VULNERABILITY, IMPACTS AND ADAPTATION ASSESSMENT IN THE EAST AFRICA REGION

CHAPTER 11:
IMPACT OF CLIMATE CHANGE ON HEALTH IN EAST AFRICA – FUTURE SCENARIOS

NOVEMBER 2017

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AIC	Akaike Information Criterion
BIC	Bayesian information criterion
CORDEX	Coordinated Regional Climate Downscaling Experiment
EAC	East African Community
FPE	Final prediction error
GARCH	Generalized autoregressive conditional heteroscedasticity
HQ	Hannan-Quinn
IPCC	Intergovernmental Panel on Climate Change
LVB	Lake Victoria Basin
MA	Moving average
MDG	Millennium Development Goal
ML	Maximum likelihood
NAPA	National Adaptation Programme of Action
NCCAP	National Climate Change Action Plan
NCCRS	National Climate Change Response Strategy
PMI	President's Malaria Initiative
RSV	Respiratory Syncytial Virus
SBC	Schwarz Bayesian criterion
SDG	Sustainable Development Goal
UCM	Unobserved components model
USAID	United States Agency for International Development
VIA	Vulnerability, Impacts and Adaptation Assessment
WHO	World Health Organization

INTRODUCTION

Healthy populations are essential for human development, well-being, and economic growth. Irrespective of where someone lives, their gender, age, or socioeconomic status, being healthy and having access to quality and effective health care services is of fundamental importance for all (WHO 2009). Numerous global, regional, and national treaties and constitutions recognize a right to the highest attainable standard of physical and mental health. Indeed, promotion of good health is central to development. This is demonstrated by the prominence of health-related issues in the former Millennium Development Goal (MDG) and current Sustainable Development Goal (SDG) frameworks. In the East African Community (EAC) Partner States, health is a priority (Box 1).

Box 1: Health, Sanitation, and Settlements as Priorities in the Five EAC Partner States

- Water resources and health are priorities 3 and 4 out of 8 priorities in the Uganda National Adaptation Programme of Action (NAPA) (Republic of Uganda, 2007).
- Malaria, diarrheal diseases, and poor hygiene and sanitation are the top three health concerns related to climate change in the Uganda NAPA (Republic of Uganda, 2007).
- Health and human settlements are priorities 5 and 10 out of 11 priorities in the Tanzania NAPA (Republic of Tanzania, 2007).
- Prolonged drought, changing rainfall, floods, and temperature rise are priorities in the 4 NAPAs (Burundi, Rwanda, Tanzania, and Uganda) and in Kenya's National Climate Change Response Strategy (NCCRS) and National Climate Change Action Plan (NCCAP) (Government of Kenya, 2010 and 2013).
- Integrated water resource management is priority 1 in the Rwanda NAPA (Republic of Rwanda, 2006).

The economic burden of morbidity and mortality can be enormous to governments. Approximately 56 million people die worldwide every year according to the World Health Organization. Among the leading causes of mortality globally are lower respiratory tract diseases and diarrheal diseases, which have an association with climate variability. Over the past decade, deaths from lower respiratory tract infections increased from 3.1 million to 3.5 million, while deaths from diarrheal diseases increased from 1.5 million to 2.2 million. When causes of death globally are stratified per country by income group, lower respiratory tract infections, diarrheal diseases, and malaria rank first, third, and sixth, respectively, in low-income countries. In high-income countries, diarrheal infections, which rank sixth, are the only one of the diseases in the top ten (Liu et al. 2012, WHO 2014b).

In Africa, the burden of disease per person from these health risks is about 75 times higher than in Western Europe. In analyzing health in Africa in general, Disability-Adjusted Life-Years (DALYs) need to be considered. Apart from Human Immunodeficiency Virus/Acquired Immuno-Deficiency Syndrome (HIV/AIDS), lower respiratory infections (which include pneumonia), diarrheal diseases (which include cholera), and malaria have been the top leading causes of DALYs between 2000 and 2010 in the World Health Organization (WHO) Africa Region (Kovats et al. 2001, Murray et al. 2015).

East Africa is located within the tropical and sub-tropical climate belt, which favors the growth, multiplication, and transmission of several vector-borne and water-borne diseases. Communicable diseases contribute to the highest morbidity, mortality, and disabilities in this region. The most common causes of mortality and morbidity are malaria, acute respiratory tract infections, diarrheal diseases, malnutrition, and HIV/AIDS (Global Burden of Diseases 2010).

Due to the high morbidity and mortality caused by malaria, lower tract respiratory diseases, and diarrheal diseases (Figure 1) this study prioritized these diseases for review and study. Hence, this report focuses in depth on the impact of climate change on malaria, pneumonia, and cholera.

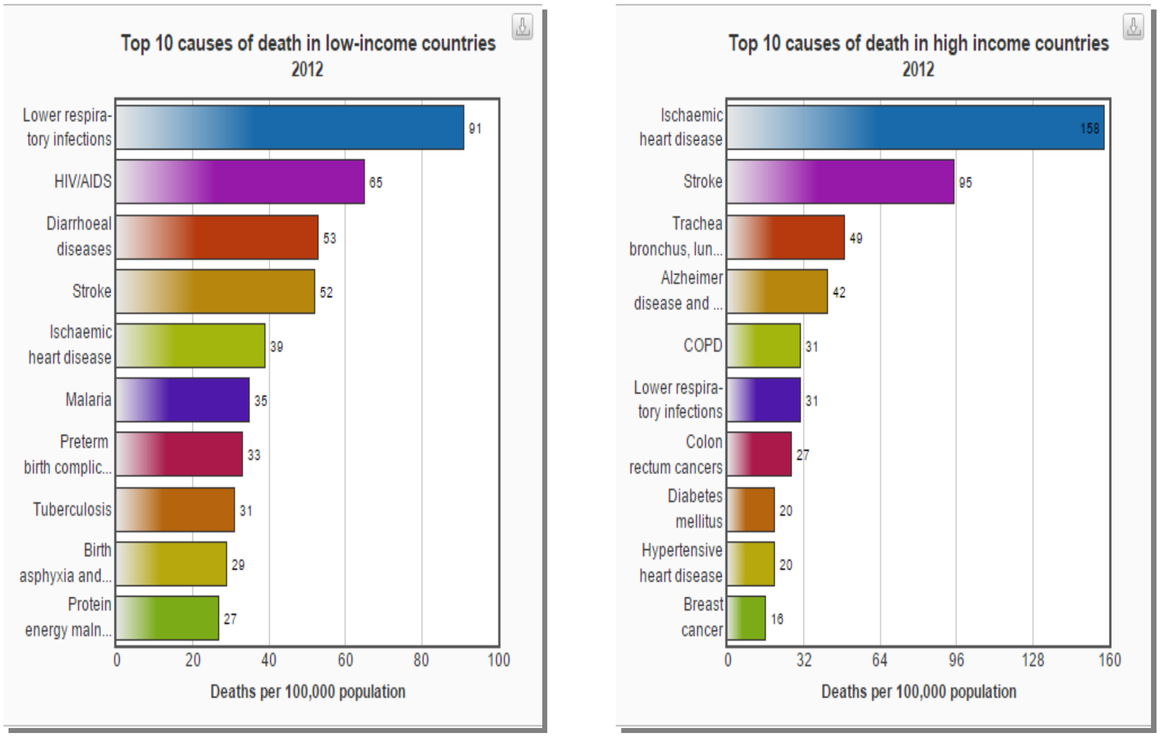


Figure 1: Top ten causes of death in low-income and high -income countries, 2012.

Source: WHO 2014.

Within the Lake Victoria Basin (LVB), the focal region for this study, the same three diseases are common killers. In Uganda, for example, more than a third of the disease burden is attributed to the three diseases. More strikingly, the incidence of malaria in the Kenya section of the LVB is one of the highest in the world and infant mortality is well above the national average (Nyangena et al. 2007). Uganda has experienced an increase in malaria incidences of 30–35 percent due to a warmer climate (Niang et al. 2014) and climate variability has been linked to the increase in the burden of disease.

Malaria is a parasitic disease spread by the bites of infected *Anopheles* mosquitoes. There are many species of malaria parasites but, of the five affecting humans, the greatest threat to health comes from the *Plasmodium vivax* and *Plasmodium falciparum*. Malaria has long been a major health concern in many parts of the world. More than 3 billion people, about half of the world's population, is at risk for malaria (WHO 2014c). Every year, this results in about 250 million malaria cases and nearly one million deaths. People living in the poorest countries are the most vulnerable with particularly high incidence of malaria in Sub-Saharan Africa.

Within Africa, 20 percent of childhood deaths are attributable to the disease and a child dies from malaria every 30 seconds.[1] In East Africa the cumulative probability of malaria deaths is high, but all the EAC Partner States are still at the level of control, and achieving elimination will be impeded by climate variability and change. The scaling up of malaria prevention measures has resulted in a significant decline throughout the EAC (Hay et al. 2002a, Hay et al. 2002d). However, malaria epidemics have been increasing in the East African highlands over the last two decades. This phenomenon is attributed to climate change, antimalarial drug resistance, land use

[1] (http://www.who.int/features/factfiles/malaria/en/index.html)

change, and vector migration (Hay et al. 2002d, Himeidan and Kweka 2012). For instance, between 2001 and 2006, malaria epidemics in Burundi, Kenya, Tanzania, and Uganda followed heavy rainfall and significantly in areas that were preceded with periods of drought (Hay et al. 2002a, WHO 2014). Further, there is evidence that malaria epidemics occurred when anomalies in maximum temperature were accompanied by sustained rainfall one month later (Wandiga et al. 2009). The LVB has been flagged as a hotspot for malaria (Wandiga et al. 2009, Nyangena et al. 2007).

Box 2: Malaria in Africa

"Malaria transmission occurs in all six WHO regions. Globally, an estimated 3.3 billion people are at risk of being infected with malaria and developing disease, and 1.2 billion are at high risk (>1 in 1000 chance of getting malaria in a year). According to the latest estimates, 198 million cases of malaria occurred globally in 2013 (uncertainty range 124–283 million) and the disease led to 584,000 deaths (uncertainty range 367,000–755,000). The burden is heaviest in the WHO African Region, where an estimated 90% of all malaria deaths occur, and in children aged under 5 years, who account for 78% of all deaths." However, increased prevention and control measures have led to a "reduction in malaria mortality rates by 47% globally since 2000 and by 54% in the WHO African Region."

Source: WHO 2014

Malaria is more stable in the regions bordering Lake Victoria due to the availability of mosquito vectors and vector breeding habitats. The region is also flat and water drainage is very poor. Whenever there is rainfall, water stagnates and creates optimal vector habitats. The region around the lake also has higher temperatures that are favorable for vector development. All five Partner States are among the 56 countries where malaria is endemic. While the burden of malaria has declined significantly in the EAC, Intergovernmental Panel on Climate Change (IPCC) reports indicate that current global climate change will likely ruin decades of hard work in malaria prevention (IPCC 2007).

The epidemiology of vector-borne and diarrheal diseases is largely influenced by climate variability, as shown by evidence from the current outbreaks and disease patterns (Githeko et al. 2000). It is estimated that by 2100, average global temperatures will have risen by 1–3.5°C. This will likely affect the temperature thresholds for disease transmission (IPCC 2007). It will also affect the spatial distribution of the mosquitoes that transmit malaria, perhaps including regions where they were not previously common. Temperature changes can affect mosquitoes in several parts of their life cycle. Rising water temperatures typically result in shorter time to maturity for larvae (Rueda et al. 1990), which increases the production of mosquitoes. Warmer temperatures also help adult female mosquitoes digest blood faster; hence, they will feed more often (Gillies 1953). Both phenomena have the potential to increase the transmission of malaria parasites, whose incubation time can also be shortened by warmer temperatures (Turell 1989), resulting in a larger population of parasites. At temperatures over 34°C, the survival of vectors and parasites is reduced (Rueda et al. 1990).

Pneumonia, another debilitating disease in East Africa, is caused by different biological agents, including bacterial and viral particles. Respiratory Syncytial Virus (RSV) is the common viral etiology of lower respiratory tract infections. The RSV is highly affected by changes in climate and is highly seasonal. Pneumonia associated with RVS mainly occurs in epidemic forms in various epidemiological settings and contributes significantly to high morbidity rather than mortality among children, thus increasing the burden on the health system (Haynes et al. 2013, Stensballe et al. 2003, Weber et al. 1998). Childhood pneumonia is responsible for 17 percent of childhood deaths worldwide (Paynter et al. 2010, WHO 2009), with deaths recorded mainly during the rainy season when temperatures are low. High temperatures are also known to increase the levels of air particulate matter, especially in urban areas, leading to increased risk from outdoor air pollution and exacerbating incidences of respiratory diseases, especially among infants (Paynter et al. 2010).

About 935,000 children under the age of five died of pneumonia in 2013 worldwide. In Kenya, pneumonia causes 23 percent of under-five mortality (MOH 2008–2009, UNICEF 2013a, WHO 2014a). In Uganda, pneumonia causes about 11 percent of under-five mortality (MOH 2011, UNICEF 2014b). Pneumonia causes 20 percent of under-five mortality in Tanzania (UNICEF 2014a), 17 percent and 16 percent of under-five mortality in Burundi and Rwanda respectively (UNICEF 2013b).

Cholera, a bacterial disease caused by *Vibrio cholerae,* kills more than five million people per year worldwide. *V. cholerae* is a water-borne bacterium whose life cycle is affected by biotic and abiotic factors that will be affected by climate change and variability (Borroto 1997). The bacterium is highly associated with planktons, forming commensal or symbiotic relationships, mainly with copepods (which serve as a reservoir of the bacteria) (Borroto 1997). The interactions of the *V. cholerae* and copepods are highly affected by environmental variables (Lipp et al. 2002).

As a water-borne disease, cholera is primarily associated with poor sanitation, poor governance, and poverty, with associations with weather and climate variability, suggesting possible changes in incidence and geographic range with climate change (Rodó et al. 2002, Koelle et al. 2005, Olago et al. 2007, Murray et al. 2012). In Tanzania, Zambia, and Zanzibar, an increase in temperature or rainfall increases the number of cholera cases (Luque Fernández et al. 2009, Reyburn et al. 2011). A hotspot map of potential disease outbreaks indicated high potential incidences of this disease due to elevated climate anomaly (Figure 2).

Cholera outbreaks have occurred in Burundi Kenya, Rwanda, Tanzania, and Uganda almost every year since 1977–1978 (Nkoko et al. 2011). For the period 1999–2008, the WHO recorded 322,532 cases of cholera in the EAC (Nkoko et al. 2011).

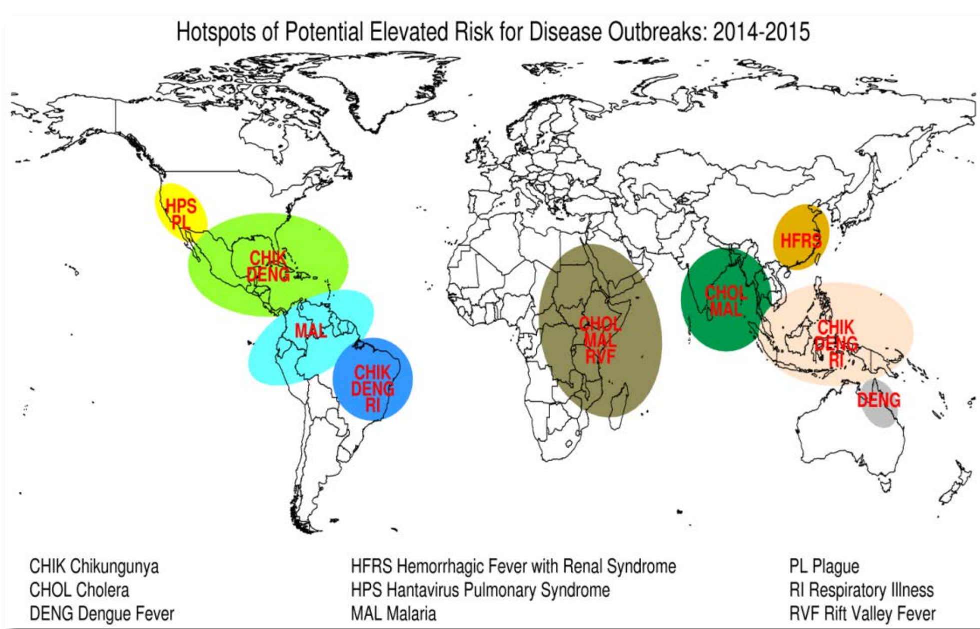


Figure 2: Disease risk based on anticipated El Niño events in 2015

Source: Anyamba et al. 2006.

Sanitation

Improved sanitation hygienically separates human excreta from human contact and includes closer facilities, less waiting time, and safer disposal of excreta. Improved sanitation has a great impact on peoples' health and economy. Access to clean and safe water and adequate sanitation are critical to poverty alleviation. Improved sanitation also reduces direct and indirect costs of sanitation-related diseases such as cholera, dysentery, typhoid, and parasitic worms and leads to increased productivity.

Meeting the MDG sanitation target required an estimated US$142 billion—about US$28 per capita—in additional investment in developing countries. This would have required an annual investment of about US$14 million (Van Minh and Nguyen-Viet 2011). Provision of proper sanitation and clean and safe water is a very good investment that offers significant returns. For example, reduced risk of water-borne and sanitation-related illnesses can help increase tourism, which can help improve livelihoods. Spending on health and sanitation in the EAC Partner States is summarized in Box 3.

Box 3: Health, Sanitation, and Settlements in EAC Partner States (EAC 2014)

- Public health expenditure per capita notably increased from US$4.9 in 2012 to US$10.6 in 2013 for Burundi, from US$7.8 to US$11.7 for Uganda, and from US$18.5 to US$21.0 for Kenya.
- Average household size over the past five years remained constant—5 members per household, except for Rwanda with 4 members.
- Rwanda had some improvement in access to safe drinking water (from 74.0 percent in 2012 to 74.2 percent in 2013) while Uganda reported a slight decline from 71 percent to 67 percent over the same period.
- Accessibility to safe drinking water in urban areas remained high (above 80 percent), with Burundi having the highest (97 percent), followed by Rwanda (92 percent) and Kenya (90 percent).

Human Settlements

Well-planned human settlements create sustainable societies, enhance market connectivity, and improve living conditions in rural and urban areas. However, rapid population growth and rural-urban migration are a growing challenge in the LVB. In 1996, the population in the Basin was estimated to be about 30 million. The population has been growing at an average rate of about 3 percent per year and was expected to have doubled by 2016 (Figure 3). The Basin therefore has a high population density, between 100 and 1,200 persons per square kilometer, most of whom are impoverished (Wandiga et al. 2009). This has placed a huge strain on the development of planned human settlements in all five EAC Partner States and the indicators show that this situation is only going to get worse.

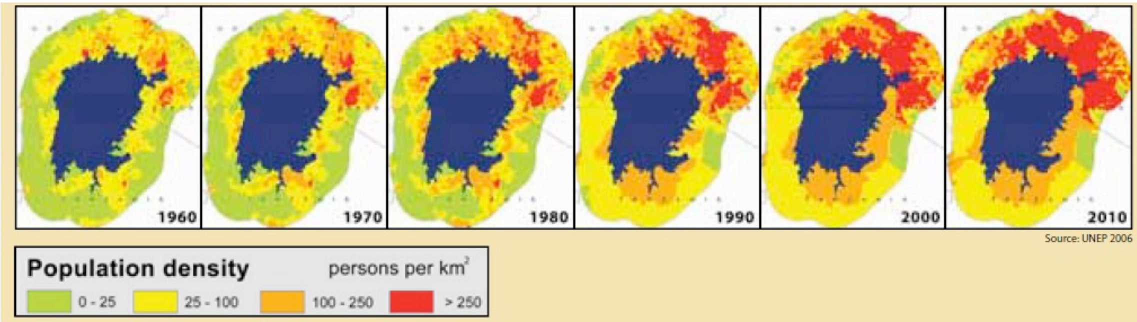


Figure 3: Trend in population density surrounding Lake Victoria, 1960-–2010

Legions of new urban dwellers live in risky situations that will be worsened by climate change. Climate variability and related extreme events, such as floods, will likely lead to high morbidity and mortality as well as outbreaks of vector-borne, water-borne, and sanitation-related infections.

More people now live in urban areas than in rural areas, with 54 percent of the world's population living in urban areas in 2014 (Figure 4). Rapid urbanization since the 1950s has radically changed demographics: in the 1950s only a third of the world's population lived in urban areas. By 2050, the United Nations estimates that this will reverse, with two-thirds living in urban centers and only a third in rural areas (UN 2013a).

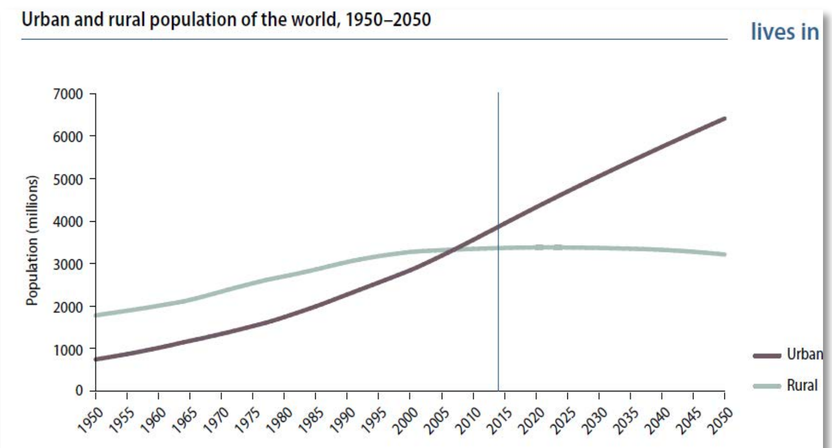


Figure 4: Urban and rural population of the world, 1950-–2015

Source: UN-Habitat 2014.

People arriving in already overstressed urban centers are forced to live in dangerous areas that are unsuitable for real estate or industrial development. Many construct their own homes in informal settlements on floodplains, in swamp areas, and on unstable hillsides, often with little or no infrastructure and basic services to support human life, safety, and development. These slum residents are often blamed by their governments for their poor living conditions. Even without additional weather-related stresses, such as extreme weather events (higher-intensity rainfall or more frequent storms), these are dangerous living environments (UN-Habitat 2011). The latest data provided by the Population Division of the United Nations reiterate that Africa is experiencing unprecedented population growth. The total African population is projected to nearly double from around one billion in 2010 to almost two billion by 2040 and may well surpass three billion by 2070 (Figure 5).

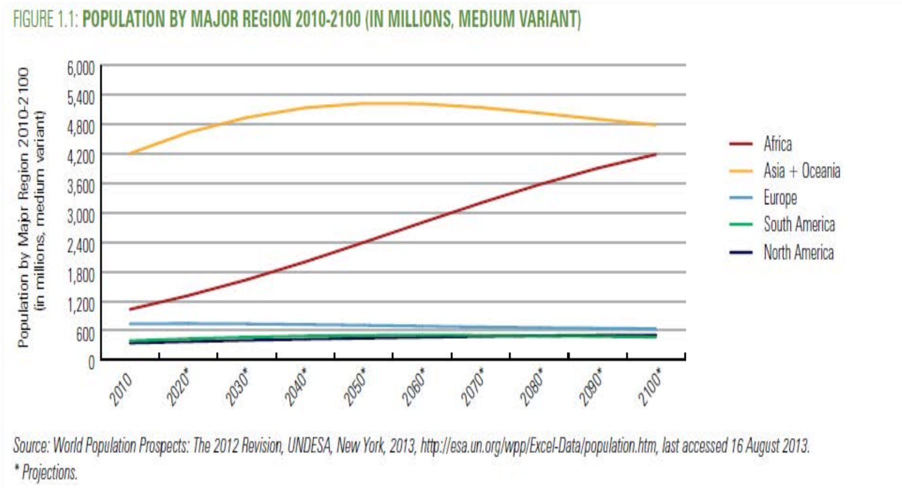


Figure 5: Population by region 2010 – 2100 (in millions, medium variant)

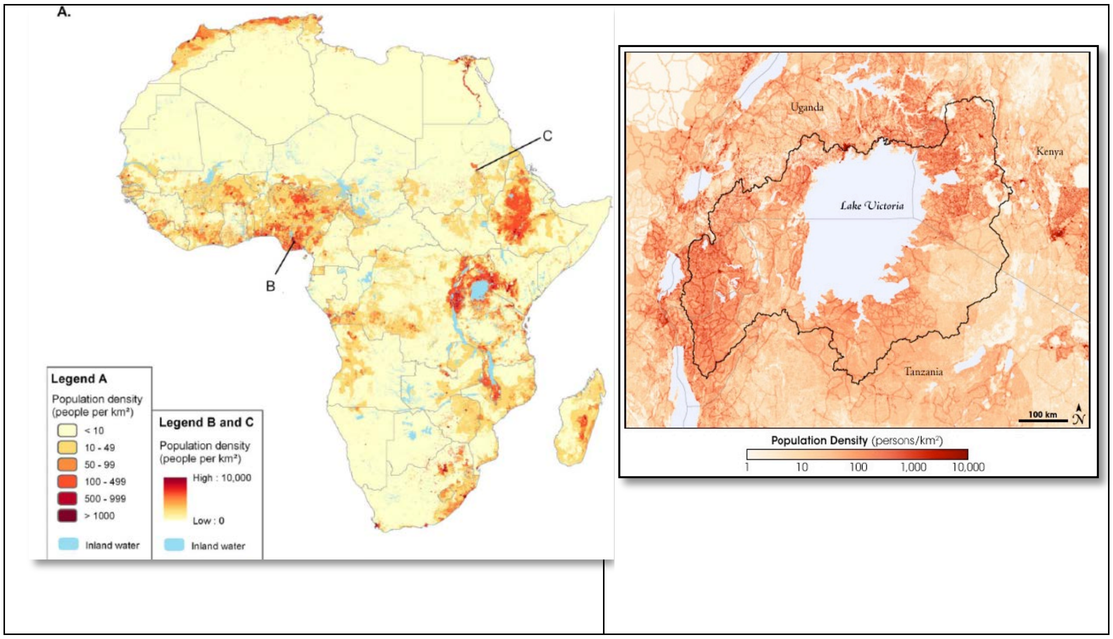
Rates of urbanization have varied considerably across the globe since 1950. Rates of urbanization in Asia fluctuated widely, mainly due to stagnation of urbanization in China in the late 1960s and early 1970s, and a subsequent upturn. Europe, Northern America, and Oceania, on the other hand, each experienced a period of stable urbanization, and overall their rate of urbanization has been slow over the past two decades. In Latin America and the Caribbean, the rate of urbanization has declined smoothly over the past six decades.

Africa is currently urbanizing faster than in the late 1990s and is expected to be the fastest urbanizing region from 2020 to 2050 (UN 2013b). The urban population in Africa is projected to triple by 2050, increasing by 0.8 billion (UN-HABITAT 2008, UN 2010). Many of Africa's evolving urban settlements are unplanned and have been associated with the growth of informal settlements; poor or no planning; lack of or poor data; lack of disaster risk reduction strategies; poor servicing and infrastructure (particularly waste management and drainage); uncontrolled settlement of high-risk areas such as floodplains, wetlands, and coastlines; ecosystem degradation; competing development priorities and timelines; and a lack of coordination among government agencies (AMCEN and UNEP 2006, Diagne 2007, Dossou and Gléhouenou-Dossou 2007, Mukheibir and Ziervogel 2007, Douglas et al. 2008, Roberts 2008, Adelekan 2010, Kithiia and Dowling 2010, Kithiia 2011). Consequently, these settlements have high levels of vulnerability and low adaptive capacity (Kithiia 2011).

Migration, particularly urbanization, typically is associated with economic opportunity. However, there are many subtleties in the scale and direction of migration flows and the general assumption that urbanization is ubiquitous and rapid throughout Sub-Saharan Africa has been challenged in recent years. Two main positions about the dynamics of African urbanization are now apparent (Potts 2012). One is that rapid urbanization is particularly associated with increased agglomeration and innovation in cities. The other position is that rural-urban migration in Sub-Saharan Africa, particularly until the early 2000s, was not accompanied by growth in investment, jobs, or formal enterprises (Fay and Opal 2000). Both positions tend to assume that rapid urbanization—an increase in the urban share of the national population—is occurring across Sub-Saharan Africa, in every country and every region (Potts 2013).

In fact, most countries in the region experienced rapid in-migration and urbanization in the early years of their independence. This was spurred by policies that encouraged modernization. But that began to change in the 1980s, when structural adjustment programs were introduced in the region. This policy shift transformed the underlying income gaps between rural and urban areas in Sub-Saharan Africa. Since then the urban economies of the EAC have found it hard to compete globally for investment in productive urban-based enterprises that could create significant numbers of formal sector jobs with steady incomes (World Bank 2009).

