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CLIMATE CHANGE AND HEALTH ACROSS AFRICA: ISSUES AND OPTIONS

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LIST OF ACRONYMS

ACPC	African Climate Policy Centre
AIDS	Acquired Immune Deficiency Syndrome
CHWG	Climate and Health Working Group
DALYs	Disability Adjusted Life Years
EWE	Extreme Weather Event
HESA	Health and Environment Strategic Alliance for the Implementation of the Libreville Declaration
HIV	Human Immunodeficiency Virus
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
NPJAs	National Plans of Joint Actions
NTDs	Neglected Tropical Diseases
SANA	Situation Analyses and Needs Assessment
SSA	Sub-Saharan Africa
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
UV	Ultraviolet
WHO	World Health Organization

ABSTRACT

Climate change is expected to alter temperature, air movements, and precipitation in various ways and to varying degrees across Africa, and this will have important consequences for human health.Climate change impacts onhuman health, along with additional impacts on the environment and on the economies of African countries, are likely to impede development in Africa.

African countries will suffer health consequences related to the impacts of climate change as their people are among the most vulnerable to climatic change in the world. This vulnerability is due in part to existing problems of poverty, weak institutions, and armed conflict. These limit the capacity of African countries to deal with the additional health challenges posed by climate change. The relative importance of climatic and socioeconomic factors is difficult to quantify, and this in turn leads to uncertainty about studies of health-climate relationships in Africa and of the design of policies to best address the problems.

The majority of human health problems that can be linked to climate change are not, strictly speaking, created by changes in climate but are current problems exacerbated by changing weather patterns and climatic conditions. Often, such changesleave people ill prepared for new health impacts. For example, climate change may affect human health through the increased frequency and intensity of extreme weather events, which are drivers of malnutrition and can directly impact health (for example during heat waves). Rising temperatures will affect a pathogen's life cycle and range, which will affect the rate of infections, especially for vector-borne diseases. The overall balance of effects from climate change on health globally is likely to be negative, and it is predicted to be much greater in Africa than in other regions.

Within Africa the type and magnitude of the health impacts of climate change vary significantly among communities and regions. Variations are due to such factors as geographic and micro-climate differences, socio-economic conditions, the quality of existing health infrastructure, communication capacity, and underlying epidemiology.

This working paper lays out the current state of knowledge regarding the direct and indirect impacts of environmental factors on health across Africa. While there are many uncertainties in the magnitude and timing of climate change, a substantial literature exists that addresses the potential health impacts of climate change and the populations that could be most at risk. This paper reviews these potential impacts with a particular focus on the direct and indirect impacts climate change is likely to have on the health of the people of Africa. Due to the emerging nature of the issue and the somewhat limited literature, significant gaps in knowledge exist about these impacts.

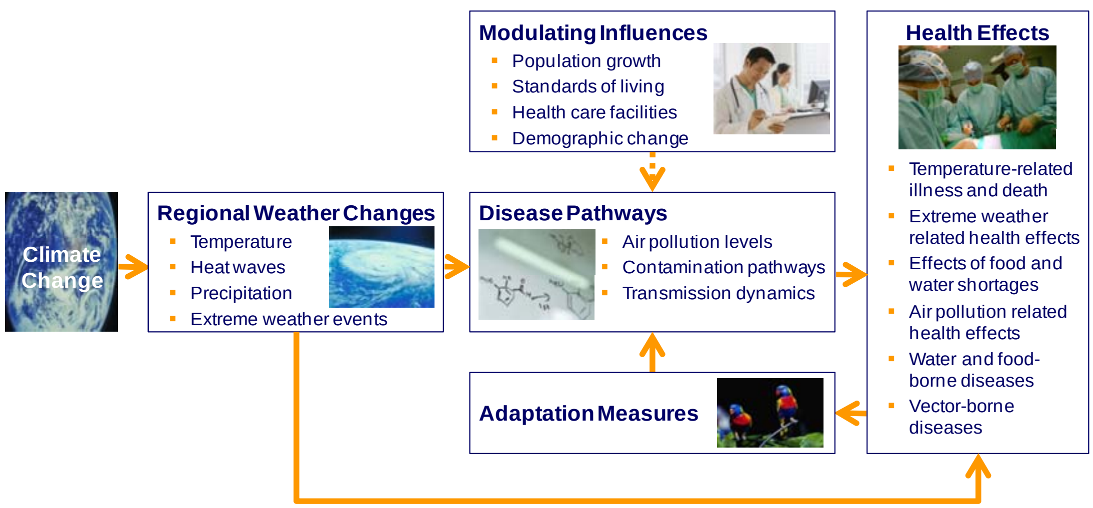
Importantly, Africa hasalready begun to address climate and health issues. An example includesthe "Libreville Declaration on Health and Environment in Africa" by African Ministers of Health and Ministers of the Environment. There have also been grass roots actions, such those being taken by the Climate and Health Working Group in Ethiopia and elsewhere. From a policy perspective, it is important to determine what might be done differently to address health concerns across Africa given that climate is expected to change in some predictable ways. In some cases doing more of the same may be appropriate (e.g., using mosquito nets and other measures to prevent malaria). In other cases completely different approaches to health care may be needed.

INTRODUCTION

It is well known that the health of a population, if it is to be sustained, requires clean air, safe water, adequate food, tolerable temperature, stable climate, and high levels of biodiversity (WHO, 1995; IPCC, 2007). Globally, climate change is expected to alter temperature, air movements, and precipitation in various ways and to varying degrees. In Africa, in particular, this will have consequences for human health. With strong connections between human health, economic health, and ecosystemhealth, the impacts of climate change on each are likely to impede the development of Africa (IPCC, 2001; Sperling, 2003; Stern, 2006).

African countries will likely suffer serious health consequences due to impacts of climate change. Many African countries have populations that are among the most vulnerable to climatic change in the world. This vulnerability is due in part to the existing problems of poverty, weak institutions, and armed conflict, problems that constrain Africa's capacity to deal with the additional health challenges posed by climate change. It is rarely possible to separate climatic and socio-economic effects when assessing the health impacts of climate change on any specific population (Figure 1). This difficulty leads to uncertainty about studies of health-climate relationships in Africa and of the design of policies to best address the problems.

Figure 1: Potential health effects of climate change and health.



(Adapted from Patz, *et al.* (2000))

The majority of human health problems that canbe linked to climate change are not strictly speaking created by changes in climate. Rather, they are current problems exacerbated or intensified by changing weather patterns and other climatic conditions. Populations are often unprepared orill-prepared for the new impacts on health. For example, climate change may affect health through increased frequency and intensity of extreme weather events (EWEs) (such as hurricanes, heat-waves, floods, and droughts). Such events are drivers of malnutrition and changes in the distribution of diseases. Rising temperatures will affect pathogen life cycles and range, thus affecting the rate of infections, especially for vector-borne diseases (Costello, *et al.*, 2009). An increase in global mean temperature will also alter heat and cold-related death rates around the globe (Costello, *et al.*, 2009). While there might be some positive benefits, such as a reduction in cold-related deaths in some temperate regions, the overall balance of effects on health globally is likely to be negative (IPCC, 2007). These effects will not be evenly distributed across the globe. Loss of healthy life years as a result of climate change is predicted to be 500 times greater in poorer African countries than in richer European ones (Ebi, 2006; McMichael, *et al.*, 2008).

Even within Africa, the type and magnitude of the health impacts of climate change will vary significantly among communities and regions. Variations will be due to many factors, such as geographic differences in temperature and precipitation, socio-economic conditions, the quality of existing health infrastructure, communication capacity, and underlying epidemiology. Therefore, in this report we lay out what is currently known about the direct and indirect impacts of environmental factors on health in Africa. While there are many uncertainties in the magnitude and timing of climate change, the existing literature contains a number of observations about potential health impacts related to climate change and about the populations that could be most at risk.

The sections below:

- identify current health issues across Africa;
- introduce the current understanding about changes in temperature, precipitation, and extreme weather events expected as part of climate change in Africa;
- present the potential impacts climate is likely to have on human health;
- analyse the direct and indirect impacts that climate change is likely to have on the people of African;
- discuss gaps in knowledge about the impacts climate change may have on human health; and
- assess options and the way forward for addressing health problems related to climate change in Africa.

Climate change and health across Africa: critical issues

In our analysis, careful attention is paid to distinguishing climate and health issues from climate change and health. The former refers to the *status quo*, that is,to the historic links between climate and health. The latter refers more specifically to the relationship between current and future anthropogenic climate change and conditions of health. For example, it is evident that the prevalence of malaria in parts Africa is related to the tropical climate in those areas. In the future, however, the nature and spread of malaria may be affected by the changes in temperature and precipitation expected in Africa.

In general, climate change will lead to increases or decreasesin the prevalence of disease, injury,and other health issues. However, it is difficult to assess how many people will be affected in different parts of Africa, what changes in mortality may occur, or what the changes in Disability Adjusted Life Years (DALYs) will be. This uncertainty is due in large part to the limited ability of models to predict patterns of climate change at national and local scales. In addition, many African countries currently face many socio-economic challenges. The effects of these challenges are sometimes difficult to separate from impacts of climate change on health.

Accordingly, a critical issue for African countries is not just what must be done to address the impacts of climate change on health but what must be done moregenerally to improve health services and conditions in Africa. What measures can be taken to mitigate and adapt to climate change to improve human healthin Africa? Perhaps most importantly, what should be done differently to address health concerns in Africa given the changes in climate that are expected? In some cases, more of the same may be required (e.g., using mosquito nets and other measures to prevent malaria). In other cases, completely different approaches to health care may be required.

Climate change trends across Africa

The IPCC report (2007) and the African Climate Trends and Projections report (2007)

Sea-surface temperatures in the open tropical oceans surrounding Africa are expected to increase only about 0.6-0.8°C (less than the global average);therefore, coastal regions are expected to warm more slowly than the interior of the continent.

- Precipitation:
  - The changes expected by most GCMs indicate relatively modest increases in moisture over most of the continent.
  - Southern Africa and parts of the Horn of Africa should expect a decline about 10 percent.
  - Seasonal changes in rainfall are not expected to be large (Joubertand Tyson, 1996; Hewitsonand Crane, 1996).
  - Parts of the Sahel, however, could experience increases in rainfall by of much as 15 percent over recent averages. Such increases, however, would follow a drought that has lasted 30 years in the region.
  - Equatorial Africa could experience a small (5 percent) increase in rainfall.
- Extreme weather events (EWEs):
  - EWEs are still poorly understood, and the evidence is not conclusive concerning changes in their frequency.
  - Heat waves, droughts, and heavy precipitationare the EWEs currently of most concern to Africans.
  - Although the prevalence of EWEs is not expected to change much as a result of climate change (IPCC, 2007), their compounding effects on other changes in climate are a cause for concern.

The likely and potential impacts these changes in climate may have on health are discussed below.

Impacts on Health

Climate change has both direct and indirect impactson human health. The direct impacts affect human biology and include injury, morbidity, and mortality caused by climate-change-relate EWEs (such as cyclones, floods, and droughts); thermal stress (heat waves and cold periods); skin and eye damage (as a result of UV radiation), and cardio-respiratory diseases directly related to changes in temperature and air quality (Table 1). However, most of the health impacts of climate change are indirect. Suchimpacts affect non-human biogeochemical systems and may include malnutrition (as a result of climate-related crop losses), reduced quantity and quality of water, and changes in the lifecycle and range of pathogens. Classification of the direct and indirect impacts of climate on health is complex. Table 1, however, summarizes these impacts for the purposes of this paper.

Table 1: Health related impacts of climate change

	Climate Changes	Health Impacts
Direct	EWEs	High levels of mortality and morbidity, change in disease prevalence and patterns
	Temperature	Thermal stress, skin cancer, eye diseases
	Air quality	Cardio-respiratory diseases, allergic disorders
Indirect	Temperature	Food availability, malnutrition, famine, infectious diseases of migrants, droughts
	Precipitation	Water-borne diseases, vector-borne diseases, droughts, food and water availability
	EWEs (+ rainfall + temperature + ecosystem)	Diseases of migrants, conflicts, food and water availability, malnutrition, famine
	Ecosystem composition and function	Food yields and quality, aeroallergens, vector-borne diseases, water-borne diseases

(The Smith School of Enterprise and the Environment, 2010)

Human healthis influenced byimpacts other than climate and climate change of course, and it is clear that health outcomes are usually the result of complex interactions between social, cultural, economic, and geographic factors, as well as climate factors and a person's pre-existing health status. Most of the impacts of climate change on health in Africa are indirect. We discuss these first before turning to the direct impacts of climate change on health.

Indirect impacts

The potential indirect health effects of climate change on the health of a community occur predominantly through changes in non-human biological or biogeochemical systems. These include changes in crop yields, in the geographical range and distribution of infectious diseases and their methods of transport, and in social pressures arising from changes in rainfall and temperature. Even without climate change, the capacity to manage health care systems in Africa is low. In addition to the impacts that climate change has on food and water security, it ultimately places additional pressure on the already inadequate human support systems.

Malnutrition

Good nutrition is essential for good health. Deficiencies in energy, fat, protein, nutrients, or vitamins lead to malnutrition and tomajor impacts on the physical and mental health of all people. Malnutrition has detrimental and lasting health consequences, often limiting physical and intellectual development, particularly of those who are affected as infants or as young children. Additionally, malnutrition vastly increases ones susceptibility to acquiring, and dying from, infectious diseases (Baroand Duebel, 2006; Schaibleand Kaufmann, 2007; Confalonieri, *et al.*, 2007). It particularly affects groups of people who are most vulnerable to changing environmental conditions, such as farmers and coastal communities, and those who are least able to purchase food, such as poor and landless wage labourers.

