The Republic of Uganda

MINISTRY OF WATER AND ENVIRONMENT

CLIMATE CHANGE DEPARTMENT

Economic Assessment of the Impacts of Climate Change in Uganda

Case study on malaria prevalence in the districts of Tororo and Kabale

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LIST OF ACRONYMS

Acronym	Definition
CPI	Consumer Price Index
DPSEEA	Driver-Pressure-State-Exposure-Effect-Action
ECMWF	European Centre for Medium-range Weather Forecasts
GPCC	Global Precipitation Climatology Centre
GDP	Gross Domestic Product
HCIV	Health Centre Type IV
HIV	Human immunodeficiency virus
IRS	Indoor residential spraying
ITN	Insecticide Treated Nets
LLINs	Long lasting insecticide nets
MoH	Ministry of Health
NAPA	National Adaptation Programme of Action
NCCP	National Climate Change Policy
NMCP	National Malaria Control Programme
RCP	Representative Concentration Pathways
SSP	Shared Socioeconomic Pathway
UMSP	Uganda Malaria Surveillance Project
USAID	United States Agency for International Development
VSL	Value of a Statistical Life

EXECUTIVE SUMMARY

Uganda has one of the highest incidence rates of malaria worldwide. It is endemic in 95% of the country and according to a recent USAID study (USAID, 2014), it is the leading cause of morbidity and mortality in Uganda. Climate change is one of many drivers that are expected to lead to changes in the burden of malaria in Uganda, and related costs to society. This study looks in depth at the potential impact of climate change on malaria in Tororo and Kabale regions in Uganda. **The overall finding of this study is that malaria has a significant economic burden on Ugandan society and that efforts need to be increased to reduce this, in the face of climate change and population growth. The costs of inaction across Uganda may be very significant indeed – and there are a number of low cost actions that may be taken to reduce this burden.**

There is **significant uncertainty** in the analysis – the knowledge base is not well developed as to the precise linkage between climate and malaria, and the evidence on the valuation of health outcomes in Uganda is also weak. Available quantitative relationships between malaria and climate are coupled with projections of climate and population to estimate future impacts. The evidence base is limited, but does indicate that with an increase in temperature **there is likely** to be an increase in the number of cases of malaria. **Only one study dealing with this linkage is from Uganda and is not methodologically strong.** Other studies from South Africa and Ethiopia point to a similar relationship but with different quantitative estimates. We use the study from Uganda to derive upper and lower bound estimates. This study has been used because it represents the best available quantitative estimates of the linkages between climate and malaria in Uganda. However, we note that because the evidence base is limited any estimates and conclusions made are subject to significant degrees of uncertainty and must be considered speculative.

Temperatures may rise in Tororo by 1.5°C to 3.5°C by 2095 under RCP scenarios 4.5 and 8.5 respectively[1]. The projections for Kabale suggest increases in temperature by 3.0 to 4.5°C by 2095 under RCP scenarios 4.5 and 8.5. There is no prediction of an increase in average annual rainfall, although there is indication of more days with a small amount of rainfall and fewer days with heavy rainfall. Population scenarios are based on the new IPCC shared socio-economic pathways for Uganda downscaled to these districts[2]. The findings indicate that there may be a limited increase in cases of malaria due to climate change (in relation to rainfall changes and temperature increase) but also a large increase due to population growth.

In Tororo the effect of the increase in population may increase the number of malaria cases by between 5,417 to 5,503 additional cases annually by 2025. Climate change may also lead to an increase in the number of cases by between 65 and 853 cases in the same period, depending on the RCP scenario applied. In Kabale the effect of the increase in population by 2025 may result in 1,568 to 1,593 additional cases, while between 56 and 320 more cases may arise due to climate related changes, with increases in temperature likely to be more significant in this region. **In the opinion of the study team, climate change is likely to lead to increased incidence of malaria in Uganda,** though the extent of this change is difficult to quantify with certainty. **These results should be considered preliminary, and indicate the importance of undertaking further analysis and research in this area.**

The economic costs of these additional cases has been estimated using data on the costs of treatment, loss of earnings and productivity, and the value attached to the loss of a life, drawing on the best data available. This is a common approach in studies of this nature. This analysis indicated that in both districts the cost associated

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[1] The Representative Concentration Pathways (RCPs) show the potential cumulative measure of anthropogenic emissions of greenhouse gases. In the Intergovernmental Panel on Climate Change's AR5 report four RCPs were used, two of which have been selected for this case study.

[2] Downscaling involves taking national level data and transforming it to the local or regional level. In this case we have country level population and GDP projections which are translated to the case of Tororo and Kabale, with assumptions that population increases in a uniform way and that GDP rises equally across the country.

with malaria could more than double as a result of population increase and predicted changes in climate, when these two factors are considered together. In Tororo, the economic cost of malaria may rise from a range of US$8.7 - 221 million annually in the current period to a range of US$20.1 - 560.5 million in 2050. In Kabale, costs associated with increased malaria infections are expected to increase from between US$0.7 - 15.8 million annually in the current period to between US$1.55 - 41.7 million in 2050.

Isolating the impact of climate change is rather artificial, as any policy to respond to malaria in Uganda will be faced with both the climate and socioeconomic changes (and other changes not addressed in this report including behaviour change). However, it is useful in highlighting the differing degree of likely importance of climate change in driving the spread of malaria into different districts, and so for completeness the climate change costs of malaria in Uganda in isolation from the socioeconomic change are estimated. The strength of the effect depends on whether the climate impact on malaria is low or high. For Tororo, the climate change associated costs range from $0.66million to $65.9million in 2050, depending on the scenarios and values used. For Kabale, the climate change associated costs range from $0.04million to $6.2million in 2050, depending on the scenarios and values used.

There is considerable uncertainty regarding these estimates, both due to the lack of studies on the monetary valuation of mortality in Uganda and the variation in climate and socioeconomic scenarios. However, given the scale of probable impacts **in both Tororo and Kabale indicated by this work, the development of** a suitable policy response is appropriate despite current uncertainties related to the likely scale and economic impacts of increased malaria incidence associated with both socioeconomic and climatic change.

There is already an active programme to reduce the incidence of malaria as well as its consequences in Uganda. Local stakeholders suggested that Long Lasting Insecticide Nets (LLINs), Indoor Residential Spraying (IRS), clearing of breeding sites and proper treatment are important actions that can be taken now. In the medium-to-long term, improved agricultural practices, such as planting crops away from houses and improved drainage, as well as the use of new drugs for treatment and prevention, were seen as other possible adaptation options. Studies indicate that both LLINs as well as IRS are likely to be cost-effective. Drawing on previous studies **we estimate that for every US$1 of expenditure on IRS the benefits in terms of mortality alone amount to US$232 and US$6,026 respectively**. However, this is strongly dependent on assumptions of the benefits of such measures. We have attempted a simple analysis which shows that in the case of Kabale IRS and LLINS may not necessarily be cost-beneficial under all conditions – but climate change may make such measures more viable.