One major reason that urbanization is now rising more slowly in some EAC countries is that net rates of migration to urban areas have been reduced by a tendency toward circular migration, with significant numbers of people returning to rural areas because of weak urban economies (Tacoli 2001). East Africa remained the world's least urbanized sub-region but with its projected average annual urban growth of 5.35 percent over 2010–20 decade it may be by far the world's most rapidly urbanizing (UN-HABITAT 2008). Figure 6 shows the distributions of human settlements in Africa, with Burundi, Rwanda, and the areas around the LVB the most densely populated areas in East Africa. In 1996, the population in the LVB was estimated to be about 30 million. The population has been growing at an average of 3 percent per year and is expected to have doubled by 2016. The Basin has a high population density, between 100 and 1,200 persons per square kilometer, most of whom are impoverished (Wandiga et al. 2009a).

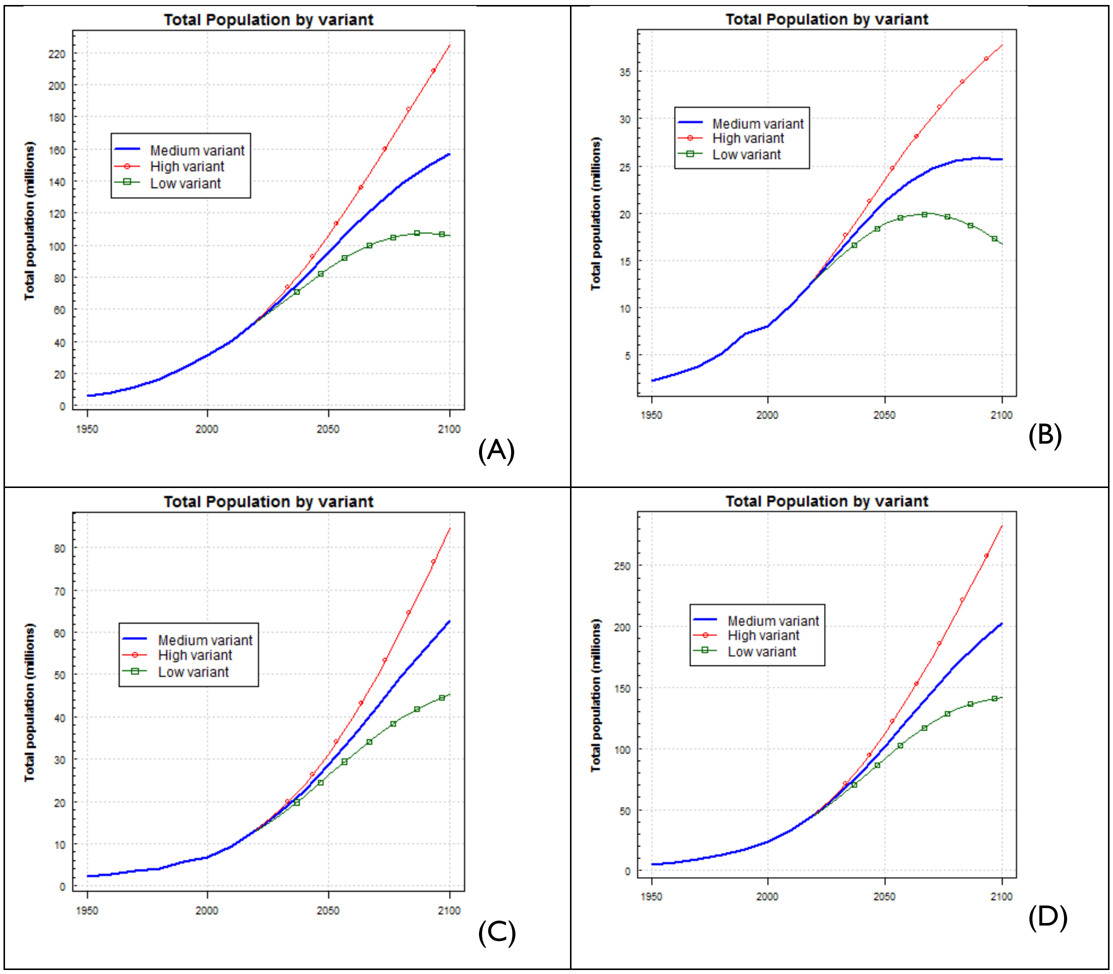


Source: Linard et al. 2012. Source: LVBC 2007

Figure 6: Spatial distribution of population and human settlements in Africa (2010) with an extract of Lake Victoria Basin

Urban growth in East Africa is largely concentrated in major cities. Smaller towns and cities exhibit more limited changes in structure and function (UNO 2010). Increasing urbanization has been observed across all EAC Partner States over the past three decades. This has led to the emergence and growth of urban and peri-urban areas (United Nations 2009, Linard et al. 2012). This rapid process has affected the socioeconomic and health processes of all the countries. By 2030, over 60 percent of the population in EAC Partner States will live in urban areas (United Nations 2009). Urbanization has led to an unmet demand for housing, water, sewerage, employment, and other basic services. Particularly significant is the emergence of informal settlements, which lack basic services such as roads, water supply, electricity, solid waste management, and suffer from overcrowding and cohabitation (United Nations 2009, Linard et al. 2012).

Communities in informal settlements are impoverished and more likely to have food shortages and water scarcity and are, therefore, susceptible to communicable diseases and poor health (United Nations 2009). Based on the national statistics for the five countries, Rwanda is the most densely populated—about 415 inhabitants per square kilometer. Burundi, Kenya, Tanzania, and Uganda, have population densities of 333, 73, 39, and 173 per square kilometer respectively (United Nations 2009, Linard et al. 2012). Figure 6 shows the population projections for East Africa by 2100. The life expectancy projections are shown in Figure 7, with East African countries showing medium levels.



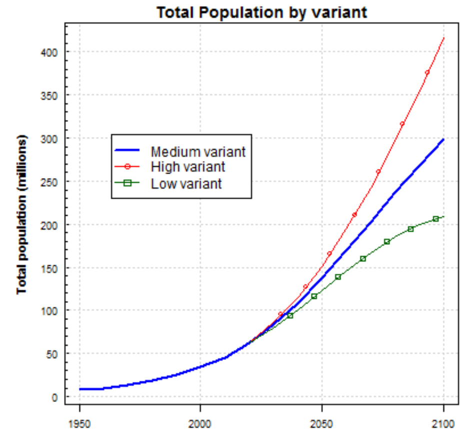


Figure 5: Projected populations of people in East Africa Burundi (A), Kenya (B), Rwanda (C), Tanzania (D), and Uganda (A, B, C, D and E respectively).

The population is predominantly rural—12 percent in Uganda, 20 percent in Kenya, and 23 percent in Tanzania. Hence, population growth is a key driver for settlements.

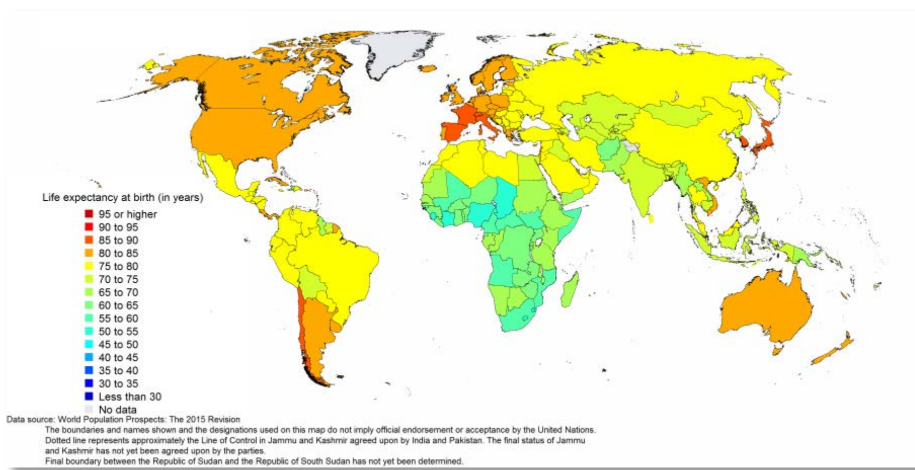


Figure 6: Life expectancy at birth, females, medium projection, 2015-–2020

The next sections describe the potential impacts of climate change on human health, sanitation, and human settlements in EAC Partner States in general, followed by a specific focus on malaria and cholera.

CLIMATE CHANGE AND THE HEALTH SECTOR

Rising temperatures and sea levels, as well as more frequent warm episodes resulting from the El Niño phenomenon, have been documented in recent decades. Malaria is a climate-sensitive disease and is the greatest burden on health in Sub-Saharan Africa. Based on historical trends, projected rainfall and temperature into the year 2100—future scenarios for 2030, 2050, and 2070—show that there will likely be an increase in malaria cases in the LVB. The projections indicate that the Basin is becoming warmer and wetter in the short rainy season, which will create an environment conducive for the spread of vector-borne and diarrheal diseases. Inter-annual and inter-decadal climate variability has a direct influence on malaria transmission and therefore should be placed high among those factors that affect human health and survival.

Seemingly simple changes in the physical environment can trigger a complex chain of physical, biological, and social interactions. Malaria, for example, is affected by various factors in the environment. These create a complex web of linkages and feedbacks, such as those that characterize changes in temperature, humidity, and surface water, which affect mosquito breeding, survival, and biting behavior. The impacts of climate change on human health are summarize in Figure 9.

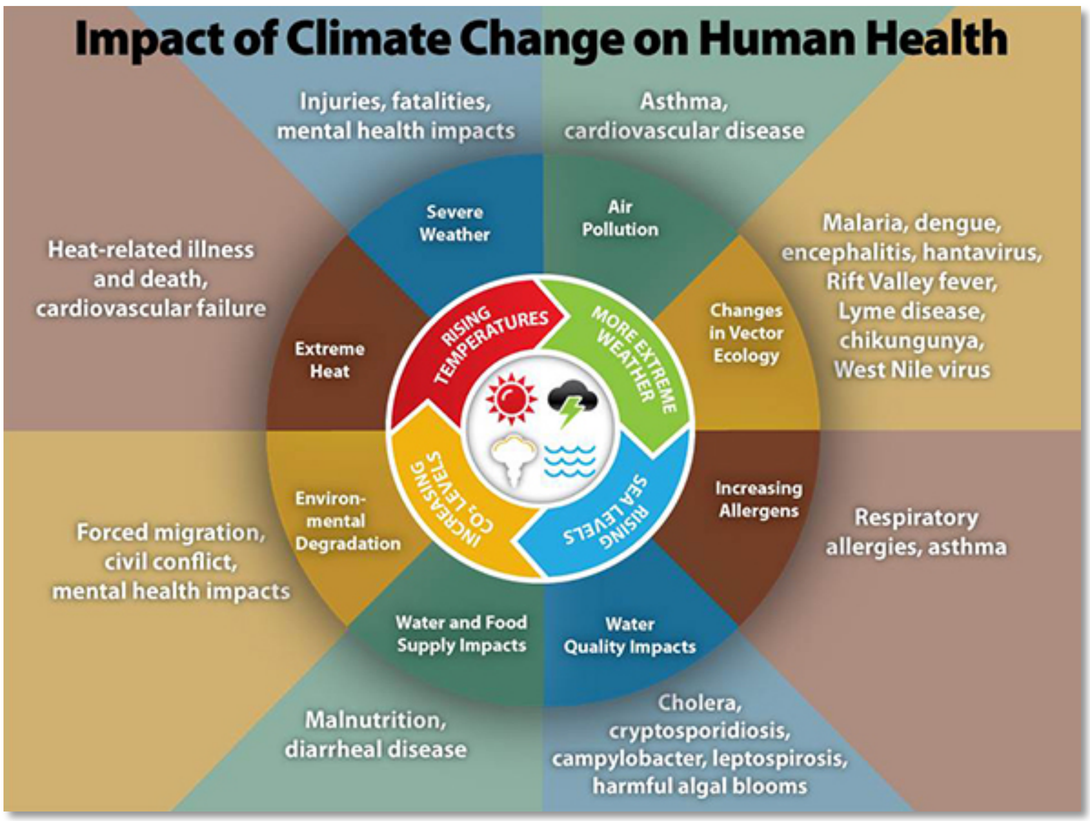


Figure 7: Impacts of climate change on health.

Source: Centers for Disease Control and Prevention
http://www.cdc.gov/climateandhealth/effects/.

Climate change will profoundly affect the social and environmental determinants of health, including clean air, safe drinking water, and sufficient food and secure shelter. Figure 10 shows the relationship between emission of greenhouse gases, climate change, and health (Watts et al. 2015).

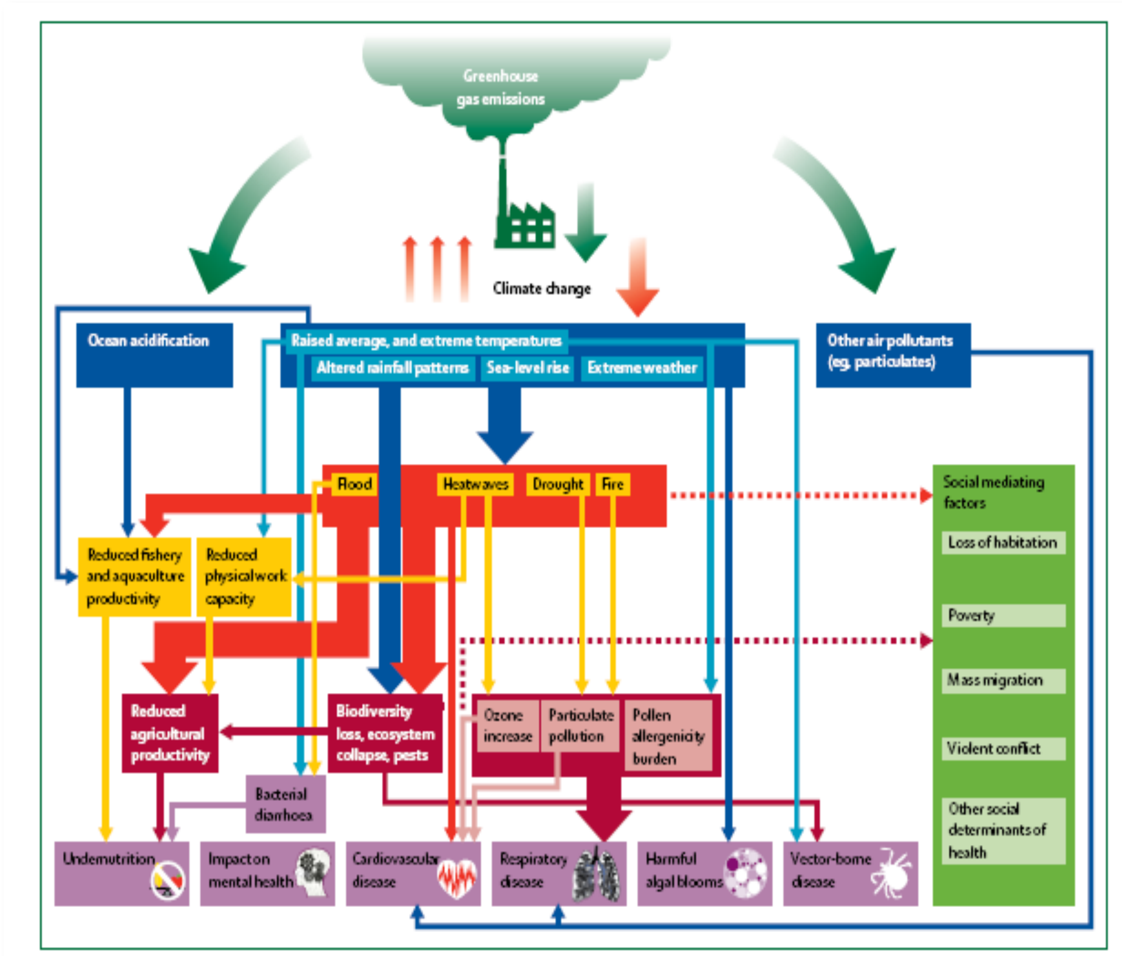


Figure 8: The relationship between greenhouse gas emissions, climate change, and health

Source: Watts et al. 2015.

An increase in the atmospheric temperature is associated with weather-related natural disasters such El Niño, which are characterized by extreme rainfall, flooding, landslides, severe droughts, and outbreaks of infectious diseases (IPCC 2014). The negative impacts of climate change are associated with extreme weather that can result in heavy rainfall, forest fires, floods, heatwaves, and drought (Watts et al. 2015). The climate change phenomenon poses a range of threats to human health and survival in multiple and interacting ways as shown in Figure 9 and 10 (Watts et al. 2015). Indirectly, climate change impacts are mediated through changes in the biosphere leading to changes in the burden of disease and distribution of disease vectors, food availability, de-settlement of human population, migration, and conflict associated with scarce resources (Watts et al. 2015). Since the 1960s, the number of weather-related natural disasters has tripled worldwide, resulting in human deaths and property and infrastructure losses, especially in developing countries (IPCC 2007).

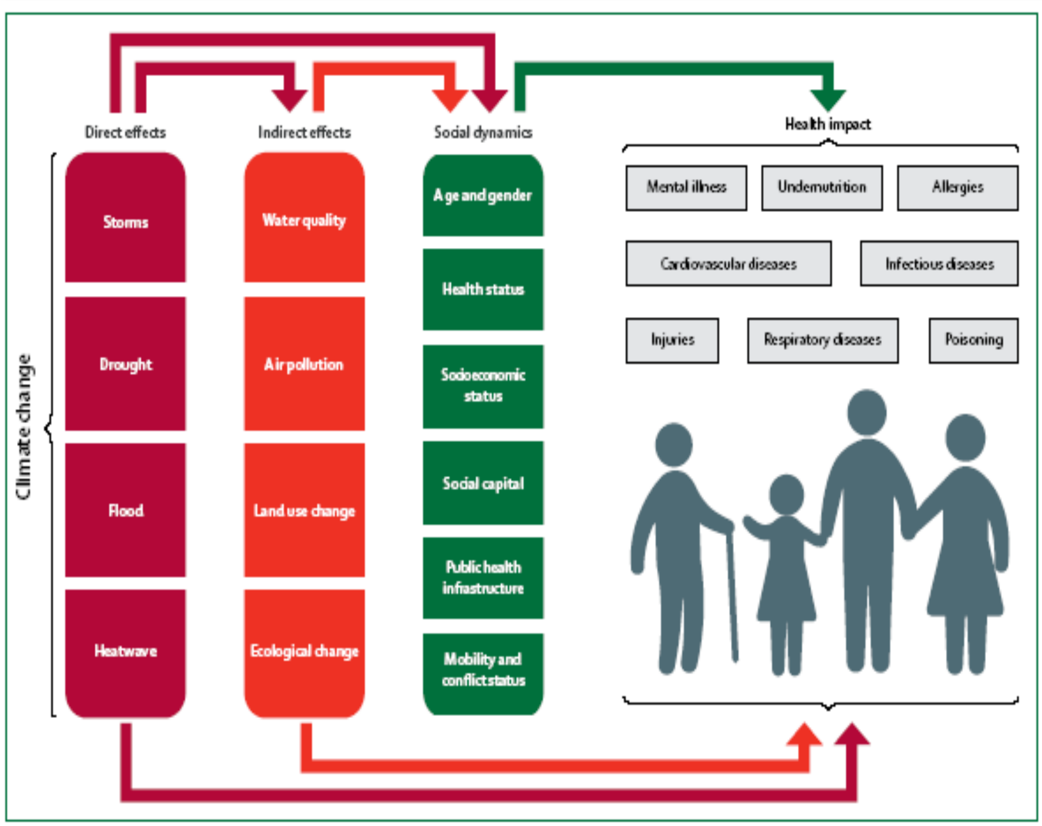


Figure 9: Direct and indirect effects of climate change on health and well-being extreme weather and resultant storm, forest fire, floods, heat waves and drought)

Source: Watts et al. 2015.

Sub-Saharan Africa is likely to be more severely affected by climate change than other regions of the world. It is projected that, by 2020, 75–250 million people in Sub-Saharan Africa will be affected by increased water stress and a 50 percent reduction in agricultural production. In addition, rising seas will lead to an increase in the transmission of water-borne diseases. If the impacts of climate change are not mitigated, by 2080 5–8 percent of the arable land in Africa is expected to be arid and semi-arid (IPCC 2014). Because the region is prone to natural disasters such as floods, droughts, and cyclones, it is considered a "global vulnerability hotspot" (ADW 2012). The potential impacts are summarized in Table 1.

Climate change poses a range of potential threats to East Africa. The EAC and its Partner States have tropical and sub-tropical climates, which favor the growth, multiplication, and transmission of several vector-borne and water-borne infectious diseases. The prevalence, mortality rates, and disability related to these diseases differ from one country to another; however, the number of years of life lost (YYL) due to premature death between 1990–2010 for all the EAC Partner States were mainly related to HIV/AIDS, malaria, and lower respiratory tract infections (Global Burden of Diseases 2010).

Table 1: Projected impacts of climate change in southern hemisphere

Risk/Impact		Observed vulnerability or change	Around 1.5°C (=2030s)	Around 2°C (=2040s)	Around 3°C (=2060s)	Around 4°C (=2080s)
Heat extreme (in the Southern Hemisphere summer)	Unusual heat extremes	Virtually absent	20–25 percent of land	45 percent of land	70 percent of land	>85 percent of land
	Unprecedented heat extremes	Absent	<5 percent of land	14 percent of land	35 percent of land	>55 percent of land
Drought		Increasing drought trends observed since 1950	Increasing drought risk in southern, central, and West Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of severe drought in southern, and central Africa, increased risk in West Africa, decrease in East Africa, but west and East African projections are uncertain	Likely risk of extreme drought in southern Africa and severe drought in central Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of extreme drought in southern Africa and severe drought in central Africa, decrease in East Africa, but West and East African projections are uncertain
Sea level rise above present (1985–2005)		About 21 cm to 2009	30cm-2040s 50cm-2070 70cm by 2080–2100	30cm-2040s 50cm-2070 70cm by 2080–2100	30cm-2040s 50cm-2070 90cm by 2080–2100	30cm-2040s 50cm-2070 105cm by 2080–2100
Health			+15-13% risk of diarrheal diseases +14–30% malaria increase in extra-tropics and highland			

Source: World Bank 2013.

The expected changes in temperature, precipitation, and humidity due to various climate change scenarios will increase disease risks and patterns by altering the biology and ecology of both disease vectors and intermediate hosts. For example, average temperatures are expected to increase by 1.0–3.5°C by 2100 in East Africa (Corner 2011). Some of the organisms that cause disease will respond with increased reproductive rates, reduced incubation periods, and other changes that will increase the risk of occurrence of water-borne and vector-borne diseases.

Modelled future global malaria impacts show that tropical highland regions of Africa, Asia, and South America may experience heightened malaria risk related to climate change (Figure 11). The extent of malaria transmission depends on some climatic factors, which influence both the distribution of malaria-carrying mosquitoes and the length of the season in which the mosquitoes are active.

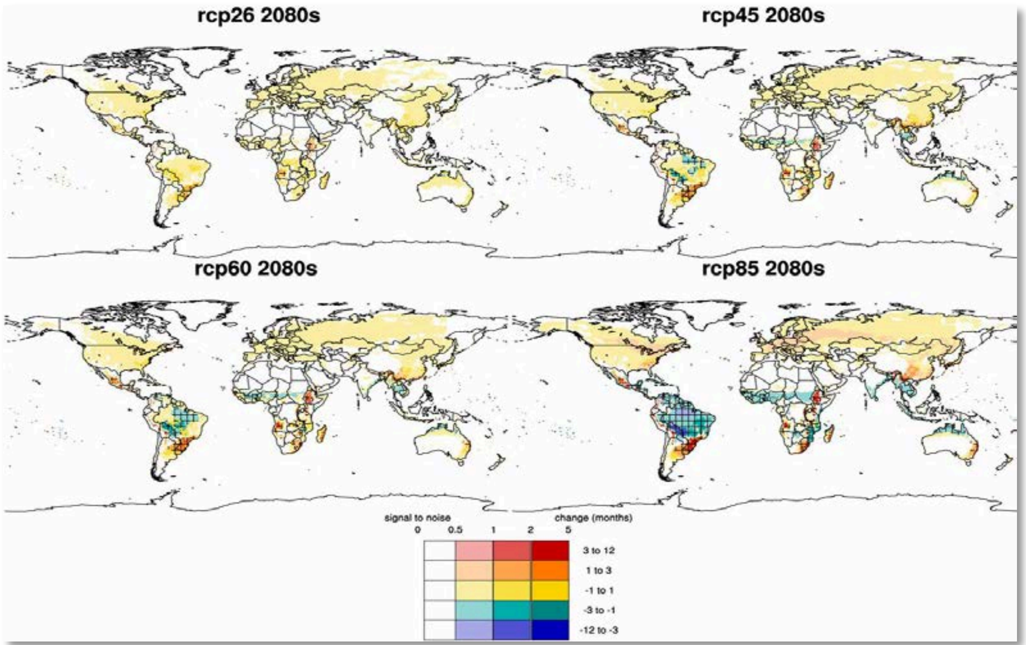


Figure 10: The effect of climate scenarios on future malaria distribution: changes in LTS. Each map shows the results for a different emission scenario (RCP).

Source: Caminade et al. PNAS 2014.

In a warmer, wetter future, the *P. falciparum* parasite, the main agent for transmission of malaria, will be able to spread to new parts of the world (Figure 12). Increased carbon dioxide concentrations will also alter the conditions in ways that could also increase the spread of malaria. Some areas will remain uninhabitable by the parasite.

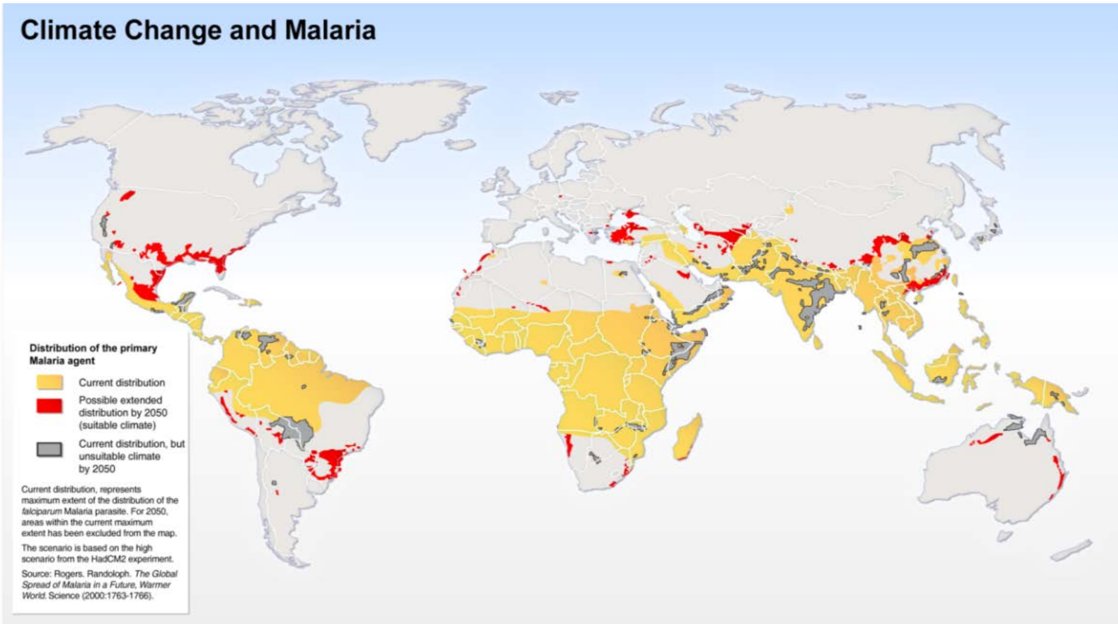


Figure 11: Climate change and malaria

Source: Hugo Ahlenius 2005, UNEP/GRID-Arendal.

Variability in temperature and precipitation has direct consequences in malaria outbreaks: increased precipitation increases the presence of the habitat conducive for disease vector larvae, which is likely to change the geography of infectious diseases by expanding the geographical range of the vectors (Hay et al. 2002a, 2002b). Increase in temperature also increases the development rate of the parasite and the vector. This increases transmission of the parasite in the highlands. A short-term increase in temperature and rainfall, as occurred in the 1997–98 El Niño, an example of inter-annual climate variability, caused *P. falciparum* malaria epidemics and Rift Valley Fever in Kenya. Research has found that this may have been due to accelerated parasite development and rapid growth in the populations of both the vector and mosquitoes (Githeko et al. 2000).

Extreme weather events may create the necessary conditions for malaria to expand its spatial range, with an unexpected impact on the human health especially in newly affected sites. Analysis of environmental factors associated with the malaria vectors *Anopheles gambiae* and *A. funestus* in Kenya found that abundance, distribution, and disease transmission are affected in different ways by precipitation and temperature (Zhou et al. 2004, Hay et al. 2002a and 2002b). Therefore, the malaria parasite has the potential to redistribute to a new habitat, leading to new disease patterns (Hay et al. 2002a).