Malnutrition is considered the most important health risk globally, as it accounts for an estimated 15 percent of the total disease burden in DALYs. At present, under-nutrition causes 1.7 million deaths per year in Africa, and it is estimated to be the largest contributor to climate-change-related mortality around the world (Patz, *et al.*, 2005). Moreover, leading scientists in development and humanitarian research agree that climate change will likely worsen existing production and consumption stresses in countries that are already food-insecure (Bloem,*et al.*, 2010, p. 133S; SchmidhuberandTubiello, 2007, p. 19704). Bloem,*et al.* (2010) explain that access to food relies on its availability and affordability, and the available evidence strongly suggests that climate change will negatively both in Africa.

The availability of food will be affected by changing temperatures, humidity, and precipitation. These climatic variables are expected to disrupt agricultural production systems in different parts of Africa and require adaptation measures. Examples of climate impacts that are affecting food security include salinization of some agricultural regions, changes in the ranges in which certain crops can be grown, and migration of crop pests (Confalonieri, *et al.* 2007; SchmidhuberandTubiello, 2007, p. 19704). In Ethiopia, significant rainfall reductions have already been observed within critical crop-growing areas (Funk, *et al.*, 2007, p. 11086). This has been attributed to anthropogenically-influenced warming of the Indian Ocean (Funk, *et al.*, 2007). Reduced rainfall has led to severe drought and has resulted in famine in parts of Djibouti, Somalia, Ethiopia, and Kenya.

A number of grim predictions have been made regarding climate change and food production in Africa. For instance,increased temperatures can be expected, and dry areas could experience increased evaporation resulting in lower soil moisture. Tropical grasslands may become more arid, and therefore, semi-arid and arid regions should expect decreased livestock productivity, an increase in the winter survival of pest species, which will put more spring crops at risk, and an increase in the survival of human pathogensand the probability of food poisoning. As to the latter, it has been observed that food bacteria, such as *Salmonella,* proliferate more rapidly in warmer temperatures (SchmidhuberandTubiello, 2007, p. 19704; McMichael, *et al.*, 2006. p, 860). While climate change may result in improved food production in some temperate regions of the world (as a result of elevated CO_2 concentrations in the atmosphere and extended growing seasons), it is expected to have negative effects in most parts of Africa(SchmidhuberandTubiello, 2007, p. 19704).

Concerningthe affordability of food, decades of data show a correlation between food prices and the nutritional status of the poor (Bloem, *et al.*, 2010, p. 133S). World food prices are particularly important for access to food in developing countries, and in Africa in particular, because these countries rely more on purchased food than domestically produced food (Bloem, *et al.*, 2010, p. 133S). Even for countries that are net food exporters, access to food at the individual level may still be a problem (Schmidhuber and Tubiello, 2007). Unless Africa can make significant improvements in agricultural yields through improved practices and thus reduce its food imports, it will make continue to be vulnerable to global food prices.

Grain is a significant indicator of food production, as it accounts for 70 percent of global food energy (McMichael, *et al.*, 2003). Some of the effects of increased food prices have already been seen in many African countries. The upsurge in food prices that preceded the global economic crisis of 2008 resulted in a decline in access to food and a rise in malnutrition in the developing world (Bloem, *et al.*, 2010, p. 133S).

Generally, expectations are that food prices will rise moderately in line with increases in temperature until about 2050. After 2050, however, food prices are expected to increase substantially with rising temperatures. The prices of sugar and rice, for example, are expected to rise by 80 percent (SchmidhuberandTubiello, 2007, p. 19706). Some studies indicate that some climate warming may lead to overall increases in some grain outputs. However, any profit is likely to be cancelled out by increases in weed infestations. One study predicts that a 1.1°C increase in temperature would reduce global grain output by about 10 percent (Brown, 2003). Given that the IPCC estimates a 2°C temperature increase in the 21st century, on the basis of Brown's study one can predict a 20 percent reduction in grain output worldwide by the end of the century. Meanwhile, others suggest that grain yields may increase marginally if the range of temperature change is narrow. These conflicting conclusions result from uncertainty about how precipitation will change in the future.

A World Health Organization (WHO) report indicates that multiple social and political factors will govern the overall effect that climate change will have on food security (McMichael, *et al.*, 2003). More understanding of how climate change contributes to malnutrition is important if effective adaptation measures are to be implemented and governance structures improved. Similarly, further research into the local effects climate change is likely to have on food yields, nutritional quality, and prices will help developing countries formulate strategies to protect their populations from the malnutrition that could result from a changing climate.

Communicable diseases

Communicable diseases result from infection by pathogens, such as viruses, bacteria, fungi, protozoa, and parasites. Communicable diseases are transmitted by physical contact with infected humans or vector organisms, or with contaminated substances (i.e., water, food, objects, and air). Climate change is expected to affect the lifecycles and modes of transmission of many infectious diseases. The ability of a pathogen to spread is affected by its ability to mature and replicate. Temperature and moisture availability are two environmental factors influenced by climate change that affect pathogen proliferation. Temperature has a particularly strong effect on the rate of pathogen replication and maturation. Further, these two climate factors may also increase the survivability and density of vectors in some areas and therefore increase the likelihood of infection up to certain thresholds (WHO, 2004).

Although the environment has a dominant influence on the diversity of pathogens in a region, this diversity is also influenced by the human population size and density, the age of a settlement, and the population's disease control efforts (Shuster-Wallace, *et al.*, 2008; Dunn, *et al.*, 2010). Change in climate will impact disease distribution, the rate of contagion, and transmission seasons with different levels of intensitydepending on the region, the carrier (whether water or vector), the disease, and the mitigation strategy. This paper focuses on selected water- and vector-borne diseases based on the current and expected tolls they are likely to have in Africa.

Transmission of pathogens between humans can occur in various ways that include physical contact, contaminated water or objects, airborne inhalation, vector organisms, or body fluids. The following sections of this paper discuss neglected tropical diseases, water-borne diseases (with emphasis on diarrhoea), and vector-borne diseases (with emphasis on malaria). We then introduce meningitis separately as an airborne disease and also discussHumanImmunodeficiency Virus (HIV) and social status as compounding factors for community health.

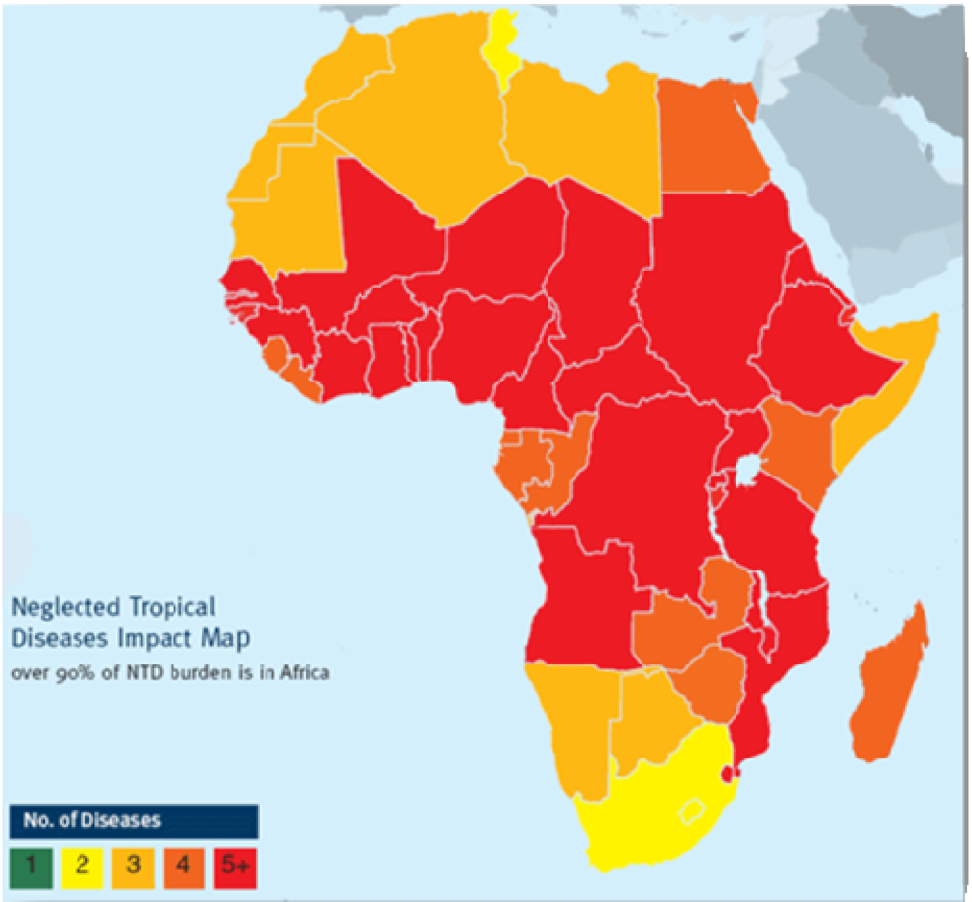
Neglected Tropical Diseases

Neglected Tropical Diseases (NTDs) are the most common conditions affecting the poorest 500 million people living in Sub-Saharan Africa (SSA). NTDs are a group of 13 major disabling conditions[1] that are distributed throughout Africa to varying degrees. In fact, many countries in Africa suffer under the burden of being host to about half of all the pathogens defined as NTDs by the WHO (Figure 2). Together, NTDs produce a burden of disease that may be equivalent to up to one-half of the malaria disease burden of SSA and more than double that caused by tuberculosis, two much more commonly known causes of death in Africa. Hotez and Kamath (2009) indicate soil-transmitted helminth infections (see footnote 1) account for up to 85 percent of the disease burden caused by NTDs and occur in more than half of the poorest people of SSA (Table 2; Hotez, 2003 and 2009). They suggest that the prevalence of this disease is connected to a number of factors, including flooding, irrigation project construction, and climate change (Mangal, *et al.*, 2008). Other factors cited include displacement of populations, urbanization, EWEs, and air pollution (Campbell-Lendrumand C. Corvalan, 2007).Giventhe connection that communicable diseases have with water and other organisms, climate change is likely to lead an increased the range and seasonal duration of suitable conditions for communicable pathogens to surviveand hence result in the spreading of communicable diseases.

Until recently, very few studies have been carried out on the connection between NTDs and climate change, although some reviewers have discussed the situation with a focus on vector-borne NTDs (Campbell-Lendrun, 2003). Table 2 ranks NTDs (and their primary carriers) according to the proportion of the population of SSA affected, from the highest to lowestpercentage.

[1] The WHO listed NTDs include soil transmitted helminths (roundworms, such as Ascarislumbricoides, which cause ascariasis; whipworm, which causes trichuriasis;and hookworms, which cause necatoriasis and ancylostomiasis), snail fever (schistosomiasis), lymphatic filariasis, trachoma, leishmaniasis, Chagas disease (American trypanosomiasis), leprosy, human African trypanosomiasis, Guinea-worm (dracunculiasis), buruli ulcer, cysticercosis, dengue/dengue haemorrhagic fever, echinococcosis, fascioliasis, onchocerciasis, rabies, and yaws.

Figure 2: Distribution of the prevalence of NTDs in Africa.



Note: The boundaries, the names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

(Source: Imperial College London, Schistosomiasis Initiative)
(available at: http://www3.imperial.ac.uk/schisto/whatwedo/ntdsinafrica).

Table 2: Examples of NTDs affected by climate change

NTDs	Trans-mission via	Estimated % of SSA population infected	African country with highest prevalence	SSA disease burden of Global total	Source
Hookworms	H_2O	29%	Nigeria	34%	Molyneux, *et al.*, 2005; de Silva, *et al.*, 2003
Ascariasis	Vector	25%	Nigeria	21%	Molyneux, *et al.*, 2005; de Silvaet,*et al.*, 2003
Schistosomiasis	H_2O	25%	Nigeria	93%	Steinmann, et al., 2006
Trichuriasis	H_2O	24%	Nigeria	27%	Molyneux, *et al.*, 2005; de Silva, *et al.*, 2003
Lymphatic filariasis	Vector	6-9%	Nigeria	37-44%	Michael and Bundy, 1997; GAELF, 2005 and 2008; ZagariaandSavioli, 2002
Onchocerciasis	Vector	5%	Yemen	>99%	WHO, 2008
Trachoma	H_2O	3%	Ethiopia	48%	WHO, 2008
Drancunculiasis	H_2O	<0.01%	Sudan	100%	WHO, 2008
Leishmaniasis	Vector	<0.01%	Sudan	No Data	Alvar, *et al.*, 2008; Reithinger, *et al.*, 2007; Bern, *et al.*, 2008; Collin, *et al.*, 2004
Human African Trypanosomiasis	Vector	<0.01%	DR Congo	100%	WHO, 2006; WHO, 2006
Buruli ulcer	H_2O	<0.01%	Cote d'Ivoire	57%	WHO, 2008, 2008
Leprosy	H_2O	<0.01%	DR Congo	14%	WHO, 2008

(Hotezand Kamath, 2009 (http://goo.gl/qgFIA andhttp://goo.gl/XJdpT))

Neglected Tropical Diseases form a large disease category that appears to result primarily from poverty (Manderson, 2009). Due to a lack of attention outside tropical areas, little is known about the pattern of spread of these diseases, about their potential link to climate change, or, more broadly, about the environmental constraints keeping various species within their characteristic ranges (Rogers and Packer, 1993).Below, we examine these diseases based on their primary modes of pathogen transmission, water-borne and vector-borne.

Water-borne diseases

Water-borne diseases are caused by protozoa, viruses,and bacteria that typically populate the intestines of humans. Water is often connected to disease spread, due to its role in the life cycle of vectors or its direct effect on the health of people. Climate change alterations to the hydrologic cycle will affect water distribution worldwide (IPCC, 2007). The IPCC expects both water availability and water quality to be affected in various parts of Africa, posing a threat to human populations.

