Global climate change: climates of the future, choices for the present[1]

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Abstract

Africa is probably the continent that is the most vulnerable to climate change and climate variability, not only because of the dependence of many of its economies on agriculture, which is strongly affected by climate, but also because of the presence of other stresses besides climate change, such as rapid population growth, land degradation, and prevalence of human diseases. Moreover, because of widespread poverty and other factors, it has low adaptive capacity in comparison to other continents. For example, climate change is likely to impact adversely on agricultural production in many areas by shortening growing seasons and reducing rainfall, which will in turn affect food security of the region. Climate change is also expected to exacerbate water shortages faced by some countries already, or to increase the risk of water stress in countries not currently affected. It is also likely to affect its major ecosystems, and indeed, changes are already being detected even faster than anticipated in some southern ecosystems. Sea-level rise is predicted to inundate low-lying lands is some countries, with potentially disastrous impacts on coastal settlements. 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.

Governments in Africa need to make choices now to build the adaptive capacity of the continent's population and ecosystems. The way that land is used is a central question that must be addressed so that there is a balance between the ecosystem services that it provides, including food, fuel, fibre and income, adequate sanitary water, biodiversity and carbon storage. Various adaptive responses for farmers are discussed, and it is concluded that to ensure that the right choices are made, it is necessary to build scientific and technical capacity in the region, and to establish effective institutions to enable practitioners to enact the choices they make.

Introduction

Climate change is widely recognised as the most serious environmental threat facing our planet today, and the major challenge facing society is to find ways to reduce greenhouse gas (GHG) emissions and to adapt to future climates. Africa is one of the most vulnerable regions in the world to climate change not only because of the dependence that economic development of Africa has at regional, national, and household scales on climate, but also because of the wide variation in climates that it has, ranging from humid-equatorial, seasonally arid, tropical, to subtropical Mediterranean.

[1] Keynote paper presented at African Technology Policy Studies Conference "Science, Technology and Climate Change Adaptation in Africa", 19-22 November 2007, Johannesburg, South Africa.

Climate change only adds to the already complex problems facing the continent. At 1.9% per annum growth rate, the population is expanding rapidly, creating pressure on its natural resources and fragile environments. A large number of this population suffers extreme poverty – the proportion of people living below the poverty line increased from 47.6% in 1985 to 59% in 2000 (UNECA, 2004), with some 313 million people living on less than US$1 per day in 2005 (UNEP, 2007). Land degradation is the overarching environmental issue of concern, affecting some 5 million km^2 of land in 1990, and contributing to loss of livelihoods (Oldeman *et al.*, 1991). Poverty is both a cause and a consequence of land degradation, creating a vicious cycle: poor people are forced to put immediate needs before the long-term quality of the land, while degraded farmland and poor yields contribute to food and income insecurity. As a result, per capita food production in Africa has declined by 12% since 1981. In addition, land degradation has widespread effects on Africa's river catchments, forests, the expansion of deserts, and adversely affects ecosystem services.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. Its Fourth Assessment Report (AR4) was completed early this year (2007). In this paper we summarise some of the main findings of the IPCC AR4, as well as drawing on other literature, in relation to global climate trends, the implications of these trends for African climates, the impacts of climate change in Africa for its agriculture, food security, ecosystems, water resources, and human health, and consider some of the choices that may have to be made in the near future to adapt to these impacts.

Global trends and implications for Africa

Global trends

Greenhouse gases

Since 1750, there have been marked increases in the global atmospheric concentrations of the greenhouse gases (GHGs) carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) as a result of human activities. These concentrations now far exceed pre-industrial values determined from ice cores spanning many thousands of years, with CO_2 having risen from a pre-industrial value of about 280 ppm to 379 ppm in 2005 (+35%), CH_4 from 715 ppb to 1774 ppb (+148%), and N_2O from about 270 ppb to 319 ppb (+18%) (IPCC, 2007). The global increases in CO_2 concentration are due primarily to fossil fuel use and land use change, while those of CH_4 and N_2O are primarily due to agriculture. These three GHGs together result in a radiative forcing of +2.3 W m^{-2} (IPCC, 2007).

Temperature

There is a general consensus that this radiative forcing is responsible for much of the rise in global mean temperatures of 0.76°C from 1850-1899 to 2001-2005. The average atmospheric water vapour content has also increased since at least the 1980s over land and ocean as well as in the upper troposphere, which is consistent with the higher saturated water vapour pressure of warmer air.