Malaria epidemics have been increasing frequency in the highlands of eastern Africa over the last two decades. Several factors account for these epidemics and include climate variability, drug resistance, land use change, and vector migration. Between 2001 and 2006 epidemics following heavy rainfall were reported in Burundi, Kenya, Tanzania, and Uganda. Notably, the areas affected by the epidemics had previously experienced periods of drought and food insecurity (Figure 13 and 14) (Himeidan and Kweka 2012, Hay et al. 2002a and 2002b, WHO 2014). Countries in the EAC affected by highland malaria have a per capita gross domestic product in the range of US$106.8–505.5, and many have a negative income growth that compromises their access to medical care outside of government subsidies and schemes.

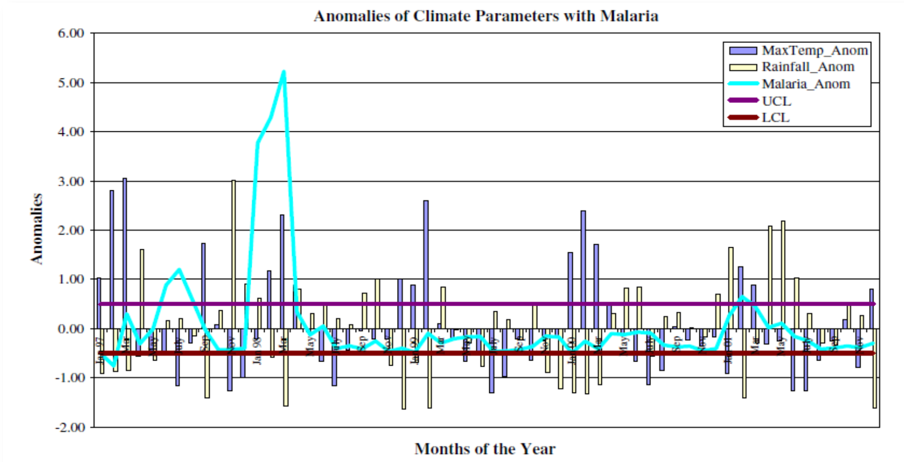


Figure 12: Temporal variation of maximum temperature, rainfall, and malaria epidemic anomalies between January 1997 and December 2001

Note: The spike in malaria anomaly in 1997 coincided with El Niño rains.

Source: Wandiga et.al. 2009.

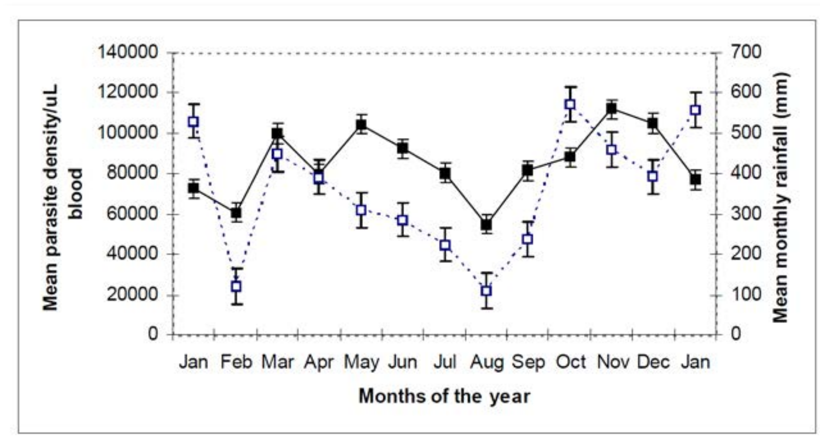


Figure 13: Parasite density increases with increasing rainfall between February and March to a peak value in May

Note: It declines to the lowest value 55,000 parasites/mL in August, but again rises to the maximum in November following the start of the second rain in September.

Source: Odongo-Aginya et al. 2005.

Cholera is a water-borne disease caused by *V. cholerae* bacteria. These bacteria typically thrive in waters with abundant phytoplankton, which support large zooplankton populations that can be a reservoir for the bacteria. As water surface temperatures rise, these populations can expand rapidly. Hence, potential future warming and increased variability of rainfall will likely increase the incidence of cholera. In the Asia, cholera incidence is influenced by local factors, such as rainfall and plankton blooms and by the global climatic conditions, such as increased sea surface temperature linked to El Niño events (Figure 15) (Colwell 1996, Borroto 1997, Lipp et al. 2002).

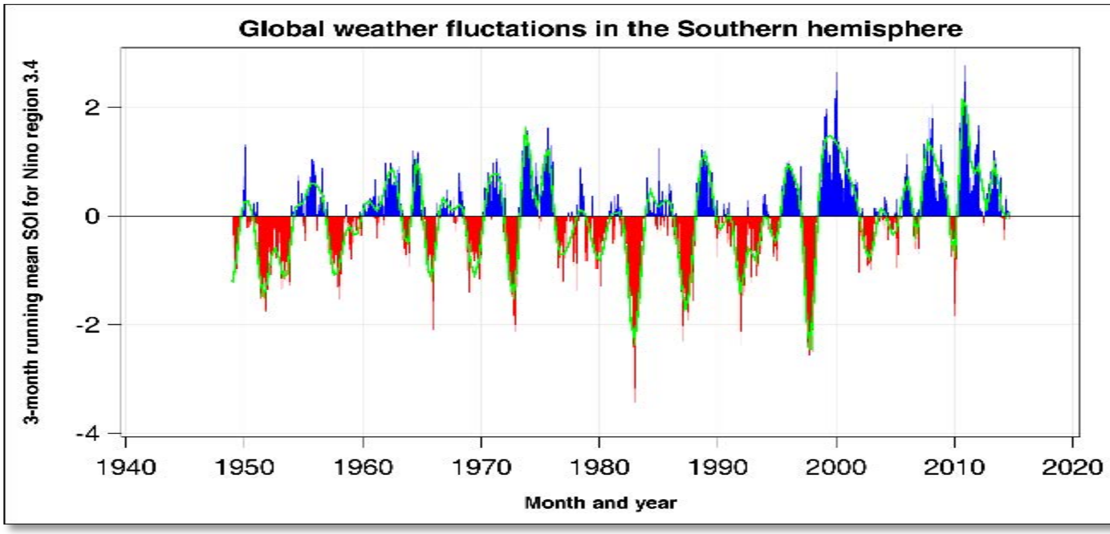


Figure 14: Changes in sea surface temperature

Increase in surface water temperature along the coast, coupled with plankton blooms driven by extremes weather associated with El Niño, are thought to amplify the population of *V. cholera*e in the environment (Colwell 1996). This increases the chances of secondary transmission of the bacterium through floods resulting from monsoon rainfall in the area (Borroto 1997). Evidence from South America shows that extremes of weather associated with El Niño (a warming of surface waters in the Central Pacific of 1°C greater than normal) coincided with an outbreak of cholera in Peru and other diarrhea-related diseases (from 1990–1995). In this period, El Niño lasted for more than three years, the longest period since 1870s (Colwell 1996). The outbreak of cholera was noted to occur more frequently during the El Niño events than during the La Niña periods since 1970 (Colwell 1996, Lipp et al. 2002).

The combination of higher temperatures, prolonged droughts, and extreme weather characterized by floods, coupled with scarce water resources and poor sanitation, make East Africa vulnerable to outbreaks of cholera and other water-borne diarrheal diseases (Wandiga 2006). A hierarchical model (Figure 16) defines the role of environmental, weather, and climate-related variables in the outbreak of cholera (Lipp et al. 2002). Changes in temperature affect glacial melt, increasing sea level, and alter the distribution of plankton species. As a consequence, saltwater intrusion in inland areas can result in increases in marine and estuarine bacteria, including *V. cholerae* (Lipp et al. 2002). Higher ambient temperatures lead to higher water temperatures in shallow bodies of water, such as ponds and rivers and shallow coastal waters. Studies have shown that both an increase in local temperature and the occurrence of floods caused by heavy rainfall can contaminate drinking water and influence the prevalence of the disease (Lipp et al. 2002, Borroto 1997, Colwell 1996).

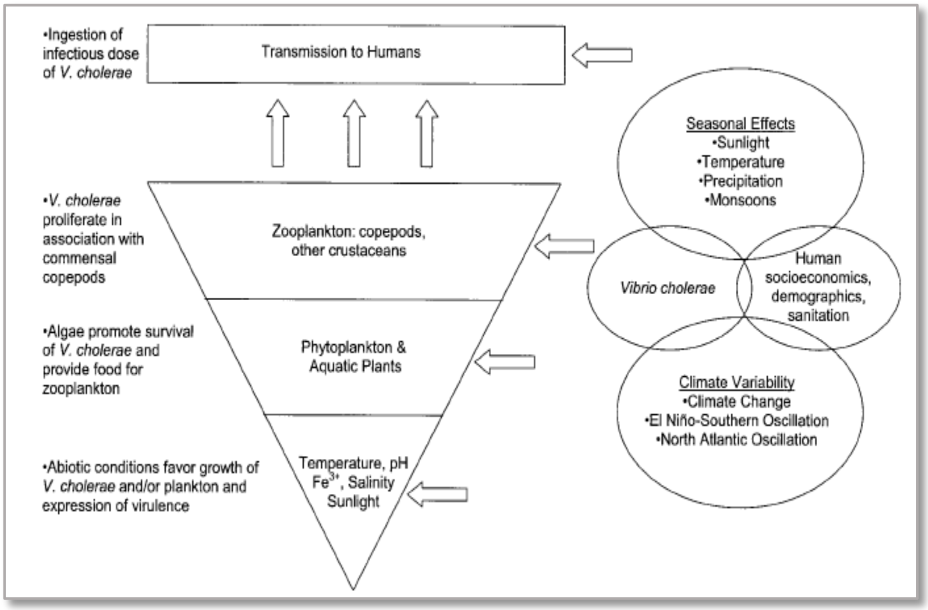


Figure 15: Hierarchical model for environmental cholera transmission (modified from Colwell and Huq)

Source: Lipp et al. 2002.

Wadinga (2006) has shown higher temperatures will likely result in an expanded range and increased prevalence of *V. cholerae*, if public health measures are not implemented. In East Africa, a similar pattern of increased cases of cholera epidemics followed extremes weather (Olago et al. 2007a, Wandiga et al. 2009b). In the period 1997–1998, an El Niño event brought extreme rainfall and excessive flooding to eastern Africa, which coincided with outbreaks of cholera in Djibouti, Kenya, Mozambique, Somalia, and Tanzania (Wandiga 2006). Along the LVB, the frequencies of cholera epidemics have been noted to coincide with the period of high flooding and high temperatures before and during El Niño years (Wandiga 2006).

High rainfall often triggers outbreaks of cholera because flooding destroys pit latrines and results in the contamination of water sources. Malaya et al. (2003) showed that coastal Tanzania has five of the eight regions with the highest number of cholera cases per capita. Dar es Salaam, which has numerous flooded areas, ditches, latrines, and septic tanks, has had repeated cholera outbreaks, as has Uganda (Mayala et al. 2003). Table 2 shows the relationship between rainfall and outbreaks of cholera in Kenya. Data from Uganda and Tanzania indicate that the incidence of cholera epidemics was higher during the El Niño periods (1997–1998) (Wandiga 2006).

Table 2: Cholera endemicity, density, and lethality in East Africa, 2000–2005

Country	Number of years reporting cholera	Median incidence per million persons 2000–2005	Mean case-fatality rate 2000–2005
Burundi	6	121	2.0
Tanzania	6	100	3.4
Uganda	6	98	3.6
Kenya	5	25	3.3

Rwanda	5	14	0.3

Source: Stoltzfu et al. 2014, modified from Gaffga et al. 2007.

Climate change could potentially increase the incidence of childhood pneumonia in tropical settings directly and indirectly. Recent studies in Nigeria have shown that the coefficient of correlation between rainfall and pneumonia is high—in the range of 50 and 90 percent—and positive, indicating that in general rainfall tends to increase cases of pneumonia infection. However, air temperature plays more important role compared to rainfall in reported cases of pneumonia infection (Paynter et al. 2010).

Several biologically plausible mechanisms may play a role in increasing the number of pneumonia cases associated with climate change. For example, an increase in rainfall will drive people into close quarters where they may be exposed to fuel smoke and crowding, as well as reducing their exposure to sunlight. Crowding will be exacerbated by large-scale population displacement (Paynter et al. 2010). Bacterial survival and virus stability in aerosols might be increased by higher humidity. Climate changes will also affect agriculture productivity and increase malnutrition, which has been shown to have a link with pneumonia: 44 percent of pneumonia deaths in children caused by undernutrition (WHO 2009). This means that childhood pneumonia is highly affected by climate and further studies are needed to understand this relationship (Paynter et al. 2010).

Children and women are more vulnerable to disease and climate change impacts. For example, due to lower immunity, children are at high risk of childhood diseases, malaria, and diarrheal diseases and need special support such as vaccination programs. Poverty and climate extremes expose children to malnutrition and mental and physical stunting. Poverty can also be a barrier to health care, where poorer people cannot afford medicine or medical care. Pregnant women are at a higher risk of malaria and this risk increases during epidemics that are, to a great extent, driven by climate (Githeko et al. 2000).

FUTURE IMPACTS ON HEALTH, SANITATION, AND HUMAN SETTLEMENTS

This health sector study indicates that future climate change will have major impacts on health, sanitation, and human settlements. Some of the potential impacts are summarized in this section.

HUMAN HEALTH

The health sector is very sensitive to climate change and the potential impacts will depend on the level of vulnerability and the adaptive capacity of the population at risk. Major events that are projected to occur include an increase in both maximum and minimum temperatures, increased rainfall, increased extreme events, and a rise in sea level that will lead to injuries, morbidity, and mortality (Table 3).

Table 3: Potential Impacts of Extreme Climate Change on the Health Sector

Phenomenon and direction of trend	Major projected impacts on human health
Projected increase in both maximum and minimum temperatures	▪ Reduced human mortality from reduced cold hazards ▪ Geographical re-distribution of vector-borne and water-borne diseases ▪ Increase in water surface temperatures that will lead to outbreak of water-borne diseases

	▪ Increased food spoilage and food-borne diseases, increasing the risk of malnutrition
Frequency of heatwaves	▪ Increased mortality especially in the elderly, sick, young, and marginalized groups ▪ Increased microbial infection pathways ▪ Increased air pollution and airborne diseases
Increase in rainfall and extreme rainfall events	▪ Reduced malnutrition due to availability of food and pasture for animals ▪ Increased depression and mental illness due to loss of livelihoods ▪ Increased injuries and mortality due to extreme events ▪ Increased vector-borne and water-borne infections ▪ Contamination of clean and safe water sources due to surface runoff ▪ Breakdown of toilets and latrines ▪ Displacement of people from their homes, creating homeless people exposed to disease outbreaks ▪ Increased outbreak of zoonotic infections ▪ Destruction of homes, buildings, and infrastructure; hence, reduced access to hospitals and health centers
Increased drought events	▪ Increased mortality due to lack of food and clean and safe water ▪ Increased water-borne and vector-borne infections ▪ Increased food-borne infections ▪ Increased risk of malnutrition
Rise in sea level	▪ Increased contamination of clean and safe water sources ▪ Displacement of people

SANITATION

Extreme events, such as floods, will lead to effects such contamination of safe water sources and a breakdown of sewage systems while droughts will reduce the availability of safe water to ensure proper hygiene is maintained. All which will lead to outbreaks of diseases (Table 4).

Table 4: Potential Impacts of Extreme Climate Change on the Sanitation Sector

Phenomenon and direction of trend	Major projected impacts on sanitation
Projected increase in both maximum and minimum temperatures	▪ Increase in water surface temperatures that will lead to outbreaks of water-borne diseases
Increase in rainfall and extreme rainfall events	▪ Increased vector-borne and water-borne infections ▪ Contamination of clean and safe water sources due to surface runoff ▪ Breakdown of toilets and latrines ▪ Displacement of people from their homes, creating homeless people exposed to disease outbreaks ▪ Increased outbreak of zoonotic infections
Increased drought events	▪ Increased water-borne and vector-borne infections ▪ Outbreak of sanitation-related diseases ▪ Reduced sanitation due to unavailability of enough water
Rise in sea level	▪ Increased contamination of clean and safe water sources ▪ Displacement of people ▪ Breakdown of sewage systems

HUMAN SETTLEMENTS

Developing countries will be extremely vulnerable to climate changes because they are both susceptible to the change and already at the limits of their capacity to cope with climatic events. These include populations in low-lying coastal regions and islands, subsistence farmers, populations in semi-arid grasslands, and the urban poor. Regions already struggling to cope with exploding populations can be expected to be exceptionally vulnerable to climate change, urban growth, and poverty (Table 5).

Table 5: Potential Impacts of Extreme Climate Change on the Human Settlements Sector

Phenomenon and direction of trend	Major Projected impacts on Human Settlements
Projected increase in both maximum and minimum temperatures	▪ Reduced human mortality from reduced cold hazards ▪ Geographical re-distribution of vector-borne and water-borne diseases ▪ Increase in water surface temperatures that will lead to outbreaks of water-borne diseases ▪ Migration to cooler areas
Frequency of heatwaves	▪ Increased mortality especially in the elderly, sick, young, and marginalized groups
Increase in rainfall and extreme rainfall events	▪ Reduced malnutrition due to availability of food and pasture for animals ▪ Increased injuries and mortality due to extreme events ▪ Landslides ▪ Increased vector-borne and water-borne infections ▪ Contamination of clean and safe water sources due to surface runoff ▪ Breakdown of toilets and latrines ▪ Displacement of people from their homes, creating homeless people exposed to disease outbreaks ▪ Increased outbreak of zoonotic infections ▪ Destruction of homes, buildings, and infrastructure; hence, reduced access to hospitals and health centers
Increased drought events	▪ Increased mortality due to lack of food and clean and safe water ▪ Increased water-borne and vector-borne infections ▪ Increased food-borne infections ▪ Increased risk of malnutrition ▪ Increased conflict
Rise in sea level	▪ Increased contamination of clean and safe water sources ▪ Displacement of people

CLIMATE CHANGE AND FUTURE PROJECTIONS IN THE LVB

To understand the likely changes in the future climate in East Africa and the LVB as a basis for defining the potential impacts and therefore adaptation options for the health, sanitation, and human settlements, studies were undertaken to model the future climate scenarios.

PROJECTING FUTURE EAST AFRICAN CLIMATE CHANGE

Climate change analysis and projections used in this study were based on the regional downscaled climate model developed under the international coordinated framework to produce an improved generation of regional climate change projection, known as CORDEX (Coordinated Regional Climate Downscaling Experiment).[2] The downscaling was performed using multiple regional climate models (RCMs) as well as statistical downscaling techniques. Three climate change scenarios were used to project rainfall and temperatures. Each scenario corresponds with a Representative Concentration Pathway (RCP)—RCP2.6, RCP4.5, and RCP8.5—the numbers referring to radiative forcings (global energy imbalances), measured in watts per square meter, by the year 2100.

The RCP2.6 pathway represents scenarios that result in very low concentrations of greenhouse gases (Van Vuuren et al. 2007). The RCP4.5 pathway represents stabilization, where total radiative forcing is stabilized before 2100 through the use of technologies and strategies that reduce greenhouse gas emissions (Wise et al. 2009). The RCP8.5 scenario represents increasing greenhouse gas emissions, and therefore increasing concentrations, over time (Riahi et al. 2007). A more detailed description of the RCPs is presented in the chapter on Climate Change in East Africa. The following observations were made on the future rainfall and temperature changes in East Africa under the RCPs.

The projected changes in the annual rainfall component under each of the three scenarios and time windows show relatively little change compared to the projected changes in the seasonal rainfall components. The short rains (October–December, or OND period) are projected to increase over most of the region under all the three scenarios (10–25 percent by 2030, and 25–50 percent by 2050; Figures 17 and 18). By contrast, the long rains (March–May, or MAM period) are projected to decrease over the northern part of the region but to increase over the southeastern part. The dry season rainfall (June–September, or JJAS) is projected to decease over most of the region. The projected annual rainfall shows a tendency to increase over the LVB.

[2] http://www.cordex.org/

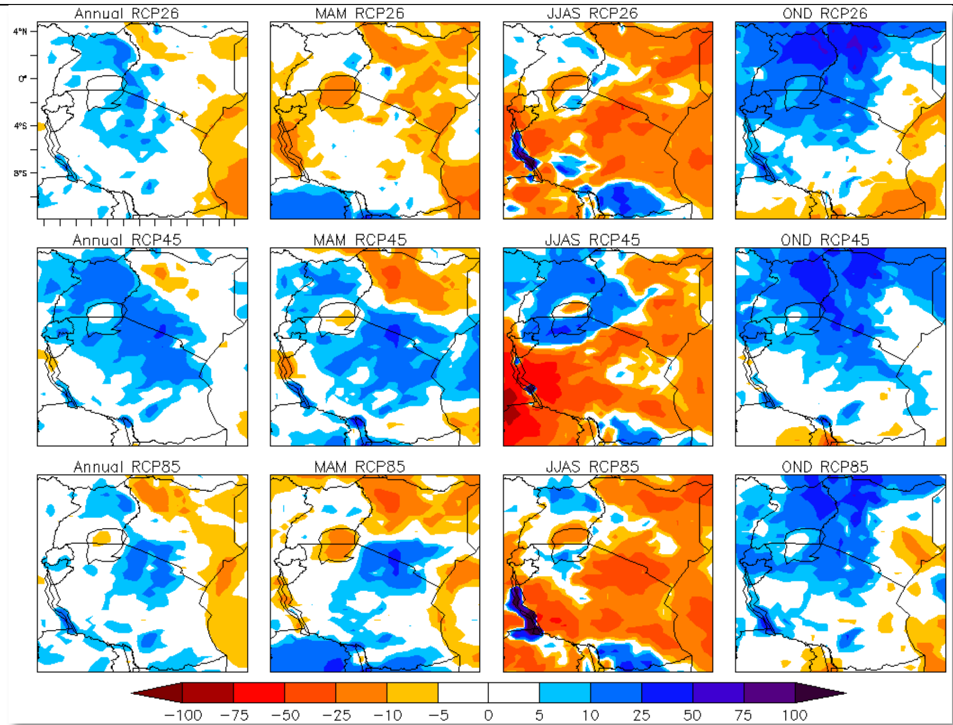


Figure 16: Projected rainfall changes over the EAC by the 2030s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

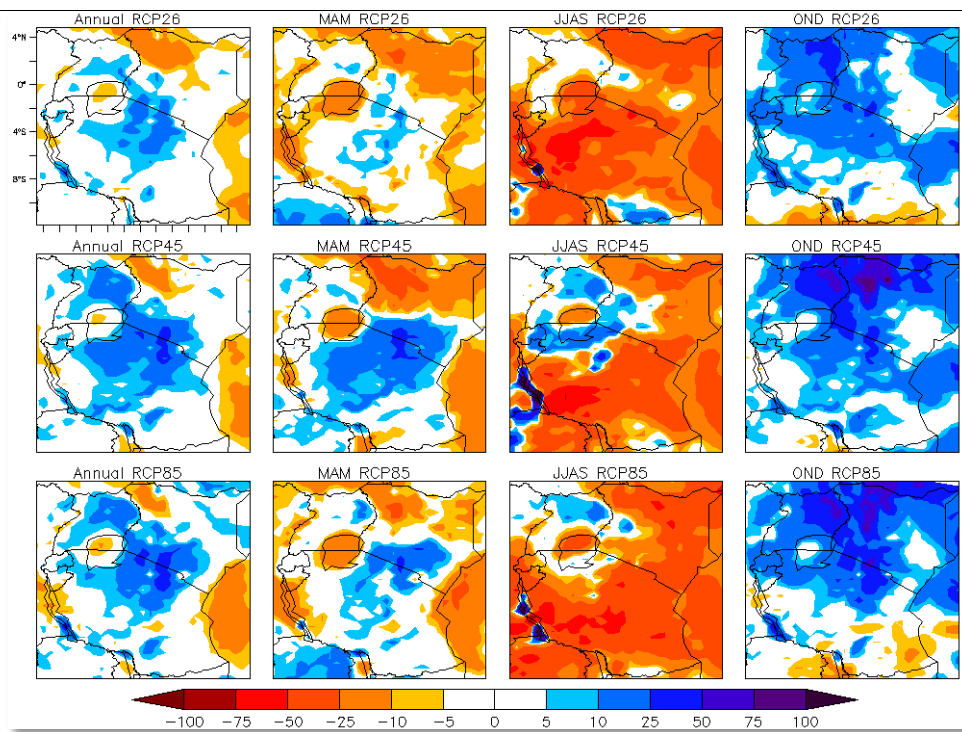


Figure 17: Projected rainfall changes over the EAC by the 2050s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

The projected changes in the maximum temperature component for the three scenarios in the 2030s and 2050s compared to the reference period (1971–2000) are shown in Figures 19 and 20. By 2030, maximum temperatures during the long rains (MAM), the dry season (JJAS), and the annual component will likely increase by 1.0–2.0°C over most of the region. The expected warming extent is greatest during the long rains (MAM) and the dry season (JJAS) and least during the short rains (OND). By 2050, annual maximum temperatures are expected to be 1.0–2.0°C higher under the RCP2.6, 1.5–2.5°C higher under the RCP4.5 and 2.5–3.5°C higher under the RCP8.5 scenarios over most of the EAC, with slightly less warming expected in some coastal areas.

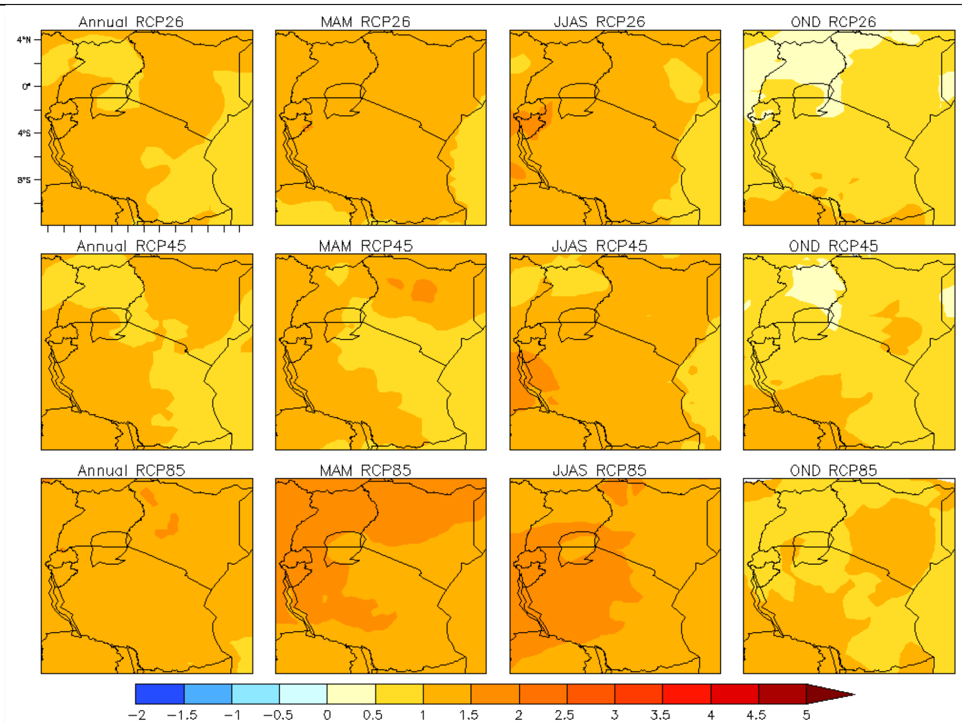


Figure 18: Projected maximum temperature changes over the EAC by the 2030s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8 (third row).

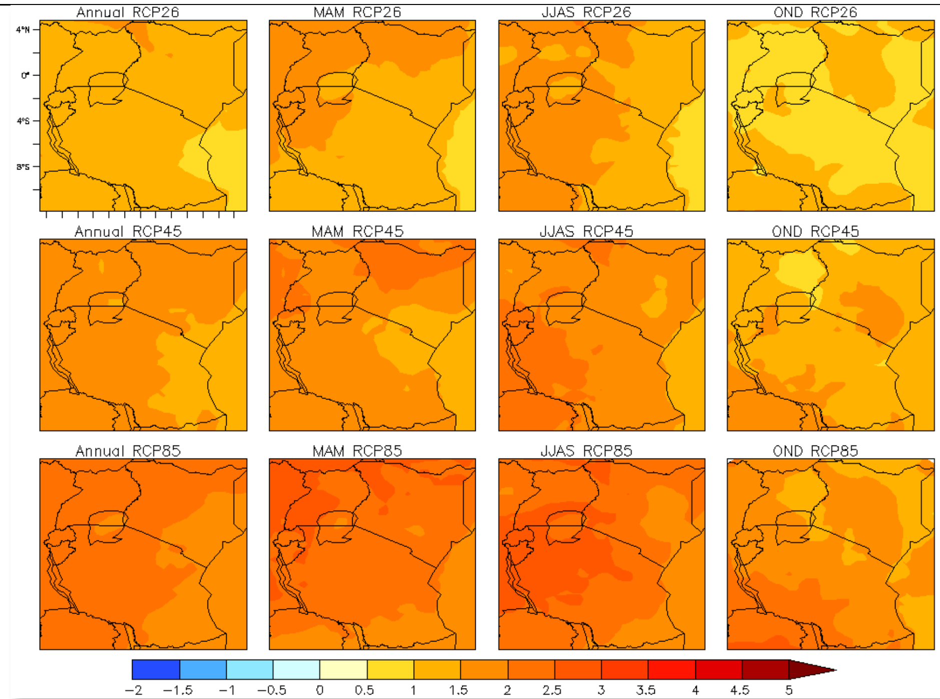


Figure 19: Projected maximum temperature changes over the EAC by the 2050s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (third row).