Currently, almost two million deaths a year, mostly young children, are caused by conditions attributable to unsafe water and lack of basic sanitation (Confalonieri, *et al.*, 2007). Water-borne disease is widespread in Africa (Figure 2 and Table 2), where 334 water-borne epidemics occurred between 1980 and 2006 (PWRI, 2008; Leroy, 2009). The spread of water-borne diseases after climate-change-related extreme weather events (including floods and heavy rainfall) or abnormallywarm seasons (including long warm periods and growing seasons) isexpected to be especially high in Africa, where there is limited infrastructure and/orprogrammes to control these diseases (SchmidhuberandTubiello, 2007, p. 19705).

Perhaps surprisingly, droughts may also cause increases in communicable diseases, as reduced river flow may result in increased pathogen loading, such as is seen in the Amazon, where cholera outbreaks are associated with the dry season (Confalonieri, *et al.*, 2007). Epidemic meningitis, although a disease spread via airborne particles and droplets, also appears to be linked with droughts, as is suggested by the recent spread of thisdisease into West Africa.

The water-borne NTDs are mostly preventable by water filtration, case containment, and access to safe water. These methods alone have been credited with bringing down the transmission and annual cases of Drancunculiasis (guinea worm) to only 4 countries worldwide since an eradication programme began in 1989. In fact,the number of cases was reduced99.91 percent between 1986 to 2009(from ~3,500,000 in 1986 to 3,190 in 2009; WHO, 2010).Aside from providing safe water supplies, treatment campaigns have also increased, with some disease treatments proving to be relatively inexpensive.

Diarrhoea

In SSA, diarrhoeal diseases are second only to acute respiratory infections as a cause of mortality of children under 5. There are an estimated 4.3 episodes per child per year and an attributed mortality rate of 4.2/1,000 people, representing 27 percent of all deaths in this age group (Zimbabwe Public Health Review, 1987). The majority of pathogens that induce diarrhoea in humans are water-borne, and, given that climate changewill affect water availability and temperature, climate change could lead to additional cases of diarrhoea. Death is caused by infection, malnutrition, and/or dehydration.

Conditions that make a population prone to diarrhoea occurred in the months following Mozambique's flooding in 2000. Eight thousand additional cases of diarrhoea and 447 deaths as a result were recorded then (IPCC, human health chapter, 2007, p. 399).In essence, the exposure of people to new diseases is one result of shifting pathogen habitats or human movements directly or indirectly induced by climate change. A healthy support system, coupled with sufficient infrastructure that can handle the new conditions, will increase the resilience of people to diarrhoea and other diseases related to water availability.

Vector-borne diseases

There has been a worldwide resurgence in, and a redistribution of, many old infectious diseases (Table 3). The WHO (1996) has estimated that 30 new infectious diseases emerged between 1975 and 1995. Some experts have suggested that some of these are possibly connected to climate change (Costello,*et al.*, 2009; McMichael, 2004). Global climate change may have a major influence on vector-borne disease epidemiology (Dobson andCarper, 1992; Epstein, 2000; Epstein, 2007; Githeko, *et al.*, 2000; Sutherst, 2004). Vector-borne infectious diseases may be transmitted to humans by contaminated arthropods (i.e., fleas, mosquitoes, ticks, sand flies, and lice) and animals (typically mammals, such as rats and, less often, birds). More than 1,400 species of human pathogen have been identified. Of these, 58 percent are transmitted from animals to humans and are twice as likely to be emerging or re-emerging as other vector-borne and water-borne pathogens. Table 3 below shows the geographic distribution of vector-borne diseases and the principle vector responsible for each. Note that the top 6 vector-borne diseases are all in Africa.Table 2above lists the percent of Africans affected by vector-borne and water-borne diseases.

Table 3: Examples of vector-borne diseases affected by climate change in decreasing order of affliction.

Disease	Vector	Current geographical distribution
1.Malaria	Mosquitoes	Tropics
2.Dengue Fever		Africa, Caribbean, Pacific, Far East
3.West Nile Fever		Worldwide
4.Yellow Fever		Africa, South America
5.Leishmaniasis	Sand flies	Africa, Central andSouth America
6.Trypanosomiasis	Tsetse flies	Africa, Central and South America

Mosquito species, such as those in the genera*Anopheles* (approximately 40 species of which spread malaria), *Culex* (*C. quinquefasciatus*causes for West Nile Virus) and *Aedes* (*A. aegypti* cause dengue and yellow fever) are responsible for the transmission of most vector-borne diseases globally and in Africa (Githeko, *et al.*, 2000). Mosquitoes carrying diseases such as malaria and dengue fever, two of the most prominent mosquito-borne diseases in Africa, are among those undergoing resurgence and redistribution (GublerandKuno, 1997; Gubler, 2005; Coelho, 2008).

Three of the key components that determine the occurrence of vector-borne diseases are presented in the World Health Organization's Task Group report *Potential Health Effects of Climatic Change*(1990). They are:

- *Occurrence*: the abundance of vectors and reservoir hosts;
- *Environment*: the prevalence of disease-causing parasites and pathogens suitably adapted to the vectors, the human or animal host and the local environmental conditions, especially temperature and humidity; and
- *Resilience*: the resilience and behaviour of the human population, which must be in dynamic equilibrium with the vector-borne parasites and pathogens.

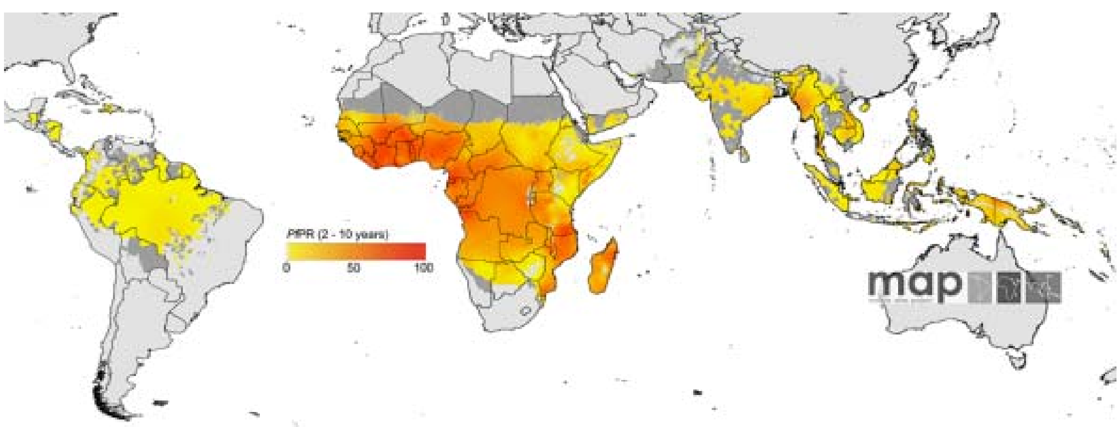
For example, temperature changes affect vector-borne diseases by The combined effects of changing temperature and precipitation may lead to a more suitable environment for the spread of vector-borne diseases and the emergence of new ones in different parts of Africa. influencing reproductive cycles and behaviours. Bite frequency generally rises with temperature and atmospheric CO_2 content (de Lucia, 2008). In general, higher ambient temperatures (up to a maximum) shorten the viral incubation period and breeding cycle in vectors (Campbell-LendrumandBertollini, 2009). Reproduction of *P. vivax* (a protozoal parasite) in mosquitoes takes 55 days at 16°C, 29 days at 18°C, and only seven days at 28°C. For *P. falciparum*, which causes the majority of severe malaria, 16.5°C-18°C is the required minimum temperature for development. There is high mortality in mosquitoes from 32°C-39°C, and at 40°C their daily survival becomes zero (Craig, *et al.*, 1999).

Some epidemiological models illustrate the potential of these vector-borne diseases to rapidly spread. Meteorological data from weather stations and satellites can be combined to determine which combination of predictor variables is most useful for describing vector distributions of a number of NTDs and, perhaps, for foretelling alterations in distribution as a result of climate change. When doing this for tsetse flies, however, only slight differences were found between the mean temperatures of places where they do and do not occur naturally (Rogers, 1993; Rogers and Randolph, 1993; Rogers and Packer, 1993). This finding may indicate that only a small change in temperature is needed to considerably affect tsetse fly distribution.

Malaria

Globally, from 700,000 to 2.7 million people dieannuallyof malaria. Some 94 percentof these deaths occur in Africa, 90 percentof which were in Sub-Saharan Africa, and 75 percent of which were children (Thompson, 2004; Patz, *et al.*, 2005; Raminand McMichael, 2009; WHO, 2008; Figure 3). As of 2010, the 41 countries with the highest death rate from malaria per 100,000 people are all in Africa. The highest rates occur in the Cote d'Ivoire (86.2 per 100,000), Angola (56.9 per 100,000), and Burkina Faso (50.7 per 100,000) (WHO, 2010). These figures suggest that one of the greatest health threats to Africa, in addition to malnutrition, is malaria.Much climate-malaria research in Africa suggests that malaria transmission, especially epidemic outbreaks, is associated with increased rainfall in typically dry regions and increased temperatures in high-altitude, typically cool regions (Connor, *et al.*, 2006, p. 22). The increased rainfall produces the moisture conditions and surface water that facilitate the breeding of malaria transmitting mosquitoes; warmer temperatures facilitate faster development for mosquito larvae and survival of adult mosquitoes. Perhaps more importantly, warm temperatures allow the malaria parasite, plasmodium, to multiply more quickly in mosquito hosts (Grover-Kopec, *et al.*, 2006, p. 2).

Figure 3: Malaria endemicity: the spatial distribution of P. falciparum



Note: The boundaries, the names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

(Hay, *et al.*, 2009)

The relationship between malaria and climate has been the more extensively studied than have relationships between climate and other illnesses in Africa (Connor, *et al.*, 2006). This is partly due to the fact that climate information can be used to produce malaria risk maps in the absence of high-quality epidemiological information (Connor, *et al.*, 2006). Moreover, as a major health issue in Africa, malaria has received more attention. The resulting research has shed light on "associations,""correlations," and "links" between malaria transmission rates and climate conditions (Grover-Kopec, *et al.*, 2006, p. 2).

A number of studies have linked warmer temperatures to increased malaria cases in the highlands of East Africa and droughtto decreased malaria cases in the Sahel region (McMichael, *et al.*, 2003, p. 51). In Ethiopia, analysis of malaria morbidity data indicates that higher minimum temperatures correlate with increased instances of malaria outbreaks (Confalonieri, *et al.*, 2007). Additional cases occur when increased temperatures occur simultaneously with increases in precipitation (Confalonieri, *et al.*, 2007). For instance, following the El Niño event in 1997, Kenya experienced a six-fold increase in the number of malaria cases compared with the previous year (McMichael, *et al.*, 2003). Research has also found a statistically significant relationship between El Niño events and malaria epidemics in Colombia, Guyana, Peru, and Venezuela (*Ibid*.). However, malariologistsstill have different views concerningthe extent of the contribution of climate change to changes in malariapatterns. Some think the contribution is relatively minor and that climate changes have a greater impact on changing patterns of dengue and other viruses, e.g., arbo and hantaviruses. Also, social and political conditions, increasing resistance to insecticides and anti-malarial drugs, and the deterioration of vector control operations explain much of the recent resurgence and deaths due to malaria (James, 1929; Dobson, 1980; Martens and Hall; Wingate, 1997; Hutchinson and Lindsay, 2006; Pascual, *et al.* 2006; Chaves, *et al.* 2008).

A significant body of research has suggested that overall global warming is expected to increase the seasonality and range of malaria, both across Africa and on a global scale (McMichael, *et al.*, 2003). The malaria infection rate is expected to increase by 16-28 percent in person-months in Africa by the year 2100 (Patz, *et al.*, 2005). The Mapping Malaria Risk in Africa (MARA/ARMA) project reports that between 2050 and 2080, malaria is expected to decline in the western Sahel and south-central Africa, as these areas are likely to become unsuitable for Malaria transmission (Thomas, *et al.*, 2004). The IPCC reports that by 2050 the previously malaria-free areas in Burundi, Ethiopia, Kenya, and Rwanda may suffer "modest incursions" of Malaria. Further, the changed range of malaria-carrying mosquitos is expected to increase the likelihood of epidemics in highland areas such as East Africa due to a lack of genetic resistance to malaria in the population (IPCC WGII 2007, Chapter 9). Elsewhere, such as in DebreZeit, Ethiopia, warming temperatures have been identified as the most likely cause for the increased malaria transmission observed between 1968 and 1993 after controlling for changes in drug resistance, mosquito control programmes, and human migration (Patz, 2005, p.311). This example refers to an "association" between malaria transmission and warming temperatures. Other factors could also have played a role (Patz, 2005, p.311).

While a majority of research supports the idea that malaria transmission rates are affected by climate, there are some studies that disagree. Confirming links with climate change as the primary cause for changes in malaria transmission rates requires that other factors that contribute to transmission rates be considered. These include the use of drug resistance and mosquito control programmes, human migration and immune status, and changes in land-use patterns (Patz, *et al.*, 2005, p. 311). For example, several studies have linked malaria prevalence and climate change in the highlands of East Africa (e.g.,Pascual, *et al.*, 2006). However, Hay, *et al.* (2002) studied four sites in that region which saw increased malaria transmission and found that climatic factors that would have enhanced suitability for malaria transmission had not changed much. He concluded that climate changes could not accountfor the increased malaria prevalence. Similarly, Jackson, *et al.* (2010) found very little correlation between rates of malaria prevalence and climate conditions in a malaria-endemic region of West Africa. Very few studies have linked increased malaria transmission to changes in climate while controlling for other confounding factors.

In spite of the conflicting findings regarding the correlation between malaria prevalence and changes in climate, it remains a fact that malaria is a serious health problem across SSA. Programmes designed to control this disease need to be increased whether or not climate change is the cause of its expansion.

