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Working Paper 20

Climate change and Health Across Africa: Issues and Options

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CLIMATE CHANGE AND HEALTH ACROSS AFRICA: ISSUES AND OPTIONS

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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	Ultra-Violet
WHO	World Health Organization

Abstract

Climate change is expected to alter temperature, air movement, and precipitation in various ways and to varying degrees across Africa with consequences for human health. With the strong connection between a population's health and economic and environmental health, the impact of climate change on each is one of the major ways in which climate change may impede the development of the African continent.

African countries will suffer health consequences due to impacts of climate change as many African countries have populations that are among the most vulnerable to climatic changes in the world. This vulnerability is due in part to existing problems of poverty, weak institutions and armed conflict, which limit a population's capacity to deal with the additional health challenges posed by climate change. The relative impact of climatic and socioeconomic factors is generally difficult to quantify. This complexity in turn affects the certainty of studies and policies on the health impact of climate change on Africa.

The majority of human health problems that can be linked to climate change are not strictly speaking created by changes in climate but are problems exacerbated by changing weather patterns and climatic conditions leaving populations ill prepared for new health impacts. For example, climate change may affect health through 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 pathogen life cycle and range affecting rate of infections, especially 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 African populations than in European populations for example.

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 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 direct and indirect impacts of environmental factors on health across Africa. While there are many uncertainties in magnitudes of climate change, particularly with timing, the existing literature makes interesting observations about potential health impacts and the populations that could be most at risk. The working paper presents the potential impacts climate change may have on human health and analyses the various direct and indirect impacts that climate change will have on African populations. Due to the emerging nature of the issue and literature, there are many gaps in knowledge on the impacts climate change will have on human health.

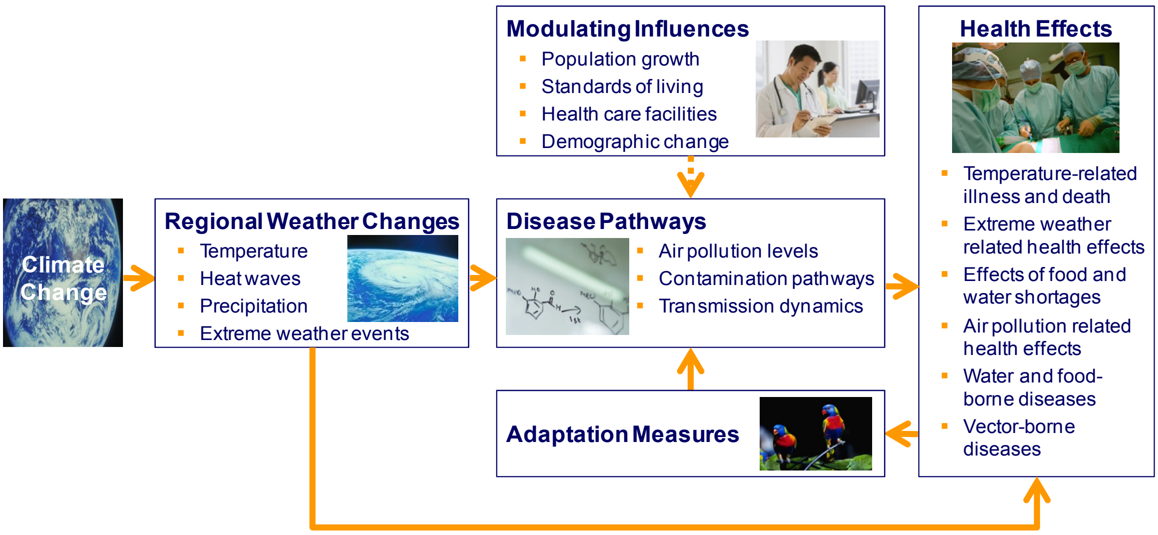
Importantly Africa is already addressing climate and health, and examples include "The Libreville Declaration on Health and Environment in Africa" by African Ministers of Health and Ministers of Environment, along with grass roots actions such those being taken by the Climate and Health Working Group in Ethiopia and elsewhere. In terms of policy an important question is: what should be done differently to address health concerns across Africa given what we expect in terms of climate change? In some cases it may be more of the same (e.g. the use of mosquito nets and other measures to prevent malaria). In other cases effective preparation or response may require completely different approaches to health care across the continent.

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 movement, and precipitation in various ways and to varying degrees across Africa with consequences on human health. With the strong connection between a population's health and economic and environmental health, the impact of climate change on each is one of the major ways in which climate change may impede the development of the African continent (IPCC, 2001; Sperling, 2003; Stern, 2006).

African countries will suffer serious health consequences due to impacts of climate change. Many African countries have populations that are among the most vulnerable to climatic changes in the world. This vulnerability is due in part to existing problems of poverty, weak institutions and armed conflict, which limit their capacity to deal with the additional health challenges posed by climate change. The relative impact of climatic and socioeconomic factors is generally difficult to quantify. This complexity in turn affects studies and policies on the health impact of climate change on Africa. In general, 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).

Figure 1: Potential health effects of climate change and health. Adapted from Patz *et al.* (2000).



The majority of human health problems that could be linked to climate change are not strictly speaking created by changes in climate. Rather, they are problems exacerbated or intensified by changing weather patterns and other climatic conditions leaving population un-or-ill-prepared for new health impacts. 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) each of which are drivers of malnutrition and changes in the distribution of diseases. Rising temperatures will affect pathogen life cycle and range affecting rate of infections, especially 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 associated with weather changes 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 world's populations as loss of healthy life years as a result of climate change is predicted to be 500 times greater in poorer African populations than in richer European populations (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 the current state of direct and indirect impacts of environmental factors on health in Africa. While there are many uncertainties in magnitudes of climate change, particularly with timing, the existing literature makes interesting observations about potential health impacts and the populations that could be most at risk.

The sections below will:

- identify current health issues across Africa;
- introduce the current understanding of changes in temperature, precipitation, and extreme weather events expected as part of climate change across Africa;
- present the potential impacts climate has on human health;
- analyse the various direct and indirect impacts that climate change will have on African populations;
- acknowledge and discuss gaps in knowledge of the impacts climate change will have on human health, and;
- assess options and the way forward to address climate change and health across 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 existing *status quo* and the historic links between climate and health. The latter relates 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 the continent is related to tropical climate across Africa. In future, however, the nature and spread of malaria across the continent may well be affected by the changes in temperature and precipitation expected within the continent.

In general, climate change will act to increase or decrease the prevalence of disease, injury or other health issues. However, it is difficult to gauge, in terms of numbers, how many more or less people will be affected in different parts of Africa, what changes in mortality there may be or the changes in Disability Adjusted Life Years (DALYs). This uncertainty is due mainly to the scarcity of models that can robustly predict patterns of climate change at national and local scales. In addition to this, many African countries currently experience a lot of socio-economic challenges, while compounding the effects of climate change on health, are difficult to separate out from those caused by climate change.

Accordingly, a critical issue for African countries and governments is not just the influence climate change may have on health, but what needs to be done to improve health services and conditions generally and especially taking into account climate change. This can be referred to as the policy dimension of climate change and health aimed at driving mitigation and adaptation measures to improve African human health. Perhaps the most important question is: what should be done differently to address health concerns across Africa given what we expect in terms of climate change? In some cases it may be more of the same (e.g. the use of mosquito nets and other measures to prevent malaria). In other cases effective preparation or response may require completely different approaches to health care across the continent.

Climate change trends across Africa

The IPCC report (2007) and the African Climate Trends and Projections report (2007) provide a good summary of key trends and outlines based on the best available projections for climate change in Africa. These are summarised below:

- With respect to temperature:
  - Land areas of the Sahara and semi-arid parts of southern Africa may warm by as much as 1.6°C (Hernes *et al.*, 1995; Ringius *et al.*, 1996).
  - In that time, equatorial countries (eg: Cameroon, Uganda, and Kenya) might warm about 1.4°C.
  - Sea-surface temperatures in the open tropical oceans surrounding Africa are expected to increase less than the global average, only about 0.6-0.8°C, therefore the coastal regions of the continent are expected to warm more slowly than the continental interior.
- Precipitation changes expected by most GCMs indicate relatively modest moisture increases over most of the continent.
  - Although southern Africa and parts of the Horn of Africa should expect a decline by about 10%.
  - Seasonal changes in rainfall are not expected to be large (Joubert & Tyson, 1996; Hewitson & Crane, 1996).
  - Parts of the Sahel could experience the greatest increases in rainfall by as much as 15% over recent averages. It is important to note here, however, that this rise in rainfall would follow a drought that has lasted 30 years in the region.
  - Equatorial Africa could experience a small (5%) increase in rainfall.
- Extreme weather events (EWEs) are still poorly understood and conclusive evidence as to changes in their frequency is not agreed upon in the literature.
  - Currently occurring EWEs that the African population need to contend with are heatwaves, droughts, and heavy precipitation).
  - Although their prevalence is not expected to change much (IPCC, 2007), their compounding effects on other climate changes are a cause for concern.