The projected changes in the minimum temperatures for the three scenarios are shown in Figures 21 and 22. The results suggest that there will likely be a greater increase in the minimum than the maximum temperatures in future. By 2030, almost all the EAC region will likely be 1.0–2.5°C warmer than the base period, with the greatest warming expected during the dry season months (JJAS) under the RCP8.5 scenario. By 2070, the projected increase in the annual minimum temperatures will likely be 4–5°C higher under the RCP8.5 scenario relative to the base period.

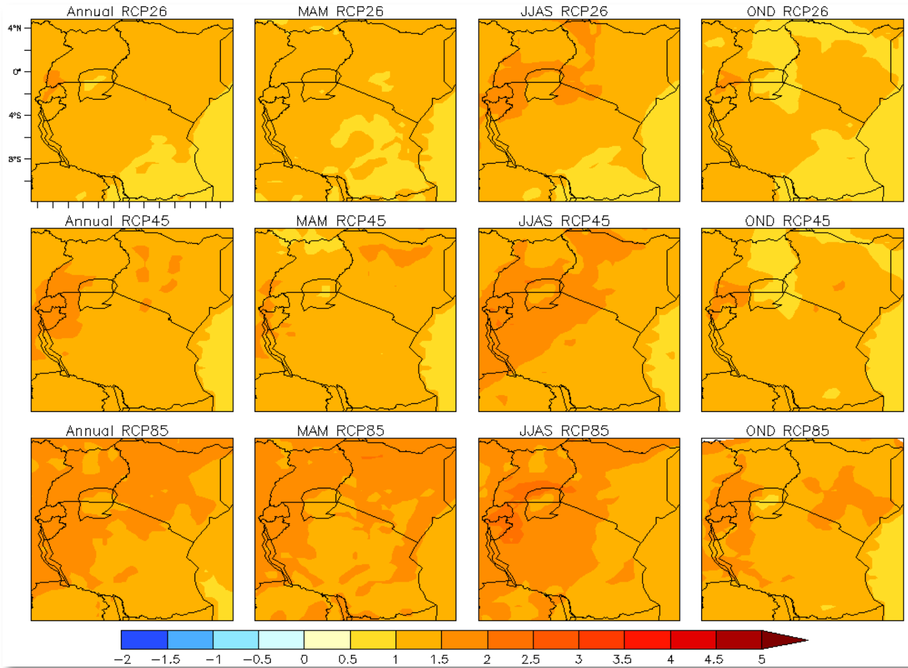


Figure 20: Projected minimum temperature changes over EAC by 2030s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row) and RCP8.5 (3rd row).

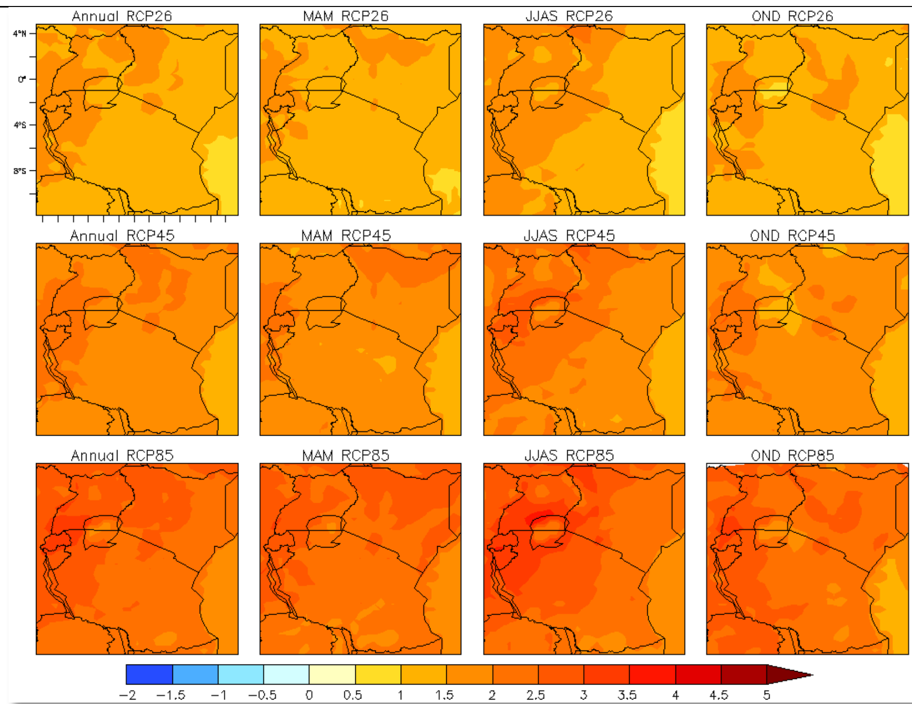


Figure 21: Projected minimum temperature changes over EAC by 2050s in the annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column) components. Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row) and RCP8.5 (3rd row).

IMPACTS OF FUTURE CLIMATE CHANGES ON MALARIA

A considerable number of studies have linked climate change with health issues on continental Africa. For example, results from the Mapping Malaria Risk in Africa project (MARA/ARMA) indicate changes in the distribution of climate-suitable areas for malaria by 2020, 2050, and 2080 (Thomas et al. 2004). By 2050, and into 2080, a large part of the western Sahel and much of southern-central Africa are likely to become unsuitable for malaria transmission. Other assessments (Ebi et al. 2005), using 16 climate change scenarios, show that changes in temperature and precipitation by 2100 could result in a shift in the geographical distribution of malaria in Zimbabwe that will expose dense human populations to transmission where the habitat had previously be unsuitable for the disease.

Therefore, changes can be expected in disease distribution, range, prevalence, incidence, and seasonality in East Africa. However, the nature and magnitude of the anticipated future changes in the LVB have not yet been quantified. The number of extremely wet seasons in the Lake Victoria region is projected to increase, suggesting that conditions there will likely become more suitable for malaria transmission in the future. Future malaria scenarios for the LVB were projected using the VARMAX (*p,q,s*) model to relate the reported malaria cases (log-transformed) to prior rainfall and minimum and maximum temperatures and forecast the anticipated malaria cases to 2100 under the three scenarios, RCP2.6, RCP4.5, and RCP8.5. The parameter estimates and univariate model diagnostics for assessing how well the selected VARMAX (*p,q,s*) models fitted the data are provided in the appendix.

The study aimed to develop case studies for this analysis from all the five EAC Partner States, However, statistical testing was limited to Kenya, Tanzania, and Uganda as data sets for other countries were not robust enough for analysis. Relationships between malaria cases for Rwanda and Burundi could not be derived due to the unavailability of historical monthly malaria data; hence, future scenarios for malaria for these two countries could not be developed. A review of historical trends for selected sites was provided in the sector baseline report.

ANALYTICAL APPROACH

Monthly malaria data from three countries Kenya, Tanzania, and Uganda spanning the period 1995–2010 were used to develop regression relationships with historic rainfall and temperature data derived from GeoCLIM. The established regression relationships were then used with projected rainfall and temperature data provided by ICPAC for the period 2006–2100 for each of the three scenarios.

The relationships between each of the sector indicators and historic rainfall or temperature were carefully statistically modelled. This involved relating the indicators to various lagged values and cumulative moving averages of rainfall and minimum and maximum temperatures using the Pearson product moment correlation that assumes bivariate normality of the two variables being correlated and linearity of the relationship between them. The Spearman rank correlation, which is more appropriate if the relationship between two variables is nonlinear and monotonically increasing or decreasing, was also calculated. Finally, the Akaike information criterion (AIC) and its corrected variant, the corrected Akaike information criterion (AICc), were computed to rank contending models (linear and nonlinear regression models) in terms of the weight of evidence in support of each.

The best AICc-supported models and rainfall or temperature components from the preceding step were then used to build final regression models and the associated intercept and slope coefficients and their standard errors and statistical significance computed. Various regression approaches were used to accommodate possibly curvilinear relationships and non-Gaussian frequency distributions of some of the sector indicator variables. This resulted in the use of standard normal-theory regressions and generalized linear models, including logistic and negative binomial regressions. The negative binomial regression included offset variables, as appropriate, whereas both the negative binomial and logistic regression models allowed for potential over dispersion of the response variables to account for possible departures in the observed mean-variance relationships from the theoretical expectations of the binomial or negative binomial distribution. The negative binomial model we used assumed a log link function and that the mean is a quadratic function of the mean. The logistic regression model assumed a logit link function and a binomial error distribution.

Established regression relationships were also visualized with the aid of graphical plots, as appropriate. The regression relationships were used to project the likely future trajectories of the sector indicators using the projected future rainfall and temperature under the three scenarios. For each response series, forecasting was done separately for each scenario.

Forecasting the likely responses of each of the health sector indicators to the projected rainfall and temperature under each of the three scenarios was done using one of two models. The first models vector (multivariate) autoregressive moving-average processes (VARMAX (*p,q,s*)). This model can be used to fit and forecast a univariate time series when only a single sector indicator series (regarded as the dependent, response, or endogenous variable) is under consideration or vector processes (i.e., multiple time series) by assuming that at each time point the observations consist of a vector of responses (sector indicators). Each of the responses can depend on its own lagged values and the lags of the other vector entries. Details on the VARMAX model are in the appendix.

Extensive multivariate or univariate model diagnostic checks were done to assess the appropriateness of the selected VARMAX (*p,q,s*) models. The diagnostic tools used were the following:

- Parameter estimates and the significance of the parameter estimates.
- Durbin-Watson test for first-order autocorrelation in the residuals.
- Jarque-Bera normality test to determine whether the model residuals represent a white noise process by testing the null hypothesis that the residuals are normally distributed. An insignificant test result means that the null hypothesis that the residuals are normally distributed cannot be rejected. This test was supplemented with visual examination of the QQ plots of the residuals.
- F tests for autoregressive conditional heteroscedastic (ARCH) disturbances in the residuals. This F statistic tests the null hypothesis that the residuals have equal covariances. If not significant, this test supports the conclusion that it is not possible to reject the hypothesis that the residuals have equal covariances.
- F tests for AR disturbance computed from the residuals of the univariate AR(1), AR(1,2), AR(1,2,3), and AR(1,2,3,4) models to test the null hypothesis that the residuals are uncorrelated. Non-significant test results for a specific lag mean that it is not possible to reject the hypothesis that the residuals are not correlated for that lag.
- Portmanteau tests (Hosking 1980) for cross-correlations of residuals at various lags. If non-significant, this test supports the null hypothesis that the residuals are not cross-correlated up to the specific lag. The selected final model was used to forecast the response series and calculate the 95 percent prediction confidence limits for lead times running up to 2100.

The second model used for forecasting the response series is the unobserved components model (UCM). This model was used only for those response series that were nonlinearly related to one of the explanatory series. The UCM is a structural time series model and a special case of the general state space model, appropriate for modelling and forecasting univariate time series. The UCM can accommodate nonlinear relationships between the response and the explanatory series. Nonlinearity was modelled using penalized cubic basis splines, or equivalently, random regression or varying coefficients regression models. In addition, the UCM can accommodate autoregression, seasonality, multiple cyclical patterns, dynamic level shifts, dynamic trend, and other features. The UCM can thus also be viewed as dynamic regression models with multiple predictors. It can provide filtered and smoothed trend and cyclical patterns. For more complex univariate or multivariate models that cannot be handled by the UCM, the general state space model, which is much more general and versatile than the UCM and can accommodate more general univariate models and multivariate time series, among other features, can be used for forecasting (Engle 2002, Engle and Granger 1987, Hosking 1980, Johansen 1995).

MODELLING RESULTS – 2030, 2050, AND 2070

The results of the analysis are summarized below by country.

Burundi. Burundi's second Demographic and Health Survey provides indicators on the overall national health situation (USG 2011). The assessment documented the following:

- Child mortality rate of 96/1000 live births
- Immunization coverage for children under 12 months of 83 percent
- Anemia prevalence in children under five of 45 percent
- Anemia prevalence in pregnant women of 19 percent
- Stunting rate in children under five of 58 percent. Stunting rates—and nutritional status—had worsened over the previous five years
- Percentage of households with at least one bed net was 53 percent. This was an improvement and a direct result of the mass distribution of bed nets launched in 2009 and continued through early 2011. Malaria control interventions have not reached the required level of >80 percent households with at least one bed net for every two people.

The historical trends in malaria cases in Burundi for the period 1996–2011 show a decline in malaria cases for the over-five population but an increase for the under-five population (Figure 23). This shows the effectiveness of measures taken to reduce child mortality due to malaria. However, these measures clearly need to be sustained beyond five years of age.

Serious limitations on data access compromised efforts to model projections of malaria in Burundi for the three RCPs for 2030, 2050, and 2070.

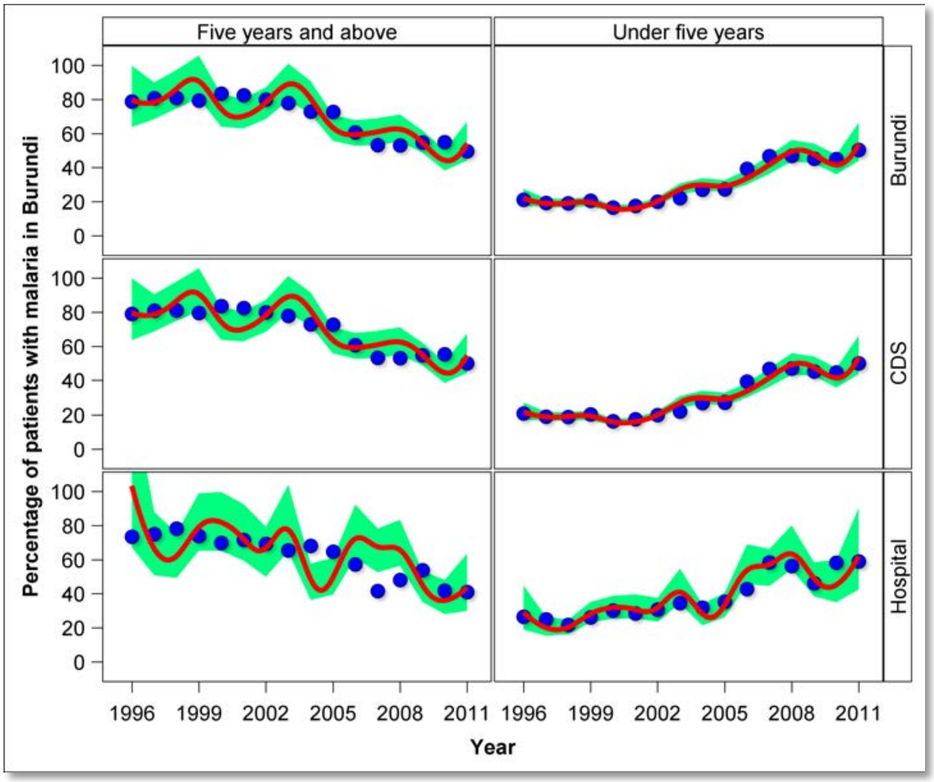


Figure 22: Percentage of patients with malaria in Burundi

Kenya. Projections for the Kenyan section of the LVB were based on historic data on malaria cases from the Central Unilever Tea Hospital and Litein Hospital, both in Kericho, and Mukumu hospital in Kakamega. Both Kericho and Kakamega are in highland regions of western Kenya. Malaria epidemics were unheard of in that area until the second decade of the 20th century as the environment was unsuitable for mosquitoes due to very low temperatures.

Population increase, agricultural development, and improvements to infrastructure in the highlands were associated with major land use and environmental changes. The changes increased the suitability of the highlands for mosquitoes. Consequently, malaria epidemics were reported as early as the 1930s and later in the 1980s and 1990s (Hay et al. 2002b and 2002c). The 1997–1998 El Niño was the strongest recorded since 1847 and produced heavy rains that were followed by a malaria epidemic. The frequency and intensity of such epidemics may be expected to increase due climate change associated with global warming. A trend of rising temperatures has already been reported for some highland regions of Kenya, such as Kericho (Malakooti et al. 1998). Several studies have also shown that Kakamega and some other highland regions have flat valleys that form suitable habitats for the malaria vectors, making these regions hot spots for malaria transmission (Malakooti et al. 1998, Wanjala et al. 2011).

The trends for reported malaria cases in the three western Kenya hospitals are shown in Figure 24. A total of 156 variables were related to malaria cases, three of which were found to have strong correlations with reported malaria cases. Linear regressions were then used to relate the malaria cases to the identified variables. The results are shown in Table 6, including R^2, the slope and intercept of the fitted regression line.

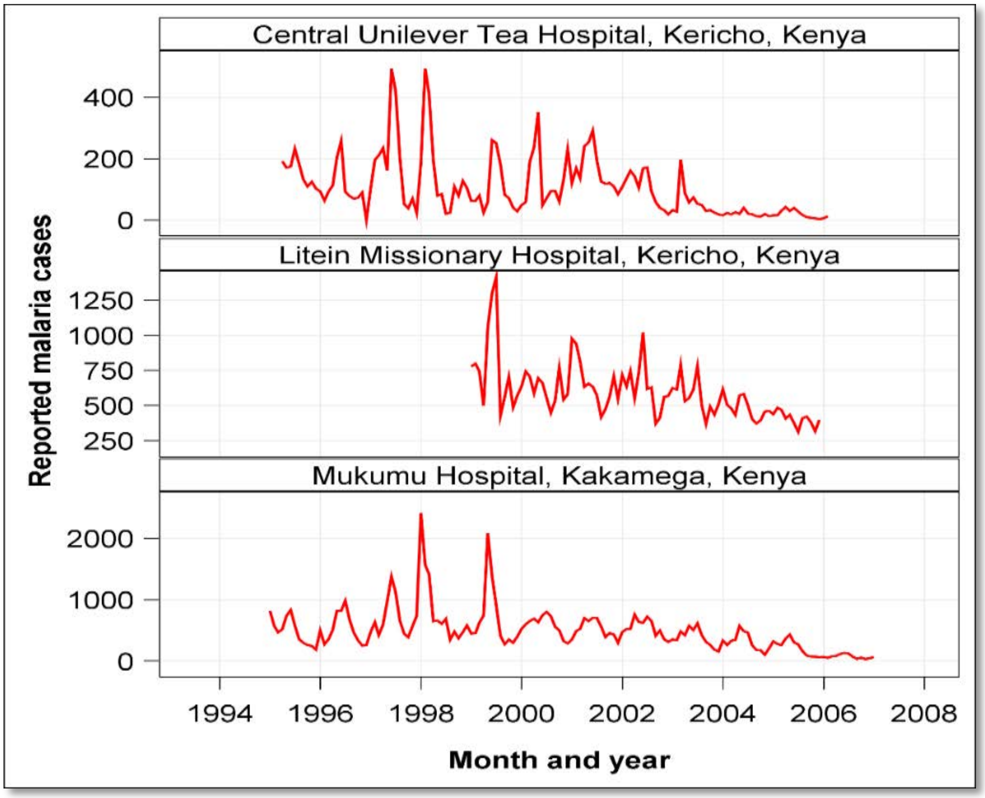


Figure 23: Reported malaria cases in three Kenya hospitals, from 1995 to –2007

Table 6: Results of the linear regression of malaria incidence

Hospital	Effect	Estimate	SE	DF	T	P>|T|
Litein Missionary Hospital, Kericho	Intercept	-1628.3929	737.6111	82	-2.208	0.030062
	Mavmaxtemp6	67.9544	22.5784	82	3.010	0.003474
Mukumu Hospital, Kakamega	Intercept	25.2664	106.4551	143	0.237	0.81273
	Mavrain4	4.0528	0.9025	143	4.491	1.45×10^{-5}
Central Unilever Tea Hospital, Kericho	Intercept	-9.0479	32.4533	129	-0.279	0.780847
	Mavrain4	1.0193	0.2781	129	3.666	0.000359

(P-values <0.05 are considered significant)

Note: Results are based on 4-month moving averages of rainfall or on 6-month moving average of the average monthly maximum temperature for three hospitals in Kenya. A numeric suffix in rainfall or temperature component name denotes the time window in months over which the running average was computed.

Figure 25 shows the established linear relationships between malaria incidences and rainfall and 4-month running mean of the total monthly rainfall in Mukumu and Unilever hospitals. These relationships suggest that malaria incidences increase linearly with increase in the 4-month running mean of the total monthly rainfall. For Litein hospital, in contrast, malaria incidences increased linearly with increase in the 6-month running mean of the average monthly maximum temperature.

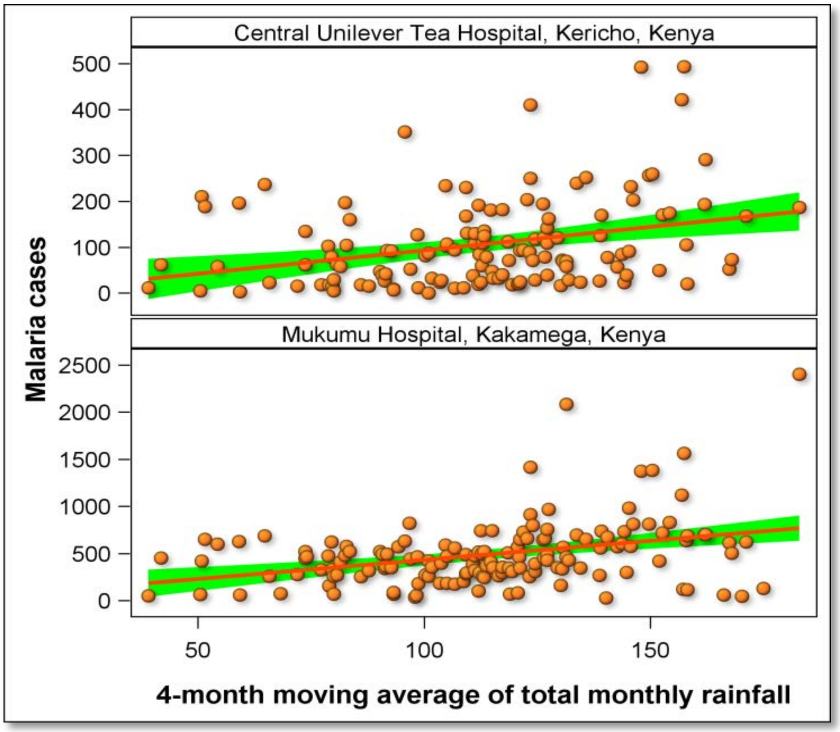


Figure 24: Regression relationships between the 4-month moving average of the total monthly rainfall and reported malaria cases in two Kenyan hospitals, located in Kericho and Kakamega

For Litein hospital, in contrast, malaria incidences increased linearly with increase in the 6-month running mean of the average monthly maximum temperature as illustrated in Figure 27.

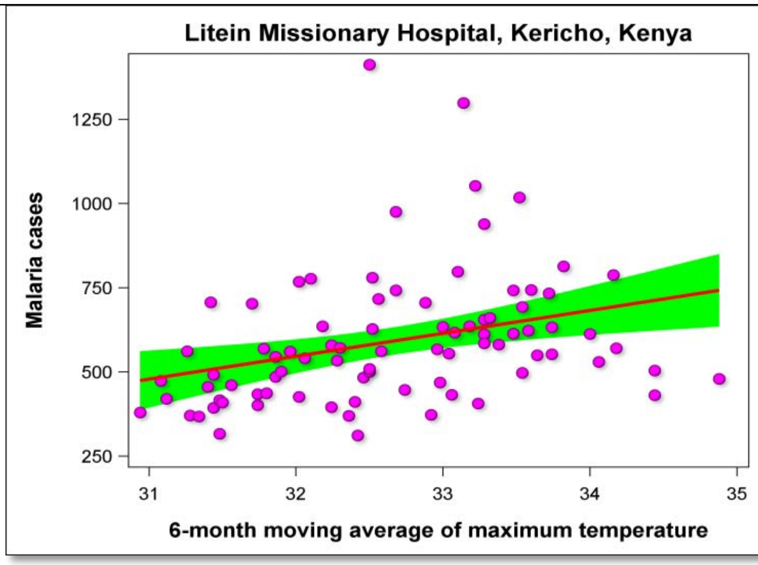


Figure 25: Regression relationship between 6-month moving average of the average monthly maximum temperature and reported malaria cases in Litein hospital in Kenya.

The projected patterns for the western Kenya highlands based on the projections for each location (hospital) are described below. The projections provide evidence of seasonality, cyclical patterns, and strong but temporally varying trends in malaria cases the nature and details of which vary among the hospital and, for each hospital, among the three scenarios. Occasional spikes suggesting epidemic outbreaks are also apparent in the projections.

For the Central Unilever Tea Hospital, the most salient features of the patterns are strong seasonal and cyclical fluctuations with temporally varying trends, amplitudes, and phases in the fluctuations of malaria cases. The cycles show evidence that protracted periods of elevated malaria transmission interrupted by periods of low transmission will likely be persistent features of the 2030s, 2050s, and 2070s. This pattern is consistent across the three scenarios but with some evidence of a larger increase in the average level of the incidences under the RCP4.5 and RCP8.5 scenarios than under RCP2.6 scenario (Figure 28). The strong seasonality in incidences is consistent with the regression relationship between historic incidences and rainfall that found a strong and significant linear increase in incidences with increase in the 4-month moving average of the total monthly rainfall for Central Unilever Tea Hospital and Mukumu Hospital and 6-month moving average of the total monthly rainfall for Litein Missionary Hospital.

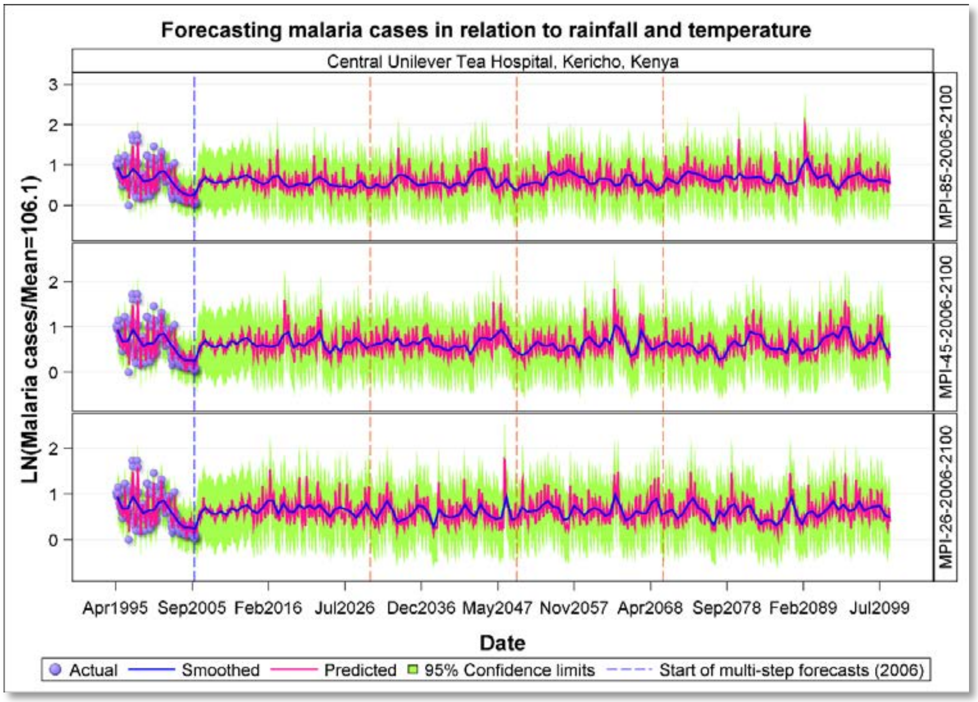


Figure 26: Historical and projected malaria cases in Central Unilever Tea Hospital in relation to rainfall and temperature from the year 1995-–2100 showing scenarios in 2030, 2050, and 2070 under scenario models RCP2.6, RCP4.5, and RCP8.5.

Litein Missionary hospital showed strong cyclic fluctuations in the transmission of the malaria parasite in all three scenarios, with time varying amplitudes and phases. Cases at this hospital responded to changes in temperature. The regression relationship between the 6-month moving average of the monthly maximum temperature and reported malaria cases in the hospital are shown in tables in the appendix. With the projected climate change effects, an increase in temperatures in this region will likely increase the survival rate of the vectors and hence increase parasite transmission (Figure 27). Malaria incidences at the hospital increase linearly with increase in the 6-month running mean of the average monthly maximum temperature.