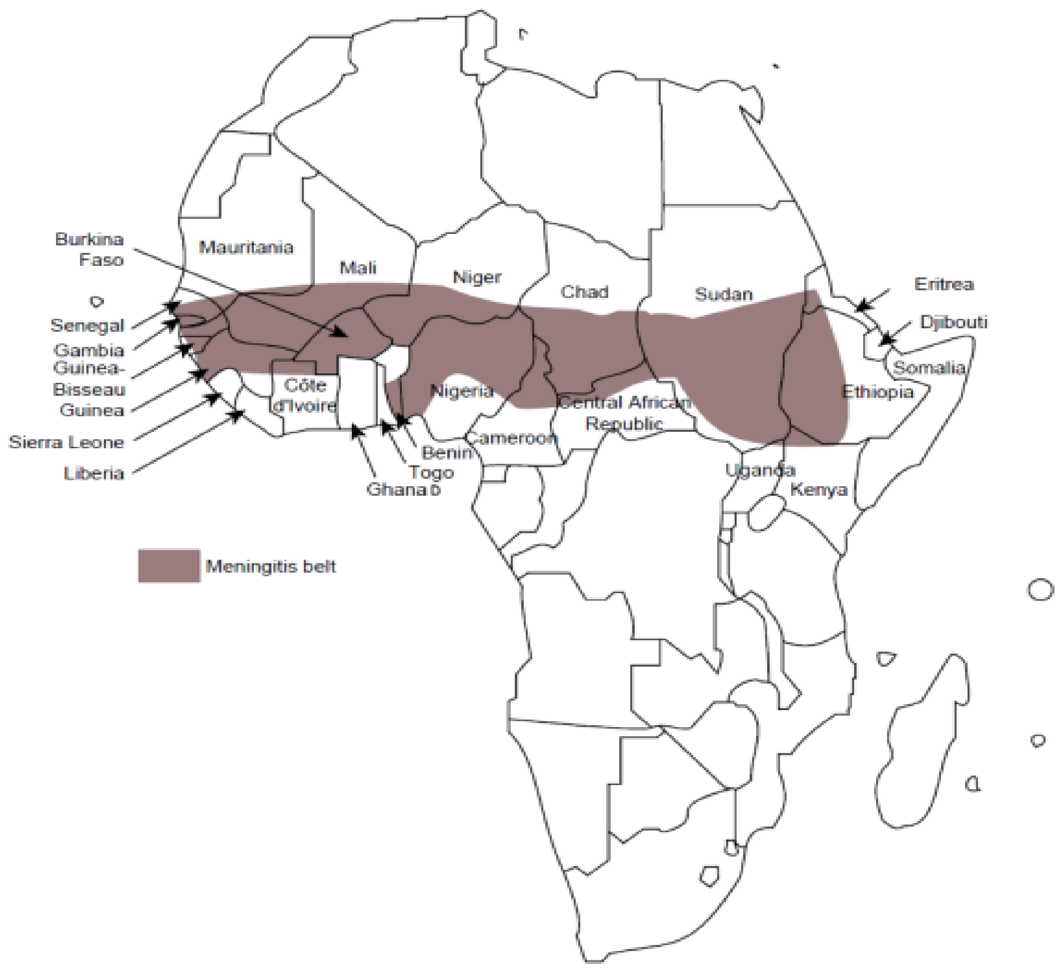
Meningitis – an airborne disease

Meningococcal meningitis is caused by the bacteria *N. meningitides,* which exists all over the world. It is one of Africa's top three climate-sensitive diseases. Roughly 350 million people live in endemic zones for this disease (McMichael, *et al.*, 2003; Palmgren, 2009). Humans are the only natural reservoir for the disease, and it is often spread between humans via respiratory droplets or saliva (i.e., through coughing, sneezing, kissing, or other forms of close and direct contact). Meningitis symptoms are apparent in some individuals but not all who have it. The disease,which is characterized by infection of the meninges, can have lifelong damaging effects to the central nervous system of some survivors. It tends to kill from 4-17 percent of its victims. The most susceptible are children, adolescents, and young adults (Menactra, 2011).

Meningococcal meningitis is an airborne disease, and epidemics are most often reported in years of severe dryness and drought and in dust laden environments. They are rarer in areas of dense forest and high humidity. The association between this disease and dust stems from studies that show that dust is likely the key element that converts the *N. meningitidis* bacteria from its benign form to its pathogenic one. The mechanisms for this conversion, however, are unclear. Although a clear causal link between increased meningitis incidence and climate factors is missing, the distribution and seasonality of meningitis is widely believed to be associated with dusty conditions that arise out of dryness and drought (IPCC, 2007, p.400). For example, South Africa has been subjected to seasonal increases of endemic meningococcal disease outbreaks during winter and spring (May-October) (Küstner, 1979). Therefore, areas prone to increasing drought conditions as a result of climate change can expect to be subject to an increase in meningitis occurrences.

Meningitis is concentrated in the semi-arid Sahel region of Africa (Figure 4).The strip of land through the Sahel with the highest concentrations of meningitis is often referred to as the "meningitis-belt." This spans Africa from Ethiopia and Sudan in the East to Senegal, Mali, and Guinea in the west (Palmgren, 2009). Epidemics of meningococcal meningitis break out in 5-to-10 year intervals in the meningitis belt. In recent years, the width of this belt appears to be expanding southward as a result of regional climate change and changes in land use (IPCC, 2007, p.400). Countries such as Kenya, Uganda, Tanzania, Togo, Cote d'Ivoire, Cameroon, and Benin, which are not accustomed to experiencing severe meningitis epidemics, and which do not technically fall in the meningitis belt, have begun to experience large-scale epidemics. This southward expansion of the meningitis-belt is also associated with the expansion of increasingly hot and dry conditions in these areas (McMichael, *et al.*, 2003).

Figure 4: African meningitis belt



Note: The boundaries, the names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

(Palmgren, 2009; WHO/EMC/BAC/98.3)

The climate change projections for the Sahel region include more frequent and longer drought as a result of expected increases in temperature and decreases in rainfall. It has been suggested that this will cause longer durations of the epidemics and perhaps even higher rates of incidence of the disease. However, because epidemiological research has not been able to confirm the correlation between the disease and climate, this cannot be declared with certainty.

Although not in the meningitis belt, South Africa has been subject to an increasing number of epidemic outbreaks of meningitis in recent decades (Küstner, 1979). Here, the disease occurs in a cyclical pattern at intervals of 8–10 years (Bikitsha, 1998). Between 1992 and1997, there were 1–2 cases per 100,000 persons (Bikitsha, 1998) in South Africa. By July 2002, 854 cases of laboratory-confirmed disease cases were reported (for the previous 3 years)in South Africa. This is an annual disease incidence rate of 0.64/100,000 population (the incidence was highest in infants less than 1 year in age)(Coulson, 2007).

With the recent availability of the group A conjugate vaccine, which is meant to target the most significant strain of the N. *meningitidis*bacteria, epidemiologists are hopeful that the problem of meningitis in Africa - and not just the meningitis belt - will begin to be controlled. The development of this vaccine is not the "be all and end all" for curbing meningitis in Africa, however. Epidemiologists would like to see improved epidemiological and environmental data sets for the dry season in Africa. Improved data will help to enhance meningitis early warning systems, and thereby enable more efficientdispersal of the vaccine.

HIV/AIDS

HIV is not likely to be directly affected by climate change. However, HIV infected individuals are at increased risk of communicable diseases, and those who are malnourished or unhealthy may be at greater risk of HIV. Given these links, it is likely that climate change will have an effect on disease patterns (Blaser and Cohn, 1986). By 2007, an estimated 33.2 million people had contracted the disease worldwide, resulting in deaths of an estimated 2.1 million people. More than 75 percent of these deaths were in SSA.

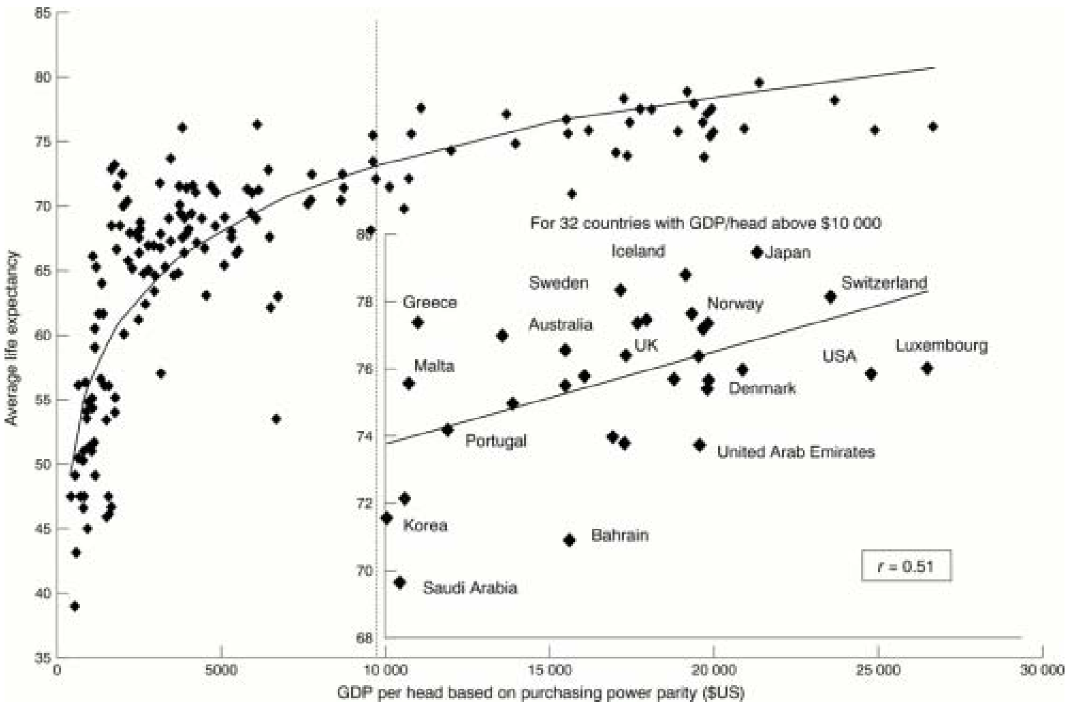
The occurrences of opportunistic disease pathogens, which define the Acquired Immune Deficiency Syndrome (AIDS), include protozoans (*Cryptosporidium*, *Microsporidium*), bacteria (*Mycobacterium avium* complex), and viruses (*Astroviridae*, *Adenoviridae*, *Rotavirus,* and *Cytomegalovirus*). Each of these can be water- and vector-borne pathogens, highlighting the need for eradication programmes. They appear to be more heavilydependent on geography than on factors such as demographics, and so it seems likely that as the geographical distribution of communicable diseases changes, infections in HIV-affected populations will change accordingly.

The expectation is that climate change may generate more migrants, as people search for food, water, or health security, or seek to flee from conflict. As populations are forced to migrate as a result of climate change, HIV infection rates could increase in certain regions, for example, as people from different areas mix or if sex work becomes a means of sustenance for formerly rural people who have migrated to the cities (McMichael, 2008).

Social status

Geopolitical, socioeconomic, demographic, and technological change compound social and economic predictability. Cultural adjustments seek to protect people from social and economic uncertainty are can lessen the impact of environmental and health stress. Such adjustments include, for example, improvements in housing conditions and better clothing. There is strong evidence that disadvantaged groups have poorer survival chances and die at a younger age than more favoured groups (Figure 5). The scale of differences in mortality is huge (Marmot, *et al.*, 2008). While a child born in some developed countries today, such as Japan or Sweden, is likely to live 80 years or more, children born in SSA are not expected to live beyond 50. Furthermore, while the carbon footprint of the world's poorest 1 billion people accounts for only about 4 percent of the world's total carbon footprint, it is these poorest people who will bear the highest costs of climate change (Costello, *et al.*, 2009). It is likely that the negative impacts of climate change will be felt more severely in SSA than in other regions of the world in spite of the fact that the continent emits relatively low CO_2(Figure 6)(Ramin and McMichael, 2009). This is largely attributable to the continent's overall limited adaptive capacity. Many of the human health issues discussed in this paper are not only just associated with poverty but are also a cause of poverty and a major hindrance to economic development. These diseases are associated with major negative economic effects in regions where they are widespread. Countries with poor or weak health services and water distribution infrastructure find that these are major factors slowing economic development (Sachs andMalaney, 2002). In countries where malaria is common, the average per capita GDP rose only 0.4 percent per yearbetween 1965 and 1990, compared to 2.4 percent per year in other countries (Ettling, *et al.*, 1994). The estimated economic impact of malaria on Africa is US$12 billion every year (Greenwood, *et al.*, 2005).This figure includes the costs of health care, working days lost due to sickness, days lost in education, decreased productivity due to brain damage from cerebral malaria, and loss of investment and tourism.