The preliminary analysis presented suggests that in areas where malaria may be less prevalent **care is needed in applying a single approach**, because in these areas the benefits may not exceed the costs for certain intervention options. Hence a strategy based on investment in surveillance and rapid treatment during periods of increased infection rates may be most cost effective in the case of Kabale – due to a low prevalence rate. **Where measures are potentially cost-beneficial at present, the impact of climate change is likely to make the case for such interventions even stronger in the future**.

There is need for cross-collaboration bringing together different ministries to ensure the health co-benefits of actions to adapt to climate change are maximized and maladaptation is avoided. For example, appropriate drainage systems need to be included in new road construction schemes to reduce the potential breeding grounds for mosquitos.

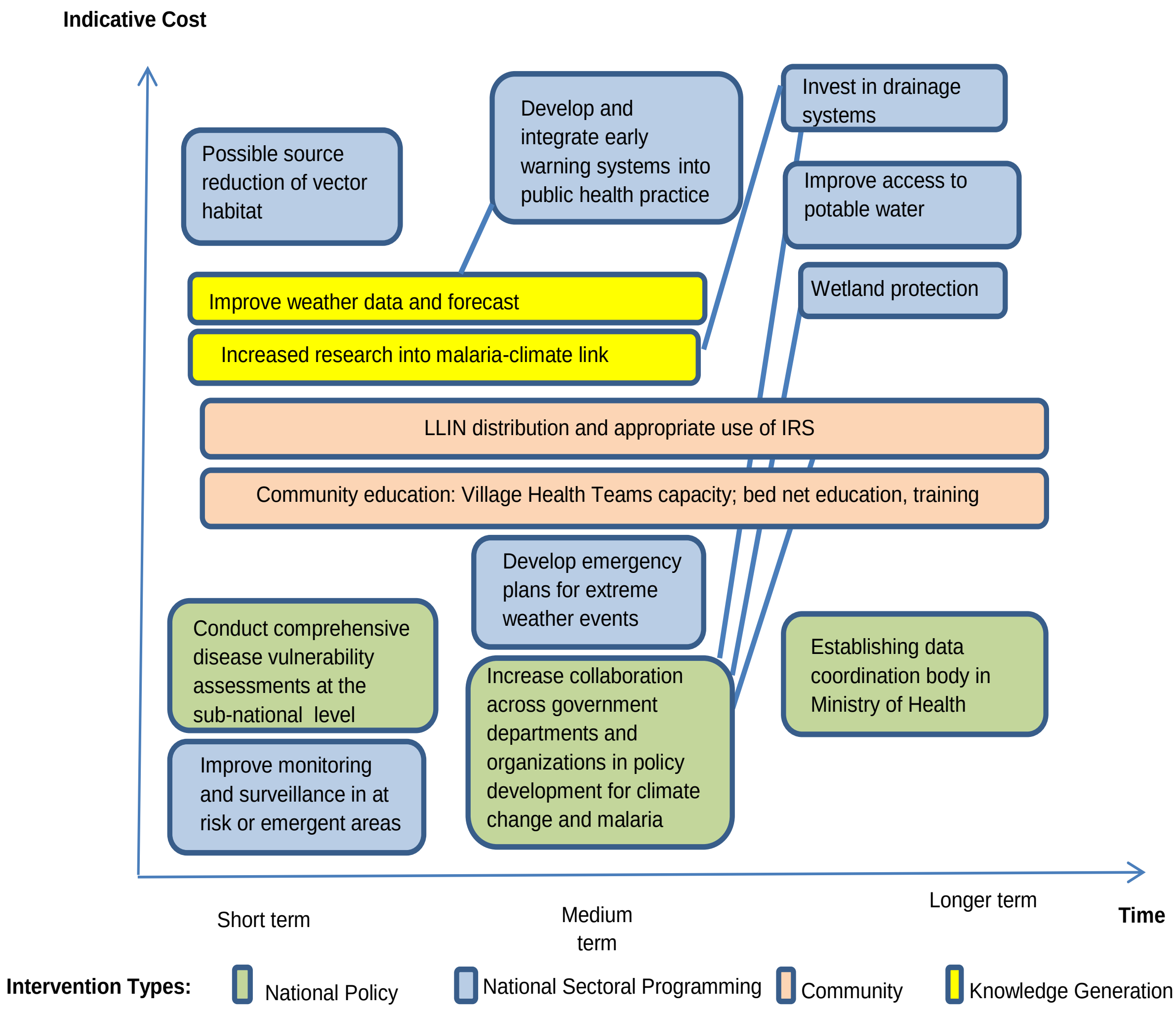
Additional actions that need to be advanced in the immediate term, ordered by priority, include:

i. Conducting more research on the linkage between climate change and malaria. Better weather data, alongside malaria surveillance data, may enable a clear understanding of the climate related risks for malaria and potentially lead to improved early warning for malaria risk.
ii. Implementing education and awareness campaigns to strengthen dissemination of information about malaria risk and the appropriate use of bednets, particularly in areas where malaria may newly appear or is expected to significantly increase in prevalence.

iii. Revising planning regimes to ensure proper drainage, control construction, and prevent encroachment on wetlands in particular.
iv. Implementing measures to ensure that farming practices take account of malaria risk, e.g. planting crops away from houses.

The spatial differentiation in climate and malaria risk suggests that a range of policy instruments need to be considered in Uganda, based on a number of key variables at the national and local level. There is no "one size fits all" policy for malaria. There is a need for investment in comprehensive disease surveillance, vulnerability assessments, and action planning across districts. More and better data, both in terms of the quantity (number of sites) and quality, is also needed to support these assessments. Engagement with local stakeholders is important to ensure the uptake of recommendations – so action is needed to support adaptive capacity at local level. Figure ES1 provides an overview of potential adaptation measures.

Figure ES1: Overview of selection of potential adaptation measures for malaria



1. INTRODUCTION

1.1. General context

There is growing concern that climate change will adversely impact the health of individuals in Uganda. The projected increases in temperature and the increasing variability of rainfall is likely to exacerbate diseases and other health determinants, such as food, water supply and sanitation and socioeconomic status.