Calculations show that more than 80% of the heat being added to the climate system is being absorbed by the ocean – indeed, measurements since 1961 indicate that the average temperature of the world's oceans has increased down to depths of at least 3000 m. This warming causes seawater to expand, contributing to sea level rise – global average sea level rose at an average rate of 1.8 mm y^{-1} over the period 1961 to 2003, but was even higher at 3.1 mm y^{-1} over the last decade of this period. The increased temperatures have also brought about a decline in mountain glaciers, snow cover and ice caps in both the north and south hemispheres, which has also contributed to the rise in sea level. It is noteworthy that the last time the polar regions were significantly warmer than present for an extended period was about 125,000 years ago, when the sea level rose 4-6 m.

Most model simulations indicate that sustained radiative forcing following a doubling of CO_2 concentrations will increase global average surface temperatures by between 2 °C to 4.5 °C, with a best estimate of about 3 °C. Under most of the scenarios used for climate change studies, a warming of about 0.2 °C per decade is projected for the next two decades. However, what is worrying is that even if the concentrations of all GHGs and aerosols are kept constant at the levels they were in the year 2000, a further warming of about 0.1 °C per decade and associated sea level rise would still occur for centuries due to the time scales associated with climate processes and feedbacks. On the other hand, if GHG emissions remain at, or even increase above current rates, then the changes in the global climate system during the 21st century would probably be even larger than those observed during the 20th century.

Precipitation

Long-term datasets from 1900 to 2005 have shown significantly increased precipitation in eastern parts of North and South America, northern Europe, and northern and central Asia. The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour. On the other hand, decreases in precipitation have been observed in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia, which together with increased temperatures since the 1970s, have resulted in more intense and longer droughts, particularly in the tropics and subtropics. Changes in sea surface temperatures, wind patterns and decreased snow-pack and snow cover have also been linked to droughts.

Model simulations of future climates predict that further increases in the amount of precipitation are very likely in high latitudes, while further decreases are likely in most subtropical land regions (possibly by as much as 20% in the A1B scenario in 2100), continuing observed patterns in recent trends.

Climate trends in Africa

Africa's climate 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 (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.

Temperature

Observed temperatures have shown a general warming trend since the 1960s, particularly in the last few years. However, these changes have not always been uniform – for example, decadal warming rates of 0.3 °C were measured in the tropical forests (Malhi & Wright, 2004) but varied between 0.1–0.3 °C in South Africa (Kruger & Shongwe, 2004). In some cases even, decreasing trends in temperature have been measured close to the coast or to major inland lakes in eastern Africa (King'uyu *et al.*, 2000).

Depending on the scenario used, annual mean surface air temperature for the period 2080-2099 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), although temperature increases of up to 9 °C in some parts of Africa under some scenarios are predicted (e.g. summer in north Africa). These predictions, however, depend on vegetation dynamics – if vegetation density were to increase, then warming may be offset by 0.8°C yr^{-1}, but if current trends in land cover conversion were to continue, which is more likely, then warming may increase even more (Bounoua *et al.*, 2000). Warming could also be slowed if atmospheric CO_2 concentration is stabilised (Arnell *et al.*, 2002).

Precipitation

Trends in precipitation are less clear than for temperature, not least because of the high spatial and temporal variability across Africa. Declines of 20-40% in annual rainfall have been observed in West Africa since 1931 (e.g. Nicholson *et al.*, 2000), and of 2-4% for the period 1960 to 1998 in the tropical rain-forest zone (e.g. Malhi & Wright, 2004). On the other hand, an increase in annual rainfall along the Guinean coast has also been observed during the last 30 years (Nicholson *et al.*, 2000), while in other regions, such as southern Africa, no long-term trend has been noted. There is some evidence that rainfall is increasing in the northern part of the continent, but declining in the southern part (Schreck & Semazzi, 2004). In many parts, increased inter-annual variability has been observed in the post-1970 period, with higher rainfall anomalies and more intense and widespread droughts reported (Richard *et al.*, 2001).

Predictions of rainfall in future climates vary widely between models, mainly because of their inability to reproduce the mechanisms of precipitation, the influence of topography, and feedback mechanisms. Other limitations include lack of information on dust aerosol concentrations, sea-surface temperature anomalies, deforestation, and soil moisture. All of these influence rainfall and runoff to varying degrees depending on the location, but 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). Despite all these problems, studies have predicted that, under the SRES A1B emissions scenario, mean annual rainfall is very likely to decrease by 20% in northern Africa by the end of the century, to increase by around +7% in tropical and eastern Africa, but that drier winters in much of southern Africa will be drier (Christensen *et al.*, 2007). 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 & Crane, 2006). There is less model agreement for the western Sahel region, with some projecting a significant drying (e.g. Hulme *et al.*, 2001) and others simulating a progressive wetting (Brovkin, 2002). Land-use changes and degradation, which are not simulated by some models, could contribute to decreases in rainfall (e.g. Huntingford *et al.*, 2005).

