: Climatic and environmental change in Africa during the last two centuries. *Climate Res*., **17**, 123-144.

Nicholson, S.E. and J.C. Selato, 2000: The influence of La Niña on African rainfall. *Int. J. Climatol*., **20**, 1761-1776.

Nicholson, S.E. and J.P. Grist, 2003: The seasonal evolution of the atmospheric circulation over West Africa and Equatorial Africa. *J. Climate*, **16**, 1013-1030.

Nicholson, S.E., B. Some and B. Kone, 2000: An analysis of recent rainfall conditions in West Africa, including the rainy season of the 1997 El Niño and the 1998 La Niña years. *J. Climate*, **13**, 2628-2640.

Njaya, F. and C. Howard, 2006: Climate and African fisheries. *Tiempo*, **59**, 13-15.

Nkomo, J.C., A.O. Nyong and K. Kulindwa, 2006: The impacts of climate change in Africa. Report prepared for the Stern Review on the Economics of Climate Change, 51 pp. http://www.hm-treasury.gov.uk/media/8AD/9E/ Chapter_5_The_Impacts_of_Climate_Change_in_Africa-5.pdf.

Obasi, G.O.P., 2005: The impacts of ENSO in Africa. *Climate Change and Africa*, P.S Low, Ed., Cambridge University Press, Cambridge, 218-230.

O'Brien, K., 2006: Are we missing the point? Global environmental change as an issue of human security. *Global Environ. Chang*., **16**, 1-3.

O'Brien, K. and C. Vogel, Eds., 2003: *Coping with Climate Variability: The Use* *of Seasonal Climate Forecasts in Southern Africa*. Ashgate Publishing, Aldershot, 176 pp.

Obura, D.O., 2001: Differential bleaching and mortality of eastern African corals. *Marine Science Development in Tanzania and Eastern Africa: Proc. 20th Anniversary Conference on Advances in Marine Science in Tanzania*, M.D. Richmond and J. Francis, Eds., Institute of Marine Science/Western Indian Ocean Marine Science Association, Zanzibar, 301-317.

Odada, E.O., D.O. Olago, K. Kulindwa, M. Ntiba and S. Wandiga, 2004: Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy option analysis. *Ambio*, **33**, 13-23.

OECD, 2004/2005: *African Economic Outlook: What's New for Africa?* Joint Project of the African Development Bank and OECD Development Centre, Paris, 540 pp.

Olsson, L., L. Eklundh and J. Ardö, 2005: A recent greening of the Sahel: trend, patterns and potential causes. *J. Arid Environ*., **63**, 556-566.

O'Reilly, C.M., S.R. Alin, P.D. Plisnier, A.S. Cohen and B.A. McKee, 2003: Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. *Nature*, **424**, 766-768.

Orindi, V.A. and A. Ochieng, 2005: Seed Fairs as a drought recovery strategy in Kenya. *IDS Bull*., **36**, 87-102.

Osman-Elasha, B., N. Goutbi, E. Spanger-Siegfried, W. Dougherty, A. Hanafi, S. Zakieldeen, A. Sanjak, H. Abdel Atti and H.M. Elhassan, 2006: Adaptation strategies to increase human resilience against climate variability and change: lessons from the arid regions of Sudan. Working Paper 42, AIACC, 44 pp.

Owens, T., J. Hoddinot and B. Kinsey, 2003: Ex-ante actions and ex-post public responses to drought shocks: evidence and simulations from Zimbabwe. *World Dev*., **31**, 1239-1255.

Owuor, B., S. Eriksen and W. Mauta, 2005: Adapting to climate change in a dryland mountain environment in Kenya. *Mt. Res. Dev*., **25**, 310-315.

Pandey, D.N., A.K. Gupta and D.M. Anderson, 2003: Rainwater harvesting as an adaptation to climate change. *Curr. Sci. India*, **85**, 46-59.

Parry, M.L., C.A. Rosenzweig, A. Iglesias, M. Livermore and G. Fisher, 2004: Effects of climate change on global food production under SRES emissions and socioeconomic scenarios. *Global Environ. Chang*., **14**, 53-67.

Pascual, M., J.A. Ahumada, L.F. Chaves, X. Rodó and M. Bouma, 2006: Malaria resurgence in the East African highlands: temperature trends revisited. *P. Natl. Acad. Sci. USA*, **103**, 5829-5834.