Several diseases that are currently endemic (i.e. common) in Uganda will likely increase in prevalence and distribution due to climate change. These include mosquito-borne diseases such as malaria and lymphatic filariasis; soil-transmitted helminthes; trachoma; and waterborne diseases such as cholera and typhoid. Other diseases that Ugandans experience in a more localized or epidemic nature include plague (caused by the bacterium *Yersinia pestis)*, trypanosomiasis (sleeping sickness), and yellow fever. There is also potential for diseases that are not yet established among humans in Uganda to be introduced as a result of climate change, such as the following mosquito-borne diseases: dengue fever, chikungungya, and Rift Valley fever (USAID, 2014). Finally, climate change threatens human health through its effects on food insecurity and malnutrition.

A literature review and consultations conducted with the Ministry of Health suggest that malaria is a major concern in the context of climate change, given the endemic as well as epidemic nature of the disease in Uganda, and also owing to the risk of temperature and rainfall changes in the region. Therefore, malaria-related implications of climate change are the focus of this report.

1.2. Objectives of this case study

An Economic Assessment of the Impacts of Climate change is currently being conducted in Uganda. As part of this nation-wide study, this case study aims to quantify the potential economic effects of malaria-related morbidity and mortality due to climate change in two districts in Uganda: Kabale (epidemic/low malaria prevalence) and Tororo (endemic/high malaria prevalence). Districts of differing magnitudes of malaria were chosen as the burden of malaria is not equal across Uganda, and also to understand the different implications of climate change in low versus high prevalence areas. The locations have also been chosen because of the availability of data on malaria (Uganda Malaria Surveillance Program).

The objectives of this case study are to:

- Predict climate change scenarios for Kabale and Tororo, and specifically temperature and rainfall patterns over the next 50 to 80 years.
- Estimate the likely impacts of climate change and development on malaria prevalence.
- Assess the current economic cost of malaria and the likely future economic cost of climate change on the prevalence scenarios.
- Recommend a range of possible adaptation strategies.

This constitutes one of five case studies of the overall study, the other four being:

- Economic assessment of the impacts of climate change in the Kampala urban area, in close collaboration with the Kampala City Council Authority (KCCA) (infrastructures and flooding).
- Economic assessment of the impacts of climate change on the coffee sector in Bududa district in the region of Mt. Elgon.

- Economic assessment of the impacts of climate change in three villages of the Karamoja region (agricultural sector) chosen from three different agro-ecological zones.
- Economic assessment of the impacts of climate change in the Mpanga river catchment (water and hydropower sectors).

Case studies provide an opportunity to assess the impacts of climate change at the local level, through consultation with various stakeholders, including local authorities, development partners, private sector operators and local communities (for detail, please see Section 2 and the Appendix to this report). In particular, stakeholders' perceptions of the impacts of climate change have been given due consideration, as well as the adaptation strategies they implement as a reaction to extreme events or new climatic patterns. This bottom-up approach will then feed into the national level assessment, providing concrete examples of the cost of climate change at the local level, and possible benefits of a range of adaptation strategies implemented locally.

2. METHODOLOGY

2.1. Description of Study Sites and Methods Summary

Figure 1: Tororo and Kabale, Uganda

Tororo is a district and city in eastern Uganda, mainly composed of savannah grassland and shrubs. The Tororo district receives 1200-1500 mm rainfall annually. The rainfall is historically bimodal, with two wet seasons (March-May and September-November) and two dry seasons (December-February and June-August). Tororo district has a daily mean temperature range between 15.8°C (minimum) and 27.8°C (maximum) (Magona et al., 2000). The Uganda Bureau of Statistics estimates the population of Tororo District in 2011 was 475,700, implying a density of population of 398 per km^2.

Kabale is a district and city in south-western Uganda, approximately 2,000 meters above sea level. It is located in the highlands of Uganda with heavily cultivated hills (Were, 1997). Rainfall (850–1,200 mm annually) occurs largely in two rainy seasons annually with fairly constant average daily minimum (9.8–12.6°C) and maximum temperatures (23.2–24.4°C) throughout the year (Lindblade et al., 2000). The Uganda Bureau of Statistics estimates the population of Kabale district was 494,500 in 2011; the area is also densely populated at 318 people per km^2 (Kakaire et al., 2010).

The two districts are located on Figure 1. Table 1 outlines the methods used in this case study, which are further explained in Sections 2.2-2.6.

Table 1: Summary of aims and methods for the case study

Aim	Methods
Description and quantification of historical malaria burden	Descriptive analysis using malaria data captured by the Uganda Malaria Surveillance Project
Forecast rainfall and temperature changes	Model simulations using two different scenarios for greenhouse gas emissions to predict rainfall and temperature changes from 2006 to 2095
Quantify the relationship between rainfall and temperature with malaria	Literature review of scientific papers for estimates of the relationship between malaria prevalence and weather data
Estimate the changes of malaria prevalence in relation to the rainfall and temperature forecasts	Analysis using the "shared socioeconomic pathways" approach developed by the Intergovernmental Panel on Climate Change
Describe (qualitatively) climate event history and impacts related to malaria	Thematic analysis of transcripts obtained from key informants interviews and community-based focus group discussions
Estimate the economic impacts of malaria related to climate change forecasts	Analysis using data collected by a literature review on the costs of illness associated with malaria
Describe current climate change actions and strategies related to malaria (and health) in Uganda	Document analysis of national level policies to provide insights into current actions and strategies at national, regional and local levels
Identification of adaptation options in addition to barriers and enabling factors	Thematic analysis of transcripts obtained from key informants interviews and community-based focus group discussions
Costing of adaptation options and evaluation of effectiveness of interventions	Analysis using data collected by a literature review on the costs associated with the adaptation options and interventions