Malaria cases in Mukumu hospital in Kakamega showed a significant relationship with a 4-month moving average of the total monthly rainfall. In this hospital, the trajectory of the projected transmission shows an increase in transmission, implying more cases can expected in the future, especially under the RCP4.5 and RCP8.5 scenarios (Figure 28). However, malaria cases can be expected to fluctuate with rainfall changes. An increase in rainfall and temperature rise in the area in the future will likely accompany an increase in malaria cases. Integrated control measures will thus be needed to reduce epidemic outbreaks and cope with the rising cases.

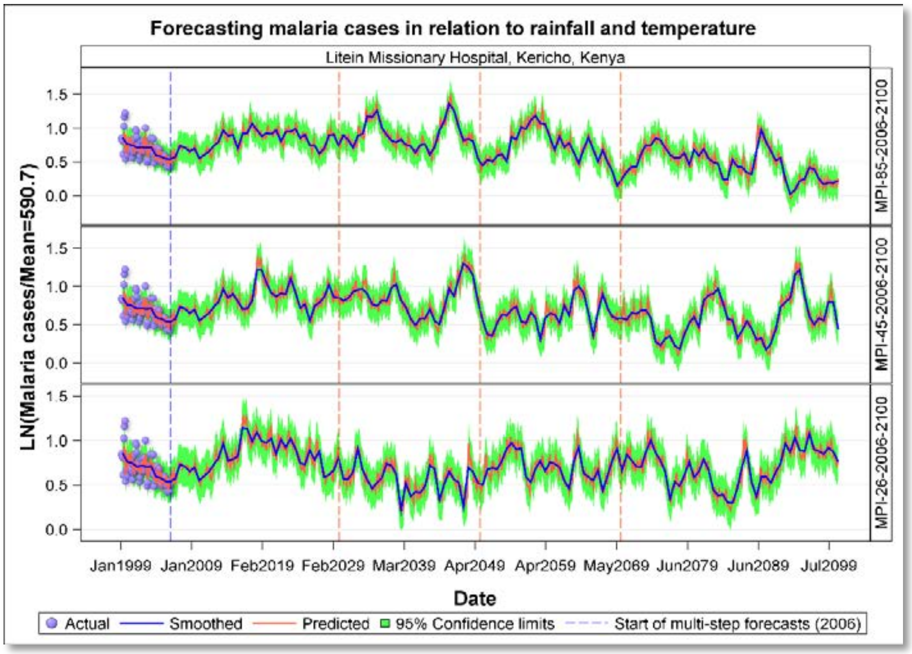


Figure 27: Historical and projected malaria cases in Litein Missionary Hospital in relation to rainfall and temperature from the year for 1995-–2100 showing scenarios in 2030, 2050, and 2070 under scenario models RCP2.6, RCP4.5, and RCP8.5.

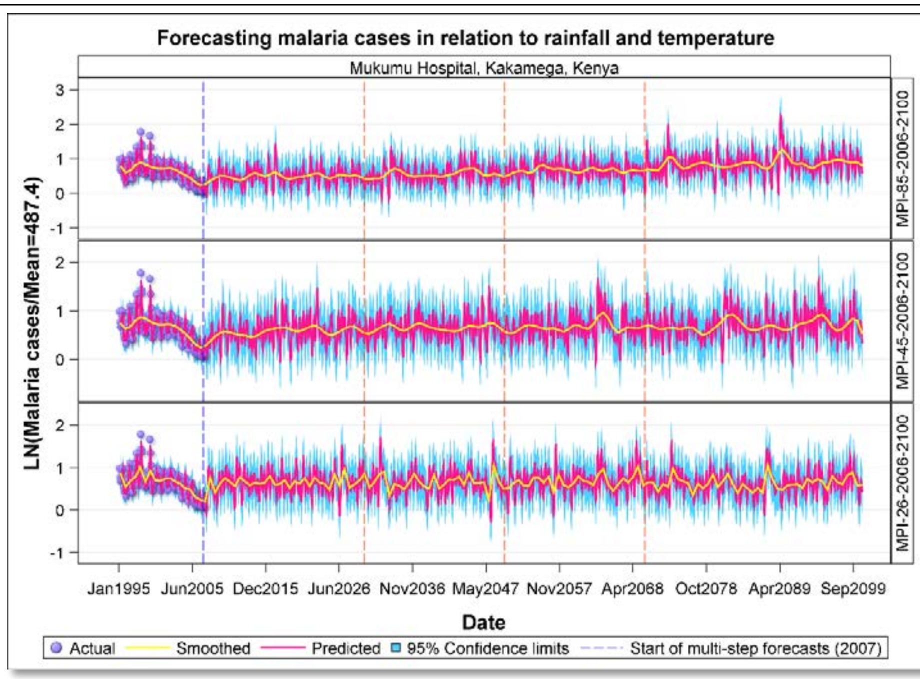


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Figure 28: Historical and projected malaria cases in Mukumu Hospital in relation to rainfall and temperature from the year for 1995-–2100 showing scenarios in 2030, 2050, and 2070 under scenario models RCP2.6, RCP4.5, and RCP8.5.

The observed and forecast malaria cases in Kenya are summarized in Figure 31.

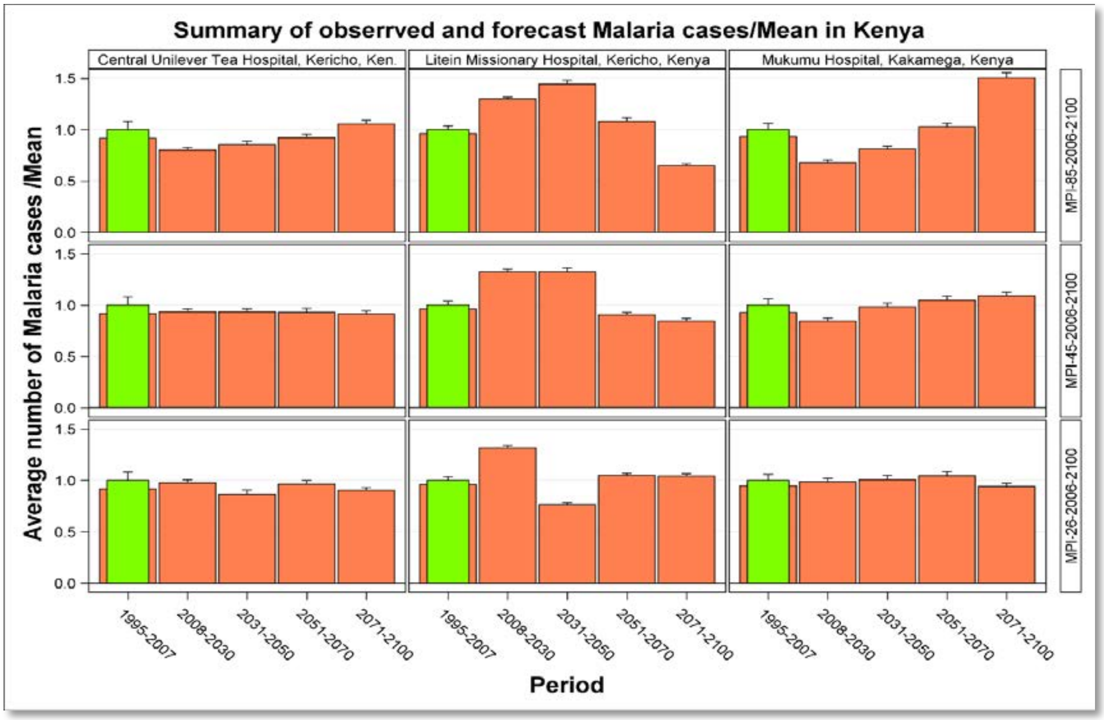


Figure 29: Summary of observed and forecast malaria cases/mean in Kenya for the period 1995-–2100 under RCP2.6, RCP4.5, RCP8.5 scenarios.

The observed malaria cases at the Central Unilever Tea Hospital for 1995–2007 show that the period had the highest mean cases reported throughout the three scenarios. RCP8.5 (MPI-85-2006–2100) show that through the years, the mean malaria cases reported in the hospital will steadily increase. This is due to variability in rainfall and temperature, as shown in earlier sections of this report.

Similar trends are seen in Mukumu Missionary Hospital under RCP8.5 (MPI-85-2006–2100), where the observed cases were high in 1995–2007, boosted by the epidemic following the 1997–98 El Niño. The subsequent period, 2008–2030, shows reduced malaria cases due to the efforts of integrated malaria control that are currently underway. However, the mean cases will rise steadily in the coming years and they will be at a peak between 2071 and 2100. Malaria cases in Mukumu relate to variability in rainfall and availability of vector breeding habitats.

Litein Missionary Hospital shows that malaria cases increased steadily from the period 1995–2007 and in 2008–2030. Cases will peak in 2031–2050 under RCP8.5 (MPI-85-2006–2100) and reduce steadily through the year 2100. Cases at Litein responded to changes in the mean temperature.

Figure 30 shows that there will be a variability in both the incidence and prevalence of malaria cases under the three scenarios in the future. In the worst-case scenario, malaria cases will increase. Malaria hotspots will need to be identified and targeted malaria control should be done in these areas to reduce the burden of the disease. New areas where the disease will spread also need integrated malaria control in place to reduce potential morbidity and mortality.

Rwanda. Through the successful implementation and scaling up of malaria control interventions Rwanda has achieved significant reductions in the burden of malaria over the past decade. All major malaria indicators decreased significantly from 2005 to 2012. Incidence declined by 86 percent, morbidity by 87 percent, mortality by 74 percent, and test positivity rate declined by 71 percent. However, Rwanda demonstrates how fragile gains in malaria control are, with significant upsurges in malaria incidences inn 2012 and 2013 relative to the declining trend characteristic of 2005–2011 (Figure 31).

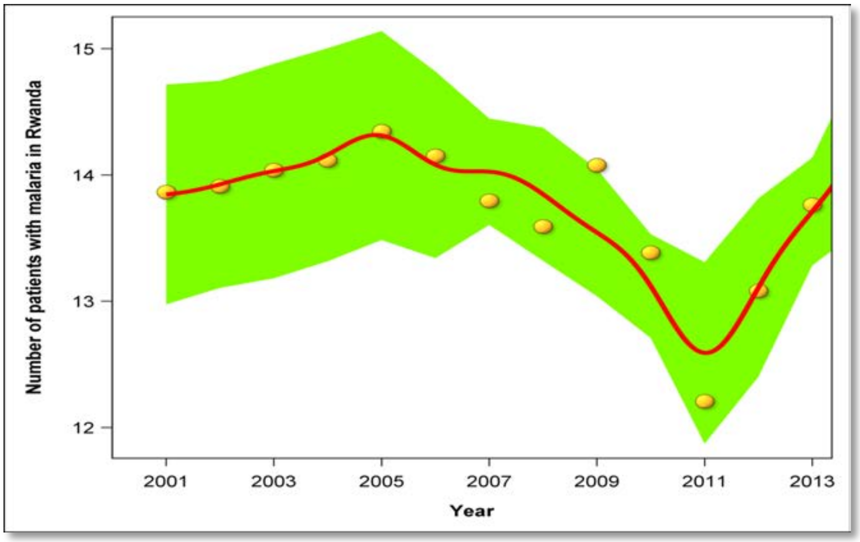


Figure 30: Malaria cases (thousands) in Rwanda, during 2001—2013

The steep upsurge in cases in 2012 and 2013 after the widespread distribution of long-lasting insecticidal nets in 2006 and 2009, implicate the role of other factors in malaria transmission.

Constraints in accessing appropriate long-term continuous time series data sets made it impossible to undertake projection studies in Rwanda.

Tanzania. Malaria endemicity and epidemiology in Tanzania is changing rapidly due to changes in climatological, topographical, and vector-related factors. Malaria is now prevalent in previously malaria-free mountainous areas, such as Babati, Hanang, Loliondo, Lushoto, and Muheza districts where records show dramatic changes in the incidence of and endemicity of malaria in the past five decades (Mboera and Kitua 2000). The burden of malaria in Tanzania remains high. Every year, 14–18 million new cases are reported, resulting in 120,000 deaths. Of these deaths, 70,000 are children under five years old. The annual incidence rate is 400–500 per 1,000 people and this number doubles for children under five years of age. Malaria is the leading cause of outpatients, inpatients, and admissions of children under five at health facilities. Malaria is considered the major cause of the loss of economic productivity in persons 15–56 years of age and an impediment to learning capacity of people 5–25 years of age. The disease is one of the most important obstacles to economic development and foreign investment in Tanzania (Makundi et al. 2007).

Analysis of the available data showed an even stronger and more pronounced relationship between malaria incidences and rainfall than was found for the two hospitals in Kenya. The 1997–98 El Niño episode was associated with a pronounced upsurge in reported malaria incidences.

The analyses show that more malaria cases were reported in Muleba for all ages and for those over five during 1997–98 than for any other year, providing direct evidence that high rainfall leads to increased malaria incidences (Figure 32). Higher incidences of anemia in under-fives were also reported for that period than for the other years. Anemia cases are related to malaria infections (Figure 33).

Further, statistical analyses of the data from Muleba Hospital established positive and significant correlations and regression relationships between malaria incidence and the 4–5-month running means of the total monthly rainfall and 3–5-month running means of the average monthly maximum temperature (Figure 34). This suggests that upsurges in cases will not occur immediately after high rainfall or maximum temperature events but rather will also respond to the carryover effects of prior rainfall conditions experienced up to 4 months earlier. This delayed or lagged effect of rainfall on malaria cases reflects a delayed response caused by the vector life cycle and disease transmission cycle.

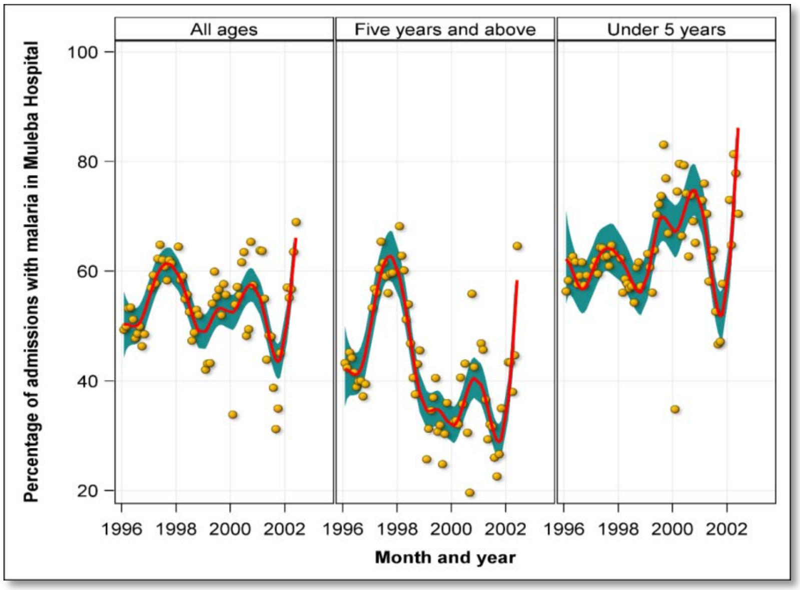


Figure 31: Percentage of malaria admissions in Muleba Hospital, Tanzania

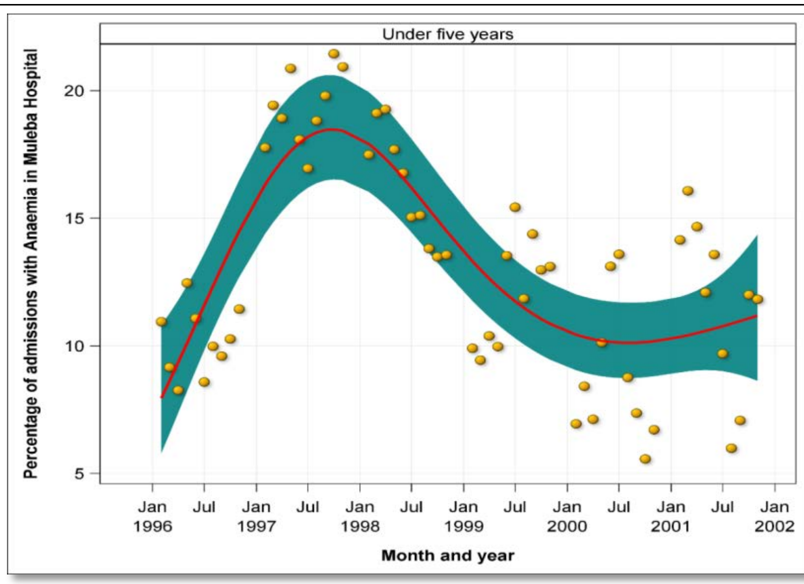


Figure 32: Percentage of admissions with anaemia in Muleba Hospital, Tanzania

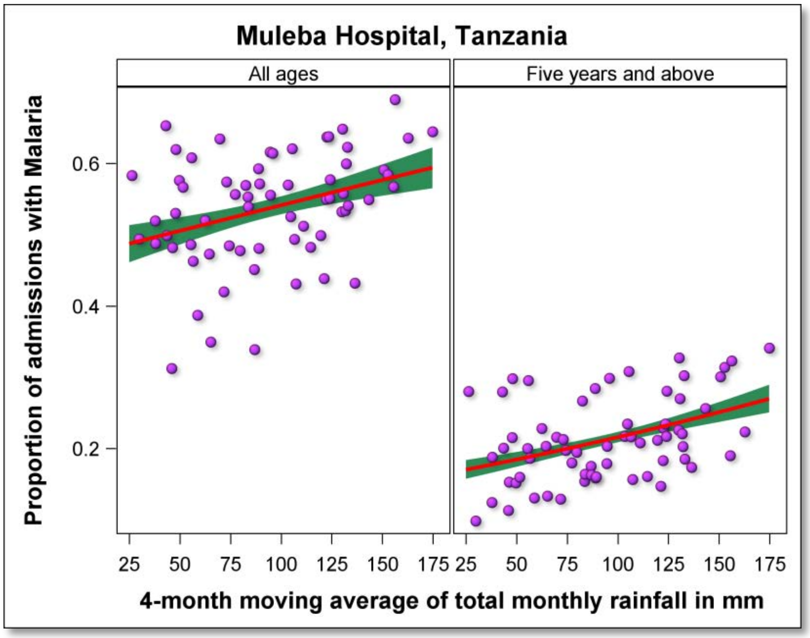


Figure 33: Regression relationship between reported malaria cases and the 4-month moving average of the total monthly rainfall for Muleba Hospital in Tanzania

Table 7: Person correlations between malaria cases and rainfall and temperature for Muleba Hospital

Age	Variable	N	Corr	95% LCL	95% UCL	P
All ages	Lagrain2	65	0.3394	0.1015	0.5369	0.005383
All ages	Mavrain4	65	0.3392	0.1013	0.5367	0.00542
All ages	Mavrain5	65	0.3054	0.0641	0.5095	0.012983
Five years and above	Mavraing4	65	0.4204	0.1935	0.6004	0.000417
Five years and above	Mavrain5	65	0.3959	0.1652	0.5814	0.000976
Five years and above	Lagrain2	65	0.3742	0.1405	0.5644	0.001957
Under 5 years	Mavmaxtemp4	65	0.2853	0.0423	0.4931	0.020864
Under 5 years	Mavmaxtemp5	65	0.2786	0.0350	0.4876	0.024247
Under 5 years	Mavmaxtemp3	65	0.2653	0.0208	0.4766	0.032346

P-values < 0.05 are significant.

Note: N is the sample size. LCL and UCL are the lower and upper confidence limits, respectively. A numeric suffix in rainfall or temperature component name denotes the time window in months over which the running average was computed.

Table 8: Results of the linear regression of malaria cases on running means of rainfall and temperature for Muleba Hospital

Age	Effect	Estimate	SE	DF	T	P>|T|
All ages	Intercept	-0.1227	0.0674	63.0	-1.821	0.07339
All ages	Mavrain4	0.0029	0.0007	63.0	4.316	5.71E-05
Five years and above	Intercept	-1.6848	0.0598	63.0	-28.176	2.04E-37
Five years and above	Mavrain4	0.0039	0.0006	63.0	6.841	3.77E-09
Under 5 years	Intercept	-3.3353	1.4992	52.0	-2.225	0.030467
Under 5 years	Mavmaxtemp4	0.0910	0.0523	62.8	1.739	0.087013

Note: A numeric suffix in rainfall or temperature component name denotes the time window in months over which the running average was computed.

Malaria projections for 2030, 2050, and 2070 were based on historical monthly data from Muleba district, which is prone to malaria. Transmission varies by season with peaks following the two rainy seasons (MAM and OND) The district experienced an epidemic in 1997–98 that was associated with heavy El Niño rains, as well as lack of antimalarial drugs and ineffective chloroquine. The severity of the impact in Muleba was examined by Garay (1998), who found that malaria admissions and malaria-related mortality for January 1998 was four time higher than the previous year and mortality in March was 12 times higher. In May 2006, the number of inpatient and outpatient malaria cases and mortality increased sharply in Muleba, especially among children under age five. Between January and May that year, the number of outpatient malaria cases doubled from 2,573 to 4,388 in children under five. Over the same period, the number of inpatient children under five increased from 1,094 to 1,927. Mortality for under-fives increased from 10 per thousand in January to 29 per thousand in May (Ministry of Health Tanzania 2006, Kinung'hi et al. 2010).

The scenarios show evidence that prolonged periods of elevated malaria transmission interspersed by periods of low transmission will likely be an enduring feature of the 2030s, 2050s, and 2070s. This pattern is consistent across the three scenarios. The projected proportions of admissions with malaria will increase in 2030, 2050, and 2070. The under-five age group responded to increases in maximum temperatures as shown in the RCP8.5 (MP1-85) scenario. The malaria cases in this age group will increase steeply in the future. The five years and above age group also shows an increase in malaria cases in both the RCP4.5 (MP1-45) and RCP8.5 (MP1-85) scenarios. More rainfall in the future will likely see increased malaria cases in this age group and in all the ages in general (Figures 35–37). Similar trends in future increase of malaria cases in five years and above in RCP8.5 are seen in Muleba. Increased control interventions in this age group will help in reducing the cases.

Figure 34: Forecasting malaria for all age groups for Muleba hospital

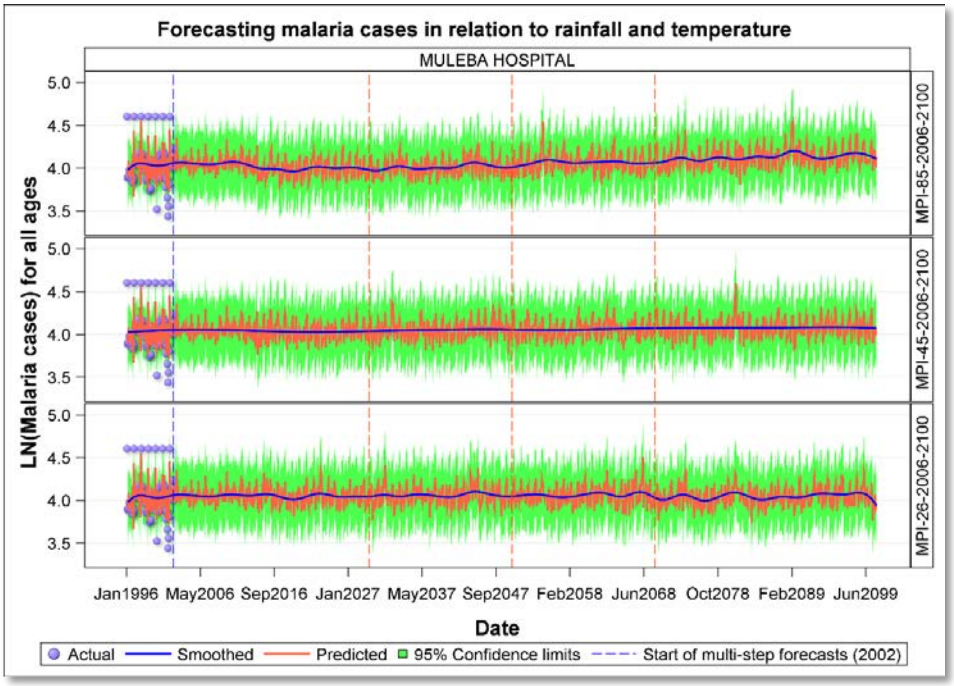


Figure 35: Projecting malaria cases for five years and above for Muleba Hospital.

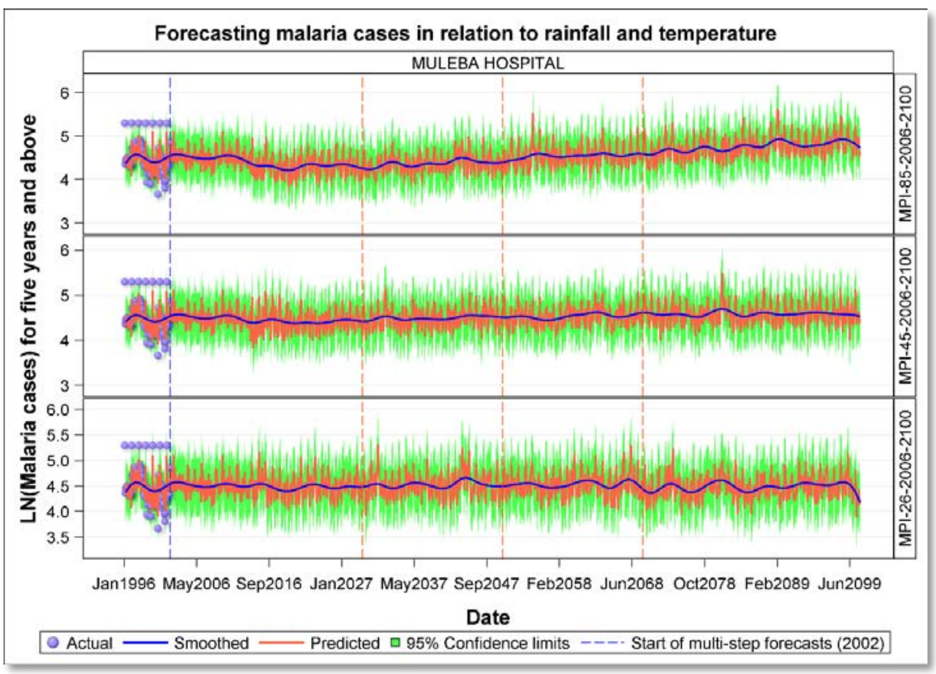
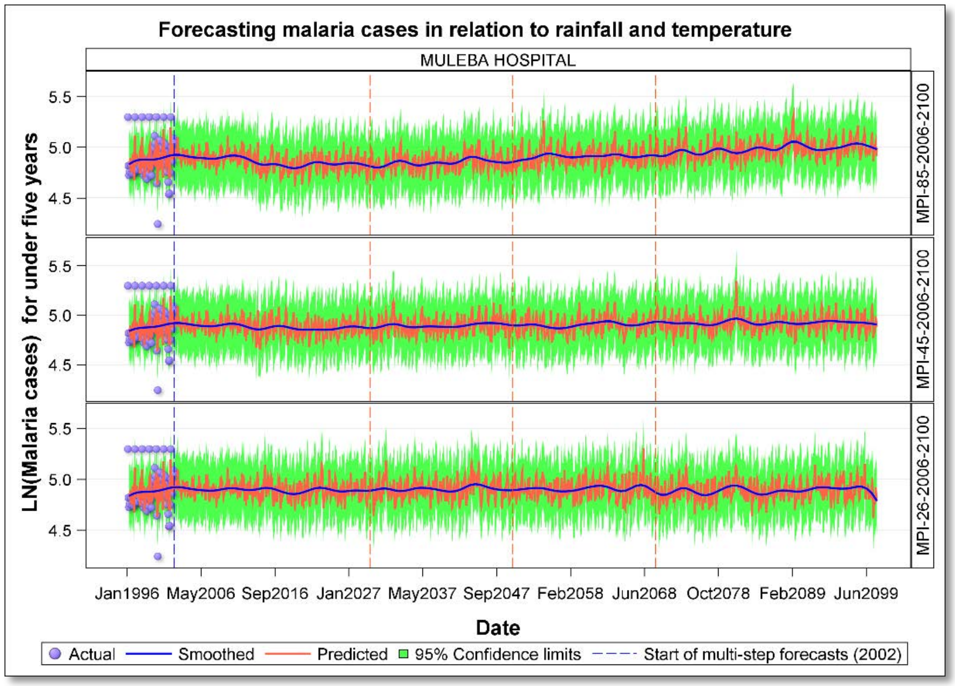
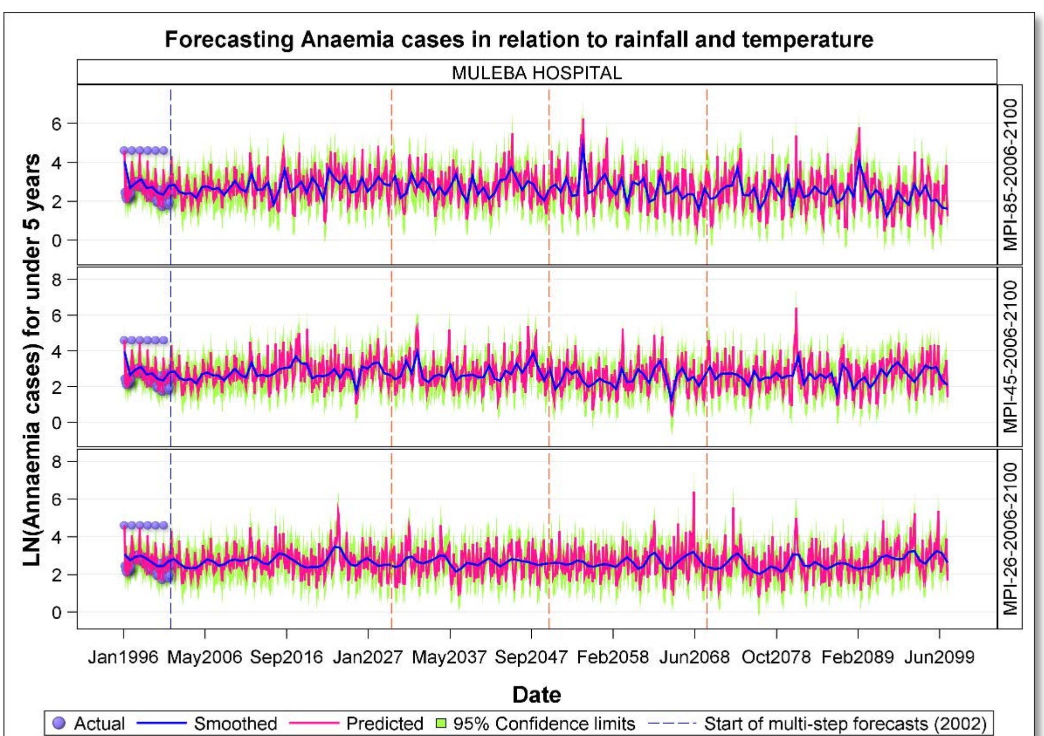


Figure 36: Projecting malaria cases for under five years for Muleba Hospital



Malaria is a major cause of anemia, a life-threatening condition in children under five years old. Pregnant women with anemia can deliver newborns with low birth weights, which can reduce chances of survival, and sometimes results in premature births. Projections show that trends in anemia cases in Muleba Hospital will remain steady, but there is an upsurge, especially in the RCP8.5 (MPI-85) scenario (Figure 38).