Patt, A., 2001: Understanding uncertainty: forecasting seasonal climate for farmers in Zimbabwe. *Risk, Decision and Policy*, **6**, 105-119.

Patt, A. and C. Gwata, 2002: Effective seasonal climate forecast applications: examining constraints for subsistence farmers in Zimbabwe. *Global Environ. Chang.,* **12**, 185-195.

Patt, A., P. Suarez and C. Gwata, 2005: Effects of seasonal climate forecasts and participatory workshops among subsistence farmers in Zimbabwe. *P. Natl. Acad. Sci. USA*, **102**, 12623-12628.

Patz, J.A. and S.H. Olson, 2006: Climate change and health: global to local influences on disease risk. *Ann. Trop. Med. Parasit*., **100**, 535-549.

Patz, J.A., M. Hulme, C. Rosenzweig, T.D. Mitchell, R.A. Goldberg, A.K. Githeko, S. Lele, A.J. McMichael and D. Le Sueur, 2002: Climate change (communications arising): Regional warming and malaria resurgence. *Nature*, **420**, 627-628.

Payet, R. and D. Obura, 2004: The negative impacts of human activities in the Eastern African region: an international waters perspective. *Ambio*, **33**, 24-33.

Phillips, J.G., E. Makaudze and L. Unganai, 2001: Current and potential use of climate forecasts for resource-poor farmers in Zimbabwe. *Impacts of El Niño and Climate Variability on Agriculture*, C. Rosenzweig, K.J. Boote, S. Hollinger, A. Iglesias and J.G. Phillips, Eds., American Society of Agronomy Special Publication 63, Madison, Wisconsin, 97-100.

Piot, P. and P. Pinstrup-Anderson, 2002: AIDS: the new challenge to food security. International Food Policy Research Institute, 2001-2002 Annual Report, 11-17.

Prospero, J.M. and P.J. Lamb, 2003: African droughts and dust transport to the Caribbean: climate change implications. *Science*, **302**, 1024-1027.

Quinn, C.H., M. Huby, H. Kiwasila and J.C. Lovett, 2003: Local perceptions of risk to livelihood in semi-arid Tanzania. *J. Environ. Manage*., **68**, 111-119.

Ramphele, M., 2004: Women's indigenous knowledge: building bridges between the traditional and the modern. *Indigenous Knowledge: Local Pathways to Development*, The World Bank, Washington, District of Columbia, 13-17.

Reason, C.J.C., 2002: Sensitivity of the southern African circulation to dipole sea-surface temperature patterns in the south Indian Ocean. *Int. J. Climatol*., **22**, 377-393.

Reason, C.J.C. and A. Keibel, 2004: Tropical cyclone Eline and its unusual penetration and impacts over the southern African mainland. *Weather Forecast*., **19**, 789-805.

Reason, C.J.C., S. Hachigonta and R.F. Phaladi, 2005: Interannual variability in rainy season characteristics over the Limpopo region of southern Africa. *Int. J. Climatol*., **25**, 1835-1853.

Reich, P.F., S.T. Numbem, R.A. Almaraz and H. Eswaran, 2001: Land resource stresses and desertification in Africa. *Agro-Science*, **2**, 1-10.

Reid, P. and C. Vogel, 2006: Living and responding to multiple stressors in South Africa: glimpses from KwaZulu Natal. *Global Environ. Chang*., **16**, 195-206.

Republic of Ghana, 2000: *Initial National Communication to the United Nations Framework Convention on Climate Change*. Ministry of Environment, Science and Technology, Accra, 171 pp.

Republic of Kenya, 2002: *First National Communication of Kenya to the Conference of Parties to the United Nations Framework Convention on Climate Change*. Ministry of Environment and Natural Resources, Nairobi, 155 pp.

République de Côte d'Ivoire, 2000: *Communication Initiale de la Côte d'Ivoire*. Ministère de l'Environnement, de l'Eau et de la Forêt, Abidjan, 97 pp.

République de Djibouti, 2001: *Communication Nationale Initiale de la Republique des Nations Unies sur les Changements Climatiques*. Ministere de l'Habitat, de l'Urbanisme, de l'Environment et de l'Amenagement de Territoire, 91 pp.

République de Guinée, 2002: *Communication Initiale de la Guinée à la Convention Cadre des Nations Unies sur les Changements Climatiques*. Ministère des Mines, de la Géologie et de l'Environnement, Conakry, 78 pp.