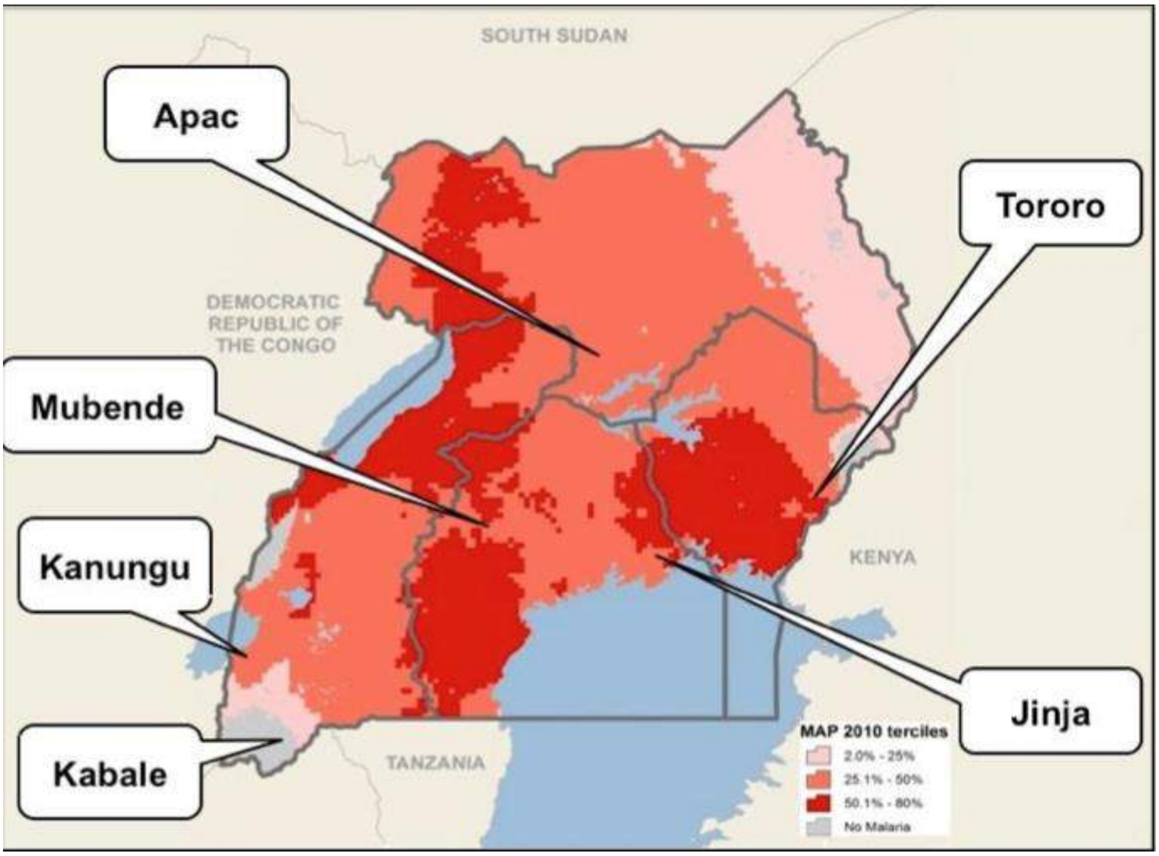
2.2. Malaria Burden

Malaria morbidity and mortality data was obtained by the Uganda Malaria Surveillance Project (UMSP). UMSP performs health facility-based malaria surveillance at several out-patient and inpatient sentinel sites[3] located in six districts of varying malaria transmission (Figure 2). Out-patient surveillance is conducted at Health Centre IVs[4] while inpatient surveillance is conducted in the paediatric wards of public hospitals (district or regional referral) located in the same districts. Data at the outpatient sites are collected using a standardized patient case record form. Data collected includes date of patient visit, patient address (village), age, sex, history of fever, history of cough, lab results (including malaria test results, haemoglobin, tuberculosis, syphilis and other tests), patient diagnoses, treatment prescribed, and whether or not the patient obtained the treatment. Data collection at the inpatient sites is more detailed when compared to the outpatient sites and a standardized case record form is also used to collect individual inpatient data. Data collected includes patient age, sex, address (village), referral status, detailed medical history, physical exam, laboratory testing, initial and final diagnosis, treatment prescribed and its administration, and the final outcome at discharge including deaths.

[3] A UMSP sentinel site is a government-run health facility which provides data on laboratory-confirmed malaria in the catchment area. This approach attempts to provide high quality individual patient data from a limited number of sites. See, e.g. http://umsp.muucsf.org/ for more detail.

[4] A Health Centre IV is a health centre with fully functioning operating theatres that provides 24 hour emergency care (see e.g. http://www.liverpoolmulagopartnership.org/index.php/lmpprojects/hciv),

Figure 2: Uganda Malaria Surveillance Programme Sentinel Sites



Source: UMSP

We also considered including the national malaria surveillance data captured by the Health Management Information System (HMIS) but due to data quality concerns including data completeness, we restricted our malaria burden description to UMSP data.

2.3. Climate Scenarios

In this report, historical (1951 to 2005: 55 years) and future (2006 to 2095: 90 years) climate model simulations, are presented for both the Tororo and Kabale districts of Uganda. The climate model simulated projections show rainfall and near-surface temperatures, under conditions of a high Carbon Dioxide (CO_2) Representative Concentration Pathway (RCP 8.5) and a medium-to-low CO_2 Representative Concentration Pathway (RCP 4.5) (Meinhausen, et al., 2011; Riahi et al., 2011). The Representative Concentration Pathways show the potential cumulative measure of anthropogenic emissions of greenhouse gases, which are used by the Intergovernmental Panel on Climate Change's AR5. RCP4.5 shows a moderate level of mitigation of greenhouse gases, resulting in some shifts in climate patterns globally, while under RCP 8.5 far less mitigation takes place, resulting in much stronger changes in climate globally[5].

For rainfall, monthly total data from the Global Precipitation Climatology Centre (GPCC)[6] provided by NOAA/OAR/ESRL PSD, Boulder, Colorado, USA[7], were downloaded for the period 1951 to 2005 (55 years) at a 0.5° x 0.5° degree resolution. For near-surface temperature, monthly averaged data from the European Centre

[5] See e.g. http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html for an overview of the four RCPs.
[6] http://gpcc.dwd.de
[7] http://www.esrl.noaa.gov/psd/data/gridded/data.gpcc.html

for Medium-range Weather Forecasts (ECMWF) Reanalysis (ERA-Interim) data products[8] were downloaded for the period 1979 to 2005 (27 years) at a resolution of approximately 0.7° x 0.7°.

Spatial averaged values of rainfall and near-surface temperatures, calculated across the four grid points that define the Tororo and Kabale Districts, were regarded as representative of the dynamical downscaled climate of the domain. For both scenarios, daily results over the periods 1951 to 2005 (55 years: historical simulations) and 2006 to 2095 (90 years: RCM 4.5 and RCM 8.5 future projections) were used to calculate monthly, seasonal and annual mean data.

The bias correction technique used in this analysis, is applied to calibrate or to make model simulated output more representative of observations. Since monthly rainfall and near-surface temperature biases are associated with both differences in the average and variability, the projected monthly output is calibrated with respect to both its average and its variability (Ho et al., 2012), using the differences in the average and variability between the observations and historically simulated values, both over the same historical reference period.