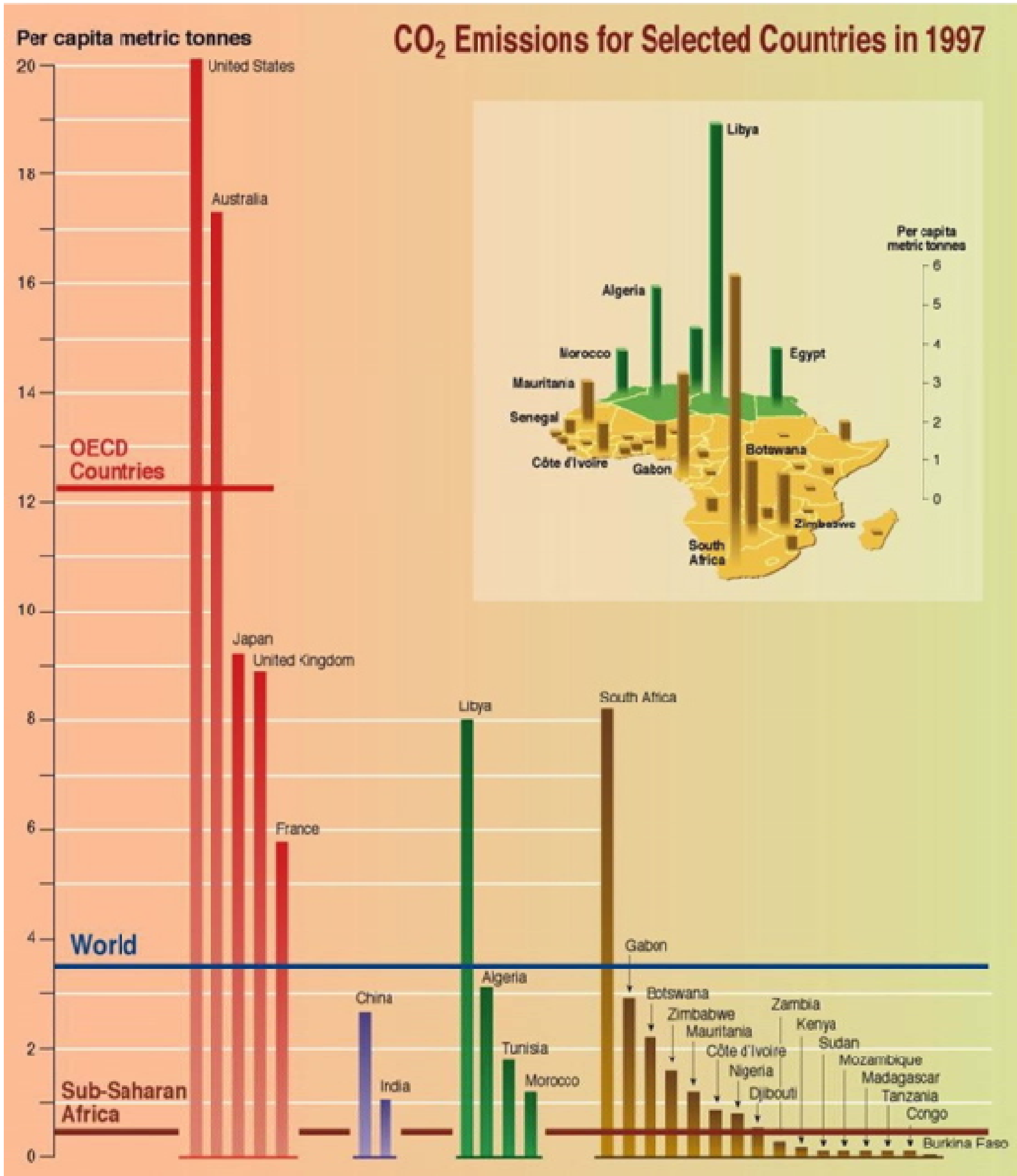
Figure 5: Association between GDP/person adjusted for $US Purchasing Power Parity and life expectancy for 155 countries circa 1993



(Lynch, *et al.*, 2000)

As a result of poverty, conflict, and changing environments, forced migration and displacement is occurring in various regions of the world. Some causes for migration related to climate change and health include increased EWEs, droughts, desertification, sea level rise, and disruption of seasonal weather patterns that can cause disease outbreaks and malnutrition. Migrants may carry infectious diseases from their place of origin to their destination and, once there, they may be susceptible to diseases to which they had not previously been exposed.Often, they live outside the established social system and may not have access to adequate healthcare services. The World Disasters Report 2001, published by the International Federation of Red Cross and Red Crescent Societies, estimates approximately 25 million people are currently on the move as forced migrants due to climate-change-related factors.

Figure 6: African CO_2 emissions compared with the world



Note: The boundaries, the names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

(UNEP, 2002)

Direct impacts

The potential direct health effects of climate change on human health occur predominantly through the impacts of climate variables on human biology. The main climatic-environmental variables are temperature, precipitation, and air quality. While the main drivers of health impacts are climatic variables, impacts are modulated by human population density, the vulnerability of local settlements, regional economic wealth, and the suitabilityof infrastructure. As a result, the direct impacts of climate on health are felt more strongly in

Africa than in wealthier parts of the world. Health impacts are the result of specific events, such as heat waves, floods, and air quality changes. Also, the direct impacts of climate on health may lead to indirect ones. Better understanding of these connections can lead to the development of appropriate adaptation and mitigation techniques that can benefit human health.

Extreme weather events (EWEs) and their direct effects

The direct health effects of climate change with the potential for greatest impacts are the forces that create droughts and floods. Unfortunately, this is an area for which there is insufficient data (IPCC WGII 2007, Chapter 9). Working Group II of the IPCC, in its discussion of climate change in Africa, is inconclusive regarding changes in the frequency or size of EWEs, but it suggested there might be a slight increase in droughts in the second half of the 21st century and that there may be more frequent and stronger tropical storms in the southern Indian Ocean. EWEs are relatively location-specific, and regions with a history of a specific EWE will tend to continue to experience it. Inland and coastal floods have been the most frequent EWE (Epstein and Mills, 2005).

Even without climate change, the impact of EWEs can be, and has been, devastating. The impact is typically greatest in the most vulnerable regions, where populations are least able to defend themselves. Death tolls in these regions are often high, typically among the poor. Extreme weather events, such as cyclones, droughts, and hurricanes have an extraordinary impact on human mortality.Table 4 outlines the number of people killed by EWEs by region. Of note is that while the frequency of EWEs is increasing, the number killed was significantly smaller in the 1990s than in the 1980s.

Table 4: Number of people killed in EWEs in the 1980s and 1990 by global region

Region	**Deaths in 1980s**		**Deaths in 1990s**	
	(‘000s)	**(% of total)**	**(‘000s)**	**(% of total)**
1.Africa	416.9	60.3	10.4	1.7
2.Eastern Europe	2.0	0.3	5.1	0.8
3.Eastern Mediterranean	161.6	23.4	14.4	2.4
4.Latin America and the Caribbean	11.8	1.7	59.3	9.9
5.South East Asia	53.9	7.8	458.0	76.2
6.Western Pacific	35.5	5.1	48.3	8.0
7.Developed	102.1	14.8	5.6	0.9
Total	691.9	100.0	601.2	100.0

(McMichael,*et al.*, 2003)

The effects on individuals of EWEs are compounded by damage to infrastructure and health systems. For example, it was difficult to deliver HIV retroviral drugs Northern Namibia after a recent flood. Once an initial disaster has passed, secondary issues may emerge, such as a lack of food, adequate clean water (Shultz, *et al.*, 2005), and increases in communicable and non-communicable diseases. Survivors have an increased risk of contracting respiratory, diarrhoeal, and communicable diseases in the aftermath of an extreme event due to population overcrowding, limited or no access to potable water and food, and exposure to chemicals, pathogens, and waste (Kovats, *et al.*, 2003). Poor drainage and storm-water management in low-income urban communities increases rates of infectious disease transmission (Confalonieri, *et al.*, 2007). Extreme weather events can cause variation in the patterns of vector-borne diseases, either by creating favourable environments for vectors or through the destruction of a vector's environment. For example, flooding can intensify the transmission of hydrophilic vectors and diseases (Connor, 1999). Long-term impacts include increases in infectious disease and mental stress, losses of infrastructure and territory, and environmentally-induced migration, which can lead to further increases in infectious diseases and conflicts over water, energy, and other increasingly scarce resources.

Ultravioletradiation-related cancers and diseases

Ultraviolet radiation (UVR) related cancers and diseases are a range of health effects that will increase in importance as human lifespans lengthen. Climate change may alter human exposure to UVR in several ways, with limited predictability and variation among regions (McMichael, *et al.*, 2003). The IPCC concluded that excessive UVR exposure was responsible for 1.5 million disability-adjusted life years and 60,000 premature deaths worldwide in 2000 from skin, eye, and cardio-respiratory diseases (Confalonieri, *et al.*, 2007). Small amounts of UVR are beneficial to health and play an essential role in the production of vitamin D. However, excessive exposure to UVR is associated with different types of skin cancer, sunburn, accelerated skin ageing, solar keratoses, and cataract and other eye diseases that reduce the effectiveness of the immune system.

Worldwide, approximately 18 million people are blind as a result of cataracts. In developing countries cataracts causes 50–90 percent of all blindness (Murray and Lopez, 1996). Of these, 5 percent of all cataract-related diseases are directly attributable to UVR exposure. Notably, the rate of cataract surgery is lowest in Africa (Yorston,*et al.*, 2001). However, aprogramme to eliminate cataract blindness in Africa by 2020 has been proposed, and there are grounds for optimism. First, the number of cataract operations is increasing rapidly in some countries. In Kenya, there were about 5000 cataract operations in 1996. By 1999, the number had increased to over 12,000, with the quality of surgery also improving (Yorston,*et al.*, 2001). Second, human resources development and access to low cost materials is making cataract surgery more widely available (Brian and Taylor, 2001). Many surgeons have been successfully trained or retrained in various types of cataract surgery, and education clinics have been set up in such countries as Ghana, Nigeria, South Africa, and Tanzania. (Francophone and Portuguese-speaking Africa have fewer training programmes at the moment (Alhassan, *et al.*, 2000)).

In the year 2000, UVR exposure led to more than 200,000 cases of melanoma and 65,000 melanoma-associated deaths globally. The WHO confirms that instances of skin cancer have been increasing steadily for the last two decades, especially in regions with high UVR exposure, such as South Africa (McMichael, *et al.*, 2003). The relationship between ozone depletion and poor skin and eye health is unclear. Also, research is needed on attitudes toward sunbathing and the use of protective measures. Measures, such as sunscreen ointments and protective eyewear require evaluation. Too much reliance on sunscreens has been identified as a potential cause of increasing skin and eye disease (Garland, *et al.*, 2002).

UVR appears to reduce the effectiveness of the human immune system by changing the activity and distribution of the cells responsible for triggering immune responses (De Faboand Noonan, 1983). For the eyes and the immune system, this is independent of skin pigmentation, so people everywhere are at risk from potential adverse effects, including increased incidence and severity of infectious disease and enhanced risk of malignant changes (Last, 1993). There is less ability to respond to increased skin and eye diseases in lower and middle income countries. People required to work outdoors will be most affected, as well as those that spend most of their youth in the sun.

Temperature and precipitation effects

Increases in average temperature represent a significant source of potential direct climate change impacts on human health. A major concern is that temperatureincreases may be greater than what is comfortable for a region and affect mortality through thermal stress (Figure 7). Heat stress affects individuals during extremes in intensity and/or frequency of local weather, usually in the coldest and warmest seasons. Environmental conditions can be further exacerbated by human activities, such as deforestation and urbanisation, which canlead to local temperature increases of as much as 3°C (Hamilton, 1989).

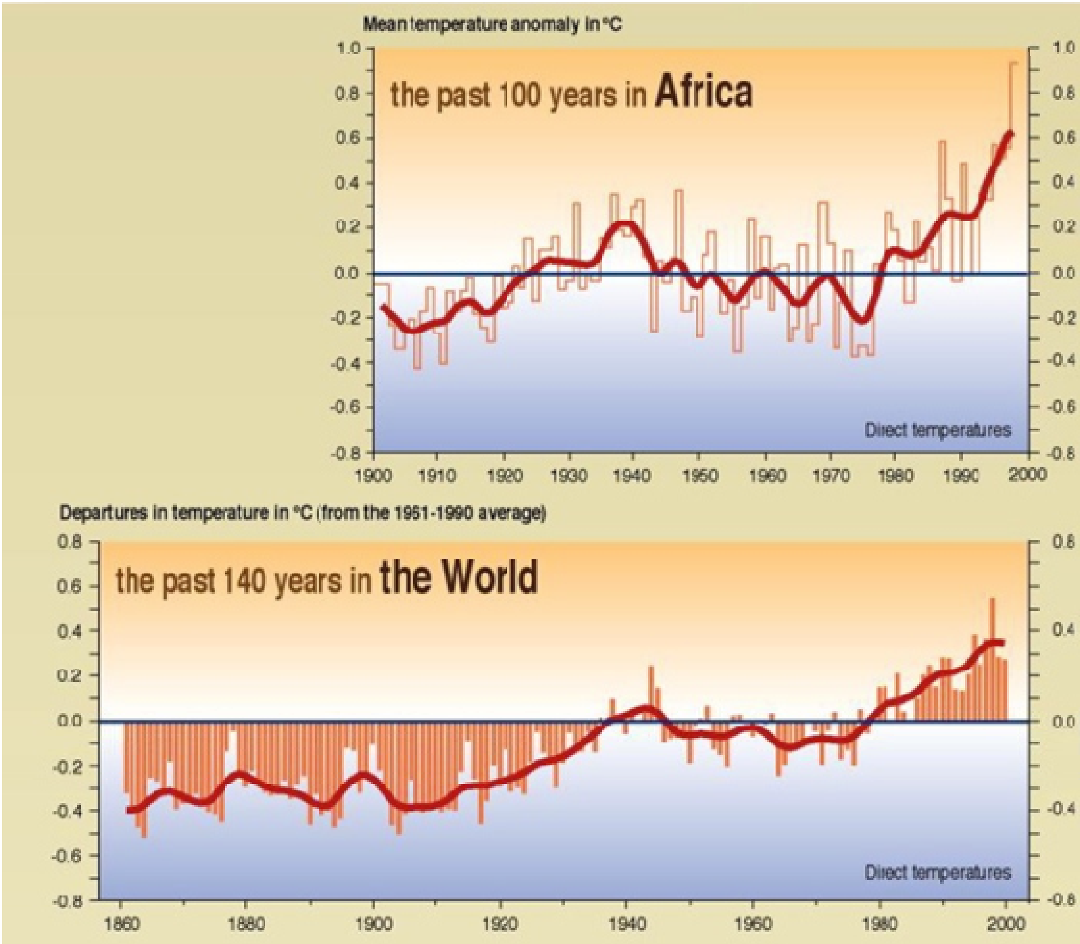
Seasonal variation in mortality has been described in many countries throughout the ages. In ancient Greece, Hippocrates described the occurrence of sudden deaths and strokes when a cold spring followed a mild winter(McKee, 1989). Research suggests that in warmer climates patients may have optimum cardiovascular health at higher temperatures (Pan, *et al.* 1995). For example in Taiwan, elderly patients have optimum cardiovascular health and the fewest deaths from coronary artery disease at a temperature range of 26-29°C (*Ibid*).