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

Impacts on Health

When addressing climate change and health it is important to be aware that climate change can directly and indirectly impact health. Direct health impacts affect human biology directly and include injury, morbidity and mortality caused by climate-induced EWEs (such as cyclones, floods, and droughts), thermal stress (heatwaves and cold periods), skin and eye damage (via 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. Indirect impacts affect non-human biogeochemical systems and include malnutrition (due to decrease crop success), water insecurity and quality changes, lifecycle and range of pathogens via water and vectors. The classification of direct and indirect heath impacts of climate is a bit complex but Table 1 below provides a summary of the breakdown used for the purposes of this paper.

Table 1: Health related impacts of climate change (The Smith School of Enterprise and the Environment, 2010).

	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

It is important to stress that climate and climate change are only some of the impacts human health is influenced by. As stated, health outcomes are usually the result of complex interactions between social, cultural, and economic characteristics, geographic settings, and pre-existing health status. Given that much of the health impact of climate change in Africa will be via the indirect route, we discuss these first before turning to the direct heath effects.

Indirect impacts

The potential indirect health effects of climate change on a communities' health will occur predominantly through changes to non-human biological or biogeochemical systems. This includes changes in crop yield, geographical range and distribution of infectious diseases and their methods of transport and results of additional social pressures that result from changes in rainfall and temperature. Ultimately these climatic changes place pressure on ill-prepared human support systems beyond food and water security and the capacity to manage already stressed health care systems.

Malnutrition

Good nutrition is essential for good health. Deficiencies in energy, fat, protein, nutrient or vitamin intake lead to malnutrition with major consequences for peoples' physical and mental health. Malnutrition has detrimental and lasting health consequences often limiting a person's physical and intellectual development, particularly those who are affected as infants or as young children. Additionally, malnutrition vastly increases peoples' susceptibility to acquiring, and dying from infectious diseases (Baro & Duebel, 2006; Schaible & Kaufmann, 2007; Confalonieri *et al.*, 2007). It affects groups of people who are most vulnerable to changing environmental patterns, such as farmers and coastal communities, and those who are least able to purchase food such as the poor and landless wage labourers.

Malnutrition is considered the most important health risk globally as it accounts for an estimated 15% of total disease burden in DALYs. At present, under-nutrition causes 1.7 million deaths per year in Africa and is currently 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 food-insecure countries (Bloem *et al.*, 2010, p. 133S; Schmidhuber & Tubiello, 2007, p. 19704). Bloem *et al.* (2010) explain that access to food relies on two key factors: availability (through the market or subsistent production) and affordability (through monetary income). Available evidence strongly indicates that climate change will negatively affect food availability and affordability across African countries.

In terms of availability, changing temperatures, humidity, and precipitation are expected to disrupt agricultural production systems in different parts of Africa requiring the need for adaptation. Examples of climate impacts affecting food security include salinisation of agricultural regions, changes in crop range, and migrating crop pests (Confalonieri *et al.* 2007; Schmidhuber & Tubiello, 2007, p. 19704). In Ethiopia, for example, significant rainfall reductions have already been observed within critical crop-growing areas (Funk *et al.*, 2007, p. 11086) and this has been attributed to anthropogenically influenced warming of the Indian Ocean (Funk *et al.*, 2007). Effects of this are being observed now as severe drought, resulting in famine, in the eastern African nations of Djibouti, Somalia, Ethiopia and Kenya.

There are a number of other grim predictions regarding climate change and food production in Africa. For instance: increased temperatures can be expected and dry areas are expected to experience increased evaporation resulting in lower soil moisture; tropical grasslands may become more arid. Therefore, semi-arid and arid regions should expect: decreased livestock productivity; winter survival of pest species should increase putting more spring crops at risk; and , human pathogen survival is expected to increase along with the probability of food poisoning. The latter has been observed as food bacteria such as *Salmonella* proliferate more rapidly in warmer temperatures (Schmidhuber & Tubiello, 2007, p. 19704; McMichael *et al.*, 2006. p, 860). While climate change may have the effect of improving food production in some temperate regions of the world - due to elevated CO_2 concentrations in the atmosphere and extended growing seasons - it is largely expected to have negative effects across Africa and other relatively food-insecure regions (Schmidhuber & Tubiello, 2007, p. 19704).

With regards to affordability, decades of data show correlations between food prices and the nutritional status of the poor (Bloem *et al.*, 2010, p. 133S). World food prices are particularly important for food access across Africa and developing countries in general, because these societies are more reliant on purchased food than domestically produced food (Bloem *et al.*, 2010, p. 133S). Although, it is recognised that even for countries that are net food exporters, there may still be insecurity of access to food at the individual level (Schmidhuber and Tubiello 2007). Without significant improvements in agricultural yields through improved practices, across Africa, reliance on food imports will make African countries vulnerable to the global food prices.

Grain is a significant indicator of food production as it accounts for 70% of global food energy (McMichael, *et al.*, 2003). Some of the effects of increased food prices have already manifested in many African countries. The upsurge in food prices preceding the financial, and global economic crisis of 2008, resulted in a decline in food access and overall micro-nutrient malnutrition for the developing world, as individuals simultaneously lost purchasing power as a result of reduced income in failing economies (Bloem *et al.*, 2010, p. 133S).

Generally, expectations are that food prices will rise moderately in line with increases in temperature until 2050. After 2050, however, food prices are expected to increase substantially as temperatures further increase, with the value of sugar and rice, for example, expected to rise by 80% (Schmidhuber & Tubiello, 2007, p. 19706). Some studies indicate the first couple of degrees of climate warming may lead to an overall increase in some grain outputs but that any profit in this may 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 10% (Brown, 2003). Given that the IPCC estimates a 2°C temperature increase in the 21st century one can, on the basis of Brown's study predict 20% reduction in grain output worldwide by the end of this century. Meanwhile, others indicate that grain yield may increase marginally within a narrow range of temperature change. These conflicting conclusions are based on lack of certainty and understanding of changing precipitation.

Across Africa, climate change is expected to have the effect of compounding reduced access to food which as stated is already a major problem in many African countries (Schmidhuber & Tubiello, 2007, p. 19703). A 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 the contribution of climate change to malnutrition is an important step towards effective adaptation through good governance. Similarly, further understanding of local effects of climate change on food yields, nutritional quality and price will contribute to developing strategies to protect future populations from the potential danger of changing weather patterns.

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, vector organisms or with contaminated substances (water, food, objects, and air). Climate changes are expected to affect the lifecycle 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 affect on the rate of pathogen replication and maturation. Further, these two climate factors also affect the survivability and density of vectors in a particular area therefore increasing 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 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). Depending on the region, carrier (water or vector), disease, and mitigation strategies, the change in climate will impact disease distribution, rate of contagion and transmission seasons with different levels of intensity. This report focuses on selected water- borne and vector- borne diseases based on their current and expected toll on people across 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. In our report, we divide our focus communicable diseases into a discussion of neglected tropical diseases (NTDs); water born diseases, with emphasis on diarrhoea; then onto vector born diseases, with emphasis on Malaria; we introduce meningitis separately as an airborne disease; followed by HIV and social status for their compounding effects on community health.