Extreme events

One-third of Africa's population live in drought-prone areas and are vulnerable to the impacts of droughts, particularly as these impacts are often accompanied by diseases such as diarrhoea, cholera and malaria (Few *et al.*, 2004). Since the end of the 1960s, droughts have mainly affected the Sahel, the Horn of Africa, and southern Africa (e.g. Trenberth *et al.*, 2007). During the mid-1980s the economic losses from droughts in Africa were calculated to be several hundred million US dollars (Tarhule & Lamb, 2003). At the other extreme, floods also cause large economic and human losses (e.g. in Mozambique – see Mirza, 2003). Recurrent floods in some countries may be linked with ENSO events, but even countries located in dry areas (e.g. Algeria, Tunisia, Egypt, Somalia) have also experienced serious flooding (Kabat *et al.*, 2002).

Model simulations predict that the number of extremely dry and wet years for the Sahel region will increase over the next 100 years (e.g. Huntingford *et al.*, 2005). Other simulations indicate that by the end of the 21st century, there could also be more frequent and intense tropical storms in the southern Indian Ocean due to an increase in sea surface temperatures (e.g. McDonald *et al.*, 2005).

Climate change, food security and African agriculture

Agricultural systems

The total land area of Africa is about 30 million km^2, of which nearly 9 million km^2 is suitable for agriculture (UNEP, 2007). Roughly 70% of the population of Africa is dependent on agriculture, which contributes about one-third of the overall GDP (Mendelsohn *et al.*, 2000) and 40% of all exports (Irwin & Ranganathan, 2007). In particular, crop production and livestock husbandry account for about half of household income. Most of African agriculture is rain-fed, and therefore is highly vulnerable to changes in climate variability, seasonal shifts, and precipitation patterns – for example, during El Niño events, prolonged droughts and/or floods are often particularly severe (Mendelsohn *et al.*, 2000). Where irrigation systems do exist, they are often inefficient (UNEP, 2004). These problems are often exacerbated by other constraints such as poor soil fertility, pests, crop diseases, and a lack of access to inputs and improved seeds. In many countries, macro-level processes such as globalization and accompanying structural adjustments involving market reforms and market liberalization have also added to people's vulnerability, particularly in the agricultural sector (UNDP, 2005). Rises in the price of fertiliser due to removal of subsidies, for example, have sometimes resulted in a move back to traditional forms of agriculture (e.g. Matthews *et al.*, 1992). Indeed, average per capita agricultural production in Africa declined by 0.4% between 2000 and 2004 (UNEP, 2007).

Assessing future trends in agricultural production in Africa, even without climate change, is difficult because of climate variability and other factors (Mendelsohn *et al.*, 2000). However, while agriculture is likely to remain a key source of income for many Africans, there are trends in some areas for increasing off-farm incomes, particularly in areas near large urban centres – up to 80% of total incomes in some cases (Bryceson, 2002). This may reduce the vulnerability of such people to climate change to some extent.

Crops

While most of the developing world experienced significant increases in crop yields resulting from the development of high-yielding varieties (HYVs) and increased use of fertilisers and irrigation during the Green Revolution in the 1970s through to the 1990s, Africa's uptake of HYVs was extremely low (Sachs et al., 2004). Consequently it has lagged behind in terms of technological advances in the area of agriculture.

On top of this, projected changes in climate are likely to severely affect agricultural production in many African countries (UNEP, 2007). Increased temperatures and accompanying decreases in water availability are predicted to reduce the length of growing seasons and yield potential, and hence the area suitable for agriculture, particularly along the margins of semi-arid and arid areas, further adversely affecting food security over the continent (Thornton *et al.*, 2006). For example, by 2100, losses of between 2-7% of GDP are likely in parts of the Sahara, 2-4% in western and central Africa, and 0.4-1.3% in northern and southern Africa (Mendelsohn *et al.*, 2000). In some countries, yields from rain-fed agriculture could be reduced by up to 50% (Boko *et al.*, 2007). Using the FAO/IIASA Agro- Ecological Zones model (AEZ), Fischer *et al.* (2005) showed that there would be a significant decrease in suitable rain-fed land extent and production potential for cereals is estimated by the 2080s, with an increase of 60-90 million hectares of arid and semi-arid land in Africa. Wheat production, in particular, was predicted to disappear from Africa by the 2080s. Other studies have indicated that maize production in southern Africa is likely to be significantly reduced (Stige *et al.*, 2006). In Egypt, climate change was predicted to 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).

However, not all changes in climate and climate variability will necessarily have negative impacts. Thornton *et al.* (2006), for example, found that 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. For mild climate scenarios, both irrigated croplands and dryland farms in some areas were predicted to benefit.