Figure 37: Historical and projected anaemia cases for under five years in Muleba Hospital



Trends in anemia cases responded to changes in rainfall and temperature. Control and prevention of malaria would lead to a reduced prevalence of anemia because of the strong relationship between anemia and the malaria parasite. The study shows that there was a regression relationship between reported malaria cases and the 4-month moving average based on the total monthly rainfall.

A summary of malaria cases for 1997–2100 shows that average number of malaria cases will remain steady in all ages and in the under-five years group under the three scenarios. More cases are seen in the under-five categories compared to all ages. In the five years and above category, the average number of cases increases over 2003–2100. With 1.6 more cases projected in 2100 than in 2003 (Figure 40). Under the three scenarios, the under-fives are the vulnerable group. Increasing cases of malaria are projected in the five years and above age group, hence the need for an all-inclusive malaria control strategy. For every 130 cases of malaria reported in 1996, 20 anemia cases were reported in the under-five age group. This trend is projected to increase in the future and to peak in 2051–2070 (Figure 39).

Figure 38: Summary of observed and forecast Malaria cases in Muleba Hospital, Tanzania

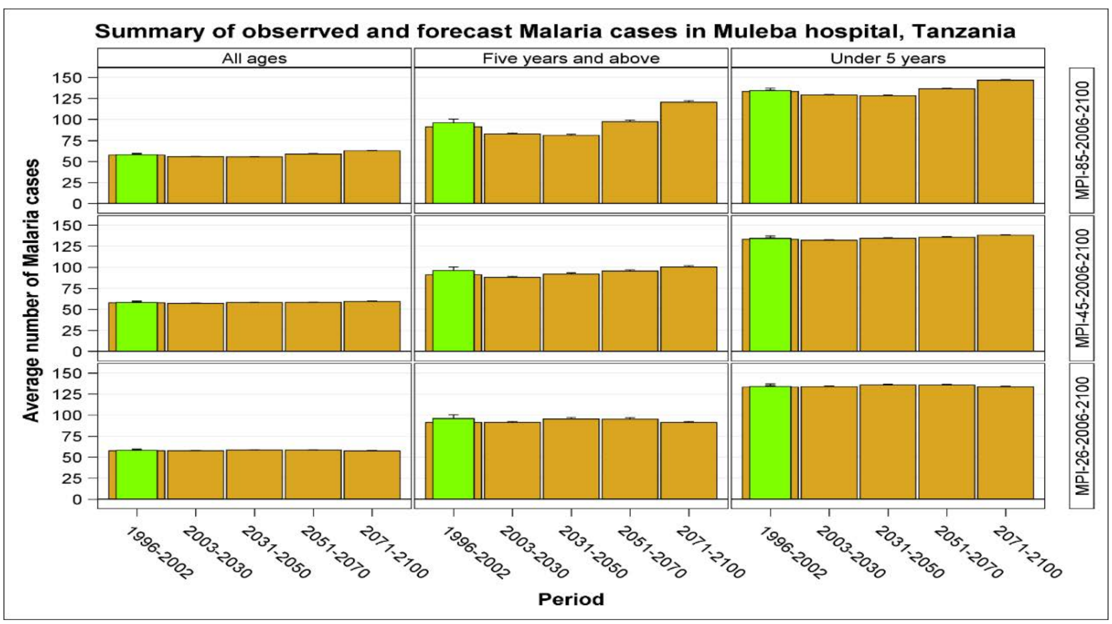
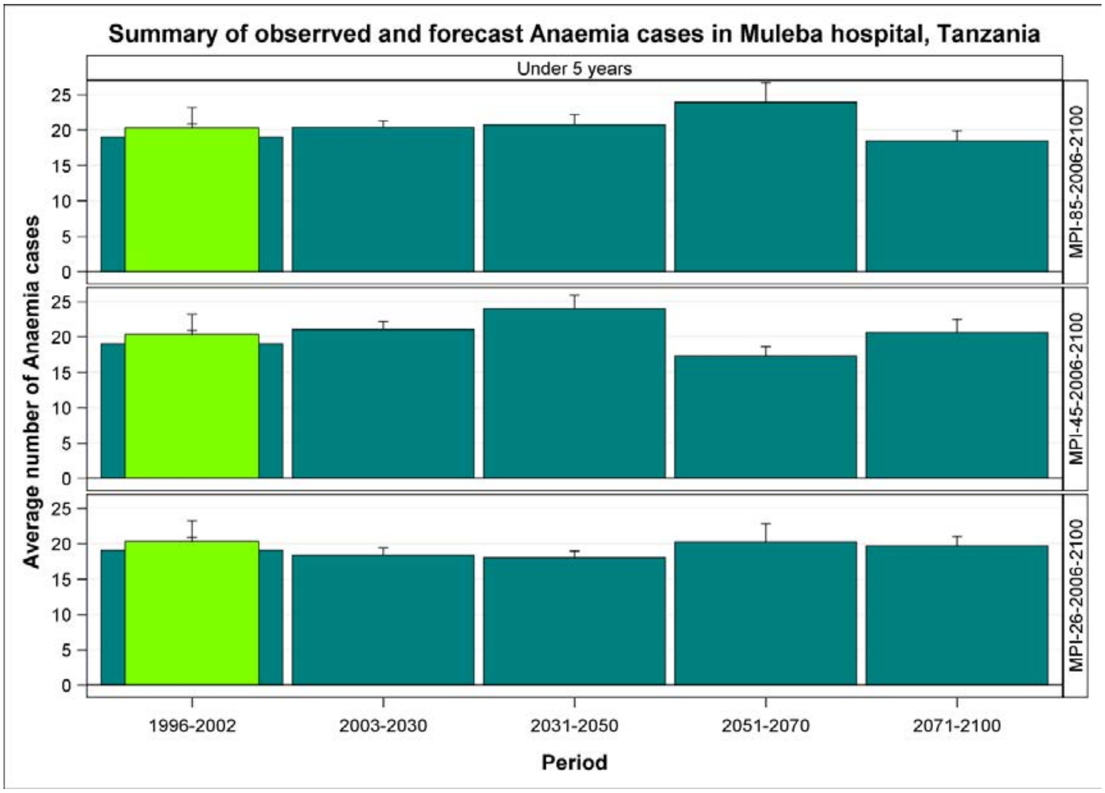


Figure 39: Summary of observed and forecast anaemia cases for Muleba hospital



Uganda. In the late 1950s and early 1960s, the eradication of malaria seemed possible, but attempts to achieve it fell short for a variety of reasons. Among the factors were DDT resistance in vector mosquitoes, resistance to household spraying among some residents, the vertical organization of vector control programs, and emergence and spread of resistance to pyrimethamine and chloroquine. Furthermore, it was realized that for most countries, eradication was not a realistic goal and that there was a need to change from highly prescriptive, centralized control programs to flexible, cost-effective, and sustainable programs adapted to local conditions and responding to local needs (Talisuna et al. 2004). In Uganda, malaria incidence has increased more than 30 times in the highlands, but its altitudinal limit has not exceeded that of the beginning of the century. Cultivation of valley bottoms and extension of settlements are in large part responsible for this increase, along with abnormally heavy rainfall that favored the severe epidemic of 1994 (Mouchet et al. 1998).

Countrywide data on malaria cases in Uganda for 1997–2011 show that far more children of five years and older were affected by malaria than children under five (Figure 40). The trends for both age classes demonstrate a persistent decline in the number of cases following the 1997–98 El Niño floods, to a low in 2003. This is followed by a persistent rise in the number of cases. It seems likely that a high investment in prevention measures, such as use of nets, following the 1997–98 rains had a positive effect for both age groups but was not maintained after.

There is a significant regression relationship between malaria cases and the 5-month running mean of the average monthly minimum temperature. The relationship shows that malaria cases recorded in the various districts of Uganda increased with either increasing minimum temperatures or rainfall depending on age class. Thus, malaria cases increased with increasing rainfall for the under-five age group, while malaria cases recorded for the five years and above age group increased with increase in the 5-month moving average of the minimum temperature (Figures 41 and 42). (A similar pattern was observed for Tanzania.)

Similar studies have also reported significant associations between inter-annual variability in temperature and malaria transmission in the African highlands (Craig et al. 2004). Minimum temperature at the start of the transmission season corresponds to the months when human-vector contact is greatest and accounts for most of the variability between years (Bouma 2003).

Other analyses for seven highland sites in East Africa reported that short-term climate variability played a more important role than long-term trends in initiating malaria epidemics (Zhou et al. 2004). The transmission of enteric pathogens is also higher during the rainy season (Nchito et al. 1998).

Figure 40: Temporal trends in reported malaria cases for five years and above and under five years in Uganda expressed as proportions.

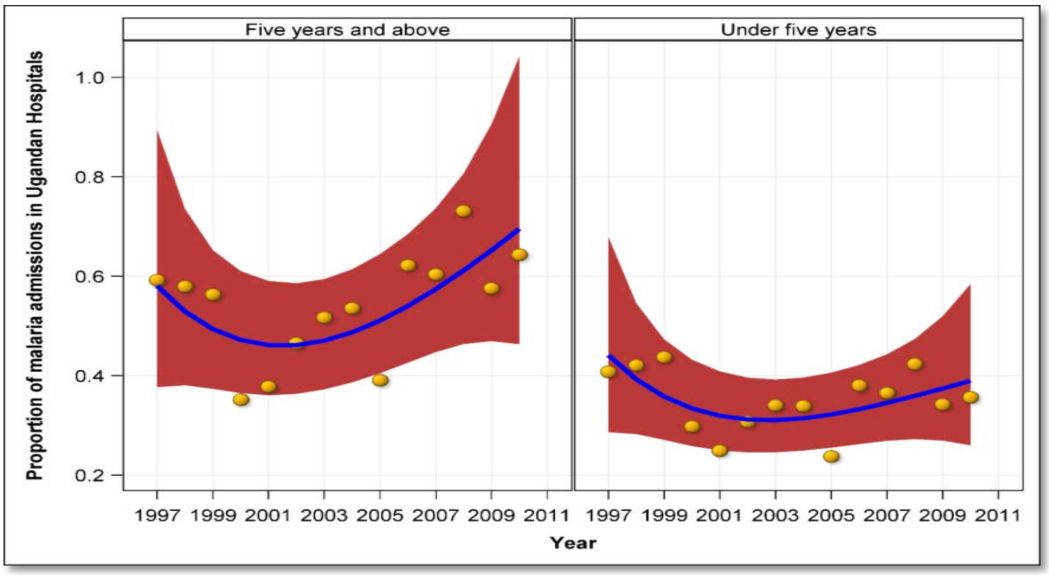


Figure 41: Regression relationship between reported malaria cases in Uganda and the 5-month moving average of the average monthly minimum temperature.

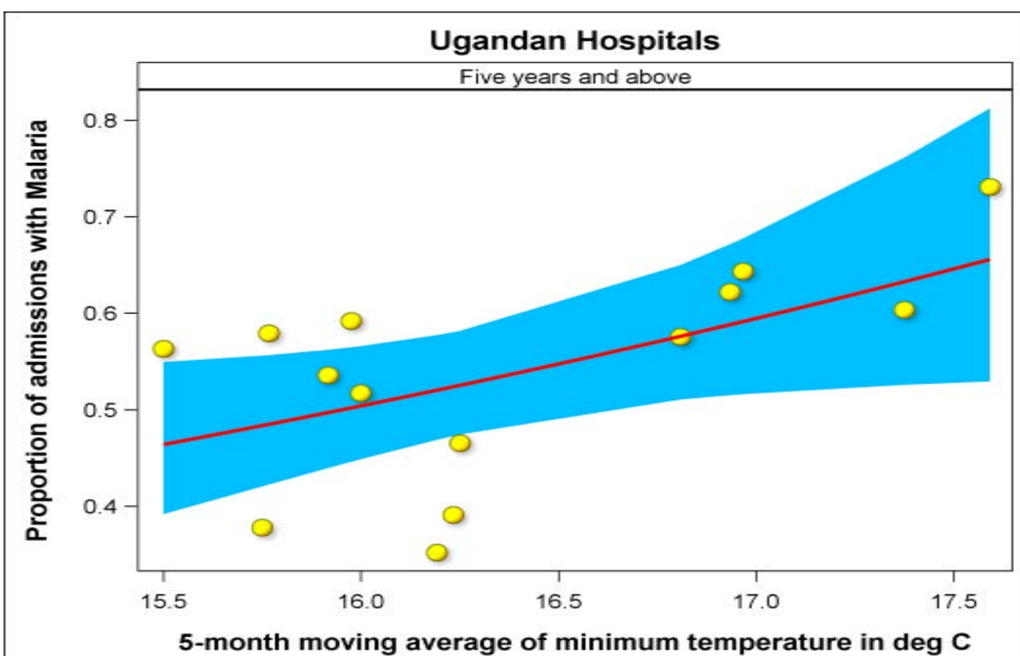


Table 9: Pearson correlations between malaria cases reported for Uganda and rainfall and temperature

Age	Variable	N	Corr	95%LCL	95%UCL	P
Five years and above	Lagmintemp5	14	0.5794	0.0483	0.8426	0.028227
Under five years	mavannual2	14	0.3135	-0.2716	0.7179	0.281936

P-values < 0.05 are significant.

Note: N is the sample size, LCL and UCL are the lower and upper confidence limits, respectively. A numeric suffix in rainfall or temperature component name denotes the time window in months over which the running average was computed.

Table 10: Results of the regression of malaria cases reported for Uganda on rainfall and temperature.

Age	Effect	Estimate	SE	DF	T	P>|T|
Under five years	Intercept	-1.7430	0.5901	12	-2.954	0.012057
Under five years	Mavannual2	0.0006	0.0005	12	1.178	0.261772
Five years and above	Intercept	-3.3344	1.1720	12	-2.845	0.014757
Five years and above	Lagmintemp5	0.1655	0.0715	12	2.315	0.03913

P-values < 0.05 are significant.

Note: A numeric suffix in rainfall or temperature component name denotes the time window in months over which the running average was computed.

Malaria projections for 2030, 2050, and 2070 were based on historic annual data on malaria cases from hospitals in different districts of Uganda. Future malaria scenarios were projected using the VARMAX(*p,q,s*) model to relate the reported malaria cases (log-transformed) to prior rainfall, and minimum and maximum temperatures, and forecast the anticipated malaria cases to 2100 under the three scenarios, RCP2.6 (labeled MPI-26-2006–2100), RCP4.5 (MPI 45-2006–2100) and RCP8.5 (MPI-85-2006–2100).

A significant regression relationship was found between reported malaria cases and the 5-month moving average of the average monthly minimum temperature. The scenarios show evidence that protracted periods of elevated malaria transmission, interrupted by periods of low transmission, will likely be persistent features of the 2030s, 2050s, and 2070s. This pattern is consistent across the three scenarios but with some evidence of a larger increase in the average level of the incidences under the RCP4.5 and RCP8.5 scenarios than under the RCP2.6 scenario.

The RCP8.5 scenario showed a very steep increase in malaria cases through 2030, 2050, and 2070 for those over age five, associated with rising minimum temperatures. In the under-five age group, malaria cases will also increase in the future, following anticipated increase in rainfall. In general, as climate variability increases, malaria cases will also be expected to increase (Figure 43 and 44).

Observed malaria cases decreased during 2009–2010, but the average level of transmission in the future is expected to remain stable under the RCP2.6 scenario. However, considerable inter-annual fluctuation in the level of transmission can be expected, as can an increase in cases depending on rainfall and temperature patterns under the RCP2.6 scenario (Figure 3.18a).

The RCP4.5 and RCP8.5 scenarios show an upward trend in malaria cases in the future. This is much more pronounced for the RCP8.5 than the RCP4.5 scenario. Proper malaria control interventions and early preparation will be necessary to control the anticipated outbreaks, morbidity, and mortality caused by malaria in the under-five age group under both scenarios (Figure 45).

The five years and above age group is becoming more vulnerable to malaria infections. The RCP8.5 scenario shows an increasing trend in the number of cases. Current control strategies mainly focus on children under five and pregnant women, leaving the over five age group at risk. Future policy recommendations to combat this emerging threat will be to include other vulnerable groups in targeted control of malaria. Distribution of bed nets should also be more universal to cover everyone who lives in regions that are endemic in malaria (Figure 46).

Figure 42: Forecasting malaria cases in relation to rainfall and temperature—Uganda

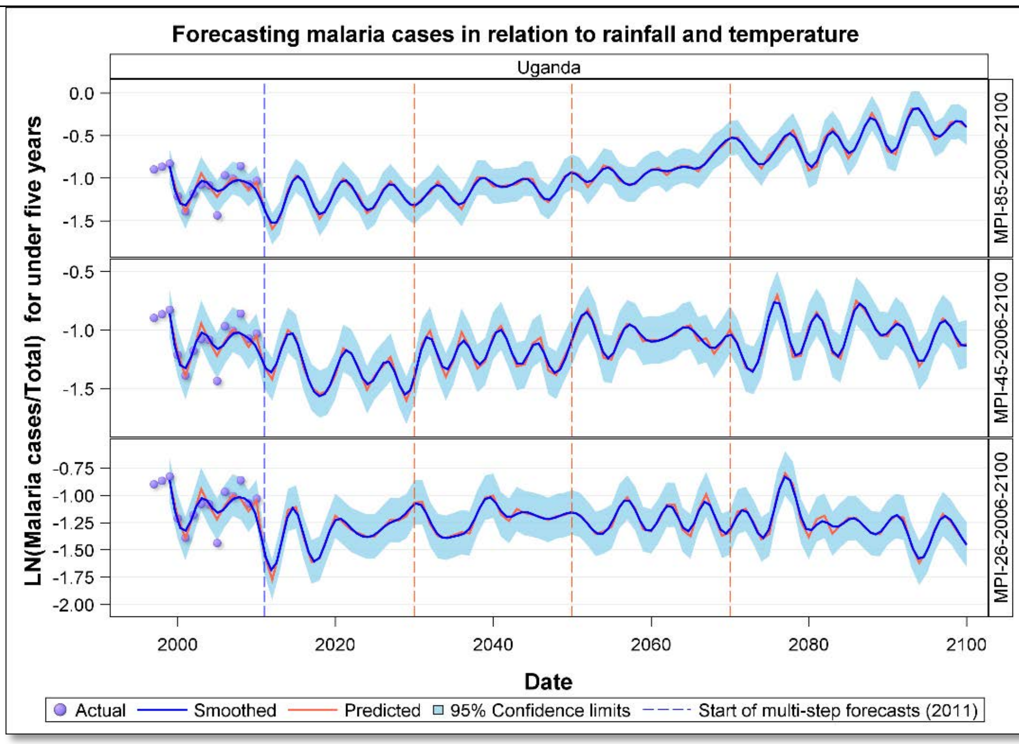


Figure 43: Historical and projected malaria cases in Uganda for under-fives in relation to rainfall and temperature for 1995–2100 showing scenarios in 2030, 2050, and 2070 under models MPI-26, MPI-45, and MPI-85

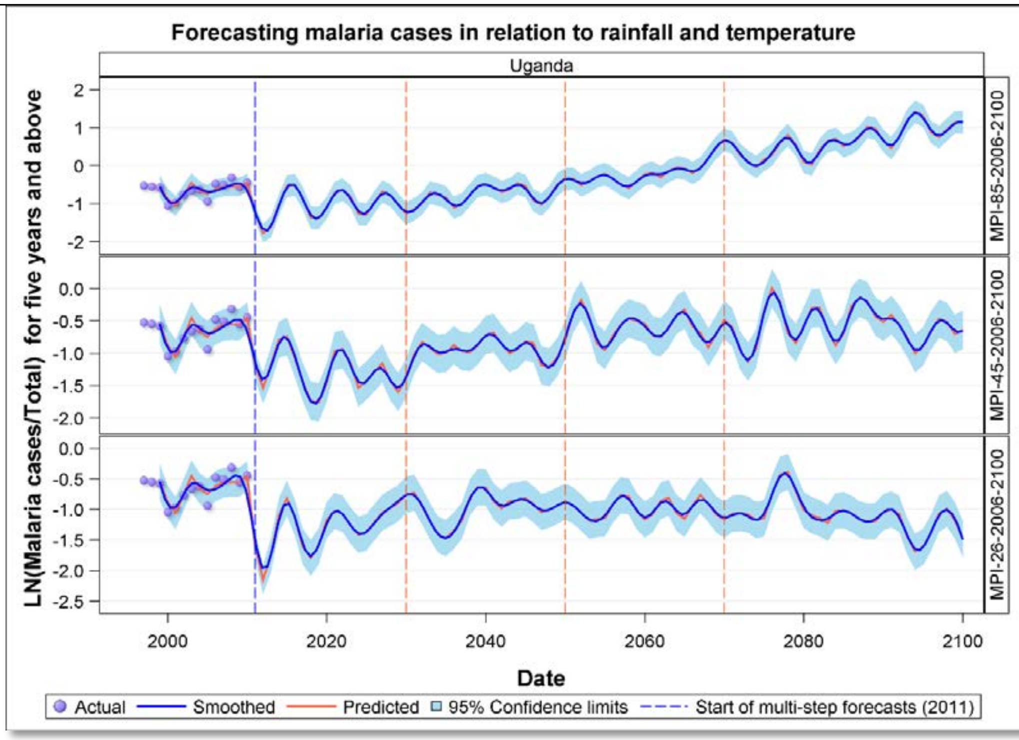


Figure 44: Historical and projected malaria cases for five years and above in Uganda in relation to rainfall and temperature for 1995–2100 showing scenarios in 2030, 2050, and 2070 under models MPI-26, MPI-45, and MPI-85.

Observed malaria cases in Uganda during 1997–2010 were slightly higher than the projected cases in 2011–2030. As for other countries in the region, a malaria epidemic was reported in Uganda in 1998 after the El Niño event (Lindblade et al. 1999). All three scenarios show increases in malaria cases. There will be at least one and a half times more cases in 2100 compared to 1997.

In the period 2071–2100, malaria cases in the over-five age group will be four times the number of observed cases in 1997 under RCP8.5 (MPI-85-2006–2100). A slight decrease occurs in 2011–2030; however, cases will steadily increase from 2030 to 2100 (Figure 47). Universal distribution of insecticide-treated bed nets is required to reduce the number of new infections in the over-five age group as it is not currently considered to be a vulnerable group.

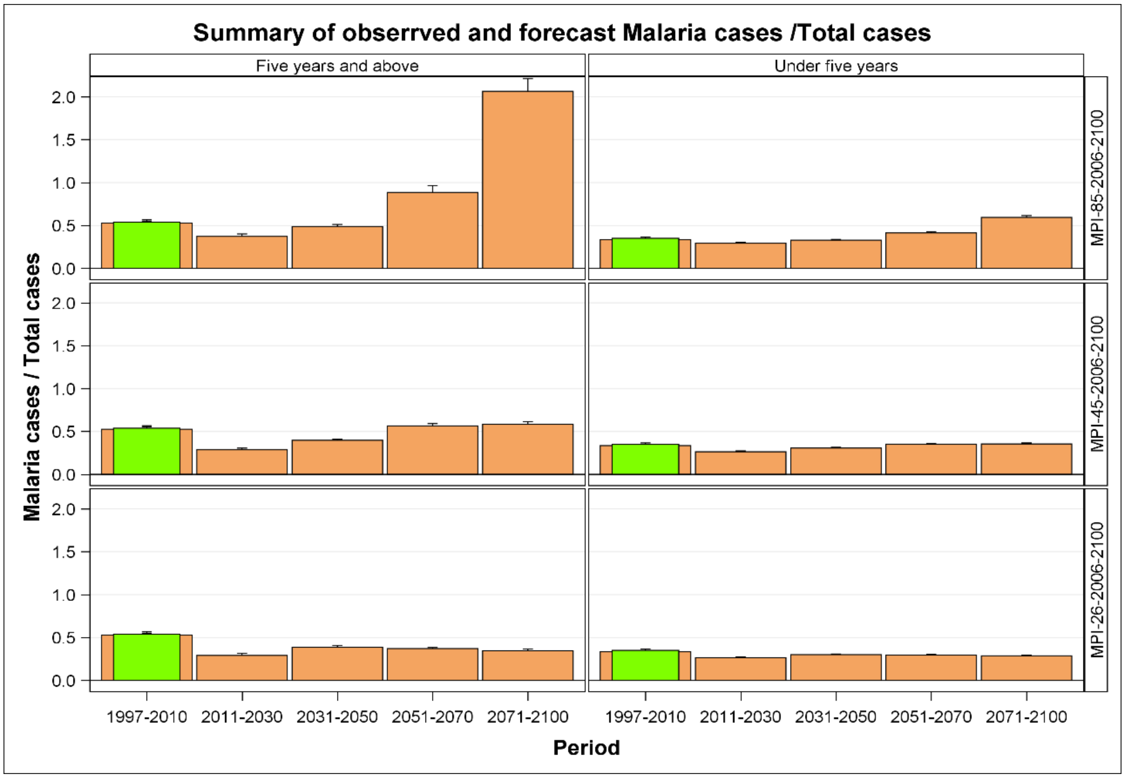


Figure 45: Summary of observed and forecast malaria cases/total cases in Uganda for 1995–2100 under MPI-26, MPI-45, and MPI-85 scenarios.

KEY UNCERTAINTIES AND RESEARCH PRIORITIES

Empirical epidemiological research on climate change and its effects on health has been done all over the world. African countries are at risk of these effects mainly due to its high poverty index. In the EAC, several studies and observed effects have been reported and the Partner States have developed national health impact assessments and National Adaptation Programs of Action (NAPAs) based on the outcomes of these surveys, which have provided valuable information on population vulnerability. However, the lack of appropriate longitudinal health data makes attribution of adverse health outcomes to observed climate trends difficult.

Advances have been made in the development of climate-health impact models that project the health effects of climate change under a range of climate and socioeconomic scenarios. The models are still limited to a few infectious diseases, thermal extremes, and air pollution. Some of the models that have been used before are shown in Table 11.