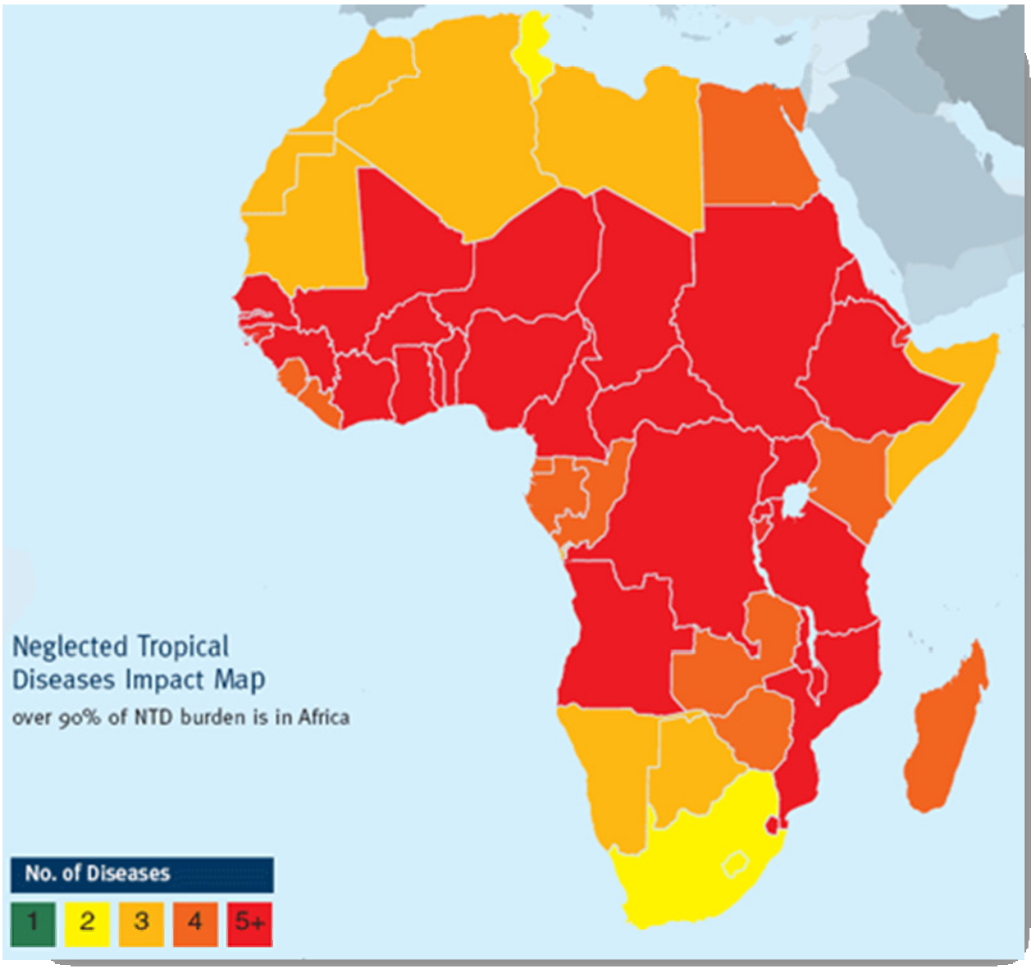
Neglected Tropical Diseases

The Neglected Tropical Diseases1 (NTDs) are the most common conditions affecting the poorest 500 million people living in Sub-Saharan Africa (SSA). The 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 WHO1 (Figure 2). Together, NTDs produce a burden of disease that may be equivalent to up to one-half of SSA's malaria disease burden 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 helminths infections (see footnote 1) account for up to 85% of the disease burden caused by NTDs and occur in more than half of SSA's poorest people (Table 2; Hotez, 2003 & 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, other EWEs, and air pollution (Campbell-Lendrum & C. Corvalan, 2007). Due to their connection with water and other organisms, the effect that climate change

[1] The WHO listed NTDs include soil transmitted helminths (roundworms such as Ascaris lumbricoides which causes ascariasis, whipworm which causes trichuriasis, 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.

has on the spreading of communicable diseases is in increasing the range and seasonal duration of suitable conditions for communicable pathogens to survive. Also note that in the survivable range of temperatures a pathogen can survive, there is a maximum.

Figure 2: Distribution of the prevalence of NTDs in Africa. Source: Imperial College London, Schistosomiasis Initiative (available at: http://www3.imperial.ac.uk/schisto/whatwedo/ntdsinafrica).



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

Table 2: Examples of NTDs affected by climate change. (Hotez & Kamath, 2009 [http://goo.gl/qgFIA & http://goo.gl/XJdpT]).

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%	Steinmannet 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 & Bundy, 1997; GAELF, 2005 & 2008; Zagaria & Savioli, 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

* SSA – sub-Saharan Africa.

Until recently, very few studies have been carried out regarding the connection of NTDs with 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 carrier) according the proportion of SSA's population affected, from the highest percentage to the lowest.

This is a large disease category that, based on regions of highest prevalence (Table 2), appears to be primarily the result of poverty (Manderson, 2009). Due to lack of attention outside these areas, little is currently known about the pattern of the spread of these diseases and their potential links to climate change or more broadly, the "environmental constraints keeping a species within its characteristic range" (Rogers and Packer, 1993). Below we look at the diseases in two categories based on primary modes of pathogen transmission: water born and vector born diseases.

Water born diseases

Water-borne diseases are caused by protozoa, viruses or bacteria which 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 distributions worldwide (IPCC, 2007). The IPCC expects water availability and quality to be affected in various parts of Africa posing a threat to human populations.

Currently almost two million deaths a year, mostly in young children, are caused by conditions that are attributable to unsafe water and lack of basic sanitation (Confalonieri *et al.*, 2007). Water-borne disease is extremely prevalent 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 disease after extreme climate-change-related weather events, such as floods or heavy rainfall or unseasonably warm seasons (such as longer warm periods, extending growing seasons)are expected to be particularly high in Africa due to limited infrastructure and control programs at the sources of these diseases (Schmidhuber & Tubiello, 2007, p. 19705).

Perhaps surprisingly, droughts may also cause increases in communicable diseases, as reduced river flow may result in increased pathogen loading as 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 the occurrence of droughts as reflected by the recent spread of the disease into West Africa.

The water borne NTDs are mostly preventable by water filtration, case containment, and access to safe water. This technique alone has been success in bringing the transmission and annual cases of Drancunculiasis (guinea worm) down to only 4 countries worldwide since an eradication program began in 1989. In fact there has been a reduction in cases in the 20 year period from 1986 to 2009 of 99.91% (from ~3,500,000 in 1986 to 3,190 in 2009; WHO, 2010). Aside from safe water supplies, treatment campaigns have also increased in prevalence, 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, with an estimated 4.3 episodes per child per year and an attributed mortality rate of 4.2/1000 representing 27% of all deaths in this age group (Zimbabwe Public Health Review, 1987). The majority of pathogens that induce diarrhoea in humans are water born, making this susceptible to climate change as temperature and precipitation changes are expected. Death is caused by infection, malnutrition, and/or dehydration. In addition to the well-documented nutritional effects of drought, caused by reduced dietary range and consumption (Confalonieri *et al.*, 2007; Campbell-Lendrum & Bertollini, 2009).

In 1998, diarrhoea was the 10th biggest cause of deaths for all ages in South Africa (SA). By 2005 diarrhoea was the third biggest killer in SA. When this data was compared with the factors contributing to diarrhoeal disease it indicated an interesting correlation between the number of people with HIV/AIDS and people not having access to private water supply. Essentially, it is exposure to new diseases, ones that a person may not already have immunity to that put people at the most risk. This exposure to new diseases is the result of shifting pathogen habitats or human movement (directly or indirectly induced by climate change).

Environmentally induced conditions that are expected to change under anticipated climate change in Africa, such as precipitation and temperature changes are the very environmental factors that support diarrhoea-causing pathogens in water. Conditions that make a population prone to diarrhoea occurred in the months following Mozambique's flooding in 2000: 8000 additional cases of diarrhoea and 447 resultant deaths were recorded (IPCC, human health chapter, 2007, p. 399). A healthy support system coupled with sufficient infrastructure that can handle the conditions will increase the resilience of an unsuspecting population to this, and other health impacts affected by water availability (cleanliness, access, regulated availability, etc.).

Vector born diseases

There has been a worldwide resurgence in, and a redistribution of many old infectious diseases (Table 3). The WHO (1996) estimates 30 new infectious diseases emerged from 1975 to 1995 with some experts suggesting 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 & Carper, 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% 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. The table below shows the geographic distribution of vector borne diseases and the principle vector responsible for each. Note that the top 6 vector borne diseases all exist in Africa. Table 2 lists the prevalence of vector born diseases, in relation to water born 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		Worldwide
4.Yellow Fever		Africa, South America
5.Leishmaniasis	Sandflies	Africa, Central & South America
6.Trypanosomiasis	Tsetse flies	Africa, Central & South America

Mosquito species, such as the genus *Anopheles* (approximately 40 species which spread malaria), Culex (*C. quinquefasciatus*; West Nile Virus) and Aedes (*A. aegypti*; dengue and yellow fever) are responsible for the transmission of most vector-borne diseases globally and across 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 (Gubler & Kuno, 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 Task Group's (1990) report Potential Health Effects of Climatic Change. 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.