Though rarely discussed in the literature, mortality due to heat waves has been extensively studied in Europe and North America. However, data is virtually absent for South America and Africa (McMichael, et al., 2006). Rising temperatures will be most dangerous for poor people in developing countries and among the most vulnerable (the young, elderly, and sick). As with the other health problems afflicting Africa, thelimited resources available to poorer populations exacerbate the problems. It is difficult to predict the effects of changes in frequency and intensity of heatwaves on mortality rates in high temperature regions like Africa, as there is a lack of data about mortality in these regions.

Air quality

Climate change is expected to reduce air quality in some areas (IPCC, 2007) and thus contribute to respiratory disorders (Kinney, 2008; McMichael, *et al.*, 2003). The relationship between climate change and air quality is complex, with many interacting mechanisms. Air quality influences can be meteorological (temperature, humidity, wind speed, wind direction, and mixing height), natural (ground-level ozone and light-catalysed air chemistry reactions, aeroallergens, forest fires, and dust from dry soils), or anthropogenic in origin (carbon-based fuels for local energy, transportation, and agriculture), resulting in eventual deposition of air pollutants (Sapkota, 2005; Confalonieri, *et al.*, 2007; Kovats, Ebi, andMenne, 2003). Particulate matter is a pollutant of concern, as it is a complex mixture of extremely small particles and liquid droplets. When inhaled, these particles can reach the deepest regions of the lungs. Exposure to particle pollution is linked to a variety of significant health problems. Vulnerability is determined by the quality of housing, the availability of air conditioning, and the urban heat island effect. Increased deaths among the elderly and urban poor can result (McMicheal, *et al.*, 1996; Piver, 1999a and b; Epstein and Mills, 2005).

Figure 7: Temperature changes in Africa compared with the world



(UNEP, 2002)

Sunlight and high temperatures, combined with other pollutants, such as nitrogen oxides and volatile organic compounds, can cause ground-level ozone to increase. Ozone forms in the troposphere by the action of sunlight on ozone precursors from the by-products of burning carbon-based fuels. At the surface, an increase in temperature accelerates photochemical reaction rates (there is usually a strong correlation between higher ozone levels and warmer days). Ground-level ozone can damage lung tissue and is especially harmful for those with asthma and other chronic lung diseases. Even those with moderate disease may be at risk when the temperature rises above 16.5°C (Levy, 2005).

The increases of air pollutants due to climate change discussed above may also influence cardio-respiratory disease by exposing patients with pre-existing conditions to temperature extremes high enough to stress the cardiovascular system(McMichael, *et al.*, 2003). The WHO (2002) has estimated that poor air quality caused by climate change was responsible for over 2.4 million premature deaths in 2000 alone (one-third outdoors and two-thirds due to poor indoor air quality) and accounts for approximately 2 percent of the global cardiopulmonary disease burden (Prüss-ÜstünandCorvalán, 2006; Watts, 2009). Exposure to outdoor air pollution accounted for approximately 2 percent of the global cardiopulmonary disease burden (WHO, 2002; Cohen, *et al.*, 2004). The array of health impacts includes headaches, nausea, cardio-respiratory diseases, and cancer.

Gaps in knowledge and research

Climate and health research is still in a rather primitive stage, and many of the direct and indirect health effects of climate change in both the regional and global context have not been fully identified or understood. Hence, although much is known about the science of climate change, there remain many uncertainties about its potential impact on health (IPCC, 2007). These uncertainties are due mainly to three main areas:

- Climate change;
- Links between climate change and health and their mechanisms; and
- Human mitigation and adaptation capabilities.

Climate change uncertainties are due to insufficient and sometimes uncertain climate data. The global climate system is complex. Simulations involve many variables that describe and relate to nature's chemical, physical, and biological processes. This complexity makes it difficult to predict future climate trends in temperature, precipitation, cloud cover, winds and the timing, and scale of weather events at regional and local levels with accuracy. The difficulty is compounded by uncertainty in future rates of GHG emissions and the willingness and ability of governments to mitigate and adapt to changing conditions. Ultimately, new techniques and approaches to climate change science are needed to reduce the uncertainties in the estimates. Improved modelling of climate change, including at the regional scale, will allow for more reliable predictions of the potential impacts of climate on human health.

Thus far, the majority of climate-health research has been undertaken in the developed world, where the tools, technology, and capacity for doing this research isavailable. The results thus far are tentative, not the least because the greatest health risks due to climate change are expected to be in the developing world where the least research has been done (Ramin and McMichael, 2009). The limited tools and technology in Africa have not produced clear findings in climate-health relationships (Connor, *et al.*, 2006). For example, the climate data used in malaria studies has not been of sufficient quantity or quality to establish clear links between malaria and climate (e.g. Tulu, 1996 vs. Hay, *et al.*, 2002). The number of meteorological stations across Africa is insufficient for other analytical purposes as well, thus providing an obstacle to tracking climate trends (Connor, *et al.*, 2006). Also, climate data widely used in Africa has often been based on low-quality observations (Connor, *et al.*, 2006).

Uncertainties in the mechanisms linking climate to health impacts constitute a second set of challenges. For instance, accuracy in predicting the effects of climate change on important health-related factors, such as crop yields and pests (weeds, insects, and plant diseases, for example) can be improved. Improvements can also be made in epidemiologic research methods to predict health impacts. Part of the challenge in achieving these improvements is that climate and health experts (climatologists and epidemiologists) tend to operate in different domains and are not fully informed on how to effectively use climate and health data to generate insights on the relation of climate and health (Connor, *et al.*, 2006). Overall, it has been difficult to build and maintain cross-sectoral relationships between the researchers, e.g. to develop climate-based early warning systems and the subsequent responses needed from the public sector (Connor, *et al.*, 2006).

Third, it is difficult to predict how humans will mitigate and adapt to climate change. Most of the effects of climate change on health discussed above can be minimised through appropriate mitigation and adaptation measures. Geopolitical, socio-economic, demographic, and technological advances will determine the ultimate impact of climate change on human populations. For instance, development of new vaccines may attenuate the relationship between temperature increases and the spread of malaria. A good example can be found in the case of meningitis, where the recent availability of the group A conjugate vaccine, which is meant to target the most significant strain of the *meningococcus* bacteria, offers hope that the problem of meningitis in Africa may ultimately be controlled.

Africa's response to climate change and health

The preceding sections make clearthat despite abiding uncertainties and complexities, there are a range of indirect and direct health impacts associated with climate change. Ministers of Health and Ministers of Environment from across Africa are aware of the potential impact of climate change on health and as such have responded with:

- The Libreville Declaration on Health and Environment in Africa (Libreville, 2008);
- The African Ministers of Health and Environment Joint Statement on Climate Change and Health (Luanda, 2010a);and
- The Health and Environment Strategic Alliance for the Implementation of the Libreville Declaration (Luanda, 2010b).

These responses reflect a proactive intent among African leaders to protect their people from the anticipated negative health consequences of climate change. The above documents contain a number of recommendations and actions aimed at improving Africa's understanding of climate and health and at the same time addressing the health impacts of climate change in Africa.

An important element contained in the Libreville Declaration is the commitment to establish a Health and Environment Strategic Alliance as a platform for planning and coordinating joint continent-wide action. Similarly, the African Ministers of Health and Environment Joint Statement on Climate Change and Health (Luanda, 2010a), which recalled the Libreville Declaration, contains a commitment by African governments to,*inter alia*:

- Undertake a comprehensive health- and environment-climate change vulnerability assessments by the end of 2012;
- Complete the Situation Analyses and Needs Assessment (SANA) process and prepare National Plans of Joint Actions (NPJAs);
- Develop an essential public health package to enhance the climate change resilience of all countries by 2014; and
- Reduce vulnerability and use ecosystem services to build natural adaptive resilience against the impacts of climate change.

Following the meeting in Libreville,the Health and Environment Strategic Alliance for the Implementation of the Libreville Declaration (HESA) was established to serve as the primary mechanism for coordinating efforts addressing climate change and health in Africa. The core mandate of HESA is to support country efforts in addressing health and environment issues, including climate change and health issues, through advocacy, collaboration, resource mobilization, capacity building, technical support, and monitoring. It is hoped that the full implementation of the Libreville Declaration and the Joint Statement will help ensure evidence-based, and properly coordinated, policies, plans, and actions.

At grass roots level, climate and health activities are already underway, notably in Ethiopia, where the Climate and Health Working Group (CHWG) has been operating for over 10 years and has been addressing the issue of climate and malaria. Similar groups have been established in Kenya and Madagascar.

In April 2011, a "Climate and Health: 10 Years On" meeting was held in Addis Ababa. It was co-organised by the International Research Institute for Climate and Society (IRI), the African Climate Policy Centre (ACPC), the CHWG, the WHO, UNDP, the UK Met Office, and the University of Exeter. The workshop reflected on nearly a decade of practice and experience in Africa since the 1999 Bamako, Mali Workshop on Climate Prediction and Diseases/Health in Africa. Some 23 recommendations[2] were made at the "10 Years On" workshop to support the effective implementation of the Joint Statement on Climate Change and Health in Africa (Luanda, 2010). Addressing policy, practice, services and data, and research and education, they included recommendations to:

- Bridge the gap between policies and practices through legislation and guidelines, appropriate planning (including vulnerability assessments), programmatic support, and multi-sectoral,gender sensitiveparticipatory processes;
- Support countries to establish integrated health surveillance and climate observation and processing systems;
- Integrate climate health risk management into cross-sector planning and practice for adaptation to climate variability and change by developing climate services and products that address disease prevention at the end-user level; and
- Ensure that climate change mitigation and adaptation strategies are informed by multidisciplinary research.

Options for consideration

Based upon a review of the literature, we suggest below a series of options to address climate change and healthfor consideration by African governments, coordinating bodies (such as HESA), and other organizations. These options need to be more thoroughly investigated, and additional research, dialogue, and discussion are needed. However, for the purposes of stimulating discussion, the following might be considered:

- Given that the ability to address the health impacts of climate change depends in part on the quality of existing health care and facilities, an important step is to invest resources in the overall health-related infrastructure in Africa.

- Many of Africa's current health problems are a result of frequent contact with contaminated water and open sewerage (UNFCCC, 2007, p.18; IPCC, 2007, p. 399, 416; Labonte, 2004). Improved infrastructure could reduce the damage and health dangers associated with EWEs.

- Comprehensive drug therapy and other mitigating or preventative measures can help enable the health sector in Africa to combat the most prominent, and often most climate-

[2] The complete set of recommendations is available online (http://portal.iri.columbia.edu/portal/server.pt/gateway/PTARGS_0_2_7668_0_0_18/Final%2010%20Years%20On%20Recommendations_April%206.11.pdf), and the report of the meeting is also available online, along with related presentations and discussions (http://portal.iri.columbia.edu/portal/server.pt/gateway/PTARGS_0_4972_7730_0_0_18/TR11-01_10YearsOn_WorkshopReport.pdf).

sensitive, infectious diseases, including malaria, meningitis, and the NTDs. Medication and other paraphernalia (i.e., mosquito nets, condoms, sterilization tablets, and sanitizers) for curing or preventing Africa's common infectious diseases are required to improve the overall health of Africa's people. These measures alone, however, would not suffice.

- An increased number of clinics and of health professionals to provide support, explain options, and give directions on drug use and preventative paraphernalia are also required. A healthier populace is critical to development and, in turn, adequate development is needed to improve the overall health of Africans. The Global Strategic Plan for Roll Back Malaria, 2005-2015, agrees. It states that "six out of eight Millennium Development Goals can only be reached with effective malaria control in place" (Kopec-Grover wt al., 2006, p.1; Connor, *et al.*, 2006, p. 21).

- There is a need to tackle the problems of food security and malnutrition in the context of climate change. There are many ways of doing this, as well as many complications. Health outcomes might benefit from investments in agricultural production systems,irrigation systems, and improved land policies, for example. A number of organizations researching such issues in the field and at the policy level. It is important that the outcomes of this research be used to inform government policies and interventions and to build climate resilience in the agriculture sector.

- Significant development potentialexists Across Africa, and, as such, there is an opportunity to ensure a key element of development, infrastructure, is climate resilient. Achieving this requires a significant increase in the awareness of climate change among development planners and ministries throughout Africa. Adequate infrastructure is important for both the delivery of, and access to, health services.

- African governments can increase their effectiveness in addressing the health impacts of climate change through the creation of knowledge management platforms for sharing information, skills, and technology between and within governments, private investors, local and international agencies, and academic groups. Particularly important is the need to increase research. Responses, actions, and policies addressing climate change should be based on the best available research. It is also important, as stated by the WHO (2009) to improve understanding of current climate-related health risks before trying to understand future or long-term health risks. Research is also needed to identify relatively hidden or unclear climate-health links, to ensure proper prioritization of response measures, and to identify the most cost-effective interventions.

- As climate change is not a completely new phenomenon, insight could be gained by studying how indigenous communities have dealt with changes over time and how this knowledge could be used to adapt climate change or to scaleup effective responses.

- There is also need for improved regional modelling of climate change so that more reliable predictions of the potential impacts on human health can be made. Improved data and research capacity is important. Collaborative programmes already existinvolving research organisations with technical and computing capacity working in partnership with African National Hydrological and Meteorological Organisations. Activities include improving national capacities and modelling and downscaling skills. Such initiatives can be scaled up and, when coupled with health and other social and economic information, can be used in developing policy.

- Governments should work hard to ensure that hydrological and meteorological data sets are easily accessible, and, given the lifesaving potential of this valuable data, use them to inform planning and policy development. Further, data sets can be improved, and the development and application of early warning systems should be promoted. There are many examples of these throughout Africa, but many more are needed, including malaria and famine early warning systems.