Livestock

A study by Seo & Mendelsohn (2006) indicated that small livestock farms are likely to benefit from warming, but large livestock farms are likely to suffer, mainly because the former tend to use goats and sheep for which temperature tolerant breeds exist, whereas the latter tend to use cattle, which are not so temperature tolerant. They showed that a warming of 2.5°C could increase the income of small livestock farms by 26% (+US$1.4 billion), but would be likely to decrease the income of large livestock farms by 22% (–US$13 billion). However, increased precipitation of 14% would be likely to reduce the income of small livestock farms by 10% (–US$ 0.6 billion), mostly due to a reduction in the number of animals kept, and 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. This was because increased rainfall implied a shift from grassland to forests and an increase in harmful disease vectors, and also a shift from livestock to crops.

Fisheries

Fishing, fish farming, and fish processing and trade are important source of revenue, employment and proteins in Africa, with an estimated 10 million people depending on them in some way or another (UNEP, 2007). Around 7.3 million tonnes of fish are produced each year, 90% of which is caught by small-scale fishermen. Exports of fish from Africa were worth US$2.7 billion in 2005.

Studies have indicated that rising temperatures of around 1.5 to 2.0°C will adversely affect fisheries in north west Africa and the East African lakes (Christensen *et al.*, 2007). 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 inland fisheries or aquaculture (Cury & Shannon, 2004). Clark (2006) concluded that fisheries in South Africa could be affected by changes in estuaries, coral reefs and upwelling, and 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.

Biofuels

There is currently considerable interest in the growing of biofuel crops such as maize and sugar cane to produce bioethanol and biodiesel to offset the use of fossil fuels in transport and industry. It is also 'carbon neutral' – the CO_2 released when it is used is captured from the atmosphere only a year or two previously. The goal in the USA is to meet 25% of its energy needs from biofuels by the year 2025 compared to the 4% at the moment, while Europe has a target to increase the share of biofuels used in transport to 10% by 2020. This has created considerable demand worldwide, with the result that the prices of maize and other feedstocks have soared - the price of maize is up 80% compared to a year ago. While countries such as Brazil have been producing biofuels from sugar cane for years, many countries in Africa, are now expanding its areas to capitalise on the worldwide boom.

However, the growing of biofuels has its downsides. Firstly, because it takes land away from food production, it has caused a knock-on effect on prices of food both for humans and animals – wheat prices, for example, have tripled in the last year. Earlier in 2007, there were large protests in Mexico against the doubling of tortilla prices which were blamed on the demand for ethanol. Secondly, bioethanol production may also not be as green as it is promoted – large amounts of fertiliser and fossil fuels are still used in its production, and a recent study indicated that the amount of CO_2 released into the atmosphere from production to consumption is only 13% less than consuming fossil fuels only (Farrell *et al.*, 2007). Thirdly, there are also likely to be knock-on effects on other ecosystem services also – there is concern that tropical forests will be cleared to make way for biofuel crops, such as palm oil or maize, and that this may result in net increases in the amount of emissions into the atmosphere, destroying large numbers of species, and disrupting the evapotranspiration feedback that forests provide to seed rainfall, thereby affecting local climate. Fourthly, as land is more-or-less a fixed resource, if it is used for fuel production, it necessarily means that there is less for other uses, such as food production, forestry, biodiversity conservation, flood risk management, and so on. A recent study by a group in Austria (Haberl *et al.*, 2007), for example, calculated that global food needs can probably be met from existing land use if agriculture is intensified, but if some of this land is used for growing fuel, then this will not be possible.

Climate change, biodiversity loss and fragile ecosystems

Ecosystem services

Ecosystems are critical in Africa, contributing significantly to biodiversity and human well-being through the provision of *ecosystem services* (Biggs et al., 2004). These have been divided into four categories – *provisioning* (e.g. food, fibre, fuel, water), *regulating* (e.g. water quality, flood and erosion control, carbon sequestration), *cultural* (e.g. recreation, aesthetic and spiritual values), and *supporting services* (e.g. carbon, water, nutrient cycling) (Irwin & Ranganathan, 2007). The Millennium Ecosystem Assessment Report highlighted the serious decline of 15 out of 24 of the world's major ecosystems, which may adversely affect the provision of ecosystem services for the welfare of future generations.

Climate change may impact on ecosystems directly, or through human activities as they respond to climate change, either through their attempts at mitigation, or through adaptation. Examples of the first of these include the effect of increased temperatures and changes in rainfall on the distribution of species and possible shifts in their geographical location, or on ecosystem processes such as mineralization of soil organic carbon, and hence soil fertility. A range of impacts on terrestrial and aquatic ecosystems has been suggested under climate change (e.g. Leemans & Eickhout, 2004). Examples of impacts through human responses include the impact of land cover change from forest to growing biofuel crops such as maize or sugar cane to reduce dependence on fossil fuels, as discussed above.