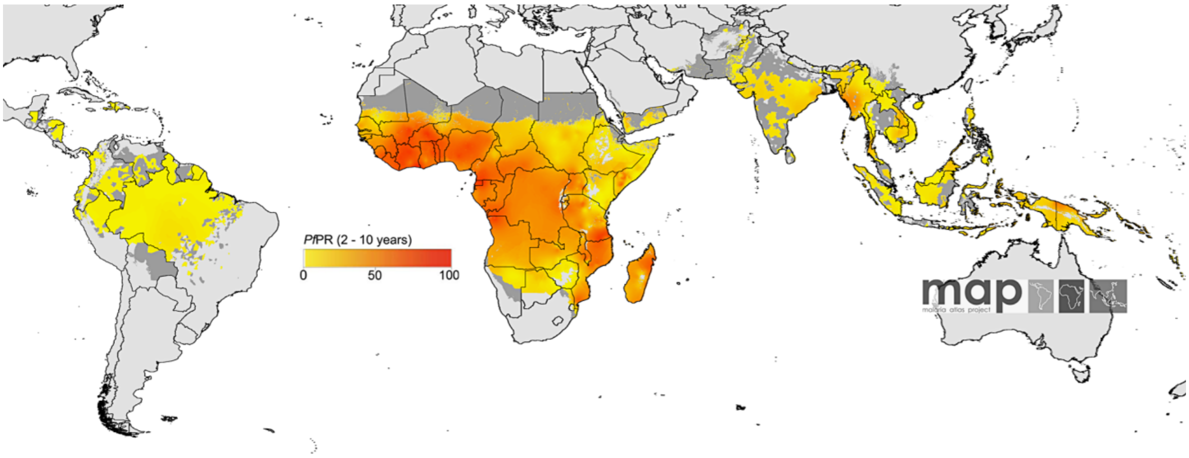
The combined effects of changing temperatures, precipitation may lead to a more suitable environment for the spread of vector-borne diseases and the emergence of new ones in different parts of Africa. For example, temperature changes affect vector-borne diseases by influencing reproductive cycles and behaviours. Bite frequency generally rises with temperature and atmospheric CO_2 content (de Lucia, 2008). In general, higher ambient temperatures (to a maximum) shorten the viral incubation period and breeding cycle in vectors (Campbell-Lendrum & Bertollini, 2009). For instance, 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 – 18°C is the required minimum temperature for development. There is high mortality in mosquitoes from 32 - 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. allied data from weather stations with satellite data 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 with climate change. The results found only very slight differences between the mean temperatures of places where tsetse do and do not occur naturally (Rogers, 1993; Rogers & Randolph, 1993; Rogers & Packer, 1993). This finding, they say, indicates that a small change in temperature might considerably affect their distribution.

Malaria

Out of the 700,000 to 2.7 million people that die of malaria annually around the world, 94 % occurred in Africa with 90 % in *SSA*, and 75 % of these are children (Thompson, 2004; Patz *et al.*, 2005; Ramin & McMichael, 2009; WHO, 2008; Figure 3). As of 2010, the 41 countries with the highest death rate from malaria per 100,000 population are in Africa, starting with Cote d'Ivoire (86.2), Angola (56.9) and Burkina Faso (50.7; WHO, 2010). These figures suggest that perhaps one of the greatest health threats to Africa, after malnutrition, is malaria. The majority of 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 reason for this is that rainfall produces the moisture conditions and surface water that facilitates breeding for malaria transmitting mosquitoes and warmer temperatures facilitate faster development for mosquito larvae and survival for adult mosquitoes; more importantly though, warm temperatures allows 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 (Hay *et al.*, 2009).



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

The relationship between malaria and climate systems has been the most extensively studied climate-related illness 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) as well as the fact the malaria is a major health issue in Africa. 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 decreased malaria cases to the drought 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). Further increasing caseload occurs when coupling increased temperature with a simultaneous increase 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.*). Controversies remain among malariologists about the extent of the contribution of climate change to malaria-changing patterns. Some think it is relatively minor, with a greater risk for dengue and other viruses, eg, arbo and hantaviruses.

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 & Hall;

Wingate, 1997; Hutchinson & Lindsay, 2006; Pascual *et al.* 2006; Chaves *et al.* 2008). Scientists also say there are an increasing number of deaths and morbidity across Africa that are due to malaria (Snall *et al.* 2009) and dengue fever (Cazelles *et al.* 2005).

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,). Malaria infection rate is expected to increase by 16-28% in person-months by the year 2100 in Africa (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 western Sahel and southern central Africa as these areas are likely to become unsuitable for Malaria transmission (Thomas *et al.*, 2004). The IPCC reports that by 2050 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 in the population to malaria (IPCC WGII 2007, Chapter 9). Elsewhere, in Debre Zeit, Ethiopia, with control on changes in drug resistance, mosquito control programs, and human migration, warming temperatures have been identified as the most likely cause for increased malaria transmission observed between 1968 to 1993 (Patz, 2005, p.311). This example refers to an 'association' between malaria transmission and warming temperatures because there may be other factors, perhaps unidentified that could have played a major 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 assert the opposite. Confirming links with climate change as the primary cause for changes in malaria transmission rates requires a series of other factors that contribute to transmission rates to be considered, such as: the use of drug resistance and mosquito control programs, human migration and immune status, and changes in land-use patterns (Patz *et al.*, 2005, p. 311). For example, despite several studies linking malaria prevalence and climate change in the highlands of East Africa (e.g. Pascual *et al.*, 2006), Hay *et al.* (2002), studied four sites in that region which experienced increased malaria transmission and found that climatic factors that would have enhanced suitability for malaria transmission, did not change very much; thus making climate unaccountable for 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.

Malaria transmission rates have not risen simply because humans are encountering more malaria-carrying mosquitos and being bitten more frequently. Many factors play a role in malaria transmission rates in a population. 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 & Hall; Wingate, 1997; Hutchinson & Lindsay, 2006; Pascual *et al*. 2006; Chaves *et al*. 2008).

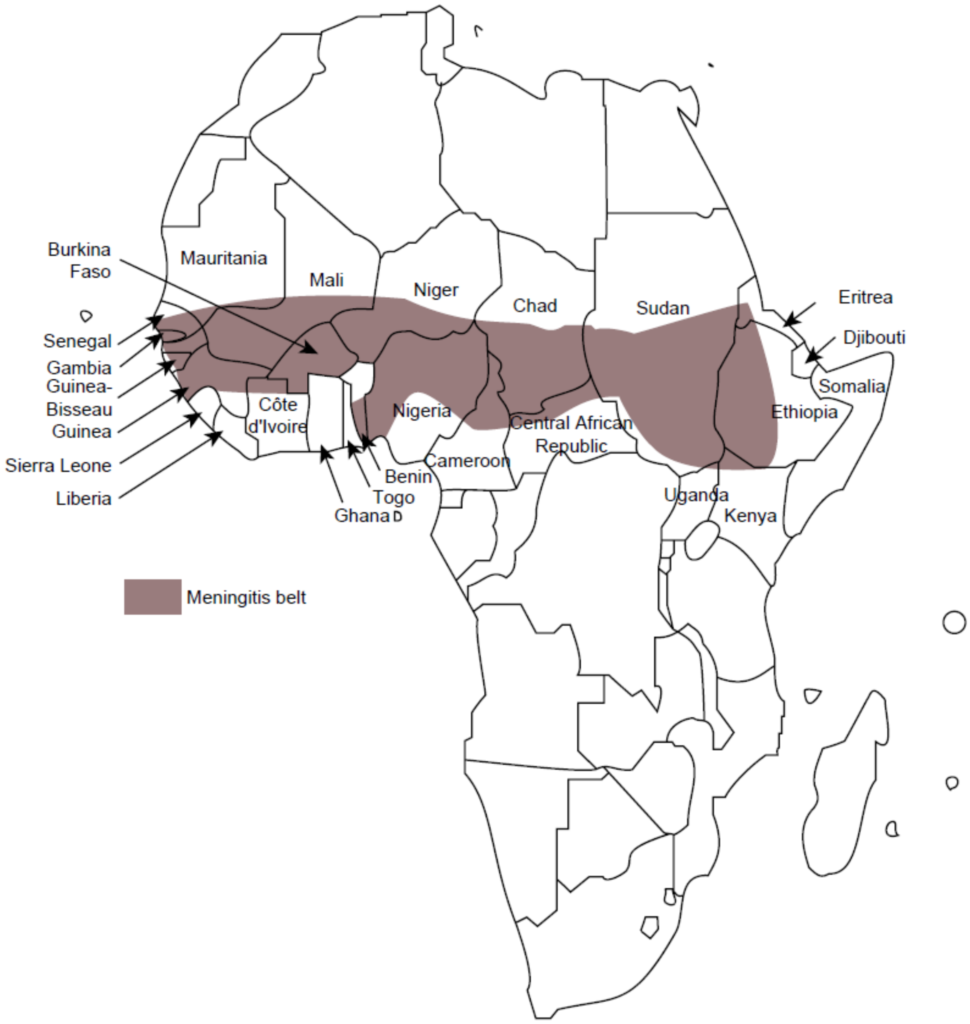
In spite of the conflicting findings regarding the correlation between malaria prevalence and changes in climate, it remains a fact that Malaria is a serious health problem across

SSA and control programs against this disease need to be amplified whether or not climate change will expand its spread.