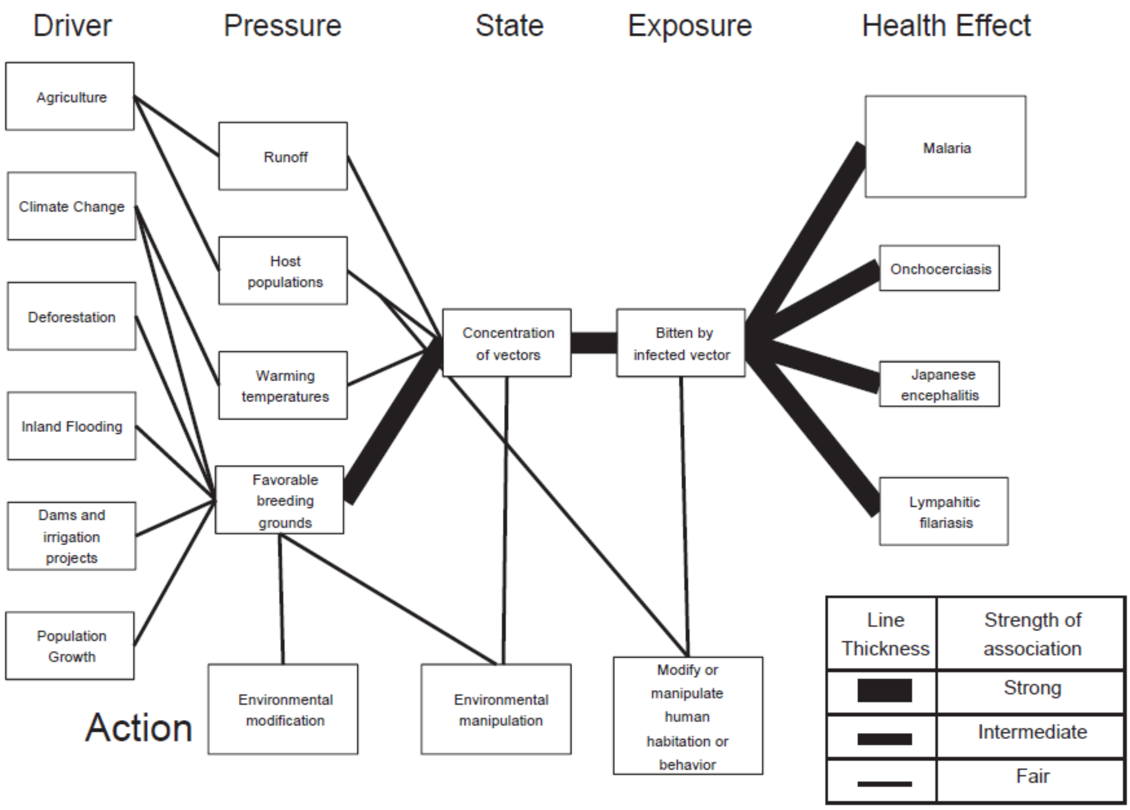
2.4. Methodological issues in the quantification of impacts of climate change on malaria prevalence

A quantitative assessment of the likely impacts of climate change on malaria prevalence in Tororo and Kabale was conducted. This was based on a literature review for estimates of the relationship between malaria prevalence and weather data from previous studies and research conducted in Uganda and elsewhere. The assessment allowed the determination of the relationship between climate and malaria cases. The evidence base is rather limited, and there is some uncertainty on the precise relationships between climate and malaria.

It is clear that climate change will not be the only driver for changes in the number of malaria cases. There are many factors that affect this. Gentry-Shields and Bartram (2014) use the Driver-Pressure-State-Exposure-Effect-Action (DPSEEA) model to assess potential factors affecting health outcomes from vector borne diseases such as malaria. The summary diagram of the DPSEEA model applied to vector borne diseases is shown in Figure 3. It can be seen that climate is one of many drivers leading to pressures including impacts on breeding grounds, which consequently leads to a change in the concentration of mosquitoes and health outcomes in terms of increased cases of malaria. Actions can be taken at a number of stages that can affect the extent of the health effect, for example: including the modification of human behaviour through education regarding bednets or appropriate use of antimalarial medication. Environmental manipulation can reduce the concentration of vectors, for example: reducing potential breeding sites for mosquitoes. Population growth is also important in affecting both encroachment on breeding grounds and the extent of the exposed population. In Figure 2, the thickness of the lines shows the strength of association between factors.

[8] https://apps.ecmwf.int/datasets

Figure 3: DPSEEA applied to vector borne diseases



Source: Gentry-Shields and Bartram (2014)

In this study, we are able to estimate the impact of changes in the number of the exposed population through population growth. To estimate this impact requires the use of "shared socioeconomic pathways" developed by the Intergovernmental Panel on Climate Change to enable the estimation of the future paths of countries and regions, which can be associated with different emissions scenarios and hence climate outcomes. Taking the results of climate change scenarios RCP4.5 and RCP8.5 for the regions and the projected socioeconomic change based on the shared socioeconomic pathways SSP1 and SSP5[9], we were able to make a first estimate of the number of cases of malaria to be induced both by population change and climate change.

In addition, information on climate event history and impact was collected via key informant interviews and community-based focus group discussions. Key informants that were interviewed from each district included:

- District level
  - District Health Officer
  - District Malaria Focal person
  - District Biostatistician
- Hospital level
  - Hospital in-charge
- Health facility level – HC IV
  - Health facility in-charge

[9] Narratives of SSP1 and SSP2 on the IASA website (http://www.iiasa.ac.at) are:
SSP1 (Sustainability). A world making relatively good progress toward sustainability, with ongoing efforts to achieve development goals while reducing resource intensity and fossil fuel dependency. It is an environmentally aware world with rapid technology development, and strong economic growth, even in low-income countries. SSP5 (Conventional Development). A world in which conventional development oriented toward economic growth as the solution to social and economic problems. Rapid conventional development leads to an energy system dominated by fossil fuels, resulting in high greenhouse gas emissions and challenges to mitigation.

- o Community level
  - ▪ Village health team members

There were three community focus group discussions conducted from each district and each focus group was selected from a different village. The groups were composed of 8 to 15 individuals, both men and women (but mostly women in all cases, who are the primary care-givers of children and of the sick in general) who had households and were living in these communities. The focus group discussions lasted typically between 1-1.5 hours.

2.5. Economic impacts of malaria

To estimate the economic impacts of malaria in Uganda, data were collected based on secondary literature on the costs of illness associated with malaria. Values from earlier Ugandan studies, including a well conducted cost-of-illness study by Nabyonga-Orem et al. (2011), needed to be adjusted for inflation using the Consumer Price Index.

The valuation of mortality required an estimate of the value of a statistical life based on the transfer of values from studies outside Uganda using an adjustment factor that is dependent on purchasing power parity gross national income (PPP GNI) per capita[10] and the income elasticity of willingness to pay. This is necessary due to a lack of existing studies on the valuation of mortality in the country[11]. Mortality risk studies are costly and few have been applied to date in developing country contexts, hence the transfer of values from developed country contexts with appropriate adjustment is fairly common. Mortality has significant costs for society – if this is not taken into account the costs of malaria are significantly undervalued. Methods for making the transfer of values are well established and used by the OECD, the World Bank and other international agencies. Use of the value of a statistical life is generally felt to be standard practice in this areas – for instance de Walque (2004) transferred values from the US to assess the benefits of HIV education in Uganda using a related method and Laxminarayan et al. (2007) used exactly the same approach for estimating the burden of tuberculosis in Sub-Saharan Africa and countries with high burdens of tuberculosis.