However, it is important to recognise that changes in ecosystems are not only due to climate change, and that there are many other drivers interacting with one another. These include fire, invasive species and land-use change (Muriuki *et al.*, 2005). Changes in the range of plant and animal species, for example, are already occurring because of forest fires destroying ‘cloud forests’ on Kilimanjaro (Agrawala, 2005).

Biodiversity

Africa takes up about 20% of the earth’s land surface, and also contains about 20% of all known species of plants, mammals, and birds in the world, as well as one-sixth of amphibians and reptiles (Siegfried, 1989). There are several unique native environments – the *fynbos* ecosystem at the southern tip of Africa, for example, has 7,300 plant species, 68% of which are unique to the region (Gibbs, 1987). Other important floral regions include Madagascar, the mountains of Cameroon, and the *afromontane* habitats that stretch from Ethiopia to South Africa at altitudes above about 2000 m (Mace *et al.*, 1998).

Biodiversity in one form or another plays an vital role for many African economies, including consumptive uses such as food, fuel, fibre, shelter, medicine, and income through wildlife trade, and nonconsumptive uses such as tourism (UNEP, 2007). Hence, many communities will be vulnerable to the biodiversity loss that could result from climate change. Many of these ecosystems mention above would be threatened by a shift in rainfall seasonality – for example, a reduction in winter rainfall or an increase in summer rainfall would alter the fire regime that is critical to the life cycle of many *fynbos* species. One study has predicted that 10-15% of species would fall within the IUCN Critically Endangered or Extinct categories by 2050, increasing to 25-40% by 2080, assuming no migration (Thuiller *et al.*, 2006). If it was assumed that migration would take place, losses would be less extreme, with these proportions dropping to approximately 10-20% by 2080. Given that not all species will be able to migrate, the true figure is likely to be between these two extremes. Montane habitats, for example, are particularly threatened by increases in temperature because many contain isolated plant populations with no possibility of migration.

Mountain ecosystems

Mountain ecosystems appear to be undergoing significant observed changes, aspects of which are likely to be linked to both climate change and complex climate-land interactions between solar radiation, micro-scale processes, glaciers, and vegetation (Kaser *et al.*, 2004). For example, it is thought that the observed glacier retreat on Kilimanjaro is partly due to a drop in atmospheric moisture content at the end of the 19th century (Kaser *et al.*, 2004). However, there is considerable evidence from around the word that global warming is also contributing to glacier retreat, and at current rates, the ice cap on Mount Kilimanjaro could disappear by 2020 for the first time in 11,000 years (Thompson *et al.*, 2002).

Desert ecosystems

Africa contains three large deserts: the Sahara, Kalahari, and Namib, which together comprise more than a quarter of the continent. The Sahara is the largest desert in the world, and spans eleven African countries. The area along the desert margins, which occupies about 5% of Africa’s land, is at the highest risk of desertification (Reich *et al.*, 2001), the main areas being in the Sudano-Sahelian region and southern Africa, with some even in the usually wet tropical zones of Central and Eastern Africa. Areas particularly at risk include the Sahel, a strip of semi-arid land running along the southern margin of the Sahara Desert, where the long-term decline in rainfall from 1970-1990 caused a 25-35 km southward shift of the Sahelian, Sudanese and Guinean ecological zones (Gonzalez, 2001). This has resulted in a loss of grassland and acacia, the loss of flora/fauna, and shifting sand-dunes in the region.

Tropical forest ecosystems

Forest land covers 6.4 million km^2 of Africa, representing 16% of global forest cover (UNEP, 2007), and about 21% of the total land area of the continent. Tropical forest ecosystems are vulnerable to changes in temperature and rainfall in the long term, although if disturbance regimes such as drought, insects and fire cross critical thresholds, their vulnerability may be more immediate. Some studies have indicated that there will be movement of tropical forest ecosystems as their minimum climatic requirements change (Lucht *et al.*, 2006). There is also some evidence from recently observed climatic changes that carbon sequestration is possibly enhanced in tropical forests (Malhi & Phillips, 2004), provided these are not offset by water limitations, deforestation or fire regimes.

Changes in forest ecosystems will have a significant feedback effect on global and local climate processes and hence climate change and variability (Christensen *et al.*, 2007). The cooling effect of an increase in vegetation density has already been mentioned above. Deforestation, land-cover change, and changes in atmospheric dust loadings also all affect the variability of climate, particularly in relation to drought (Wang & Eltahir, 2000). Africa currently has the highest deforestation rate in the world, losing an estimated 40,000 km^2, or 0.62%, of its forests annually, compared to the global average deforestation rate of 0.18% (FAO, 2005). As a result, natural forests are being replaced by extensive areas of secondary forests, grasslands, and degraded lands. It is estimated that, by the 2080s, the proportion of arid and semi-arid lands in Africa is likely to increase by 5-8%. A major driver of deforestation is conversion of tropical forests to agriculture by burning – an estimated 70% of detected forest fires occur in the tropics, with 50% of them being in Africa. A second major driver of deforestation in many areas is the demand for fuelwood and charcoal as sources of energy – 80% of the overall African population relies primarily on biomass to meet its energy needs. This demand is only likely to increase with increasing population and urbanisation compounded by volatile oil prices.