Meningitis – an airborne disease

Meningococcal meningitis is caused by the bacteria *N. meningitidis* that exists all over the world. However, in no region of the world is it as great a problem as in the Sahel region of Africa (Figure 4). For Africa as a whole, meningitis is one of the continent's top three climate sensitive diseases, with roughly 350 million people living in endemic zones for this disease (McMichael *et al.*, 2003; Palmgren, 2009). Humans are the only natural reservoir for this 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), with the symptoms apparent on some individuals and non-apparent on others. The disease, as it is characterized by the infection of the meninges, can have lifelong damaging effects to the central nervous system in some survivors and it tends to kill from 4-17% of its victims. The most susceptible victims of this disease are typically children, adolescents and young adults (Menactra, 2011).

Figure 4: African meningitis belt (Palmgren, 2009; WHO/EMC/BAC/98.3).



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

Meningococcal meningitis is an airborne disease, for which epidemics are most often reported in years of severe dryness and drought, in dust laden environments and rarely in areas of dense forest and high humidity. The association between this disease and dust stems out of suggestions from a number of studies, that dust is likely the key element that converts the *N. meningitidis* bacteria from its benign form to its pathogenic one. The mechanisms for how this conversion might occur, 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 during the winter and spring months (May–October) of endemic meningococcal disease outbreaks (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. In fact the strip of land along the Sahel with highest concentrations of meningitis is often referred to as the 'meningitis-belt.' This spans from Ethiopia and Sudan in the East to Senegal, Mali and Guinea in the west (Figure 4; Palmgren, 2009). Epidemics of meningococcal meningitis break out in 5 to-10 years intervals in the meningitis belt. In recent years, the width of this meningitis 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 typically not accustomed to experiencing severe epidemics of meningitis, and which do not technically belong to the meningitis belt, have begun to experience large scale epidemics of the disease. This southward expansion of the meningitis-belt into these countries is also associated with the expansion of increasingly hot and dry conditions into these areas (McMichael *et al.*, 2003).

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 certainly.

Further still, the disease's unique regional characteristics and its prevalence driven by environmental conditions has shown clear patterns of outbreaks of the disease in South Africa. Though not in the meningitis belt, in recent decades, South Africa has been subject to increasing number of epidemic outbreaks of meningitis (Küstner, 1979). Here, the burden of disease occurs in a cyclical pattern at intervals of 8–10 years (Bikitsha, 1998).

Success has been observed, the incidence of clinical notification to the national Department of Health (Pretoria, South Africa) has decreased since the late 1980s: for the period 1992–1997, there were 1–2 cases per 100,000 persons (Bikitsha, 1998). By July 2002 (over the three previous years), 854 cases of laboratory-confirmed disease cases were reported in SA. This is an annual disease incidence rate of 0.64/100,000 population (Incidence was highest in infants <1 year of age; Coulson, 2007). Furthermore, 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, across 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 confer that epidemiological and environmental data sets of the dry season in Africa, need to be improved in order to enhance meningitis early warning systems, and thereby efficiently target and disperse this 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 contracted the disease worldwide killing an estimated 2.1 million people, with greater than 75% of these deaths in SSA.

The occurrences of opportunistic diseases, 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 born pathogens, highlighting the need for eradication programs. These appear to be more heavily-dependent on geography than other factors such as demographics and so it seems likely that as geographical distribution of communicable diseases evolves, infections in HIV-affected populations will change accordingly.

The expectation is that climate change may generate more migrants as people search for security, whether it is for food, water, safety, or health care. As populations are forced to migrate as a result of climate change, HIV infection rates would increase in certain regions, as people from different areas mix or if sex work becomes a means of sustenance for rural/farmer migrants who are forced to make a life for themselves in the city (McMichael, 2008).

Social status

Geopolitical, socioeconomic, demographic and technological evolution compound social and economic unpredictability. Cultural adjustments in time that protect us from social and economic uncertainties are there to lessen the impact on the relationship between environmental stress and mortality rates, 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 the differences in mortality is immense (Marmot *et al.*, 2008). While a child born in some developed countries today, such as Japan or Sweden, can be expected to live to 80 years, children born in a country in *SSA* are not expected to live past 50 years. Furthermore, while the carbon footprint of the world's poorest 1 billion people accounts for roughly 4% of the world's total carbon footprint, it is these vulnerable populations that will bear the highest costs of climate change (Costello *et al.*, 2009). In fact, some have asserted that the negative impacts of climate change will be suffered more severely in *SSA* - in spite of the continents relatively low emissions (see Figure 6) - than in other regions (Ramin and McMichael, 2009). This is largely attributable to the continent's overall limited adaptive capacity. Many of the human health issues discussed are not just commonly 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 they are a major factor in their slow economic development (for example, Malaria in SSA; Sachs & Malaney, 2002). In countries where malaria is common, average per capita GDP has risen (between 1965 and 1990) only 0.4% per year, compared to 2.4% per year in other countries (Ettling *et al.*, 1994). The estimated economic impact of malaria on Africa is $12 billion USD every year (Greenwood *et al.*, 2005; includes 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).