2.6. Adaptation policy analysis

Document analysis of national level policies was conducted to provide insights into current actions and strategies at national, regional and local levels.

A further web search was conducted to identify existing studies on malaria control in Uganda, to provide evidence on the costs and effectiveness of such measures. Estimates of costs from these previous studies were compared with estimates of the monetary value of benefits calculated using the method described above.

This analysis was supplemented by interviews with key stakeholders in the two districts (see Appendix). Particular focus was put on the identification of the barriers and enabling factors in the districts based on interviews. Thematic analysis, which is the examination of themes within qualitative data, was conducted on the interview transcripts.

[10] Purchasing power parity gross national income estimates taken from World Bank database.

[11] We note that a previous cost-benefit analysis for DFID estimated the Disability Adjusted Life Years gained from interventions and valued these using per capita incomes. This approach would not consider the wider benefits to society of avoided mortality and the use of income directly as a proxy for the value of life is not consistent with best practice in the view of the study team.

3. Malaria in Uganda

Uganda has one of the highest incidence rates of malaria worldwide (WHO, 2012). In Uganda, malaria is the leading cause of morbidity and mortality. Each year, there are an estimated ten to twelve million clinically confirmed cases (MoH, 2005) from a population of 35 million[12], noting that a person may get malaria more than once per annum. A national household survey in 2009 estimated malaria prevalence among children less than five years old to be 42% (UBOS, 2010). Furthermore, approximately 30,000 children under the age of five die from the disease each year in Uganda (Yeka, 2012) and the WHO has ranked Uganda ninth in the world in terms of the number of malaria-related deaths (WHO, 2012).

3.1. Climate and malaria

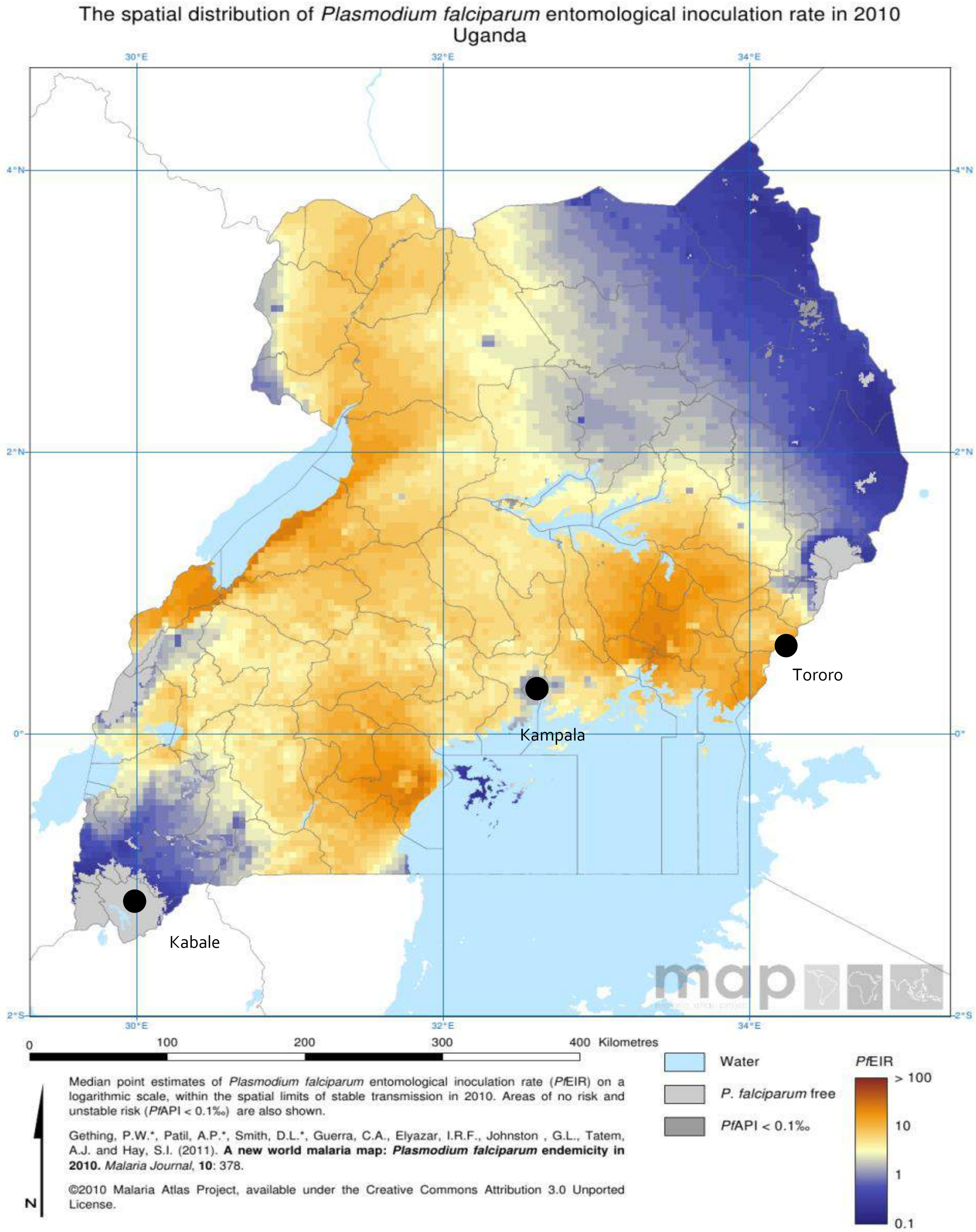
According to a recent USAID study (USAID, 2014), malaria is endemic in 95 percent of Uganda (MoH, 2005) and epidemic, sporadic, or non-existent in the remaining 5 percent of the country, notably in the highland areas (Malaria Atlas Project, 2014). The spatial distribution of the inoculation rate for the disease in Uganda in 2010 is shown in Figure 4. Temperature is a limiting factor for the malaria vector (*Anopheles)* and parasite (*Plasmodium*). In the context of climate change, increases in temperature are, in the view of the study team, likely to allow malaria to proliferate in regions where it previously was not established or where it occurred in a sporadic nature, such as in regions with high altitude, generally thought to be above 1,500-2,000 m (Alonso et al., 2011). Increasing temperatures have been shown to increase the speed of development of the parasite and mosquito, which, in turn, will influence the survival of the parasite and mosquito (Lindsay and Martens, 1998). People living in high altitude regions in Uganda have less immunity to malaria, creating highly susceptible populations (Wandiga et al., 2010). The introduction of malaria in these areas, without preventative or control measures in place, could lead to high morbidity and mortality among both children and adults.