Table 11: Projected impacts of climate change on malaria

Health effect	Metric	Model	Climate scenario, with time slices	Temperature increase and baseline	Population projections and other assumptions	Main results	Reference
Malaria, global and regional	Population at risk in areas where climate conditions are suitable for malaria transmission	Biological model, calibrated from laboratory and field data, for falciparum malaria	HadCM3, driven by SRES A1FI, A2, B1, and B2 scenarios; 2020s, 2050s, 2080s		SRES population scenarios; current malaria control status used as an indicator of adaptive capacity	Estimates of the additional population at risk for >1 month transmission range from >220 million (A1FI) to >400 million (A2) when climate and population growth are included The global estimates are severely reduced if transmission risk for more than 3 consecutive months per year is considered, with a net reduction in the global population at risk under the A2 and B1 scenarios	van Lieshout et al. 2004
Malaria, Africa	Person-months at risk for stable falciparum transmission	MARA/ARMAa model of climate suitability for stable falciparum transmission	HadCM3, driven by SRES A1FI, A2a, and B1 scenarios; 2020s, 2050s, 2080s	1.1 to 1.3°C in 2020s 1.9 to 3.0°C in 2050s 2.6 to 5.3°C in 2080s	Estimates based on 1995 population	By 2100, 16–28% increase in person-months of exposure across all scenarios, including a 5–7% increase in (mainly altitudinal) distribution,	Tanser et al. 2003

Health effect	Metric	Model	Climate scenario, with time slices	Temperature increase and baseline	Population projections and other assumptions	Main results	Reference
						with limited latitudinal expansion Countries with large areas that are close to the climatic thresholds for transmission show large potential increases across all scenarios	
Malaria, Africa	Map of climate suitability for stable falciparum transmission [minimum 4 months suitable per year]	MARA/ARMAa model of climate suitability for stable falciparum transmission	HadCM2 ensemble mean with medium-high emissions; 2020s, 2050s, 2080s		Climate factors only (monthly mean and minimum temperature, and monthly precipitation)	Decreased transmission in 2020s in southeast Africa By 2050s and 2080s, localized increases in highland and upland areas, and decreases around Sahel and south-central Africa	Thomas et al. 2004
Malaria, Zimbabwe, Africa	Climate suitability for transmission	MARA/ARMAa model of climate suitability for stable falciparum transmission	16 climate projections from COSMIC Climate sensitivities of 1.4 and 4.5°C; equivalent CO_2 of		None	Highlands become more suitable for transmission Lowlands and regions with low precipitation show varying degrees of change, depending on climate sensitivity,	Ebi et al. 2005

Health effect	Metric	Model	Climate scenario, with time slices	Temperature increase and baseline	Population projections and other assumptions	Main results	Reference
			350 and 750 ppm 2100			emissions scenario, and GCM	
Malaria, Britain	Probability of malaria transmission	Statistical multivariate regression, based on historic distributions, land cover, agricultural factors and climate determinants	1–2.5°C average temperature increase, 2050s	1–2.5°C average temperature increase	None; no changes in land cover or agricultural factors	Increase in risk of local malaria transmission of 8–15% Highly unlikely that indigenous malaria will be re-established	Kuhn et al. 2002
Malaria, Australia	Geographical area suitable/unsuitable for maintenance of vector	Empirical-statistical model (CLIMEX) based on current distribution, relative abundance, and seasonal phenology of main malaria vector	CSIROMk2 and ECHAM4 driven by SRES B1, A1B, and A1FI emissions scenarios 2020, 2050	0.4–2.0°C annual average temperature increase in the 2030s, and 1.0–6.0°C in the 2070s, relative to 1990 (CSIRO)	Assumes adaptive capacity; used Australian population projections	'Malaria receptive zone' expands southward to include some regional towns by 2050s Absolute risk of reintroduction very low	McMichael et al. 2004
Malaria, India, all states	Climate suitability for falciparum and vivax malaria transmission	Temperature transmission windows based on observed associations between temperature and malaria cases	HadRM2 driven by IS92a emissions scenario	2–4°C increase compared with current climate	None	By 2050s, geographical range projected to shift away from central regions toward southwestern and northern states The duration of the transmission window is	Bhattacharya et al. 2006

Health effect	Metric	Model	Climate scenario, with time slices	Temperature increase and baseline	Population projections and other assumptions	Main results	Reference
						likely to widen in northern and western states and shorten in southern states	
Malaria, Lake Victoria Basin		Temperature transmission based on observed associations between temperature and malaria cases for 5 sites – 2 Kenya; 3 Tanzania; 2 Uganda; 1 Rwanda	Climate projections based on regional climate models based on three scenarios RCP2.6, RCP4.5, and RCP8.5		None; no changes in land cover or agricultural factors Adaptive capacity the same		CAMCO 2016

Adapted from IPCC (2007) and update with local scale studies from LVB.

ADAPTATION PRACTICES, OPTIONS, AND CONSTRAINTS

ADAPTATION PRACTICES, OPTIONS, AND CONSTRAINTS

Malaria is a climate-sensitive disease and is the greatest burden on health in Sub-Saharan Africa. Based on historical trends, projected rainfall and temperature to the year 2100—future scenarios of 2030, 2050, and 2070—show that a likely increase in malaria cases in the LVB. The projections indicate that the LVB is becoming warmer and wetter in the short rainy season and this will create a conducive environment for vector-borne and diarrheal diseases. Inter-annual and inter-decadal climate variability has a direct influence on malaria transmission and therefore should be placed high among the factors that affect human health and survival.

Depending on the types of questions asked and answered, a vulnerability assessment may help identify adaptation strategies that will lead to options for mitigating some of the identified vulnerabilities. Various other issues—limited political power, social or economic marginalization, exposure and sensitivity to hazards, strength of local institutions, and climate change—all interact to make people vulnerable. When stressors beyond climate change are involved, it becomes necessary to define a risk-management framework.

Vulnerability may be spatial and may vary from place to place; it may also be temporally dynamic, varying between dry and wet seasons as well as in scale (households versus national level). Vulnerability may also be mediated by institutions, both formal and informal. Given that vulnerability is highly variable in time and scale and specific to context, it is appropriate that adaptation practices and options are site-specific, scale-specific, and context-specific. A range of options may be needed from hard (e.g., infrastructure, re-engineering) to soft (e.g., policy, behavior change, capacity building, institutional innovation) options. Both discrete approaches focused on climate change and integrated approaches with development outcomes that are climate-proofed may be proposed.

In identifying adaptation options, it is important to note that there are high levels of uncertainty regarding the scale and intensity of potential climate impact as well as the socioeconomic pathways. For example, emergence of new technologies, political change, and improved economies may alter the context under which initial vulnerability was defined. In other instances, non-climatic stressors and drivers may amplify the impacts and hence effectiveness of options designed depends on clarity about as many factors as possible. To deal with uncertainty, it is often preferable to use options and low-regret measures that may not be optimal under one scenario but may fare well under a number of scenarios, any of which is possible. Further use of pathways with benchmarks and thresholds at which new direction is taken based on feedback from monitoring and evaluation can be beneficial.

Adaptation planning requires complex interactions between human and natural systems, hence the need for a combination of science and local knowledge, together with innovation in institutional and policy frameworks. Identifying options and their proposed outcomes aims to increase resilience and reduce vulnerability.

Three components of climate change are useful for consideration: extremes, heightened variability, and long-term change. Options selected may create response mechanisms to specific impacts of climate change or reduce vulnerability to climate change through building capacity to help reduce the range of challenges.

Various efforts may be included, such as those that:

- Reduce vulnerability and drivers, such as development projects
- Build response capacity, such as in policy, communication, information, mapping
- Manage climate risks, through disaster response or climate-proofing
- Confront climate change, such as through relocation.

Two key factors determine the choice of options: existing capacity of affected communities and quality of information available about projected impacts. Lower capacity necessitates investment in more development projects to reduce vulnerability while high climate impact requires investment in specific climate change adaptation projects. In both building capacity to deal with uncertainty is a priority.

It is best that defined options build on existing coping strategies as far as this is possible. The following criteria are useful in selecting options:

- Costs
- Social and political acceptance
- Environmental impacts
- Legal and administrative requirements
- Technical feasibility.

Additional criteria may include effectiveness, efficiency, equity, urgency, and flexibility. Further, practicality, robustness, legitimacy, synergy, and coherence may be useful considerations in selecting options. Costs, benefits, and alignment with existing priorities provides value for money and can enhance efficiency and effectiveness. Often a selection is made between no-regret and low-regret options or options that may produce high co-benefits.

OPTIONS AND THE HEALTH SECTOR IN THE LVB

In planning adaptation, it is important to note that infectious diseases result from a range of determinants: individual (behavior); social (economics, health care), and environmental including climatic conditions. Therefore, adaptation measures should include actions in not only in the health sector but also in other sectors, such as meteorology (weather forecasts and early warning systems), sanitation, and civil defense. Strategies undertaken in these sectors reduce environmental risk of infection and improve the efficacy of public services for the protection of the population. Hence, adaptation strategies in the health sector should focus on both the primary prevention (reducing exposure to infections) as well as secondary prevention (health care).

Many communities in East Africa are affected by health stresses due to climate change. Epidemic outbreaks in the EAC Partner States have been associated with El Niño years. The drivers of vulnerability for the health sector in the LVB, together with climate change, include poverty, high population density, unavailability of safe water, and availability of proper latrines and toilets and lack of proper health care system (Nkoko et al. 2011, Olago et al. 2007). Adaptation options aimed at providing access to safe water and improved sanitation to reduce diarrheal diseases, and implementing surveillance programs to identify and respond to outbreaks of malaria and other infectious diseases are therefore critical.

In East Africa, current national and international programs and measures that aim to reduce the burdens of climate-sensitive health determinants and outcomes may need to be revised, reoriented, and expanded to address the additional pressures of climate change. The degree to which programs will need to be augmented will depend on many factors: the current burden of climate-sensitive health outcomes; the effectiveness of current interventions; projections of where, when, and how the burden could change; access to the human and financial resources needed to implement activities; stressors that could increase or decrease resilience to impacts; and the social, economic, and political context within which interventions are implemented (Ebi et al. 2006, Yohe and Ebi 2005).

The projected impacts of climate change are long-term; this will require modification of current risk-management approaches to focus on both short-term and long-term risks. This requires incorporation of current climate change concerns into ongoing development programs and measures along with regular surveillance and evaluations to determine the effectiveness of the program to cope with the projected risks.

Already some measures are in place to reduce vulnerability and address impacts of climate change in the health sector. Some examples are in Table 13.

However, The EAC Partner States have challenges and constraints, including scarcity/low motivation of health professionals, financial barriers to accessing health care, poor quality of health services, poor access to essential medicines, and weak health information systems. Other constraints include public health and other infrastructure and how much is invested in the health system (McMichael and Woodruff 2004). Public awareness, effective use of local resources, appropriate governance arrangements, and community participation are necessary to mobilize and prepare for climate change (McMichael and Woodruff 2004). Furthermore, the status of and trends in other sectors affect public health, particularly water quantity and quality, sanitation, food quality and quantity, the urban environment, and ecosystems. These will also be affected by climate change, creating feedback loops that can increase or decrease population vulnerability to climate change effects and the cost of inaction can be extremely high for a country.

When designing adaptation measures to climate change and its potential impacts, many questions must be answered. In health, sanitation, and human settlements, measures must be put in place to counter the effects of extreme weather changes that can result in floods and droughts. Current measures that are being used to reduce the burden of disease and vulnerability must be considered and if need be, new or additional interventions need to be introduced, especially where existing efforts are not effective or sufficient. Groups vulnerable to the potential impacts must be considered first, hence the need for targeted interventions. In most cases, women, young children, and the elderly are the most at risk. In some cases, especially in the future projections of malaria, children over five are becoming more vulnerable to the disease. The timing of the interventions is very important, hence the need for early warning and forecasting systems. Innovations in institutional and policy frameworks at sub-national, national, and regional levels are critical to help communities to adapt to the projected extreme, highly variable, and long-term climate change effects in the LVB. Options are shown in Table 12.

Table 12: Examples of existing measures in place to reduce vulnerability and address impacts of climate change in the health sector

Scale	*Reduce vulnerability*	*Build responses*	*Manage climate risk*	*Confront climate change*
Household level	▪ Household health insurance schemes ▪ Improved hygiene and nutrition	▪ Use of prevention measures such as treated mosquito nets, ventilation, and access to safe water	▪ Environmental management ▪ Prevention and preparedness	▪ Avoiding deforestation and habitat degradation
Community level	▪ Community-based health insurance ▪ Improved access to clean water	▪ Improved water, sanitation, and hygiene projects	▪ Improved monitoring and surveillance	▪ Disaster preparedness at community level ▪ Habitat restoration
Sub-national level (county, province, parish, etc.)	▪ County-level integrated projects to reduce poverty ▪ Improved infrastructure projects	▪ County-level budgetary allocation for climate change preparedness ▪ Health policies to address impacts of climate change	▪ Rapid response capacity to prevent epidemics such as cholera	▪ Sustainable financing mechanisms
National level	▪ Improved literacy through access to free basic education	▪ Research and knowledge generation on key selected diseases, especially malaria ▪ Improved health and disease information management systems	▪ Sectoral planning addresses impacts of climate change ▪ Sustainable financing mechanisms	▪ Prevention, preparedness, response, and recovery plans for selected diseases

Table 13: Options matrix for reducing vulnerability and increase resilience in the health sector

Impact	*Reduce vulnerability*	*Build response*	*Manage climate risk*	*Confront Climate change*
Vector biology: ▪ ***Change in vector life cycle due to increase in temperature***	▪ Entomological surveillance of life cycle changes of vectors	▪ Fund research on insecticidal resistance, life cycle change, and behavior change ▪ Build capacity for vector research and monitoring ▪ Disseminate research findings for policy making and action planning	▪ Implement sustainable and environmentally friendly vector prevention and reduction programs	▪ Fund entomological research, identification of biological control options, and intervention pathways in response to changes in vector life cycles
▪ ***Increase in vector range due to changes in seasonal rainfall***	▪ Surveillance and monitoring of distribution and range of vectors with special focus of documenting new habitats	▪ Design and implement vector control programs to reduce populations of vectors ▪ Train communities on the potential impacts of climate change, impacts of extreme events, and response options	▪ Improve awareness at household and community level of emerging trends in vector population to reduce exposure	▪ Build capacity for prevention and preparedness at new habitats for communities and households to adapt prevention measures and timely treatment to reduce transmission rates
▪ ***Change in ecological niche of vectors***	▪ Design and implement household, community, and sub-national environmental management approaches to reduce mosquito breeding habitats	▪ Implement campaigns at household, community, and sub-national levels to address non-climatic drivers of change	▪ Use appropriate environmentally friendly larvicides and biological control agents to reduce mosquito populations	▪ Research, modeling, and monitoring of current and potential niches for vectors

Impact	*Reduce vulnerability*	*Build response*	*Manage climate risk*	*Confront Climate change*
	▪ Develop communication and dissemination tools to initiate rapid response at community and household levels to reduce expansion of range of vectors	leading to new habitats and ecological niches for vectors ▪ Communication and public awareness on current, potential and realized niches for vectors	▪ Define threshold for triggering prevention and preparedness actions as well as response and recovery planning	
Disease prevalence: ▪ ***Increased incidence of malaria due to changes in temperature, seasonality in rainfall, and flooding***	▪ Ensure adequate medical institutions (hospitals, clinics) both public and private sector have access to prophylaxis, equipment, and resources to maintain disease at non-epidemic levels ▪ Enhance epidemiological surveillance at community and regional levels ▪ Facilitate access to health care services, including prevention and early detection services ▪ Identify and support social networks to facilitate prevention and care	▪ Develop quick, easy-to-use diagnostic kits for use at local health centers ▪ Develop information management systems to define trends in incidence and projections under various climate scenarios for selected habitats/regions, especially highlands ▪ Enhance and strengthen health initiatives and emergency preparedness – sufficient medical kits and stocks	▪ Develop early warning systems for epidemics, especially after extreme hydro-meteorological events taking into account the lag and facilitate access ▪ Strengthen health risk management through communication and community awareness initiatives ▪ Build volunteer capacity and facilitate volunteer training	▪ Build partnerships across government, private sector, and local community to support rapid and effective response ▪ Design a rapid response strategy and emergency response unit with strategic resources ▪ Fund vaccination research for malaria as well for new drugs

Impact	*Reduce vulnerability*	*Build response*	*Manage climate risk*	*Confront Climate change*
Socioeconomic impacts ▪ ***Population displacement and migration due to long-term climate change***	❖ Integrate climate-proofing in development projects (e.g., climate-smart agriculture) ❖ Projects on water harvesting and irrigation to enhance water access and availability	❖ Strengthen existing social networks ❖ Capacity building programs on alternatives to enhance adaptive capacity at household and community levels	❖ Provide incentives to adopt new technologies and practices ❖ Research existing coping strategies and upscaling	❖ Invest in the conservation of and sustainable use of biodiversity and ecosystem services
Poor nutrition due to poverty exacerbated by high variability and long-term climate change	❖ Promote dietary diversity at community level ❖ Development projects to address poverty reduction and enhance food security	❖ Community-level training on hygiene and nutrition ❖ Develop disaster and emergency response strategy to include nutrition supplementation in recovery phase	❖ County-level and national sectoral planning to address nutritional deficiency in selected priority regions	❖ Promotion of diversified cropping systems and mixed agriculture
Limited access due to infrastructure destruction by flooding	❖ Ensure access to and availability of frontline medical personnel who are effectively equipped	❖ Train community-level volunteers and paramedics	❖ Ensure availability of well-trained and well-equipped medical staff at county level and provide budgetary allocation	❖ Develop a malaria disaster response strategy at national and county levels
Destroyed health care infrastructure due to flooding	❖ Climate-proof existing hospitals and clinic to be able to provide for emergencies during epidemics and disasters	❖ Build partnerships with paramilitary and related agencies to provide emergency services during disasters	❖ Integrate medical response and recovery with disaster and emergency preparedness at	❖ Include health infrastructure in disaster response and recovery planning at national and county levels

Impact	*Reduce vulnerability*	*Build response*	*Manage climate risk*	*Confront Climate change*
		❖ Build capacity at community and household levels for emergency response	sub-national planning level	
Contaminated water resources due to flooding	❖ Climate-proofed design and building of water sources, such as wells, boreholes, reservoirs, and water supply infrastructure ❖ WASH projects to enhance access to and availability of clean water to household and community level ❖ Design and climate-proof sanitation infrastructure in flood prone areas	❖ Training and capacity building at household and community level on hygiene ❖ Build capacity at local hospitals and clinics for quick and accurate diagnosis of cholera ❖ Provide adequate equipment, resources, and medical supplies to local clinics and hospitals	❖ Enhanced surveillance and monitoring of water quality ❖ Epidemiological surveillance for cholera and other water-borne diseases ❖ Research and mapping flood risk for planning and decision-making	❖ Integrate human health issues in urban planning and management to increase resilience and reduce vulnerability ❖ Establish rapid response units at national and county levels to contain cholera epidemics
Reduced quantity and quality of water due to climate variability and change	❖ Development projects to enhance access to water, including rain harvesting ❖ Expand water supply infrastructure in water-scarce areas	❖ Provide access to finance to enable households safely store water ❖ Build capacity at household and community level for water conservation	❖ Invest in water conservation approaches ❖ Enhance public-private partnerships to address water scarcity in vulnerable communities	❖ Sectoral planning at national and county levels to address water availability and access for vulnerable communities

EAC Policy and Institutional Changes and Programs

Health is a fundamental human right and an important indicator of development. Its protection from the negative impacts of climate change is the responsibility of individuals, households, communities, national governments, and the international community. The EAC Partner States have shown their commitment to addressing the impacts of climate change on their natural resources, environment, and sustainable development and have developed a Climate Change Policy (EACCCP) to guide the national governments and other stakeholders in the preparation and implementation of collective measures to address climate change (EAC 2012). The policy seeks to provide the Partner States with a strategic and cooperative approach that is aligned with national development policies, strategies, and plans. It is also tied to regional and sub-regional policies, strategies, plans, and programs, the latter including the Protocol for Sustainable Development of Lake Victoria Basin and the Fourth EAC Development Strategy (Viljoen 2013). The policy helps to ensure sustainable EAC development through strategies, projects, and actions that address key priorities.

Despite these efforts, health concerns still need to be incorporated in the countries' NAPAs in a way that links them with ongoing efforts to strengthen national health systems and adapt to changing patterns of diseases. The current and future adverse impacts of climate change on human health, sanitation, and settlements may be reduced through adaptation and mitigation strategies. In each EAC Partner State the existing relevant legislation draws its strength and legitimacy from the international conventions and treaties, such as the United Nations Framework Convention on Climate Change (ratified by all the member states) and the Kyoto Protocol, as well as in each country's own constitution. The EAC countries have also individually embraced the African Plan of Action for Public Health Adaptation to Climate Change (2012–2016), but most have not fully developed a strategy for its implementation.

In all the Partner States, human health is a key component of the social pillar of midterm and long-term development plans (e.g., Kenya's Vision 2030; Rwanda's Economic Development and Poverty Reduction Strategy, Vision 2020, and National Strategy for Green Growth and Climate Resilience; Tanzania's MKUKU-II and Vision 2025, and others). It is also a concern for achieving health-related SDGs. However, despite the efforts countries are making, challenges related to scarcity of financial, physical, and human resources continue to slow progress toward achieving the health goals (WHO 2009). Climate change offers some significant opportunities: improved technologies to reduce vulnerability and build resilience in key subsectors, such as water, sanitation, and urban settlements; and possibilities of accessing funds from new financing mechanisms that are likely to support mitigation and adaptation action plans (UNDP-UNEP 2011).

Apart from Kenya where health sector services have been devolved to counties, most EAC Partner States still have centralized systems. Nevertheless, efforts should be directed toward embracing opportunities available both nationally and internationally for climate change mitigation and adaptation, particularly with the objective of reducing vulnerability to climate-related disease burden in the region.

Malaria remains a significant public health problem in the EAC and is identified as an impediment to socioeconomic growth and welfare. The governments, through their respective National Malaria Control Programs have undertaken actions supported by development partners such as the Global Fund to Fight AIDS, Tuberculosis, and Malaria, the U.S. President's Malaria Initiative (PMI), the World Bank, and UNICEF. The EAC Partner States have developed strategic plans for malaria control aimed at significantly reducing morbidity and mortality from malaria in their populations and the coordination of the Roll Back Malaria partnerships.

However, a major issue and priority for the five EAC countries is the weak awareness and linkage of the existence of the health sector–related challenges to climate change and its impacts on the heath sector, which leads to insufficient intervention. Many reports, program reviews, and research agendas do not mention the role and potential impact of climate variability and change on health. Even though it is known that the extreme episodes of weather and climate impact on all areas of life, specific information on the part attributable to those phenomena is lacking. The literature on the health sector impacts of climate change needs to be reviewed. In addition, available data on malaria, cholera, and pneumonia from health management information systems, epidemiological surveillance, and national demographic and health surveys needs to inform evidence-based policy, strategic decision-making, and adaptation planning and monitoring.

This study has shown that programs to eradicate malaria have focused on the children under five and have been effective, but the neglect of the children older than age five is leading to an upsurge of malaria cases in this cohort. Hence, strategic, tactical, and policy interventions need to be reviewed to ensure that gains made by these programs are not lost once the children reach age five. Current approaches should be reviewed and more robust programs should be developed to cater to and sustain the benefits for older cohorts.

Further, addressing impacts of climate change on the health sector requires a multisectoral approach at national, sub-national, and community levels. Hence, the water and transport sectors—as well as those dealing with natural resources and disaster management and response—are critical. Further, the private sector and research community play a huge role in the generation, dissemination, and financing of information. It is imperative that integrated approaches are used in planning and decision-making to achieve sustainable outcomes.

In light of the need to have a diversified approach to planning for adaptation in the health sector based on the findings of this study, an analysis of policy options is presented in Table 14.

Table 14: Climate adaptation policy options health – malaria and sanitation

	Policy	Advantages	Disadvantages
Information-based	❖ National institutions should consistently monitor human health, sanitation, and settlements (e.g., disease surveillance, epidemic outbreaks, vaccination, water quality and safety, types and areas where settlements are developing) ❖ Multi-sector partnerships are essential	❖ Better information may result in improved health and sanitation, prevention of epidemic outbreaks and development of proper settlements that follow regulations set by ministries of health, environment, and settlement—promotion of one health system	❖ Can be costly ❖ Can be difficult to work in integrated way because of the interests of the various sectors
	❖ Regional climate organizations such ICPAC, EAC, and national meteorological departments of the EAC countries provide monthly, seasonal, and annual climate data of past and projected to various stakeholders managing health, sanitation, and settlements	❖ Provides critical insight into the past and future, improving decision-making in the health sector	❖ Can have significant barriers that limit their use and application (e.g., accessibility, uncertainty, credibility, cost, difficult to understand, and accuracy)
	❖ International, regional health research organizations, EAC, and universities (climate change–related departments) develop scenarios of possible future climate conditions (and their impacts on health and climate-sensitive diseases like malaria) with stakeholders with the health ministries taking the lead in coordinating activities	❖ Establishes "buy-in" early in knowledge-creation and decision-making processes and increases likelihood of outcomes and actions ❖ Allows decision-makers to contemplate uncertainties associated with climate change and health	❖ Can be costly and time-intensive and needs coordination among the various sectors ❖ Need to develop modelling capacities of various institutions involved in managing health issues
	❖ International, regional health research organizations, EAC, and universities educate the public, decision-makers, and media so that they can understand climate risk and its importance in maintaining high health and sanitation standards to prevent disease outbreaks	❖ Can increase public understanding of importance of climate risk and health ❖ May foster support for appropriate policy measures and financing ❖ Results in increases in data for evaluating climate processes and for monitoring effectiveness of adaptation decisions	❖ Can risk delayed action in the name of more knowledge and understanding ❖ Can be costly in the collection of data and processing of information ❖ Barriers and institutional constraints exist between countries and regions for standardizing and sharing of data

	Policy	Advantages	Disadvantages
		❖ Can lead to empowerment through citizen-science	
Regulatory (includes formal-command and control and informal voluntary methods)	❖ Regional and national health institutions, counties/districts, and judiciary (national and EAC levels) develop sanitation and settlement policies and legal protections to prioritize disease outbreak, proper sanitation, dumping of wastes, recycling, regulate zonation, and settlement types	❖ Can be a common regulatory means to achieve health objectives ❖ Can be clear and easy to enforce where ecosystem damage can be easily identified (e.g., pollutants and land contamination) ❖ Will help build common interest in sanitation and improve living standards of the population	❖ Requires effective monitoring and penalties for noncompliance to be successful; enforcement capacity can be weak or nonexistent (e.g., fragile nations and communities)
	❖ Regional and national financial institutions through public-private partnerships should provide funds and subsidies for building informal settlements to the required standards	❖ Have been used to close the gap between various social groups by providing minimal living standards including health for all	❖ Few financial services will provide such funding unless the returns are guaranteed ❖ Needs strong support from the government
	❖ National land use and planning ministries within the EAC and LVB need to zone land for various uses (e.g., limiting floodplain development, building in sensitive areas). Pit latrine location near shallow groundwater regions	❖ Can be effective at directing various types of buildings and settlements to clearly demarcated geographical areas, or harmful development away from recharge zones and water purification areas such as swamps ❖ Can be effective in saving lives during floods ❖ Can be effective in prevention of contamination of clean and safe water	❖ Requires state capacity to effectively carry out appropriate zoning actions ❖ Equity issues can be prevalent; often the marginalized are forced to slums and ecologically sensitive areas, the subsequent protection of which can lead to displacement and relocation

	Policy	Advantages	Disadvantages
Public Investment Programs and international cooperation		sources and prevent diarrheal disease outbreaks	
	❖ The EAC governments, working with local communities, should preserve state and local land reserves, including communal management of protected areas, such as forests and recharge areas that will be priorities of clean water availability for improved health and prevention of epidemic outbreaks	❖ Devolution of management to local users can result in multiple benefits for people and improve their health ❖ Can support empowerment and autonomy of community and health systems	❖ Land tenure and land use rights can be costly to administer and politically challenging to confer ❖ Uncertainty about ecological shifts because of changing climate regime can be difficult to anticipate and including these in plans can be challenging
	❖ EAC countries should encourage innovations and improvements in health and sanitation infrastructure that can enhance delivery of health services, reduce leakage of human wastes into clean water sources, help prevent flood-related mortality and increase resiliency	❖ Can protect and ensure supply of clean water ❖ Improve efficiency of health facilities ❖ Improve recycling and proper waste management ❖ Can increase production of alternative sources of energy (from waste) ❖ Can improve livelihoods	❖ Costly and needs trained people and strong institutions at both national and local levels
	❖ The EAC governments should cancel investment policies that can have a negative impact on health, sanitation, and settlements (e.g., industries producing hazardous fumes leading to air pollution, production of nuclear wastes) ❖ EAC countries should encourage innovations and improvements in health and sanitation infrastructure that can enhance delivery of health services, reduce leakage of human wastes into clean water	❖ Addresses unsustainable use of and negative impacts on ecosystems at the level of the socioeconomic system, with the potential to have highly transformative effects over time ❖ Can protect and ensure supply of clean water ❖ Improve efficiency of health facilities ❖ Improve recycling and proper waste management	❖ Requires significant political will and leadership ❖ Entrenched institutional structures and interest groups can stymie efforts to transform institutional practices ❖ Costly and needs trained people and strong institutions at both national and local levels

	Policy	Advantages	Disadvantages
	sources, help prevent flood-related mortality and increase ❖ resiliency	❖ Can increase production of alternative sources of energy (from waste) ❖ Can improve livelihoods	
	❖ SDG Goal 3: ensure healthy lives and promote well-being for all at all ages ❖ SDG GOAL 6: Ensure access to water and sanitation for all ❖ SDG GOAL 13: take urgent action to combat climate change and its impacts ❖ The EAC governments should cancel investment policies that can have a negative impact on health, sanitation, and settlements (e.g., industries producing hazardous fumes leading to air pollution, production of nuclear wastes) ❖ Many more efforts are needed to fully eradicate a wide range of diseases and address many different persistent and emerging health issues	❖ These goals are set to benefit nations and define global development agenda that will benefit humanity ❖ Improves the bi- and multi-level agreements on cross-boundary resource management issues on matters of health, sanitation, and settlements and climate change – pushes for similar goals to all the EAC countries ❖ Addresses unsustainable use of and negative impacts on ecosystems at the level of the socioeconomic system, with the potential to have highly transformative effects over time ❖ Enables states to take on obligations they otherwise might not	❖ Are often non-binding ❖ Consequences for noncompliance are difficult to enforce ❖ Requires significant political will and leadership ❖ Entrenched institutional structures and interest groups can stymie efforts to transform institutional practices

RESEARCH PRIORITIES

Considerable uncertainty will remain about projected climate change at geographical and temporal scales of relevance to decision-makers, increasing the importance of risk-management approaches. A better understanding is needed of the factors that convey vulnerability and, more importantly, the changes that need to be made in health care, emergency services, land use, urban design, and settlement patterns to protect populations against extreme climate change effects.