République Démocratique du Congo, 2000: *Communication Nationale Initiale de la République Démocratique du Congo (année 1994)*. Ministère des Affaires Foncières, Environnement et Développement Touristique, Kinshasa, 207 pp.

République du Congo, 2001: *Communication Nationale Initiale*. Ministère de l'Industrie Minière et de l'Environnement, Brazzaville, 56 pp.

Richard, Y., N. Fauchereau, I. Poccard, M. Rouault and S. Trzaska, 2001: 20th century droughts in Southern Africa: spatial and temporal variability, teleconnections with oceanic and atmospheric conditions. *Int. J. Climatol*., **21**, 873-885.

Riebeek, H., 2006: Lake Victoria's falling waters. Earth Observatory Features, NASA. http://earthobservatory.nasa.gov/Study/Victoria/printall.php.

Robinson, J.B. and D. Herbert, 2001: Integrating climate change and sustainable development. *Int. J. Global Environ*., **1**, 130-149.

Rocha, L.A., D.R. Robertson, C.R. Rocha, J.L. Van Tassell, M.T. Craig and B.W. Bowens, 2005: Recent invasion of the tropical Atlantic by an Indo-Pacific coral reef fish. *Mol. Ecol*., **14**, 3921-3928.

Rockström, J., 2003: Resilience building and water demand management for drought mitigation. *Phys. Chem. Earth*, **28**, 869-877.

Ron, J., 2005: Paradigm in distress? Primary commodities and civil war. *J. Conflict Resolut*., **49**, 443-450.

Roncoli, C., K. Ingram and P. Kirshen, 2001: The costs and risks of coping with drought: livelihood impacts and farmers' responses in Burkina Faso. *Climate Res*., **19**, 119-132.

Rosegrant, M.W. and S.A. Cline, 2003: Global food security: challenges and policies. *Science*, **302**, 1917-1919.

Rowell, D.P., 2003: The impact of Mediterranean SSTs on the Sahelian rainfall season. *J. Climate*, **16**, 849-862.

Ruosteenoja, K., T.R. Carter, K. Jylhä and H. Tuomenvirt, 2003: Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios. Finnish Environment Institute No. 644, Helsinki, 83 pp.

Sachs, J.D., 2005: *The End of Poverty*: *Economic Possibilities for our Time*. Penguin, New York, 416 pp.

Sachs, J. and P. Malaney, 2002: The economic and social burden of malaria. *Nature*, **415**, 680-685.

Sachs, J.D., J.W. McArthur, G. Schmidt-Traub, C. Kruk, M. Bahadur, M. Faye and G. McCord, 2004: Ending Africa's poverty trap. *Brookings Papers on Economic Activity*, **1**, 117-240.

SAFARI, 2004: South African Regional Science Initiative (CSIR, YB, NASA, ZMD and WITS, 2004): SAFARI 2000; reprinted from *J. Geophys. Res., AGU Special Collection*, **108**, 2003. http://www.agu.org/contents/sc/ViewCollection.do?collectionCode=SAF1&journalCode=JD.

Schreck, C.J. and F.H.M. Semazzi, 2004: Variability of the recent climate of eastern Africa. *Int. J. Climatol*., **24**, 681-701.

Schreider, G. and B. Knerr, 2000: Labor migration as a social security mechanism for smallholder households in sub-Saharan Africa: the case of Cameroon. *Oxford Development Studies*, **28**, 223-236.

Schulze, R., J. Meigh and M. Horan, 2001: Present and potential future vulnerability of eastern and southern Africa's hydrology and water resources. *S. Afr. J. Sci*., **97**, 150-160.

Schwind, K., 2005: Going local on a global scale: rethinking food trade in the era of climate change, dumping and rural poverty. *BackGrounder*, **11**, 1-4.

Scoones, I., 2005: Governing technology development: challenges for agricultural research in Africa. *IDS Bull*., **36**, 109-114.

Scoones, I., S. Devereux and L. Haddad, 2005: Introduction: New directions for African agriculture. *IDS Bull*., **36**, 1-12.

Seck, M., M.N.A. Mamouda and S. Wade, 2005: Case Study 4: Adaptation and mitigation through "produced environments": the case for agriculture intensification in Senegal. *IDS Bull*., **36**, 71-86.