- Many of the current limitations on adaptation and mitigation responses to climate-change-related health concerns in Africa are due to limited access to finance. Strategic allocation of climate finance with the aim of mitigating climate-related health risks, including those that are already prevalent, could be crucial to improving Africa's overall health status in a warming world.

As highlighted in this paper, climate change and health is a complex issue. Addressing climate change and health concerns requires integrated analysis of social, economic, environmental, and climate dimensions of development and health. The list of options above is not exhaustive, and each requires further investigation. Any feedback we receive on the content of this working paper and the options introduced will be greatly appreciated and warmly received by the ACPC (acpc@uneca.org).

References[3]

AlhassanMB ,Kyari F, Achi IB, Ozemela CP, Abiose A. 2000. Audit of outcome of cataract extraction and posterior chamber intraocular lens training course. British Journal of Ophthalmology, 2000, 84: 848–851.

Alvar J, Aparicio P, Aseffa A, Den Boer M, Canavate C, Dedet JP, *et al.*The Relationship between Leishmaniasis and AIDS: the Second 10 Years. ClinMicrobiol Rev. 2008 Apr; 21(2):334–359. Available from: http://dx.doi.org/10.1128/CMR.00061-07.

Amazigo U, Noma M, Bump J, Benton B, Liese B, *et al.* 2006. Onchocerciasis (chapter 15). In: Jamison DT, Feachem RG, Makgoba MW, Bos ER, Bingana FK, Hofman KJ, Rogo KO, editors. Disease and mortality in Sub-Saharan Africa.Second edition. Washington (D.C.): World Bank. pp. 215–222.

Anderson RM, May RM, Anderson B. 1992.Infectious Diseases of Humans: Dynamics and Control (Oxford Science Publications). New ed. Oxford University Press, USA. Available from: http://www.worldcat.org/isbn/019854040X.

Baro, Mamadouand T. F. Duebel. 2006. Persistent Hunger: Perspectives on Vulnerability, Famine, and Food Security in Sub-Saharan Africa. Annual Anthropological Review. 35:521-38.

Bern C, Maguire JH, Alvar J. 2008.Complexities of assessing the disease burden attributable to leishmaniasis.PLoSNegl Trop Dis 2(10): e313. doi:10.1371/journal.pntd.0000313.

Bikitsha N. Meningococcal meningitis in South Africa.1998. Epidemiological Comments;24:2-9.

Blaser, M. J. and D. L. Cohn. 1986. Opportunistic infections in patients with AIDS: clues to the epidemiology of AIDS and the relative virulence of pathogens. Rev. Infect. Dis. 8:21-30.

Bloem, M. W., R. D. Semba, and K. Kraemer. 2010. Castel Gandolfo workshop: An introduction to the impact of climate change, the economic crisis, and the increase in the food prices on malnutrition. The Journal of Nutrition 140: 132S–135S.

Boatin B, Richards, F. Control of Onchocerciasis. Advances in Parasitology. 2006. 61:349–394. Available from: http://dx.doi.org/10.1016/S0065-308X(05)61009-3.

Brian G, Taylor H. 2001. Cataract blindness challenges for the 21st century. Bulletin of the World Health Organization, 79: 249–256.

Campbell-Lendrum and C. Corvalan, Climate change and developing-country cities: implications for environmental health and equity, J Urban Health 84 (S3) (2007), pp. i109–i117.

Campbell-Lendrum, D. and R. Bertollini. 2009. Protecting health from climate change. Geneva: World Health Organisation.

[3] All web links live as of September 13, 2011.

Cazelles B, Chavez M, McMichael AJ, Hales S. 2005. Nonstationary Influence of El Niño on the Synchronous Dengue Epidemics in Thailand. PLoS Med. Apr;2(4):e106+. Available from: http://dx.doi.org/10.1371/journal.pmed.0020106.

Climate and Health: 10 Years On, 2011. Workshop Report available online (10 MB): http://portal.iri.columbia.edu/portal/server.pt/gateway/PTARGS_0_4972_7730_0_0_18/TR11-01_10YearsOn_WorkshopReport.pdf

Climate and Health: 10 Years On, 2011. Final Recommendations, 6 April. Available from: http://portal.iri.columbia.edu/portal/server.pt/gateway/PTARGS_0_2_7668_0_0_18/Final%2010%20Years%20On%20Recommendations_April%206.11.pdf

Coelho FC, Codeço CT, Struchiner CJ. 2008. Complete treatment of uncertainties in a model for dengue R0 estimation. Cadernos de Saúde Pública. April24(4). Availablefrom: http://dx.doi.org/10.1590/S0102-311X2008000400016.

Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Künzli N, Gutschmidt K, Pope CA III, Romieu I, Samet JM, Smith KR.2004. Urban air pollution. In: Ezzati M, Lopez AD, Rodgers A.

Collin S, Davidson R, Ritmeijer K, Keus K, Melaku Y, *et al.* 2004. Conflict and kala-azar: Determinants of adverse outcomes of kala-azar among patients in southern Sudan. Clin Infect Dis 38(5): 612–619. 10.1086/381203.

Confalonieri, U., B. Menne, R. Akhtar, K. Ebi, M. Hauengue, and R. Kovats. 2007. Human health. In M. Parry, O. Canziani, J. Palutikof, P. v. Linden, and C. Hanson (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

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

Costello, A., Abbas, M., Allen A., Ball, S., Bell, S., Bellamy R., Friel, S., *et al.*, 2009. Managing the health effects of climate change. Lancet, 373: 1693–733.

Coulson GB, von Gottberg A, du Plessis M, Smith AM, de Gouveia L, Klugman KP, et al. Meningococcal disease in South Africa, 1999–2002. Emerg Infect Dis [serial on the Internet]. 2007 Feb [date cited].Available from http://www.cdc.gov/EID/content/13/2/273.htm.

Craig M. A Climate-based Distribution Model of Malaria Transmission in Sub-Saharan Africa. Parasitology Today. 1999. March. 15(3):105-111. Available from: http://dx.doi.org/10.1016/S0169-4758(99)01396-4.

de Silva NR, Brooker S, Hotez PJ, Montresor A, Engels D, *et al.* 2003. Soil-transmitted helminth infections: updating the global picture. Trends Parasitol 19(12): 547–551.

WHO.Declaration of Helsinki. 1975. (first revision).

DeLucia, E. H., C. L. Casteel, P. D. Nabity, and B. F. O'Neill. 2008. Insects take a bigger bite out of plants in a warmer, higher carbon dioxide world. PNAS. 105 (6): 1781-1782. doi: 10.1073/pnas.0712056105.

Dobson, M. J. 1980. "Marsh Fever" the geography of malaria in England. Journal of Historical Geography. 6:357-89.

doi:10.1016/S0140-6736(05)66420-3. PMID 15850634.

Downing T, Ringius L, Hulme M, Waughray D. Adapting to climate change in Africa. Mitigation and Adaptation Strategies for Global Change. 1997. Mar;2(1):19–44. Available from: http://dx.doi.org/10.1007/BF02437055.

Dunn, R. R., T. J. Davies, N. C. Harris, and M. C. Gavin. 2010. Global drivers of human pathogen richness and prevalence. Proceedings of the Royal Society B: Biological Sciences. DOI: 10.1098/rspb.2010.0340.

Ebi KL, Semenza JC. Community-Based Adaptation to the Health Impacts of Climate Change.American Journal of Preventive Medicine. 2008 Nov;35(5):501–507. Available from: http://dx.doi.org/10.1016/j.amepre.2008.08.018.

EM-DAT: The OFDA/CRED International Disaster Database. 2007. Availableat www.em-dat.net, Université Catholique de Louvain, Brussels, Belgium.

Epstein PR. Chikungunya fever resurgence and global warming. Amer J Trop Med Hyg;76:403–404. Availablefrom: http://www.fujipress.jp/finder/xslt.php?mode=presentand#38;inputfile=DSSTR000300020002.xml.

Epstein PR. Is Global Warming Harmful to Health? Scientific American. 2000 Aug;283(2):50–57. Available from: http://dx.doi.org/10.1038/scientificamerican0800-50.

Epstein, P., and E. Mills. 2005. Climate Change Futures: Health, Ecological, and Economic Dimensions. Boston: Harvard Medical School.

Ettling, M; McFarland DA, Schultz LJ, Chitsulo L. 1994."Economic impact of malaria in Malawian households". Trop Med Parasitol (Tropical Medicine and Parasitology) (Routledge) (45 (1)): 74–9.

FAO. 2006. State of Food Insecurity in the World 2006. Food and Agriculture Organization of the United Nations, VialedelleTerme di Caracalla, 00153 Rome, Italy ISBN 92-5-105580-7.

Funk, C., M. D. Dettinger, J. C. Michaelsen, J. P. Verdin, M. E. Brown, M. Barlow, and A. Hoell. 2008. Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. PNAS 105 (32): 11081–11086.

Githeko, A. K., S. W. Lindsay, U. E. Confalonieri, and J. A. Patz. 2000. Climate change and vector-borne diseases: a regional analysis. Bull World Health Organ. 78(9) Genebra. DOI: 10.1590/S0042-96862000000900009.

Global Alliance to Eliminate Lymphatic Filariasis (GAELF).2005. Global alliance to eliminate lymphatic filariasis—progress as of January 2005.

Gould E. 1997. Dengue and dengue haemorrhagic fever D. J. Gublerand G. Kuno (editors). Wallingford: CAB International,.xii+478pp. Price £75.00 (US$ 135.00). ISBN 0-85199-134-3.Transactions of the Royal Society of Tropical Medicine and Hygiene. 1998 Apr;92(2):239+. Available from: http://dx.doi.org/10.1016/S0035-9203(98)90768-4.

Grover-Kopec, E., M. B. Blumenthal, P. Ceccato, T. Dinku, J. A. Omumboand S. J. Connor. 2006. Web-based climate information resources for malaria control in Africa. Malaria Journal 5:38 doi:10.1186/1475-2875-5-38.

Gubler D. 2005. The emergence of epidemic dengue fever and dengue hemorrhagic fever in the Americas: a case of failed public health policy. Rev PanamSaludPublica [serial on the Internet]. 17(4): 221-224. Available from: http://www.scielosp.org/scielo.php?script=sci_arttextandpid=S1020-49892005000400001andlng=en. doi: 10.1590/S1020-49892005000400001.

Hay SI, Guerra CA, Gething PW, Patil AP, Tatem AJ, Noor AM, *et al.* A World Malaria Map: Plasmodium falciparum Endemicity in 2007. PLoS Med. 2009 Mar;6(3):e1000048+. Available from: http://dx.doi.org/10.1371/journal.pmed.1000048.

Hay, S. I., D. J. Rogers, S. E. Randolph, D. I. Stern, J. Cox, G. D. Shanks and R. W. Snow. 2002. Hot topic or hot air?: Climate change and malaria resurgence in East African highlands. TRENDS in Parasitology 18 (12): 530-534.

Hernes, H., Dalfelt, A., Berntsen, T., Holtsmark, B., Naess, L.O., Selrod, R. and A. Aaheim (1995): Climate Strategy for Africa. Cicero Report No. 3, Cicero, Oslo, Norway, 83pp, cited in Balakrishna, P. and E. Warner (2003), op. cit.

Hewitson BC, Crane RG. Climate downscaling: techniques and application. Climate Research. 1996;7:85–95. Available from: http://dx.doi.org/10.3354/cr007085.

Hotez PJ, Bethony J, Bottazzi ME, Brooker S, Buss P. Hookworm: "The Great Infection of Mankind". PLoS Med. 2005 Mar;2(3):e67+. Available from: http://dx.doi.org/10.1371/journal.pmed.0020067.

Hotez, P. J. and A. Kamath. 2009. Neglected Tropical Diseases in Sub-Saharan Africa: Review of Their Prevalence, Distribution, and Disease Burden. PLoSNegl Trop Dis. 3(8): e412. DOI: 10.1371/journal.pntd.0000412.

Hutchinson RA, Lindsay SW. Malaria and deaths in the English marshes.The Lancet. 2006 Jun;367(9526):1947–1951. Available from: http://dx.doi.org/10.1016/S0140-6736(06)68850-8.

IPCC (WGI). 2001a. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. J.T. Houghton and Ding Yihui, eds. Cambridge: Cambridge University Press.

IPCC (WGII). 2001b. 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: Cambridge University Press.

IPCC (WGII) 2007, Chapter 9. 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.

IPCC. 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., *et al.* (eds.)]. Cambridge University Press, Cambridge, U.K., and New York, N.Y., U.S.A. "http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm" (Viewed 2010-04-24)

Jackson, M. C., Johansen, L., Furlong, C., Colson, A. and Sellers, K. F. 2010.Modelling the effect of climate change on prevalence of malaria in western Africa.StatisticaNeerlandica, 64: 388–400.

Jd S, Mh M. the magnitude of the global problem of acute diarrhoeal disease: a review of active surveillance data. bull world health organ. 1982;60:604–613.

Joubert AM, Hewitson BC. Simulating present and future climates of southern Africa using general circulation models.Progress in Physical Geography. 1997 Mar;21(1):51–78. Available from: http://dx.doi.org/10.1177/030913339702100104.

Kovats, S., K. Ebi, ,and B. Menne. 2003. Health and Global Environmental Change - SERIES No. 1. Geneva: World Health Organisation.

Küstner H. Meningococcal infection—changing epidemiological patterns in South Africa.Epidemiological Comments. 1979. p. 1-15.

Labonte, R. T. Schrecker, D. Sanders, W. Meeus. 2004. Fatal indifference: the G8, Africa and global health. Landsdowne, South Africa: University of Cape Town Press.

Leroy, M. 2009. Environment and conflict in Africa: reflections on Darfur. Addis Abab, Ethiopia: University for Peace.

Levy, J. I., S. M. Chemerynski, and J. A. Sarnat. 2005. Ozone exposure and mortality: an empiric bayesmetaregression analysis. Epidemiology. 16: 458–468.