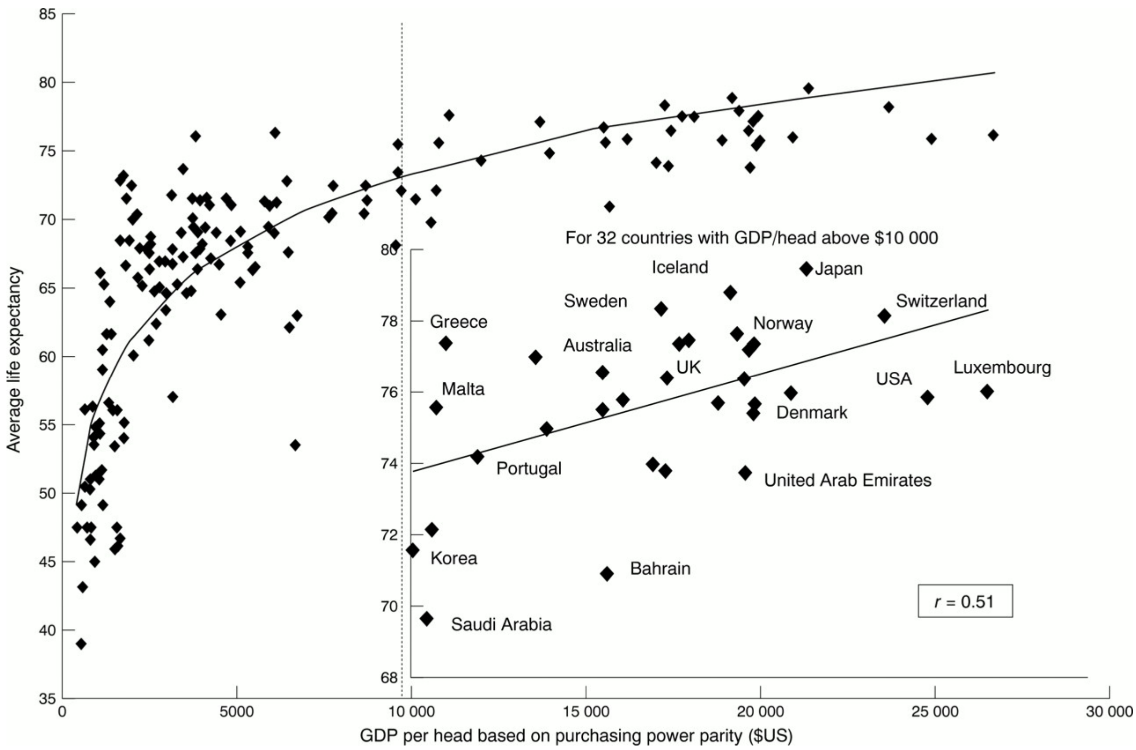
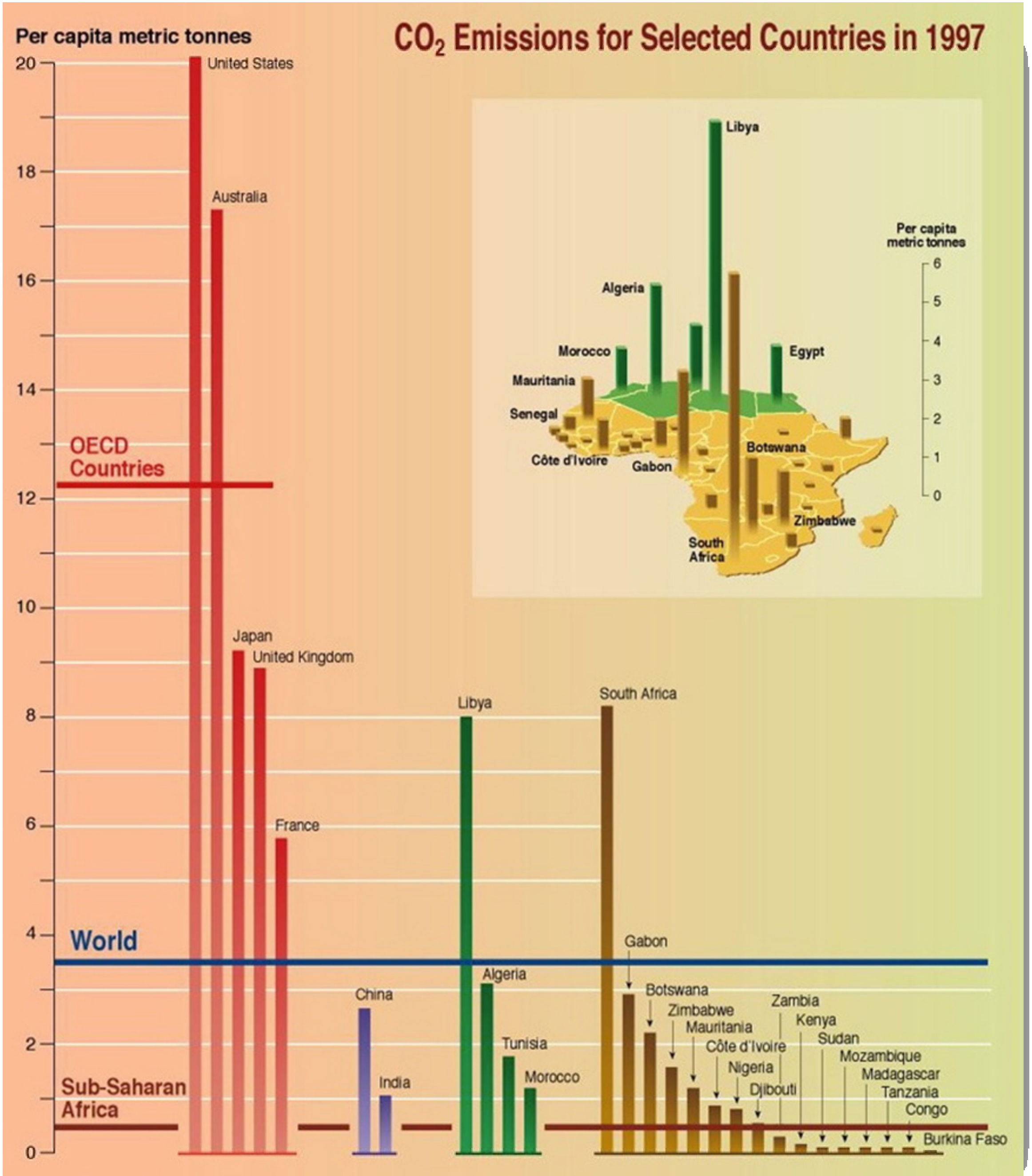


Figure 6: African CO_2 emissions compared with the world (UNEP, 2002).



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

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 which cause disease outbreaks and malnutrition. Also, migrants may carry the infectious diseases of their place of origin to their destinations and, once there, they may be susceptible to diseases they had not been previously exposed to. 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 issues.

Direct impacts

Potential direct health effects of global climate change upon an individual's or population's health will occur predominantly through the impacts of climate variables upon human biology. The main climatic-environmental variables concerned here are temperature, precipitation and air quality. It is important to point out whilst the main drivers are climatic variables, impacts are modulated by human population density, the vulnerability of local settlements, regional economic wealth and the strength of infrastructure. As a result, these impacts are felt more strongly across Africa than in richer regions where they are often neglected as issues. These issues are the result of specific events, such as heat waves, floods, air quality changes, often leading to indirect effects. Better understanding of these connections can lead to the development of appropriate adaptation and mitigation techniques for the benefit of a population's health.

Extreme weather events 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 changes in Africa, is inconclusive with regards to any changes in the frequency or size of EWEs but suggests there might be a slight increase in droughts for example in the second half of the 21st century and that there may be more frequent and stronger tropical storms off the southern Indian Ocean. Since EWEs are relatively location specific, regions with a history of a specific EWE will tend to continue to experience such events. 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 have been, devastating. The impact of EWEs is typically the greatest in the most vulnerable regions, where populations are least able to defend themselves, resulting in disproportionate death tolls, typically amongst 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 1980's and 1990's by global region (McMichael *et al.*, 2003).

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

The effects on individuals of EWEs are compounded by damage to infrastructure and health systems, for example it was difficult for HIV retroviral drugs to be delivered to Northern Namibia due to the floods there earlier this year. Once the initial disaster has passed, secondary issues may emerge, such as a lack of food and 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 stresses, losses of infrastructure and territory and environmentally-induced migration which can lead to further increases in infectious diseases, conflicts over water, energy and other increasingly scarce resources, resulting in political tension.

UV related cancers and diseases

This is a range of health effects that will increase in importance as population's lifespan begin to 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, 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, with the rate of cataracts surgery the lowest in Africa (Yorston *et al.*, 2001). As a result, in developing countries cataracts causes 50–90% of all blindness (Murray & Lopez, 1996). Of these, 5% of all cataract-related diseases are directly attributable to UVR exposure.

In the year 2000, UVR exposure had led to more than 200,000 cases of melanoma and 65,000 melanoma-associated deaths globally. A program to eliminate cataract blindness in Africa by 2020 has been proposed, and there are grounds for this optimism that this is possible. Firstly, the number of cataract operations is increasing rapidly in some countries. In Kenya, there were a little over 5000 cataract operations in 1996 (as reported to the National Prevention of Blindness Committee). By 1999, this had increased to over 12 000, with the quality of surgery also improving (Yorston *et al.*, 2001). Secondly, human resources development and access to low cost materials is making cataract surgery more widely available (Brian & Taylor, 2001). Many surgeons have been successfully trained or retrained in various types of cataract surgery with education clinics set up in such countries as Ghana, Nigeria, South Africa and Tanzania. It has been noted that Francophone and Portuguese-speaking Africa has fewer training programmes at the moment (Alhassan *et al.*, 2000).