Semazzi, F.H.M. and Y. Song, 2001: A GCM study of climate change induced by deforestation in Africa. *Climate Res*., **17**, 169-182.

Seo, S.N. and R. Mendelsohn, 2006a: Climate change impacts on animal husbandry in Africa: a Ricardian analysis. Centre for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No. 9, University of Pretoria, Pretoria, 42 pp.

Seo, S.N. and R. Mendelsohn, 2006b: Climate change adaptation in Africa: a microeconomic analysis of livestock choice. Centre for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No.19, University of Pretoria, Pretoria, 37 pp.

Simmons, R.E., P. Barnard, W.R.J. Dean, G.F. Midgley, W. Thuiller and G. Hughes, 2004: Climate change and birds: perspectives and prospects from southern Africa. *Ostrich: Journal of African Ornithology*, **75**, 295-308.

Slingo, J.M., A.J. Challinor, B.J. Hoskins and T.R. Wheeler, 2005: Introduction: food crops in a changing climate. *Philos. T. Roy. Soc. B*, **360**, 1983-1989.

Sokona, Y. and F. Denton, 2001: Climate change impacts: can Africa cope with the challenges? *Clim. Policy*, **1**, 117-123.

St-Pierre, N.R., B. Cobanov and G. Schnitkey, 2003: Economic losses from heat stress by US livestock industries. *J. Dairy Sci*., **86**, 52-77.

State of Eritrea, 2001: *Eritrea's Initial National Communication under the United Nations Framework Convention on Climate Change (UNFCCC)*. Ministry of Land, Water and Environment, Asmara, 99 pp. http://unfccc.int/resource/docs/natc/erinc1.pdf.

Stern, N., 2007: *The Economics of Climate Change: The Stern Review*. Cambridge University Press, Cambridge, 692 pp.

Stige, L.C., J. Stave, K.S. Chan, L. Ciannelli, N. Pretorelli, M. Glantz, H.R. Herren and N.C. Stenseth, 2006: The effect of climate variation on agro-pastoral production in Africa. *P. Natl. Acad. Sci. USA*, **103**, 3049-3053.

Strzepek, K. and A. McCluskey, 2006: District level hydro-climatic time series and scenario analysis to assess the impacts of climate change on regional water resources and agriculture in Africa. Centre for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No.13, University of Pretoria, Pretoria, 59 pp.

Sultan, B., K. Labadi, J.F. Guégan and S. Janicot, 2005: Climate drives the meningitis epidemics onset in West Africa. *PLoS Med*., **2**, 43-49. http://medicine.plosjournals.org/archive/1549-1676/2/1/pdf/10.1371_ journal.pmed.0020006-S.pdf.

Swaminathan, M.S., 2000: Climate change and food security. *Climate Change and Development*, L. Gomez-Echeverri, Ed., UNDP Regional Bureau for Latin America and the Caribbean and Yale School of Forestry and Environmental Studies, 103-114. http://environment.yale.edu/doc/786/climate_change_and_development/.

Swart, R., J. Mitchell, T. Morita and S. Raper, 2002: Stabilisation scenarios for climate impacts assessment. *Global Environ. Chang*., **12**, 155-165.

Tadross, M.A., B.C. Hewitson and M.T. Usman, 2005a: The interannual variability of the onset of the maize growing season over South Africa and Zimbabwe. *J. Climate*, **18**, 3356-3372.

Tadross, M., C. Jack and B. Hewitson, 2005b: On RCM-based projections of change in southern African summer climate. *Geophys. Res. Lett*., **32**, L23713, doi:10.1029/2005GL024460.

Tanser, F.C., B. Sharp and D. le Sueur, 2003: Potential effect of climate change on malaria transmission in Africa. *Lancet*, **362**, 1792-1798.

Tarhule, A. and P.J. Lamb, 2003: Climate research and seasonal forecasting for West Africans: perceptions, dissemination, and use? *B. Am. Meteorol. Soc*., **84**, 1741-1759.

ter Kuile, F.O., M.E. Parise, F.H. Verhoeff, V. Udhayakumar, R.D. Newman, A.M. van Eijk, S.J. Rogerson and R.W. Steketee, 2004: The burden of co-infection with human immunodeficiency virus type 1 and malaria in pregnant women in sub-Saharan Africa. *Am. J. Trop. Med. Hyg*., **71**, 41-54.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira and Co-authors, 2004: Extinction from climate change. *Nature*, **427**, 145-148.