Libreville, 2008 (WHO, 2009).The Libreville Declaration on Health and Environment in Africa.Available online:
http://www.afro.who.int/index.php?option=com_docmanandtask=doc_downloadandgid=3286

Luanda, 2010a. The African Ministers of Health and Environment Joint Statement on Climate Change and Health.Available online:
http://www.afro.who.int/index.php?option=com_docmanandtask=doc_downloadandgid=6068

Luanda, 2010b. The Health and Environment Strategic Alliance for the Implementation of the Libreville Declaration. Available online:

http://www.afro.who.int/index.php?option=com_docmanandtask=doc_downloadandgid=6071

Lynch, J., P. Due, C. Muntaner, and G. Davey Smith. 2000. Social capital—Is it a good investment strategy for public health? J Epidemiol Community Health. 54:404-408 doi:10.1136/jech.54.6.404.

Manderson L, Aagaard-Hansen J, Allotey P, Gyapong M, Sommerfeld J. 2009. Social Research on Neglected Diseases of Poverty: Continuing and Emerging Themes. PLoSNegl Trop Dis. 3:e332. doi: 10.1371/journal.pntd.0000332.

Mangal TD, Paterson S, Fenton A. 2008. Predicting the impact of long-term temperature changes on the epidemiology and control of schistosomiasis: A mechanistic model.PLoS ONE 3(1): e1438. doi:10.1371/journal. pone.0001438.

Marmot M, Friel S, Bell R, Houweling TAJ, Taylor S. Closing the gap in a generation: Health equity through action on the social determinants of health. Lancet. 2008; 372(9650): 1661–1669.

Martens P, Hall L. Malaria on the move: human population movement and malaria transmission. Emerging infectious diseases. 2000. 6(2):103–109. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2640853/.

Mccarthy JJ. Climate Change 2001: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2001. Available from: http://www.grida.no/climate/ipcc_tar/.

McMichael A, Haines A, Kovats R, Slooff R. Climate Change and Human Health. 1996;Available from: http://www.deepdyve.com/lp/springer-journals/a-j-mcmichael-a-haines-r-sloof-s-kovats-eds-climate-change-and-human-p0dZ2hV8MY.

McMichael AJ, Hanke T. HIV vaccines 1983â“2003.Nature Medicine. 2003 Jul;9(7):874–880. Available from: http://dx.doi.org/10.1038/nm0703-874.

McMichael, A., D. Campbell-Lendrum, C. Corvalán, K. Ebi, A. Githeko, and J. Scheraga. 2003. Climate change and human health: risks and responses. Geneva: World Health Organisation.

McMichael, A.J. 2004. Environmental and Social Influences on Emerging Infectious Diseases: Past, Present and Future. Philosophical Transactions of the Royal Society B: Biological Sciences 359(1447): 1049- 1058.

McMichael, A. J., R. E Woodruff, and S. Hales. 2006. Climate change and human health: present and future risks. Lancet 367: 859–69.

Menactra. 2011. Menactra: Causes and Presentations of Invasive Meningococcal Disease (IMD). Menactra: Meningococcal (Groups A, C, Y and W-135) Polysaccharide Diphtheria Toxoid Conjugate Vaccine. Retrieved August 27, 2011, from http://menactra.ca/index.cfm?fa=view.showandcname=Causes

Michael E. Global mapping of lymphatic filariasis.Parasitology Today. 1997 Dec;13(12):472–476. Available from: http://dx.doi.org/10.1016/S0169-4758(97)01151-4.

Molyneux DH, Hotez PJ, Fenwick A (2005) "Rapid-impact interventions": how a policy of integrated control for Africa's neglected tropical diseases could benefit the poor. PLoS Med 2(11): e336. doi:10.1371/journal.pmed.0020336.

Murray CJL, Lopez AD. 1996. A comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. In: Murray CJL, Lopez AD, editors. The global burden of disease. Cambridge (MA): Harvard School of Public Health.

Pamlgren, H. 2009. Meningococcal disease and climate, in Climate change and infectious disease. Umea˚, Sweden: CoAction Publications.

Pascual, M., J. A. Ahumada, L.F. Chaves, X. Rodo, M. Bouma.2006. Malaria resurgence in the East African highlands: Temperature trends revisited. Proceedings of the National Academy of Sciences of the United States of America 103: 5829–5834.

Patz, J., D. Campbell-Lendrum, T. Holloway, and J. Foley. 2005. Impact of regional climate change on human health. Nature. 438:310-317.

Poverty and climate change: reducing the vulnerability of the poor through adaptation; 2003.

Prüss-Üstün, A. and C. Corvalán. 2006. Preventing disease through healthy enviroments. Geneva: World Health Organisation.

PWRI (The Public Works Research Institute). 2008. Technical report on the trends of global water-related disasters. Technical Note No. 4088, Tsukuba, Japan,PWRI.

Ramin, B. M. and A. J. McMichael. 2009. Climate change and health in sub-Saharan Africa: a case-based perspective. Ecohealth 6 (1): 52-57.

Randolph SE, Rogers DJ. 1997. A generic population model for the African tick Rhipicephalusappendiculatus. Parasitology. 1997;115(03):265–279. Available from: http://dx.doi.org/10.1017/S0031182097001315.

Randolph, S. E. 2004 Evidence that climate change has caused `emergence' of tick-borne diseases in Europe?, International Journal of Medical Microbiology Supplements, Proceedings of the VII International Potsdam Symposium on Tick-Borne Diseases. 293(37): 5-15, ISSN 1433-1128, DOI: 10.1016/S1433-1128(04)80004-4. http://www.sciencedirect.com/science/article/B7W65-4GWT3V0-4/2/d667c32fa021c22335ebd62df88db180. (Viewed 2010-04-24).

Reithinger R, Brooker S, Kolaczinski JH (2007) Visceral leishmaniasis in eastern Africa—current status. Trans R Soc Trop Med Hyg 101(12): 1169–1170. 10.1016/j.trstmh.2007.06.001.

Rogers, D.J. 1993. Remote sensing and the changing distribution of tsetse flies in Africa. Insects in a Changing Environment, R. Harrington and N. Stork (eds), pp. 178-193.

Rogers, D.J., and S.E. Randolph. 1993. Distribution of tsetse and ticks in Africa, past, present and future. Parasitol. Today 9:266-271.

Rogers, D.J., Packer, M.J. 1993. Vector-borne diseases, models, and global change. The Lancet 342, 1282–1284.

Rogers, David J, Packer, Michael J, Lancet, 1993. Vector-borne diseases, models, and global change.Parasitol Today. 342 (8882). Rogers DJ, Randolph SE. Distribution of tsetse and ticks in Africa: past, present and future. 1993; 9: 266-72.

Sachs J, Malaney P. 2002. "The economic and social burden of malaria". Nature 415 (6872): 680–5. doi:10.1038/415680a. PMID 11832956.

Sapkota, A., J.M. Symons, and J. Kleissl. 2005. Impact of the 2002 Canadian forest fires on particulate matter air quality in Baltimore city. Environ SciTechnol. 39: 24–32.

Schaible, U. E. and S. H. E. Kaufmann.2007. Malnutrition and Infection: Complex Mechanisms and Global Impacts. PLoS Med. 4(5):e115. DOI: 10.1371/journal.pmed.0040115.

Schmidhuber J. and F. N. Tubiello. 2007. Global food security under climate change. PNAS 140 (50): 19703–19708.

Shuster-Wallace, C. J., V. I. Grover, Z. Adeel, U. Confalonieri, S. Elliott. 2008. “Safe Water as the Key to Global Health.” © The United Nations University, 2008.

Snow, R. W., C. A. Guerra, A. M. Noor, H. Y. Myint, and S. I. Hay. 2005. The global distribution of clinical episodes of Plasmodium falciparum malaria. Nature. 434(7030): 214–7. doi:10.1038/nature03342.

Sperling, Frank ed. 2003. Poverty and Climate Change: Reducing the Vulnerability of the Poor through Adaptation, report by the African Development Bank, Asian Development Bank, UK Department for International Development (UK), Federal Ministry for Economic Co-operation and Development (Germany), Ministry of Foreign Affairs – Development Co-operation (Netherlands), OECD, United Nations Development Programme, United Nations Environment Programme and World Bank.

Steinmann P, Keiser J, Bos R, Tanner M, Utzinger J. 2006.Schistosomiasis and water resources development: systematic review, meta-analysis, and estimates of people at risk. Lancet Infect Dis 6(7): 411–425. 10.1016/S1473-3099(06)70521-7.

Stern, Nicholas. 2006. The Economics of Climate Change, The Stern Review, Cambridge University Press.

Sutherst, R. W. 2004. Global change and human vulnerability to vector-borne diseases.Clin.Microbiol.Rev. 17:136-173.

Thomas C. Environmental and Health Research: Overlapping Agendas. Global Environmental Politics. 2001 Nov;1(4):10–17. Available from: http://dx.doi.org/10.1162/152638001317146345.

Thomson, M. C., I. Jeanne and M. Djingarey. 2009. Dust and epidemic meningitis in the Sahel: a public health and operational research perspective. IOP Conf. Series: Earth and Environmental Science 7 012017 doi:10.1088/1755-1307/7/1/012017.

Tulu, A. N. 1996. Determinants of malaria transmission in the highlands of Ethiopia. The impact of global warming on morbidity and mortality ascribed to malaria. PhD thesis, University of London.

UNEP. 2002: Vital climate graphics. United Nations Environment Programme. Retrieved August 27, 2011 from http://www.grida.no/publications/vg/africa/

UNFCCC. 2007. Climate change: impacts, vulnerabilities and adaptation in developing countries. United Nations Framework Convention on Climate Change Secretariat. Seehttp://unfccc.int/resource/docs/publications/impacts.pdf.

Walsh DS, Portaels F, Meyers WM (2008) Buruli ulcer (mycobacterium ulcerans infection). Trans R Soc Trop Med Hyg 102(10): 969–978. 10.1016/j.trstmh.2008.06.006.

Watts, G. 2009. The health benefits of tackling climate change. The Lancet Series.

WHO. 1988. Persistent diarrhoea in children in developing countries: memorandum from a WHO meeting. BLT.66:709.

WHO. 1990. (World Health Organisation) Tropical Diseases, 4-15. Geneva, Switzerland.

WHO. 1995. World health report 1995. Geneva.

WHO. 1996. World Health Report 1996: fighting disease, fostering development, Geneva: WHO. See http://www.who.int/whr2001/2001/archives/1996/index.htm.

WHO. 1997. International Agency for Research on Cancer "Solar and ultraviolet radiation" IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 55, November 1997.

WHO, 1998.Control of epidemic meningococcal disease.WHO practical guidelines.2nd edition 1998. WHO/EMC/BAC/98.3. Available from:
http://www.who.int/csr/resources/publications/meningitis/whoemcbac983.pdf

WHO. 2000. International Agency for Research on Cancer "Do sunscreens prevent skin cancer" Press release No. 132, June 5, 2000.

WHO. 2002. The World Health Report 2002. Reducing risks, promoting healthy life.World Health Organization, Geneva (last accessed 14 May 2002).

WHO.2002b. Global Health Observatory, Mortality and burden of disease, deaths, 2002 (date accessed 17/06/10).

WHO. 2004. Using climate to predict infectious disease outbreaks: a review. © World Health Organization 2004. Communicable Diseases Surveillance and Response, Protection of the Human Environment, Roll Back Malaria, Geneva, 2004.

WHO. 2006. African trypanosomiasis (sleeping sickness).

WHO. 2006. Neglected tropical diseases. Hidden successes, emerging opportunities. Geneva: WHO; WHO/CDS/NTD/2006.2.

WHO. 2006. Vaccine Preventable Diseases: Monitoring system. http://www.who.int/vaccines-documents/GlobalSummary/GlobalSummary.pdf. (Viewed 2010-04-24).

WHO. 2006. World Health Organization 2006 Human African trypanosomiasis (sleeping sickness): epidemiological update. WklyEpidemiol Rec. 81(8). : 71–80.

WHO. 2008. Buruli ulcer: Progress report, 2004–2008. WklyEpidemiol Rec. 83(17). : 145–154.

WHO. 2008. Dracunculiasis eradication. WklyEpidemiol Rec. 83(18). : 159–167.

WHO. 2008. Global health atlas. Global Alliance for the Elimination of Blinding Trachoma database.

WHO. 2008. Global leprosy situation, beginning of 2008. WklyEpidemiol Rec. 83(33). : 293–300.

WHO.2008. Status of onchocerciasis in APOC countries". 2008.

WHO. 2009. "Dracunculiasis Epidemiological Data (1989-2008)". World Health Organization. http://www.who.int/dracunculiasis/epidemiology/Epidemiological_data.pdf. (Viewed 2010-04-24).

WHO. 2009. Protecting health from climate change: global research priorities. World Health Organization. Geneva, Switzerland: WHO Press.

WHO. 2009. "State of the world's vaccines and immunization. Third edition".2009-11-24. http://www.who.int/immunization/sowvi/en/index.html.(Viewed 23 April 2010).

WHO.2009. WHO World Malaria Report 2009. http://whqlibdoc.who.int/publications/2009/9789241563901_eng.pdf. (Viewed 2010-04-24).

WHO, 2010.World Malaria Report 2010.

World Resources Institute (WRI). 2007. Earth Trends. Available at http://www.wri.org.(Viewed 2010-04-24).

Yorston David, AbioseAdenike, Congdon Nathan, Prajna N. Venkatesh, Venkataswamy G., Gritz David C. Discussion. Bull World Health Organ [serial on the Internet]. 2001 [cited 2011 Sep 12] ; 79(3): 257-261. Available from: http://www.scielosp.org/scielo.php?script=sci_arttextandpid=S0042-96862001000300016andlng=en. http://dx.doi.org/10.1590/S0042-96862001000300016

Zagaria N, Savioli L (2002) Elimination of lymphatic filariasis: a public-health challenge. Ann Trop Med Parasitol 96: Suppl 2S3–S13. Available from: http://dx.doi.org/10.1179/00034980215002347.