Key research priorities on climate change and health include:

- Develop proper longitudinal health data collection and data storage systems
- Develop methods to quantify the current impacts of climate and weather on a range of health outcomes, particularly in low- and middle-income countries
- Develop health impact models for projecting climate change–related impacts under different climate and socioeconomic scenarios
- Investigate the costs of the projected health impacts of climate change; effectiveness of adaptation; and the limiting forces, major drivers, and costs of adaptation
- Advance research on climate change and human health, including health sector adaptation
- Investigate the long-term health impacts of extreme climate events
- Assess climate impacts on health of vulnerable groups
- Study the long-term consequences of extreme events on affected communities
- Model nonlinear human health responses to climate
- Investigate how climate change modifies human security and the risk of conflict through changes in resource scarcity, likelihood of migration, capacity of the government to respond, and frequency and intensity of extreme weather events
- Identify vulnerabilities of displaced populations
- Address loss of access to critical services including medical care and education for marginalized groups
- Analyze relationships between climate extremes and human conflict.

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APPENDIX

The VARMAX Model
The VARMAX (*p,q,s*) models used allow for explanatory series or variables (commonly referred to as independent, input, predictor, regressor, or exogenous variables), which, in this case is either rainfall, minimum temperatures, maximum temperatures, their lagged values, or moving averages. The VARMAX (*p,q,s*) also allows for cointegration (Engle and Granger 1987, Johansen 1995) among the multiple sector indicator series or response variables. Informally, cointegration means that each sector indicator series (i.e., each of the multiple response series) might be a nonstationary process. Such a process displays no tendency to return to a mean or deterministic trend function in the long term if perturbed by an impulse or a shock (e.g., a severe drought). However, one or more linear combinations of the sector indicator series (multiple response series) are stationary and thus remain near some constant. A linear combination is simply the sum of the different component sector indicator series, each multiplied by some appropriately chosen constant.

The VARMARX (*p,q,s*) model used for forecasting can accommodate the following features:

- Simultaneous modelling of several time series (vector).
- Accounting for relationships among the component series with current and past values of the other series (X).
- Feedback from the response series and cross-correlated explanatory series.
- Cointegration of component series to achieve stationarity.
- Autoregressive errors (*p*).
- Moving-average errors (*q*).
- Seasonality (*s*).
- Mixed autorergressive and moving-average errors.
- Lagged values of the explanatory series.
- Unequal or heteroscedastic covariances for the residuals that use generalized autoregressive conditional heteroscedasticity (GARCH) models (Engle 2002).
- Testing the dependence of one sector indicator series on another (testing for weak exogeneity).
- Testing for Granger causality between two specified groups of variables.
- Putting various restrictions on the estimated parameter coefficients of the model or their linear combinations and testing hypotheses on linear combinations of the parameter coefficients.

The VARMAX (*p,q,s*) models the dynamic relationships between the response and the predictor variables and forecasts the response variables using the projected future values of the predictor variables (rainfall, minimum and maximum temperatures). The model can be represented in various forms, including in state space and dynamic simultaneous equation or dynamic structural equations forms. The model also allows representation of distributed lags in the explanatory variables. For example, malaria cases in year *t* can be related to malaria cases in year *t*-1, and *t*-2 plus to annual rainfall in year *t*, *t*-1, *t*-2, minimum and maximum temperatures in years *t*, *t*-1, *t*-2, etc., simultaneously.

When building the VARMAX (*p,q,s*) models various lags in rainfall, minimum and maximum temperature were tested and allowed for so that most of the models can be characterized as autoregressive and moving-average multiple regression models with distributed lags. The significance of seasonal deterministic terms for the monthly sector indicator time series data was also included in the models and tested for. For some response variables dead-start models were used as that do not allow for present (current) values of the explanatory variables. Heteroscedasticity was tested in the residuals and, where appropriate, GARCH-type (generalized autoregressive conditional heteroscedasticity) conditional heteroscedasticity of residuals was allowed for.

Several information-theoretic model selection criteria were used to automatically determine the tentative AR (autoregressive, *p*) and MA (moving average, *q*) orders of the VARMAX (*p*,*q*,*s*) models. The specific criteria used were the Akaike information criterion (AIC), the corrected AIC (AICC), Hannan-Quinn (HQ) criterion, Schwarz Bayesian criterion (SBC), also known as Bayesian information criterion (BIC), and the final prediction error (FPE). As additional AR order identification aids, partial cross-correlations were used for the response variable, Yule-Walker estimates, partial autoregressive coefficients and partial canonical correlations. Parameters of the selected full models were estimated using the maximum likelihood (ML) method. Roots (eigenvalues) of the characteristic functions for both the AR and MA parts of the VARMAX (*p*,*q*,*s*) models were evaluated for their proximity to the unit circle to infer evidence for stationarity of the response series.

Table 15: Model parameter estimates for malaria and anemia

Hospital, region	Equation	Parameter	Estimate	Standard error	t Value	Pr > |t|	Variable	Disease	Age
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	CONST1	-0.02145	0.14481	-0.15	0.8825	1		
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	XL0_1_1	0.31768	0.09735	3.26	0.0014	rain5_6(t)		
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	XL0_1_2	0.45515	0.21789	2.09	0.0387	max2(t)		
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	XL0_1_3	0.00196	0.09921	0.02	0.9843	min2(t)		
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	AR1_1_1	-0.13201	0.06933	-1.9	0.0591	log_cases2(t-1)		
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	AR2_1_1	0.62155	0.06865	9.05	0.0001	log_cases2(t-2)		
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	MA1_1_1	-1	0.02791	-35.83	0.0001	e1(t-1)		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	CONST1	0.26651	0.10814	2.46	0.0158	1		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	XL0_1_1	0.1079	0.0315	3.42	0.001	rain4_6(t)		

Litein Missionary Hospital, Kericho, Kenya	log_cases2	XL0_1_2	0.58994	0.75788	0.78	0.4386	Mavmax3(t)		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	XL0_1_3	-0.33025	0.10798	-3.06	0.003	Mavmin2(t)		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	AR1_1_1	0.34767	0.10371	3.35	0.0012	log_cases2(t-1)		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	AR2_1_1	0.55469	0.11569	4.79	0.0001	log_cases2(t-2)		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	MA1_1_1	0.09585	0.09983	0.96	0.3398	e1(t-1)		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	MA2_1_1	0.90415	0.09927	9.11	0.0001	e1(t-2)		
Mukumu Hospital, Kakamega, Kenya	log_cases2	CONST1	-0.31719	0.32753	-0.97	0.3345	1		
Mukumu Hospital, Kakamega, Kenya	log_cases2	XL0_1_1	0.25572	0.06724	3.8	0.0002	rain4_6(t)		
Mukumu Hospital, Kakamega, Kenya	log_cases2	XL0_1_2	-3.28699	1.64777	-1.99	0.048	Mavmax3(t)		
Mukumu Hospital, Kakamega, Kenya	log_cases2	XL0_1_3	0.38364	0.30633	1.25	0.2125	Mavmin2(t)		
Mukumu Hospital, Kakamega, Kenya	log_cases2	AR1_1_1	0.38694	0.20118	1.92	0.0564	log_cases2(t-1)		

Mukumu Hospital, Kakamega, Kenya	log_cases2	AR2_1_1	0.29066	0.18805	1.55	0.1244	log_cases2(t-2)		
Mukumu Hospital, Kakamega, Kenya	log_cases2	MA1_1_1	-0.47197	0.20627	-2.29	0.0236	e1(t-1)		
Mukumu Hospital, Kakamega, Kenya	log_cases2	MA2_1_1	-0.22424	0.1078	-2.08	0.0393	e1(t-2)		
Muleba Hospital	logP	CONST1	2.35352	1.03276	2.28	0.0257	1	Anemia	Under 5 years
Muleba Hospital	logP	XL0_1_1	2.80014	0.50611	5.53	0.0001	Mavrain7(t)	Anemia	Under 5 years
Muleba Hospital	logP	XL0_1_2	7.16067	2.78101	2.57	0.0121	max(t)	Anemia	Under 5 years
Muleba Hospital	logP	XL0_1_3	4.62806	1.63937	2.82	0.0062	max3(t)	Anemia	Under 5 years
Muleba Hospital	logP	XL0_1_4	-2.08371	1.0383	-2.01	0.0486	min2(t)	Anemia	Under 5 years
Muleba Hospital	logP	AR1_1_1	-0.3111	0.11298	-2.75	0.0075	logP(t-1)	Anemia	Under 5 years
Muleba Hospital	logP	MA1_1_1	-0.82341	0.10022	-8.22	0.0001	e1(t-1)	Anemia	Under 5 years
Muleba Hospital	logP	CONST1	7.09902	1.49103	4.76	0.0001	1	Malaria	All ages

Muleba Hospital	logP	XL0_1_1	0.60312	0.10075	5.99	0.0001	Mavrain7(t)	Malaria	All ages
Muleba Hospital	logP	XL0_1_2	-4.14528	1.25292	-3.31	0.0014	Mavmax3(t)	Malaria	All ages
Muleba Hospital	logP	XL0_1_3	1.38371	0.82015	1.69	0.0956	Mavmin2(t)	Malaria	All ages
Muleba Hospital	logP	AR1_1_1	-1.01815	0.09279	-10.97	0.0001	logP(t-1)	Malaria	All ages
Muleba Hospital	logP	AR2_1_1	-0.18802	0.09641	-1.95	0.0548	logP(t-2)	Malaria	All ages
Muleba Hospital	logP	MA1_1_1	-1.78767	0.12594	-14.19	0.0001	e1(t-1)	Malaria	All ages
Muleba Hospital	logP	MA2_1_1	-0.83823	0.12752	-6.57	0.0001	e1(t-2)	Malaria	All ages
Muleba Hospital	logP	CONST1	3.92789	1.85663	2.12	0.0376	1	Malaria	Five years and above
Muleba Hospital	logP	XL0_1_1	1.00917	0.19529	5.17	0.0001	Mavrain7(t)	Malaria	Five years and above
Muleba Hospital	logP	XL0_1_2	-10.86087	2.07415	-5.24	0.0001	Mavmax3(t)	Malaria	Five years and above
Muleba Hospital	logP	XL0_1_3	3.73474	1.1891	3.14	0.0024	Mavmin2(t)	Malaria	Five years and above
Muleba Hospital	logP	AR1_1_1	-0.90884	0.09907	-9.17	0.0001	logP(t-1)	Malaria	Five years and above
Muleba Hospital	logP	AR2_1_1	0.06764	0.0846	0.8	0.4264	logP(t-2)	Malaria	Five years and above

Muleba Hospital	logP	MA1_1_1	-1.59167	0.14302	-11.13	0.0001	e1(t-1)	Malaria	Five years and above
Muleba Hospital	logP	MA2_1_1	-0.59167	0.14208	-4.16	0.0001	e1(t-2)	Malaria	Five years and above
Muleba Hospital	logP	CONST1	8.09306	1.485	5.45	0.0001	1	Malaria	Under 5 years
Muleba Hospital	logP	XL0_1_1	0.39676	0.10708	3.71	0.0004	Mavrain7(t)	Malaria	Under 5 years
Muleba Hospital	logP	XL0_1_2	-1.83791	1.41079	-1.3	0.1965	Mavmax3(t)	Malaria	Under 5 years
Muleba Hospital	logP	XL0_1_3	1.39137	0.69122	2.01	0.0476	Mavmin2(t)	Malaria	Under 5 years
Muleba Hospital	logP	AR1_1_1	-0.86342	0.13529	-6.38	0.0001	logP(t-1)	Malaria	Under 5 years
Muleba Hospital	logP	AR2_1_1	-0.14146	0.09393	-1.51	0.1361	logP(t-2)	Malaria	Under 5 years
Muleba Hospital	logP	MA1_1_1	-1.45443	0.1696	-8.58	0.0001	e1(t-1)	Malaria	Under 5 years
Muleba Hospital	logP	MA2_1_1	-0.45443	0.16392	-2.77	0.007	e1(t-2)	Malaria	Under 5 years
Uganda	logtotal	CONST1	-19.94153	8.12213	-2.46	0.0303	1		Five years and above

Uganda	logtotal	XL0_1_1	0.00055	0	.	.	mavannualrain2(t)		Five years and above
Uganda	logtotal	XL0_1_2	0.76308	0.38727	1.97	0.0723	mavmax3(t)		Five years and above
Uganda	logtotal	XL0_1_3	-0.21166	0.23778	-0.89	0.3909	mavmin2(t)		Five years and above
Uganda	logtotal	AR1_1_1	0.54843	0.21304	2.57	0.0244	logtotal(t-1)		Five years and above
Uganda	logtotal	AR2_1_1	-0.55786	0.23798	-2.34	0.0371	logtotal(t-2)		Five years and above
Uganda	logtotal	MA1_1_1	0.17568	0.31565	0.56	0.5881	e1(t-1)		Five years and above
Uganda	logtotal	MA2_1_1	-1	0.29609	-3.38	0.0055	e1(t-2)		Five years and above
Uganda	logtotal	CONST1	-13.68234	7.36143	-figure 8 6	0.0878	1		Under five years
Uganda	logtotal	XL0_1_1	0.00056	0	.	.	mavannualrain2(t)		Under five years
Uganda	logtotal	XL0_1_2	0.52289	0.29987	1.74	0.1067	mavmax3(t)		Under five years

Uganda	logtotal	XL0_1_3	-0.21436	0.14831	-1.45	0.174	mavmin2(t)		Under five years
Uganda	logtotal	AR1_1_1	0.44972	0.2176	2.07	0.061	logtotal(t-1)		Under five years
Uganda	logtotal	AR2_1_1	-0.73017	0.16115	-4.53	0.0007	logtotal(t-2)		Under five years
Uganda	logtotal	MA1_1_1	0.31108	0.28743	1.08	0.3004	e1(t-1)		Under five years
Uganda	logtotal	MA2_1_1	-1	0.21264	-4.7	0.0005	e1(t-2)		Under five years

Portmanteau Test for Cross-Correlations of Residuals. The results show tests for white noise residuals based on the cross-correlations of the residuals. Insignificant test results show that the null hypothesis that the residuals are uncorrelated cannot be rejected.

Table 16: Portmanteau test for cross-correlations of residuals

Hospital	Up to lag	Degrees of freedom	Chi-Square	Pr > ChiSq	Disease	Age
Central Unilever Tea Hospital, Kericho, Kenya	4	1	1.77	0.1836		
Central Unilever Tea Hospital, Kericho, Kenya	5	2	2.29	0.3187		
Central Unilever Tea Hospital, Kericho, Kenya	6	3	5.01	0.1707		
Central Unilever Tea Hospital, Kericho, Kenya	7	4	7.96	0.0931		

Central Unilever Tea Hospital, Kericho, Kenya	8	5	10.23	0.0689		
Central Unilever Tea Hospital, Kericho, Kenya	9	6	20.04	0.0027		
Central Unilever Tea Hospital, Kericho, Kenya	10	7	21.43	0.0032		
Central Unilever Tea Hospital, Kericho, Kenya	11	8	21.43	0.0061		
Central Unilever Tea Hospital, Kericho, Kenya	12	9	21.51	0.0106		
Litein Missionary Hospital, Kericho, Kenya	5	1	6.53	0.0106		
Litein Missionary Hospital, Kericho, Kenya	6	2	10.23	0.006		
Litein Missionary Hospital, Kericho, Kenya	7	3	10.36	0.0157		
Litein Missionary Hospital, Kericho, Kenya	8	4	10.4	0.0342		
Litein Missionary Hospital, Kericho, Kenya	9	5	10.61	0.0597		
Litein Missionary Hospital, Kericho, Kenya	10	6	11.03	0.0873		
Litein Missionary Hospital, Kericho, Kenya	11	7	11.12	0.1334		
Litein Missionary Hospital, Kericho, Kenya	12	8	12.13	0.1457		
Mukumu Hospital, Kakamega, Kenya	5	1	0.31	0.5762		
Mukumu Hospital, Kakamega, Kenya	6	2	3.13	0.2095		
Mukumu Hospital, Kakamega, Kenya	7	3	3.18	0.365		

Mukumu Hospital, Kakamega, Kenya	8	4	7.81	0.0988		
Mukumu Hospital, Kakamega, Kenya	9	5	8.36	0.1375		
Mukumu Hospital, Kakamega, Kenya	10	6	8.46	0.2062		
Mukumu Hospital, Kakamega, Kenya	11	7	11.96	0.1018		
Mukumu Hospital, Kakamega, Kenya	12	8	13.97	0.0826		
Muleba Hospital	3	1	2.96	0.0856	Anemia	Under 5 years
Muleba Hospital	4	2	3.39	0.1835	Anemia	Under 5 years
Muleba Hospital	5	3	4.23	0.2375	Anemia	Under 5 years
Muleba Hospital	6	4	13.86	0.0077	Anemia	Under 5 years
Muleba Hospital	7	5	13.96	0.0159	Anemia	Under 5 years
Muleba Hospital	8	6	14.63	0.0233	Anemia	Under 5 years
Muleba Hospital	9	7	14.94	0.0368	Anemia	Under 5 years
Muleba Hospital	10	8	16.54	0.0353	Anemia	Under 5 years
Muleba Hospital	11	9	16.6	0.0553	Anemia	Under 5 years
Muleba Hospital	12	10	26.62	0.003	Anemia	Under 5 years
Muleba Hospital	5	1	2.63	0.105	Malaria	All ages

Muleba Hospital	6	2	2.93	0.2314	Malaria	All ages
Muleba Hospital	7	3	3.96	0.2662	Malaria	All ages
Muleba Hospital	8	4	7.94	0.0937	Malaria	All ages
Muleba Hospital	9	5	10.21	0.0694	Malaria	All ages
Muleba Hospital	10	6	10.98	0.089	Malaria	All ages
Muleba Hospital	11	7	13.16	0.0684	Malaria	All ages
Muleba Hospital	12	8	19.85	0.0109	Malaria	All ages
Muleba Hospital	5	1	8.92	0.0028	Malaria	Five years and above
Muleba Hospital	6	2	12.97	0.0015	Malaria	Five years and above
Muleba Hospital	7	3	22.43	<.0001	Malaria	Five years and above
Muleba Hospital	8	4	22.75	0.0001	Malaria	Five years and above
Muleba Hospital	9	5	23.14	0.0003	Malaria	Five years and above
Muleba Hospital	10	6	24.24	0.0005	Malaria	Five years and above
Muleba Hospital	11	7	26.08	0.0005	Malaria	Five years and above
Muleba Hospital	12	8	30.95	0.0001	Malaria	Five years and above
Muleba Hospital	5	1	1.34	0.2474	Malaria	Under 5 years

Muleba Hospital	6	2	1.86	0.3943	Malaria	Under 5 years
Muleba Hospital	7	3	1.95	0.5833	Malaria	Under 5 years
Muleba Hospital	8	4	2.97	0.5637	Malaria	Under 5 years
Muleba Hospital	9	5	2.97	0.7051	Malaria	Under 5 years
Muleba Hospital	10	6	3.1	0.796	Malaria	Under 5 years
Muleba Hospital	11	7	5.16	0.641	Malaria	Under 5 years
Muleba Hospital	12	8	10.53	0.2299	Malaria	Under 5 years
Uganda	5	1	1.83	0.1761		Five years and above
Uganda	6	2	1.98	0.3718		Five years and above
Uganda	7	3	1.99	0.5739		Five years and above
Uganda	8	4	3.57	0.4673		Five years and above
Uganda	9	5	3.63	0.6038		Five years and above
Uganda	10	6	3.64	0.7257		Five years and above
Uganda	11	7	3.64	0.8205		Five years and above
Uganda	5	1	6.75	0.0094		Under five years
Uganda	6	2	7.44	0.0242		Under five years

Uganda	7	3	7.47	0.0583		Under five years
Uganda	8	4	7.5	0.1118		Under five years
Uganda	9	5	7.59	0.1803		Under five years
Uganda	10	6	7.62	0.2674		Under five years
Uganda	11	7	7.62	0.3669		Under five years

Table 17: Univariate model ANOVA diagnostics for malaria and anemia

Hospital	Variable	R-square	Standard deviation	F value	Pr > F	Disease	Age
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	0.6104	0.24853	31.86	<.0001		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	0.5151	0.1044	11.23	<.0001		
Mukumu Hospital, Kakamega, Kenya	log_cases2	0.7606	0.1521	61.28	<.0001		
Muleba Hospital	logP	0.4319	0.48429	8.11	<.0001	Anemia	Under 5 years
Muleba Hospital	logP	0.5462	0.15822	11.86	<.0001	Malaria	All ages
Muleba Hospital	logP	0.5602	0.24356	12.56	<.0001	Malaria	Five years and above
Muleba Hospital	logP	0.4281	0.14121	7.38	<.0001	Malaria	Under 5 years
Uganda	logtotal	0.6724	0.11509	1.17	0.4649		Five years and above
Uganda	logtotal	0.7428	0.09302	1.65	0.3288		Under five years

Table 18: Univariate model white noise diagnostics for malaria and anemia

The results test whether the residuals are correlated and heteroscedastic. The Durbin-Watson test statistics to test the null hypothesis that the residuals are uncorrelated. The Jarque-Bera normality test tests the null hypothesis that the residuals are normally distributed. The F statistics and their p-values for ARCH (1) disturbances test the null hypothesis that the residuals have equal covariances.

Hospital, region	Variable	Durbin-Watson statistics	Jarque-Bera Normality test		ARCH(1) test			
Hospital	**Variable**		**χ^2**	**Pr >ChiSq**	**F Value**	**Pr > F**	**Disease**	**Age**
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	1.97458	21.04	<.0001	5.73	0.0182		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	1.89234	13.42	0.0012	28.37	<.0001		
Mukumu Hospital, Kakamega, Kenya	log_cases2	1.98313	511.15	<.0001	0.08	0.7845		
Muleba Hospital	logP	1.88417	60.6	<.0001	0.11	0.7413	Anemia	Under 5 years
Muleba Hospital	logP	2.04576	3.86	0.1451	6.88	0.0106	Malaria	All ages
Muleba Hospital	logP	1.81909	1.48	0.4771	0	0.9499	Malaria	Five years and above
Muleba Hospital	logP	1.94434	3.07	0.2155	9.24	0.0033	Malaria	Under 5 years
Uganda	logtotal	2.24631	0.24	0.8883	3.58	0.0911		Five years and above

Uganda	logtotal	2.34006	0.31	0.8583	0.15	0.7092		Under five years

Table 19: Univariate AR model diagnostics for malaria

The F statistics and their p-values for AR(1), AR(1,2), AR(1,2,3), and AR(1,2,3,4) models of residuals test the null hypothesis that the residuals are uncorrelated.

		AR(1)		AR(1,2)		AR(1,2,3)		AR(1,2,3,4)			
Hospital, Region	**Variable**	**F Value**	**Pr >F**	**F Value**	**Pr >F**	**F Value**	**Pr >F**	**F Value**	**Pr >F**	**Disease**	**Age**
Central Unilever Tea Hospital, Kericho, Kenya	log_cases2	0.01	0.9028	0.01	0.9929	0.54	0.6537	0.42	0.7967		
Litein Missionary Hospital, Kericho, Kenya	log_cases2	0.22	0.6415	0.16	0.8558	1.74	0.1661	1.83	0.1317		
Mukumu Hospital, Kakamega, Kenya	log_cases2	0	0.9585	0.02	0.9764	0.08	0.9729	0.05	0.9944		
Muleba Hospital	logP	0.53	0.4689	0.54	0.5879	1.14	0.3406	1.07	0.3796	Anemia	Under 5 years
Muleba Hospital	logP	0.09	0.7644	0.56	0.5722	0.38	0.7694	0.41	0.8038	Malaria	All ages
Muleba Hospital	logP	0.39	0.5323	1.27	0.2863	0.86	0.4652	0.73	0.5777	Malaria	Five years and above
Muleba Hospital	logP	0.04	0.8512	0.18	0.8391	0.12	0.9453	0.3	0.8799	Malaria	Under 5 years
Uganda	logtotal	0.14	0.7129	0.37	0.7055	0.22	0.8781	0.23	0.9032		Five years and above
Uganda	logtotal	0.3	0.5943	1.16	0.3661	0.79	0.5512	3.17	0.1851		Under five years

Table 20: Roots of AR and MA characteristic polynomials

The modulus of the roots of its AR polynomial should be less than 1 for a time series to be stationary

Hospital	Index	Real part	Imaginary part	Modulus	Arctangent	Degree	Disease	Age
Central Unilever Tea Hospital, Kericho, Kenya	1	0.72514	0	0.7251	0	0		
Central Unilever Tea Hospital, Kericho, Kenya	2	-0.85715	0	0.8571	3.1416	180		
Litein Missionary Hospital, Kericho, Kenya	1	0.93863	0	0.9386	0	0		
Litein Missionary Hospital, Kericho, Kenya	2	-0.59096	0	0.591	3.1416	180		
Mukumu Hospital, Kakamega, Kenya	1	0.76626	0	0.7663	0	0		
Mukumu Hospital, Kakamega, Kenya	2	-0.37932	0	0.3793	3.1416	180		
Muleba Hospital	1	-0.3111	0	0.3111	3.1416	180	Anemia	Under 5 years
Muleba Hospital	1	-0.24236	0	0.2424	3.1416	180	Malaria	All ages
Muleba Hospital	2	-0.77579	0	0.7758	3.1416	180	Malaria	All ages
Muleba Hospital	1	0.06916	0	0.0692	0	0	Malaria	Five years and above
Muleba Hospital	2	-0.978	0	0.978	3.1416	180	Malaria	Five years and above

Muleba Hospital	1	-0.21978	0	0.2198	3.1416	180	Malaria	Under 5 years
Muleba Hospital	2	-0.64363	0	0.6436	3.1416	180	Malaria	Under 5 years
Uganda	1	0.27421	0.69474	0.7469	1.1949	68.4609		Five years and above
Uganda	2	0.27421	-0.69474	0.7469	-1.1949	-68.4609		Five years and above
Uganda	1	0.22486	0.82438	0.8545	1.3045	74.743		Under five years
Uganda	2	0.22486	-0.82438	0.8545	-1.3045	-74.743		Under five years
Central Unilever Tea Hospital, Kericho, Kenya	1	-1	0	1	3.1416	180		
Litein Missionary Hospital, Kericho, Kenya	1	1	0	1	0	0		
Litein Missionary Hospital, Kericho, Kenya	2	-0.90415	0	0.9042	3.1416	180		
Mukumu Hospital, Kakamega, Kenya	1	-0.23599	0.41055	0.4735	2.0925	119.8905		
Mukumu Hospital, Kakamega, Kenya	2	-0.23599	-0.41055	0.4735	-2.0925	-119.8905		
Muleba Hospital	1	-0.82341	0	0.8234	3.1416	180	Anemia	Under 5 years
Muleba Hospital	1	-0.89383	0.19823	0.9156	2.9234	167.4958	Malaria	All ages
Muleba Hospital	2	-0.89383	-0.19823	0.9156	-2.9234	-167.4958	Malaria	All ages

Muleba Hospital	1	-0.59167	0	0.5917	3.1416	180	Malaria	Five years and above
Muleba Hospital	2	-1	0	1	3.1416	180	Malaria	Five years and above
Muleba Hospital	1	-0.45443	0	0.4544	3.1416	180	Malaria	Under 5 years
Muleba Hospital	2	-1	0	1	3.1416	180	Malaria	Under 5 years
Uganda	1	0.08784	0.99613	1	1.4828	84.9607		Five years and above
Uganda	2	0.08784	-0.99613	1	-1.4828	-84.9607		Five years and above
Uganda	1	0.15554	0.98783	1	1.4146	81.0519		Under five years
Uganda	2	0.15554	-0.98783	1	-1.4146	-81.0519		Under five years

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