Thomas, D.S.G. and C. Twyman, 2005: Equity and justice in climate change adaptation amongst natural-resource-dependent societies. *Global Environ. Chang*., **15**, 115-124.

Thomas, D.S.G., M. Knight and G.F.S. Wiggs, 2005: Remobilization of southern African desert dune systems by twenty-first century global warming. *Nature*, **435**, 1218-1221.

Thompson, L.G., E. Mosley-Thompson, M.E. Davis, K.A. Henderson, H.H. Brecher, V.S. Zagorodnov, T.A. Mashiotta, P.N. Lin and Co-authors, 2002: Kilimanjaro ice core records: evidence of Holocene change in tropical Africa. *Science*, **298**, 589-593.

Thomson, M.C., F.J. Doblas-Reyes, S.J. Mason, R. Hagedorn, S.J. Connor, T. Phindela, A.P. Morse and T.N. Plamer, 2006: Malaria early warnings based on seasonal climate forecasts from multi-model ensembles. *Nature*, **439**, 576-579.

Thornton, P.K., R.H. Fawcett, K.A. Galvin, R.B. Boone, J.W. Hudson and C.H. Vogel, 2004: Evaluating management options that use climate forecasts: modelling livestock production systems in the semi-arid zone of South Africa. *Climate Res*., **26**, 33-42.

Thornton, P.K., P.G. Jones, T.M. Owiyo, R.L. Kruska, M. Herero, P. Kristjanson, A. Notenbaert, N. Bekele and Co-authors, 2006: Mapping Climate Vulnerability and Poverty in Africa. Report to the Department for International Development, ILRI, Nairobi, 200 pp.

Thuiller, W., O. Broennimann, G. Hughes, J.R.M. Alkemade, G.F. Midgley and F. Corsi, 2006: Vulnerability of African mammals to anthropogenic climate change under conservative land transformation assumptions. *Glob. Change Biol*., **12**, 424-440.

Tiffen, M., 2003: Transition in sub-Saharan Africa: agriculture, urbanization and income growth. *World Dev*., **31**, 1343-1366.

Tol, R.S.J., B. O'Neill and D.P. van Vuuren, 2005: A critical assessment of the IPCC SRES scenarios. http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/ensemblessres.pdf.

Toulmin, C., R. Leonard, K. Brock, N. Coulibaly, G. Carswell and D. Dea, 2000: Diversification of livelihoods: evidence from Mali and Ethiopia. Research Report 47, Institute of Development Studies, Brighton, 60 pp.

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai, 2007: Observations: Surface and atmospheric climate change. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds., Cambridge University Press, Cambridge, 235-336.

Turner, M., 2003: Environmental science and social causation in the analysis of Sahelian pastoralism. *Political Ecology: An Integrative Approach to Geography and Environment-Development Studies*, K.S. Zimmerer and T.J. Bassett, Eds., Guilford Press, New York, 159-178.

Turpie, J., H. Winkler, R. Spalding-Fecher and G. Midgley, 2002: Economic impacts of climate change in South Africa: a preliminary analysis of unmitigated damage costs. Energy and Development Research Centre, University of Cape Town, Cape Town, 64 pp.

UNAIDS, 2004: 2004 Report on the Global AIDS Epidemic. 4th Global Report, Joint United Nations Programme on HIV/AIDS, Rome, 236 pp. http://www.unaids.org/bangkok2004/report_pdf.html.

UNDP, 2004: *Reducing Disaster Risk: a Challenge for Development*. UNDP Bureau for Crisis Prevention and Recovery, New York, 161 pp. http://www.undp.org/bcpr/disred/documents/publications/rdr/english/rdr_english.pdf.

UNDP, 2005: Human Development Report 2005. United Nations Development Programme, New York, 388 pp. http://hdr.undp.org/reports/global/2005/pdf/HDR05_complete.pdf.

UNEP, 2004: GEO Year Book 2003. The United Nations Environment Programme Global Environmental Outlook Report, 76 pp. http://www.unep.org/geo/yearbook/yb2003/index.htm.

UNEP, 2005: GEO Year BOOK 2004/5. The United Nations Environment Programme Global Environmental Outlook Report, 96 pp. http://www.unep.org/geo/pdfs/GEO%20YEARBOOK%202004%20(ENG).pdf.