In endemic regions, increases in temperature can result in higher transmission intensities, caused by the acceleration of mosquito and parasite development, resulting in a higher burden of the disease in these regions. It is thought that temperatures of 30-32˚C are optimal for the parasite and mosquito in spreading malaria (Parham and Michael, 2009; Craig et al., 1999). If, however, temperatures exceed 33˚C, the transmission of malaria may decrease.

Increased flooding or rainfall could also increase the burden of this disease, given that there will be more breeding sites and increased humidity affecting mosquito longevity and parasite development (Protopopoff et al., 2009). Conversely, increases in severe rainfall events may wash out any mosquito larvae in these pools or aquatic environments, consequently decreasing mosquito and parasite populations (Paaijmans et al., 2007). In the possible case of increased temperatures and shifting to a wetter dry season, the burden of malaria is likely to increase in endemic areas given the climate suitability for increased vector and parasite development. On the other hand, the potential increases in malaria may be offset or surpassed by improvements in malaria treatment and prevention. In conclusion, it is expected that increased temperatures will increase transmission intensities as will increased precipitation. There are, however, thresholds above which higher transmission intensities do not occur as a result of increased rainfall (Usher, 2010). The quantification of the impact requires a careful and critical examination of studies that have statistically analysed the relationships; this is done in Section 5.2.

[12] Source: http://unstats.un.org/unsd/demographic/sources/census/2010_PHC/Uganda/UGA-2014-11.pdf

Figure 4: Spatial distribution of *Plasmodium Falciparum* inoculation rate in 2010 in Uganda

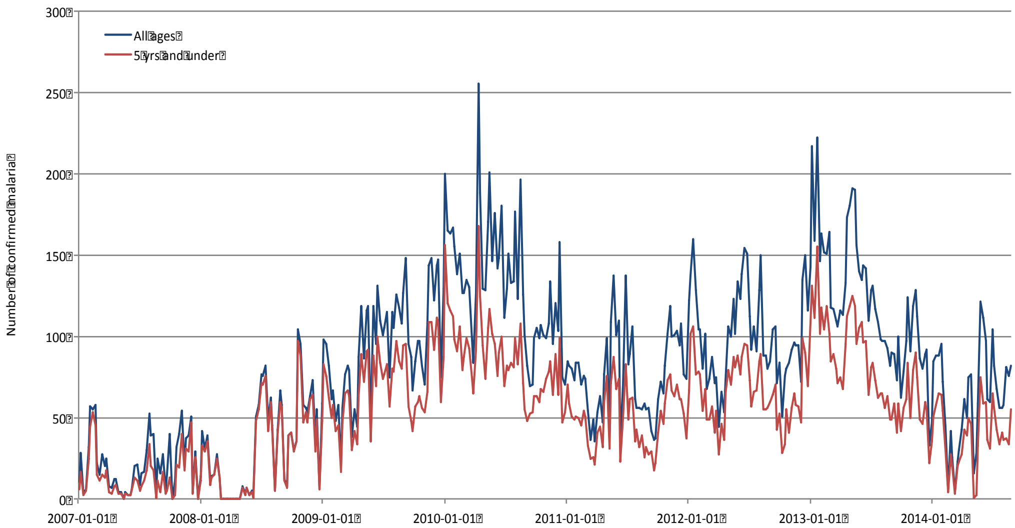


Source: Malaria Atlas Project, 2014

3.2. Historical malaria burden in Tororo

Figure 5 shows the weekly cases of confirmed malaria reported from the Tororo health centre (UMSP data). There have been 32,350 cases reported from January 2007 to August 2014 and approximately 68% of those cases are children five years and under. The weekly average of cases is 82 with a range from 0 to 255. There appears to be a downward trend in confirmed malaria for all ages and for children five years and under.

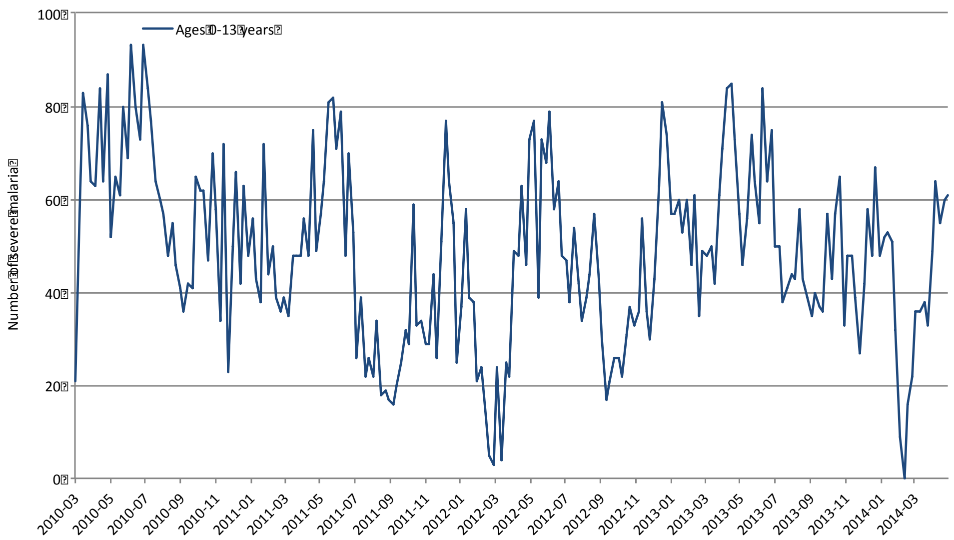
Figure 5: Weekly confirmed cases of malaria from the Tororo outpatient clinic



Source: UMSP

Figure 6 displays the weekly cases of severe malaria for children 13 years and under admitted to the Tororo hospital. There have been 10,607 cases of severe malaria in children 13 years and under in the hospital from March 2010 to May 2014 and approximately 95% of those patients are children five years and under. There has been 151 malaria-related deaths among these cases (that have been reported and captured) and 93% of the deaths are in children five years and under. The yearly average of severe malaria for Tororo hospital, for children 13 years and under, is approximately 2,500 with 36 malaria-related deaths. There appears to be a slight downward trend in severe malaria for children 13 years and under.