Coastal ecosystems

The main coastal ecosystems in Africa, mangroves and coral reefs, including species associated with them such as manatees, marine turtles and migratory birds, are likely to be affected to some extent by climate change. (Boko *et al.*, 2007). Sea-level rise could also mean that mangroves colonise coastal lagoons (Rocha *et al.*, 2005), and estuaries suffer from inundation of salt marshes (Clark, 2006).

The potential impact of ocean warming on coral reefs was highlighted by the coral bleaching observed in the Indian Ocean and Red Sea following the 1997/1998 extreme El Niño, with over 50% mortality in some regions (Spalding *et al.*, 2001). Warming, coupled to other threats such as sedimentation, pollution and over-fishing, could lead to the disappearance of low-lying corals and the biodiversity associated with them. On the other hand, there may be an increase in less desirable species – for example, there have been recent outbreaks of the 'crown-of-thorns' starfish in Egypt and neighbouring countries (Kotb *et al.*, 2004), and algae and dinoflagellates can proliferate in warmer waters, increasing the risk of people being affected by toxins such as ciguatera when they eat seafood. In the long term, these impacts will adversely affect fisheries and tourism.

Climate change, water scarcity and environmental sustainability

Impact on water resources

The impacts of projected changes in temperature, precipitation and sea levels will have varying consequences on the availability of freshwater around the world, especially in Africa. Currently, one third of the African population live in drought prone areas, mainly in the Sahel and Southern Africa (Brooks, 2004), and about 25% experience high water stress. With the present population trends and patterns of water use, many African countries will exceed the limits of their economically usable water resources before 2025, with an estimated 480 million of people then facing either water scarcity or stress, even in the absence of climate change (Ashton, 2002). This potentially may lead to an increase of water conflicts. However, as discussed above, the impact of climate change on water resources across the continent will not be uniform because of the high inter-annual and multi-decadal variability in rainfall.

Stream flows are likely to be influenced by climate variability, increasing during rainstorms and decreasing during dry periods. It also changes during different seasons of the year, decreasing during the summer months when evaporation rates are higher and shoreline vegetation is actively growing and removing water from the ground. The possible range of Africa-wide climate change impacts on stream flow is predicted to increase significantly between 2050 and 2100, from -15% to + 5% above the 1961-1990 baseline in 2050 , rising to -19% to +14% in 2100 (Strzepek & McCluskey, 2006). Changes in runoff and hydrology are also linked to climate through their complex interactions (e.g. de Wit & Stankiewicz, 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.

In terms of lake levels, observations since the 1960s in Lakes Tanganyika, Victoria and Turkana have shown interannual lake-level fluctuations, which are probably due to periods of intense drought followed by increases in rainfall and extreme rainfall events. For example, Lakes Victoria, Tanganyika, and Malawi rose respectively by about 1.7 m, 2.1 m, and 1.8 m in the year following the 1997 flood, and very high river-flows were recorded in the Congo River at Kinshasha (Conway, 2005).

Issues that affect access to water, including water governance, also need to be considered in any discussion of vulnerability to water stress in Africa. Water access and water resource management are highly variable across the continent (Ashton, 2002). Even for the 69% of the population who live in areas where water is relatively abundant, water quality may be an issue – lack of access to clean drinking water and sanitation 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 (Vörösmarty *et al.*, 2005). The complex interactions between over-fishing, industrial pollution and sedimentation etc. degrade local water sources (Odada *et al.*, 2004). Population changes, land-use changes and domestic growth strategies are also important in water management decision-making in addition to climate change (Conway, 2005).

Impact on environmental sustainability

Increasing frequency of droughts and floods associated with climate variability could have a negative impact on the sustainability of environment and ecosystems. Some countries can even experience drought and floods in the same year – in 2006, for example, flooding in East Africa was followed by periods of extended drought, while in Ethiopia drought in the early part of the year was followed by floods later. Incidence of floods and droughts often have a direct impact on food security and environmental sustainability.