UNEP/GRID-Arendal, 2002: Vital Climate Graphics. United Nations Environment Programme, GRID-Arendal, 65 pp. http://grida.no/climate/vital/index.htm.

UNESCO-WWAP, 2006: Water: A Shared Responsibility. United Nations World Water Development Report 2. United Nations Educational, Scientific and Cultural Organisation (UNESCO) and the United Nations World Water Assessment Programme, 601 pp.

UNFPA, 2003: *The Impact of HIV/AIDS: A Population and Development Perspective*. Population and Development Strategies No. 9, United Nations Population Fund, 147 pp.

Union des Comores, 2002: *Communication Nationale Initiale. Convention Cadre des Nations Unies sur les Changements Climatiques*. Ministère du Développement, des Infrastructures, des Postes et Télécommunications et des Transports Internationaux, Moroni, 72 pp.

USAID, 2003: RCSA food security strategic option: synthesis of selected readings. Report prepared by Nathan and Associates for USAID Regional Centre for South Africa, 175 pp.

Usman, M.T. and C.J.C. Reason, 2004: Dry spell frequencies and their variability over southern Africa. *Climate Res*., **26**, 199-211.

Utzinger, J., Y. Tozan, F. Doumani and B.H. Singer, 2001: The economic payoffs of integrated malaria control in the Zambian Copper Belt between 1930 and 1950. *Trop. Med. Int. Health*, **7**, 657-677.

Van Drunen, M.A., R. Lasage and C. Dorland, Eds., 2005: *Climate Change in Developing Countries: An Overview of Study Results from the Netherlands Climate Change Studies Assistance Programme*. CABI Publishing, Amsterdam, 320 pp.

van Jaarsveld, A.S., R. Biggs, R.J. Scholes, E. Bohensky, B. Reyers, T. Lynam, C. Musvoto and C. Fabricius, 2005: Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAfMA) experience. *Philos. T. Roy. Soc. B*, **360**, 425-441.

van Lieshout, M., R.S. Kovats, M.T.J. Livermore and P. Martens, 2004: Climate change and malaria: analysis of the SRES climate and socio-economic scenarios. *Global Environ. Chang*., **14**, 87-99.

Verhagen, A., A.J. Dietz and R. Ruben, 2001: Impact of climate change on water availability, agriculture and food security in semi-arid regions, with special focus on West Africa. Global Change NOP-NRP Report 410200076. Dutch National Institute for Public Health and Environment, Bilthoven, 140 pp.

Vincent, K., 2004: Creating an index of social vulnerability to climate change for Africa. Working Paper 56, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, 50 pp.

Vizy, E.K. and K.H. Cook, 2001: Mechanisms by which Gulf of Guinea and eastern North Atlantic sea surface temperature anomalies influence African rainfall. *J. Climate*, **14**, 795-821.

Vogel, C., 2005: "Seven fat years and seven lean years?" Climate change and agriculture in Africa. *IDS Bull*., **36**, 30-35.

Vörösmarty, C.J., E.M. Douglas, P.A. Green and C. Revenga, 2005: Geospatial indicators of emerging water stress: an application to Africa. *Ambio*, **34**, 230-236.

Wahab, H.M., 2005: The impact of geographical information system on environmental development, unpublished MSc Thesis, Faculty of Agriculture, Al-Azhar University, Cairo, 148 pp.

Wang, G. and E.A.B. Eltahir, 2000: Role of vegetation dynamics in enhancing the low-frequency variability of the Sahel rainfall. *Water Resour. Res*., **36**, 1013-1022.

Wang, G. and E.A.B. Eltahir, 2002: Impact of CO_2 concentration changes on the biosphere-atmosphere system of West Africa. *Glob. Change Biol*., **8**, 1169-1182.

Wang, G., E.A.B. Eltahir, J.A. Foley, D. Pollard and S. Levis, 2004: Decadal variability of rainfall in the Sahel: results from the coupled GENESIS-IBIS atmosphere-biosphere model. *Clim. Dynam*., **22**, 625-637.

Warren, R., N. Arnell, R. Nicholls, P. Levy and J. Price, 2006: Understanding the regional impacts of climate change: research report prepared for the Stern Review on the Economics of Climate Change. Tyndall Centre for Climate Change Research, Working Paper 90, University of East Anglia, Norwich, 223 pp.