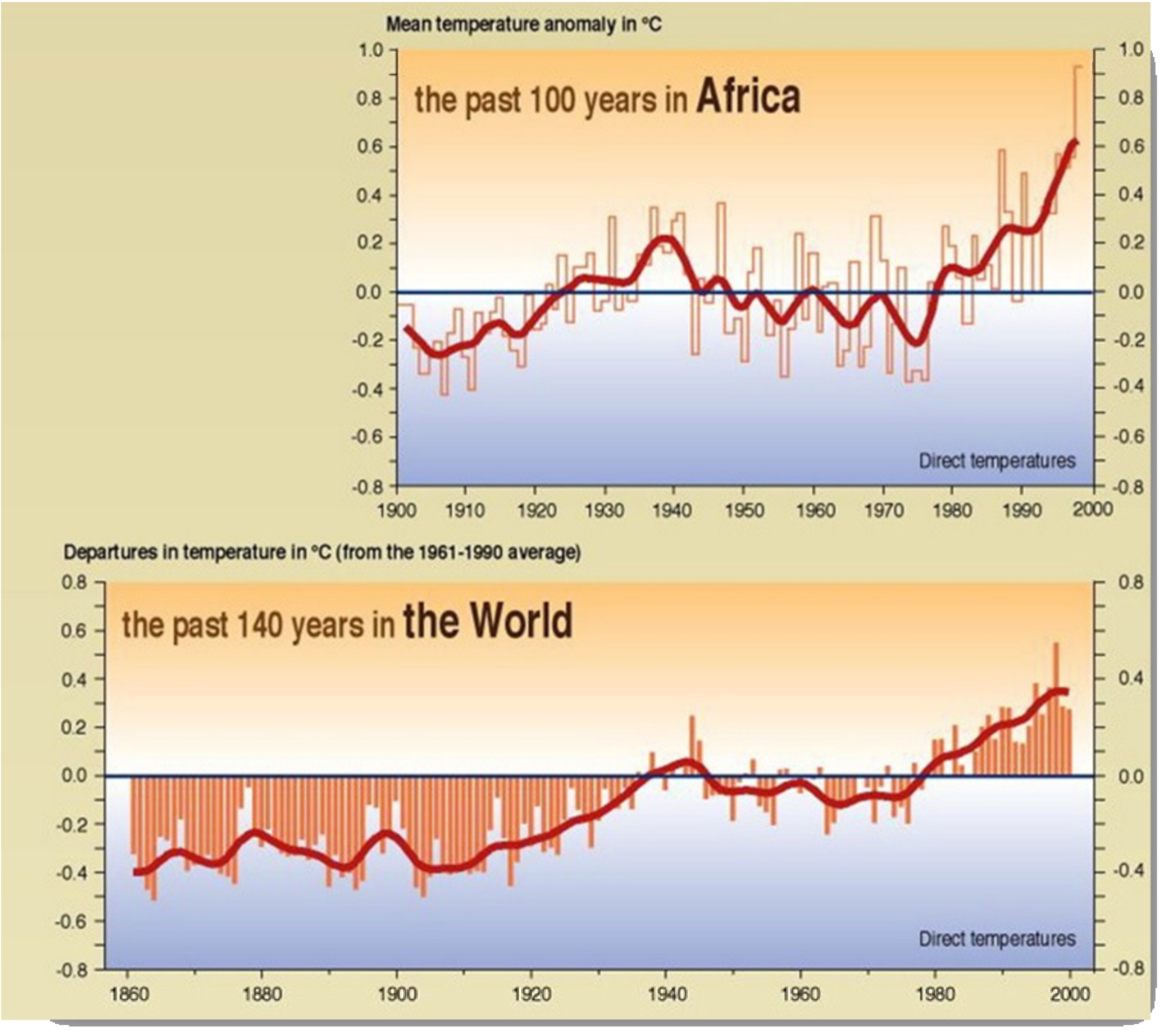
The WHO confirms that instances of skin cancer have been increasing steadily in the two decades, especially in regions with high UVR exposure, with South Africa highlighted (McMichael, *et al.*, 2003). The relationship between ozone depletion and poor skin and eye health is unclear. Scientists point out the difficulties of distinguishing ozone depletion between pollution and climate. Research is needed on attitudes toward sunbathing and the use of protective measures. Protective measures, such as sunscreen ointments and creams, 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).

The effect UVR has on the human immune system appears to be a reduction in effectiveness by changing the activity and distribution of the cells responsible for triggering immune responses (De Fabo & Noonan, 1983). For the eyes and the immune system, this is independent of skin pigmentation, so all 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). The ability to respond to increases of skin and eye diseases will be lower in lower and middle income countries. Populations required to work outdoors will be most affected, as well as those that spend their youth in the sun.

Temperature and precipitation effects

Increases in average temperature represent a very significant source of potential direct climate change impacts on human health. A major concern is that such increases may lead to temperatures beyond those comfortable (called heat stress) for a region affecting mortality through thermal stress (Figure 7). Heat stress affects individuals during extremes (in intensity and/or frequency) of local weather - in the coldest or warmest seasons for example. These environmental conditions can be further exacerbated by human activities such as deforestation and urbanisation by affecting local climates by increasing local temperatures by 3+ °C (Hamilton, 1989).

Figure 7: Temperature changes in Africa compared with the world (UNEP, 2002).



Seasonal variation in mortality has been described in many countries throughout the ages. In ancient Greece, Hippocrates (Hippocrates Vol. 1., McKEE, 1989) described the occurrence of sudden deaths and strokes when a cold spring followed a mild winter. 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 corresponding to 26-29°C (*Ibid*).

Though rarely discussed in the literature, mortality due to heatwaves have 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 (young and elderly, sick and poor). As with the other health affects afflicting Africa, this is exacerbated due to limited resources available to poorer populations. There is difficulty in predicting the effects of changes in frequency and intensity of heatwaves on mortality rates in high temperature regions like in Africa due to the lack of data about mortality in these regions.

Air quality

Climate change is expected to reduce air quality in some areas (IPCC, 2007) contributing to respiratory disorders (Kinney, 2008; McMichael, *et al.*, 2003). The relationship between climate change and air quality is complex with many interacting mechanisms. For example, air quality influences can be of climatic/meteorologic (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 (using carbon based fuels for local energy use, transportation, and agriculture) origin, resulting in eventual deposition of air pollutants (Sapkota, 2005; Confalonieri, *et al.*, 2007; Kovats, Ebi, & Menne, 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, resulting in increased deaths among the elderly and urban poor (McMicheal *et al.*, 1996; Piver, 1999a and b; Epstein & Mills, 2005).

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 (through photochemistry) from the by-products of burning carbon-based fuels. At the surface, an increase in temperature accelerates photochemical reaction rates (strong correlation between higher ozone levels and warmer days – but not always). 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 from temperature rises above 16.5°C (Levy, 2005).

The increases of air pollutants due to climate change discussed above may influence cardio-respiratory disease (McMichael *et al.*, 2003) as well as by exposing patients with pre-existing conditions to dangerous temperature extremes, which stress the cardiovascular system. 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 (1/3 by outdoor and 2/3 by indoor poor air quality) and accounts for approximately 2% of the global cardiopulmonary disease burden (Prüss-Üstün & Corvalán, 2006; Watts, 2009). Exposure to outdoor air pollution accounted for approximately 2% 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 regional and global context have not been fully identified or understood. Hence, although a lot is known about the science of climate change, there remain many uncertainties of its potential impact on health (IPCC, 2007). These uncertainties relate mostly to three main areas:

1. Climate change uncertainties;

2. Links between climate change and health and their mechanisms, and;
3. Human mitigation and adaptation capabilities.

Climate change uncertainties are due to insufficient data and 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. These lead to difficulties in predicting 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 in predicting these natural phenomena are compounded by uncertainty in future rates of GHG emissions and governments' willingness and ability to mitigate and adapt to changing conditions. Ultimately, new techniques and approaches to climate change science are needed to deal with the uncertainties that inevitably surround these estimates. Improved modelling of climate change, including regional models will allow for more reliable predictions of the potential impacts on human health, and improved regional understanding.

So far, the majority of wide scoping climate-health research has been carried out in the developed world, where the tools, technology and capacity for carrying out this research are available. This leads to very tentative results not the least because the greatest health risks due to climate change are expected to be borne amongst those least capable to responding, in the developing world (Ramin and McMichael, 2009). Limited tools and technology across Africa has produced inaccurate findings in climate-health relationships (Connor *et al.*, 2006). For example, climatology data, used for surveying malaria have not given consistent information on the links between malaria and climate (e.g. Tulu, 1996 vs. Hay *et al.*, 2002). Furthermore, the number of meteorological stations across Africa is insufficient for many analytical purposes, thus providing an obstacle to tracking climate trends (Connor *et al.*, 2006). Also, climatology data widely used in Africa has often been based on out-dated and inconsistent observations (Connor *et al.*, 2006).

The second set of challenges are uncertainties regarding mechanisms which link health impacts to climate change. For instance, accuracy in predicting the effect of climate change on important health-related factors such as crop yield and pests (weeds, insects, plant diseases, etc) can be improved. Improvements can also be made in epidemiologic research methods to predict health impacts through model accuracy of the processes through which impacts will occur. Part of the challenge in achieving these improvements is that climate experts and health experts (such as epidemiologists) tend to operate separately, and are not fully informed on how to effectively employ information from both sectors to generate insightful data on the interrelation of climate and health (Connor *et al.*, 2006). Overall, it has been difficult to build and maintain cross-sectoral relationships between the researchers of climate-based early warning systems and the subsequent responses needed from the public sector (Connor *et al.*, 2006).