As already discussed, increasing sea levels, another major impact of climate change, threaten the sustainability of many coastal and marine ecosystems with wider implications on social and economic sectors. Increasing sea levels may result in reduced productivity of coastal fisheries; mass migration of population from the coast; salt water intrusion; loss of recreational beach facilities with negative impacts on tourism and loss of coastal infrastructure such as ports. Sea levels around Africa are projected to rise by 15-95 cm by the year 2100 (IPCC, 2001). Sea level rise threatens lagoons and mangrove forests in Africa and has an impact on urban centres and ports, such as Cape Town, Maputo, and Dar Es-Salaam. Intrusion of saltwater will affect freshwater quality and the health of freshwater fish. Increasing damage to coral reef systems may have far-reaching implications for fisheries, food security and tourism (Spalding *et al.*, 2001). Some reports show that a 1 m rise in sea level in the Atlantic Ocean may have catastrophic impacts on large coastal cities such as Banjul (Gambia), part of Lagos (Nigeria) and Alexandria (Egypt). The cost of adaptation to avoid this , however, may put a heavy burden on countries' GDPs (Nicholls & Tol, 2006).

Climate change and human health

Africa is already facing a fall in life expectancy due to HIV/AIDS that affects more than 20% of the adult population in some countries. Under-five mortality is also an issue since fourteen countries in Africa have their current rate higher than those observed in 1990.

More than in other continents, the health effects of climate change are unequally distributed, and are particularly severe in countries with already high disease burdens such as sub-Saharan Africa. There are expected to be some benefits to health, including fewer deaths due to exposure to the cold and reductions in climate suitability for vector-borne diseases in some regions. However, the projected health impacts of climate change are predominately negative, with the most severe impacts being seen in low-income countries, where the capacity to adapt is weakest.

Generally, climate change effects on human health can be classified into two categories: direct effects concerning non-infectious health problems, resulting mainly from exposure to extreme weather; and indirect effects through influences on the levels of pollution in the air, on the agricultural, marine and freshwater systems that provide food and water, and on the vectors and pathogens that cause infectious diseases. In the latter, infectious agents (such as protozoa, bacteria and viruses) and their associated vector organisms (such as mosquitoes, ticks and sandflies) lack thermostatic mechanisms, and reproduction and survival rates are thus strongly affected by fluctuations in temperature (Patz *et al.*, 2005).

Direct health effects

The 2003 heat wave in Europe is the most striking recent example of health risks directly resulting from temperature change. Exposure to both extreme hot and cold weather is associated with increased morbidity and mortality. Heat mortality follows a J-shaped function with a steeper slope at higher temperatures. Although most studies to date show clear vulnerability to heat in cooler temperate regions, there is some evidence that sub-tropical regions may well show a similar sensitivity as location-specific temperature rise (e.g. Sao-Paulo, Brazil), and possibly also tropical regions.

Effects on infectious diseases

Malaria and other mosquito-borne diseases

There is widespread acceptance that malaria, one of the world most serious and complex health problems, will be very likely affected by climate change. However, the effects are diversely estimated. The IPCC 4th Assessment Report mentions many short term effects of drought on the increase in the outbreak of these infectious diseases. A reduction in mosquito activity during drought would increase the population of non immune persons, resulting in a much larger proportion of susceptible hosts to become infected, thus potentially increasing transmissions. Droughts may also favour increases in mosquito populations due to reduction in mosquito predators. Stagnation and contamination of drainage canals and small rivers is mentioned as another drought-related factor that would increase the risk of infection. Similarly, 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).

On the other hand, the report states that in the long term, the incidence of mosquito-borne diseases such as malaria may decrease because the mosquito vector lacks the necessary humidity and water for breeding. Examples of Senegal and Niger are given where malaria has decreased in association with long-term decreases in annual rainfall. However, despite the known causal link between climate and malaria transmission dynamics, there is still much uncertainty about the potential impact of climate change on malaria at local and global scales, because of the paucity of concurrent detailed historical observations of climate and malaria, the complexity of malaria disease dynamics, and the importance of non-climatic factors, including socio-economic development, immunity and drug resistance, in determining infection and infection outcomes.

Water-related diseases

Water-related diseases such as diarrhoea already cause high childhood mortality in low-income countries. Climate variability and climate extremes may also affect infant mortality through diseases related to contaminated or insufficient water, although the extent of this has not been quantified. Likewise, cholera outbreaks are often associated with flood events and faecal contamination of the water supplies.

HIV/AIDS

There are very few studies about the climate change impacts on 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. The IPCC 4th Assessment Report reports a study in southern Africa, suggesting that HIV/AIDS amplifies the effect of drought on nutrition. But the key factor so far identified as linking climate change and HIV/AIDS is migration. Several studies have shown that labour migrants tend to have higher HIV infection rates than non-migrants.

More importantly, HIV/AIDS would increase future vulnerability to climate change in Africa. The future course of HIV/AIDS will significantly influence how well populations can cope with challenges such as the spread of climate-related infections, food shortages, increased frequencies of storms, floods and droughts.