Washington, R. and M.C. Todd, 2005: Atmospheric controls on mineral dust emission from the Bodélé depression, Chad: the role of the Low Level Jet. *Geophys. Res. Lett*., **32**, L17701, doi:10.1029/2005GL023597.

Washington, R. and A. Preston, 2006: Extreme wet years over southern Africa: role of Indian Ocean sea surface temperatures. *J. Geophys. Res.– Atmos*., **111**, D15104, doi:10.1029/2005JD006724.

Washington, R., M. Harrison and D. Conway, 2004: African climate report. Report commissioned by the UK Government to review African climate science, policy and options for action, 45 pp.

Washington, R., M. Harrison, D. Conway, E. Black, A. Challinor, D. Grimes, R. Jones, A. Morse and Co-authors, 2006: African climate change: taking the shorter route. *B. Am. Meteorol. Soc*., **87**, 1355-1366.

WHO, 2005: *Using Climate to Predict Infectious Disease Epidemics*. World Health Organization, Geneva, 56 pp. http://www.who.int/entity/globalchange/publications/infectdiseases.pdf.

WHO/UNICEF, 2000: Global water supply and sanitation assessment: 2000 report. World Health Organization, Geneva, 87 pp. http://www.who.int/entity/water_sanitation_health/monitoring/jmp2000.pdf.

World Bank, 2006a: *World Development Indicators*. The International Bank for Reconstruction and Development, The World Bank, Washington, District of Columbia, 242 pp. http://devdata.worldbank.org/wdi2006/.

World Bank, 2006b: *World Development Report, 2006: Equity and Development*. Co-publication of The World Bank, Washington, District of Columbia and Oxford University Press, Oxford, 336 pp.

World Tourism Organization, 2003: *Climate Change and Tourism: Proc. 1st International Conference on Climate Change and Tourism*, Djerba, Tunisia. World Tourism Organization, 55 pp. http://www.world-tourism.org/sustainable/climate/final-report.pdf.

World Tourism Organization, 2005: *Tourism Vision 2020*. World Trade Organisation, Washington, District of Columbia. http://www.world-tourism.org /facts/wtb.html.

World Water Forum, 2000: *The Africa Water Vision for 2025: Equitable and Sustainable Use of Water for Socioeconomic Development*. UN Water/Africa, 34 pp.

Yamin, F., A. Rahman and S. Huq, 2005: Vulnerability, adaptation and climate disasters: a conceptual overview. *IDS Bull*., **36**, 1-14.

Yohe, G. and M. Schlesinger, 2002: The economic geography of the impacts of climate change. *J. Econ. Geogr*., **2**, 311-341.

Yousif, H.M., 2005: Rapid urbanisation in Africa: impacts on housing and urban poverty. , in ECA, 2005, Assessing sustainable development in Africa. *Assessing sustainable development in Africa*, Africa's Sustainable Development Bulletin, Economic Commission for Africa, Addis Ababa, 55-59.

Zeng, N., 2003: Drought in the Sahel. *Science*, **302**, 999-1000.

Zhou, G., N. Minakawa, A.K. Githeko and G. Yan, 2004: Association between climate variability and malaria epidemics in the East African highlands. *P. Natl. Acad. Sci. USA*, **101**, 2375-2380.

Ziervogel, G., 2004: Targeting seasonal climate forecasts for integration into household level decisions: the case of smallholder farmers in Lesotho. *Geogr. J*., **170**, 6-21.

Ziervogel, G. and R. Calder, 2003: Climate variability and rural livelihoods: assessing the impact of seasonal climate forecasts in Lesotho. *Area*, **35**, 403-417.

Ziervogel, G. and T.E. Downing, 2004: Stakeholder networks: improving seasonal forecasts. *Climatic Change*, **65**, 73-101.

Ziervogel, G., M. Bithell, R. Washington and T. Downing, 2005: Agent-based social simulation: a method for assessing the impact of seasonal climate forecast applications among smallholder farmers. *Agr. Syst*., **83**, 1-26.

Ziervogel, G., A.O. Nyong, B. Osman, C. Conde, S. Cortés and T. Downing, 2006: Climate variability and change: implications for household food security. AIACC Working Paper No. 20, 25 pp. http://www.aiaccproject.org/working_papers/Working%20Papers/AIACC_WP_20_Ziervogel.pdf.