Thirdly, it is difficult to predict how humans will mitigate and adapt to climate change, confounding modelling attempts. Most of the effects of climate change on health discussed above can be minimised through appropriate mitigation and adaptive 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 increase and malaria spread. 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, offer hope that the problem of meningitis across Africa might ultimately to be controlled.

Africa's response to climate change and health

The preceding sections indicate that 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 amongst African leaders to protect their people from the anticipated negative health consequences of climate change. The above mentioned 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 across 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 as well as they prepare National Plans of Joint Actions (NPJAs)
- Develop an essential public health package to enhance the climate change resilience status of all countries by 2014, and;
- Reduce vulnerability and use ecosystems services to build natural adaptive resilience against the impact of climate change.

Already, following the meeting in Libreville the Health and Environment Strategic Alliance for the Implementation of the Libreville Declaration (HESA) has been established to serve as the primary mechanism for coordinating efforts at addressing climate change and health across Africa. The core mandate of HESA is to support country efforts in addressing health and environment issues (including climate change and health) through advocacy, collaboration, resource mobilization, capacity building, technical support and progress monitoring.

It is hoped that the full implementation of the Libreville Declaration and the Joint Statement would help ensure evidence based, and properly coordinated policies, plans and actions.

At grass roots level there are already climate and health activities 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 of 2011, a "Climate and Health: 10 Year On" was held in Addis Ababa and co-organised by the International Research Institute for Climate and Society (IRI), the African Climate Policy Centre (ACPC), CHWG, the World Health Organisation, 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 Bamako Workshop (1999) on Climate Prediction and Diseases/Health in Africa. From the Climate and Health: 10 Years On Workshop (2011) a series of 23 recommendations[2] to support the effective implementation of the Joint Statement on Climate Change and Health in Africa (Luanda, 2010) were agreed regarding policy, practice, services and data, and research and education. These included, for example:

- Bridging the gap between policies and practices through legislation and guidelines, appropriate planning, including relevant vulnerability assessments, programmatic support and multi-sectoral and participatory processes that are gender sensitive.
- Supporting countries to establish integrated health surveillance and climate observation and processing systems;
- Integrating 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 end-user level.
- Ensuring that climate change mitigation and adaptation strategies are informed by multidisciplinary research.

Options for consideration

Based upon a review of the literature, there are a series of options that may be considered by African governments, coordinating bodies such as HESA, and by other organizations to address climate change and health. These options need a deeper investigation and much further research, dialogue and discussion, but for the purposes of stimulating such a process, options that might be considered include:

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

[2] The complete set of recommendations are 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 on-line with an elaboration of 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).

- 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 mitigative or preventative measures are useful so that the health sector in Africa can combat the most prominent, and often climate-sensitive, infectious diseases, for example malaria and meningitis, plus the NTDs, etc. Medication and other paraphernalia (i.e. mosquito nets, condoms, sterilization tablets and sanitizers) for curing or preventing Africa's common infectious diseases are required in order to build the overall health status of Africa's population. These measures alone, however, would not suffice.

- An increased presence of clinics and health professionals, providing support, explaining options and giving directions on the use of drugs and preventative paraphernalia are also required to improve the effectiveness of these measures. A healthier populace is critical to development and in turn adequate levels of development are needed to improve the overall health status of the populace. The Global Strategic Plan for Roll Back Malaria, 2005–2015, agrees, having asserted "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 problem 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 investment in agricultural production systems, improved land policy and investment in irrigation systems for example. There are a number of organizations researching such issues in the field and at the policy level. It is important that the outcomes of such research continue to be used to inform government policies and interventions, coupled with building climate resilience in the agriculture sector.

- Across Africa there is significant development potential, and as such there is the opportunity to ensure a key element of development, infrastructure, is climate resilient by taking climate change into account when planning and designing infrastructure. Achieving this requires significant increase in the awareness of climate change among development planners and ministries in African countries. Infrastructure is important both for the delivery of, and access to, health services.

- African governments can increase the effectiveness of 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 working. A key issue for consideration is the need for increased research. It is important to ensure that responses, actions and policies are 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. Robust research is also needed to identify relatively hidden or unclear climate-health links, ensure proper prioritization of response measures and identify the most cost-effective interventions measures.

- As climate change is not a completely new phenomenon, it would be very insightful to learn how indigenous communities have dealt with changes over previous generations and how these could be adapted for scaled-up effective responses to climate change.

- There is need for improved regional and local modelling of climate change to allow for more reliable predictions of the potential impacts on human health. Improved data and research capacity is important. There are already collaborative programmes involving research organisations with technical and computing capacity working in partnership with National Hydrological and Meteorological Organisations to improving national capacities and improve modelling and downscaling of the effects of climate change on all sectors including health. Such initiatives can be scaled up and when coupled with health and other social and economic information, can be utilised in the formulation of policy.

- Due to their lifesaving potential, governments should work hard to make hydro meteorological data sets easily accessible and use them to inform planning and development. Further, this information can be improved and the application and development of early warning systems promoted. Examples of such technology applied across Africa, but not as pervasively as needed, include malaria and famine early warning systems.

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

As highlighted in this working paper, climate change and health is a complex issue, and addressing climate change and health requires integrated analysis of social, economic as well as environmental and climatic dimensions of development and health. The list of options above is not exhaustive and each requires such an integrated analyses and further investigation. As such any feedback on the content of this working paper and the options presented will be greatly appreciated and warmly received by the ACPC (acpc@uneca.org).

References[3]

Alhassan MB , 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. Clin Microbiol 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. Infectious Diseases of Humans: Dynamics and Control (Oxford Science Publications). New ed ed. Oxford University Press, USA; 1992. Available from: http://www.worldcat.org/isbn/019854040X.

Baro, Mamadou & 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. PLoS Negl Trop Dis 2(10): e313. doi:10.1371/journal.pntd.0000313.

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

Blaser, M. J. & 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, & 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, Richardsjr 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.

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

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. & R. Bertollini. 2009. Protecting health from climate change. Geneva: World Health Organisation.

Cazelles B, Chavez M, McMichael AJ, Hales S. Nonstationary Influence of El Niño on the Synchronous Dengue Epidemics in Thailand. PLoS Med. 2005 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. Complete treatment of uncertainties in a model for dengue R0 estimation. Cadernos de Saúde Pública. 2008 Apr;24(4). Available from: 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, & R. Kovats. 2007. Human health. In M. Parry, O. Canziani, J. Palutikof, P. v. Linden, & 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 Mar;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, & 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, & 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. Available at 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. Available from: http://www.fujipress.jp/finder/xslt.php?mode=present&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., & 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, Viale delle Terme 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, & 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, & 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. Dengue and dengue haemorrhagic fever D. J. Gubler & G. Kuno (editors). Wallingford: CAB International, 1997. 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. Omumbo & 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 Panam Salud Publica [serial on the Internet]. 17(4): 221-224. Available from: http://www.scielosp.org/scielo.php?script=sci_arttext&pid=S1020-49892005000400001&lng=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 & 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. & A. Kamath. 2009. Neglected Tropical Diseases in Sub-Saharan Africa: Review of Their Prevalence, Distribution, and Disease Burden. PLoS Negl 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. Statistica Neerlandica, 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, , & 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, & J. A. Sarnat. 2005. Ozone exposure and mortality: an empiric bayes metaregression 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_docman&task=doc_download&gid=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_docman&task=doc_download&gid=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_docman&task=doc_download&gid=6071

Lynch, J., P. Due, C. Muntaner, & 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. PLoS Negl 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, & 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, & 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.show&cname=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, & 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. & 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 Rhipicephalus appendiculatus. 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, & J. Kleissl. 2005. Impact of the 2002 Canadian forest fires on particulate matter air quality in Baltimore city. Environ Sci Technol. 39: 24–32.

Schaible, U. E. & 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, & 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. <http://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. Wkly Epidemiol Rec. 81(8). : 71–80.

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

WHO. 2008. Dracunculiasis eradication. Wkly Epidemiol 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. Wkly Epidemiol 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, Abiose Adenike, 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_arttext&pid=S0042-96862001000300016&lng=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.