Meningitis

An expansion in the geographical distribution of meningitis is also noticed in West Africa in recent years, attributable to environmental change driven by both changes in land use and regional climate change. About 162 million people in Africa live in areas with a risk of meningitis and 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.

Current choices

We have tried to show in this paper that, based on the findings of the IPCC 2007 Fourth Assessment Report, Africa's climates, economies and ecosystems have already been affected by global warming and are likely to experience further change yet. There is an urgent need, therefore, for African governments, their partners and other stakeholders to plan on how to cope with the impacts of climate change and to help the people of Africa to adapt to these changes. Adaptation is not an option for Africa, but a necessity (Thornton *et al.*, 2006). This will not be easy, however, as Africa's adaptive capacity is low due to the extreme poverty of many of its people, compounded by frequent natural disasters such as droughts and floods, and poor institutional and infrastructural support.

To address the problems of climate change in the future, choices have to be made now. While a certain amount of reactive adaptation will of necessity occur, the design and use of proactive strategies can enhance adaptation. Such strategies should aim at increasing adaptive capacity to climate variability and climate change over the longer term. *Ad hoc* responses will always be necessary to alleviate immediate problems of food security, but it is important that adaptation to climate change is also factored into longer-term national development plans to aimed at reducing disaster risk, poverty and other issues. In the following we discuss some of the choices that we consider important to be made now to ensure long-term sustainability.

Land use

A major choice that needs to be made is the way in which land is used. A balance needs to be found between providing the basic necessities of life such as food, fibre, fuel, water and income, without affecting other ecosystem services such as water quality, flood and erosion control, biodiversity and carbon storage, or less tangible services such as aesthetic and spiritual uses. The current debate about the use of land for biofuels is a case in point – we need to choose whether tropical forests should be cleared to make way for maize or sugar cane in order to develop national economies, but possibly resulting in increased net emissions into the atmosphere, loss of biodiversity, and adverse effects on regional rainfall. Or whether land previously used for growing subsistence crops be switched to growing biofuel crops so that those subsistence farmers go hungry. We need to develop ways of assessing the tradeoffs and synergies between all of these different ecosystem services, so that we make the best choices.

Agricultural practices

We also need to extend the range of technological options available to farmers, for them to choose how they adapt to climate change. Although they have developed several adaptation options to cope with current climate variability, such options may not be sufficient for future changes of climate. Below we list some potential technologies that can help the agricultural sector choose how to adapt to climate change.

- Seasonal weather forecasts to provide information for farmers about which crops they should grow, when to plant, when to harvest, etc. There is also evidence that short-term weather forecast can help in predicting incidence of diseases such as malaria.
- Technologies to enhance resilience to drought, including dam building, water-harvesting systems to supplement irrigation practices, water conservation practices, drip irrigation, and the use of drought-resistant and early-maturing crop varieties.
- Knowledge of the appropriate crops to grow – one study has shown 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 (Kurukulasuriya & Mendelsohn, 2006).
- Biotechnology research to develop drought- and pest-resistant rice, drought-tolerant maize and insect-resistant millet, sorghum and cassava.
- Identification of most appropriate livestock species for future climates, and breeding of higher heat tolerance into existing livestock species.

Institutions

However, for these options to be effective, one very important choice that governments must make is to provide an appropriate institutional framework to enable people to adapt – Brooks (2005) has argued that if adaptation is to be successful and sustainable, it must have in place effective governance systems, civil and political rights, and literacy. Examples of some options that governments may choose to help build resilience include provision of national grain reserves, grain future markets, weather insurance, large scale irrigation schemes, food price subsidies, cash transfers, and school feeding schemes (Devereux, 2003). Micro-financing and social welfare grants are other institutional options that can help if they are supported by local institutional arrangements on a long-term sustainable basis (Chigwada, 2005). At the farm level, many farming households are adapting by diversifying their production, but for this to happen there needs to be a market for alternative produce. Earning off-farm income is another adaptation mechanism, but there need to be opportunities available (Bryceson, 2002). All of these require appropriate choices to be made by national and local governments.

Science and technology capacity

Underpinning all of this is the role that science and technology must play in providing the knowledge and the tools to make the right choices. Limited scientific capacity and other scientific resources are factors that frustrate adaptation (Washington *et al.*, 2006), so an important choice that needs to be made is to invest more in building this capacity. In the IPCC Fourth Assessment Report, Boko *et al.* (2007) include in their list of priorities for Africa the need for African scientists to build 'hubs' or centres of excellence to provide opportunities for young scientists to improve research in the fields of climate-change impacts, vulnerability and adaptation. The African Technology Policy Studies Network and its partner academic institutions organising this conference can play an important role in this process.

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