Figure 6: Weekly cases of severe malaria from the Tororo Hospital

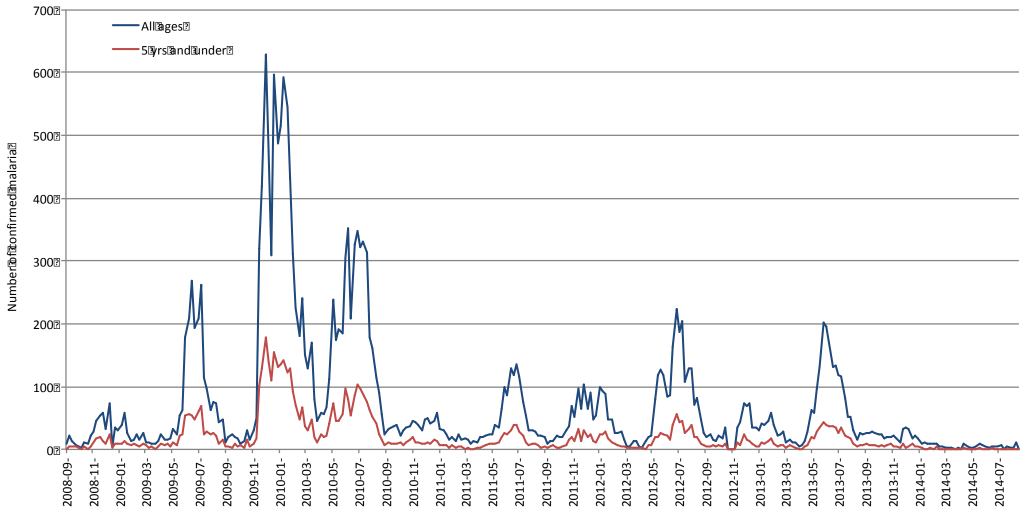


Source: UMSP

3.3. Historical malaria burden in Kabale

Malaria is more epidemic than endemic in nature for Kabale, which is supported by the rapid onset of cases (outbreak), followed by a low number of cases (Figure 7). It also appears that there were no obvious outbreaks reported or captured by the UMSP site for 2014. There have been 22,825 cases reported from August 2008 to August 2014 and approximately 27% of those cases are children five years and under. The weekly average of cases is 75 with a range from 0 to 628.

Figure 7: Weekly confirmed cases of malaria from the Kabale outpatient clinic



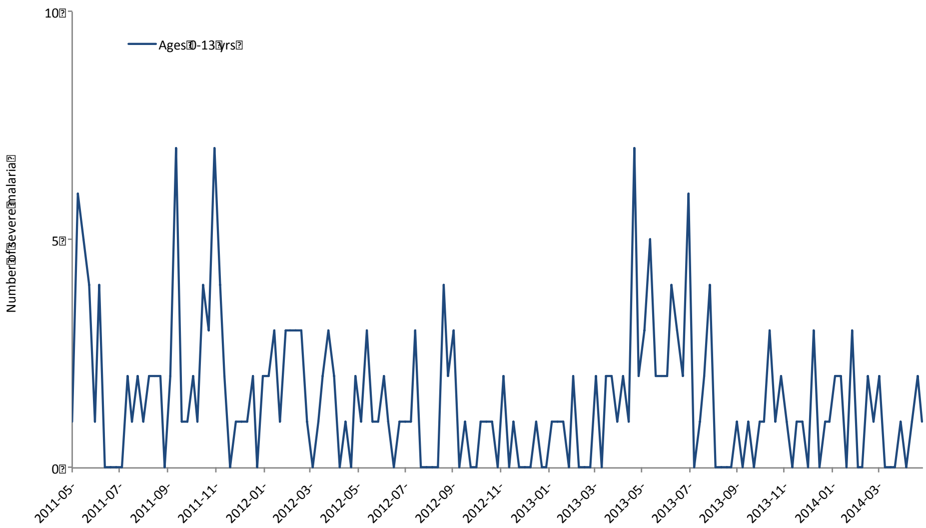
Source: UMSP

Figure 8 displays the weekly cases of severe malaria for children 13 years and under admitted to the Kabale hospital. There have been 231 cases of severe malaria from May 2011 to May 2014 and approximately 85% of these are aged under 5 (Table 2). There has been 9 malaria-related deaths among these cases (that have been reported and captured) and 89% of the deaths (n=8) are in children five years and under. The yearly average of severe malaria for Kabale hospital, for children 13 years and under, is approximately 77 with 3 malaria-related deaths.

To allow for the estimation of future impacts, we take the current levels of malaria to be the average of the most recent years with reliable data – so for Tororo the current rate of cases is taken to be 8,030 cases treated at hospital and for Kabale the current number of cases is taken to be 2707 cases treated at hospital[13].

[13] Here we have used the years 2010-2013 for Tororo and 2011-2013 for Kabale, as the data most reliable in those periods.

Figure 8: Weekly cases of severe malaria from the Kabale Hospital



Source: UMSP

Table 2: Yearly totals of severe malaria (ages <14) and confirmed malaria (all ages) for Tororo and Kabale

	Tororo		Kabale	
Years	Severe malaria* (inpatient)	Confirmed malaria* (outpatient)	Severe malaria* (inpatient)	Confirmed malaria* (outpatient)
2007	-	1,111	-	-
2008	-	1,719	-	415*
2009	-	4,923	-	5,245
2010	2,461*	**6,923**	-	9,064
2011	2,298	**3,911**	68*	2,267
2012	2,122	**5,228**	67	3,092
2013	2,809	**6,369**	74	2,554
2014	917*	**2,166***	22*	188*
Total	**10,607**	**32,350**	**231**	**22,825**

*Note incomplete years of data collection: Tororo inpatient (March 2010 to May 2014); Tororo outpatient (January 2007 to August 2014); Kabale inpatient (May 2011 to May 2014); Kabale outpatient (August 2008 to August 2014).

To estimate the total number of cases, we need to also identify the numbers who would be self-medicating. The results of the Nabyonga-Orem et al. study, presented in Table 3 shows that the proportion consulting clinics differed between Kabale and Tororo. Adjusting for this means that there are even more cases of malaria in Tororo and Kabale than suggested above, which only considers data from clinics. Using the data in Table 3, and assuming that the same proportions of people use the treatment types currently as in the earlier study, we can estimate that the total number of cases in Tororo is 11,628 cases and for Kabale 3,366 cases currently.

Table 3: Treatment types for Malaria in Tororo and Kabale

	Tororo		Kabale	
Treatment type	**Count**	**% using treatment**	**Count**	**% using treatment**
None	11	2.5	6	2.2
Self	126	28.3	45	16.6
Herbalist	1	0.2	0	0.0
Clinic	308	69.1	218	80.4
Other	0	0	2	0.7
Total	446	100	271	100

Source: Nabyonga-Orem et al. (2011)

4. BASELINE CLIMATE SCENARIOS

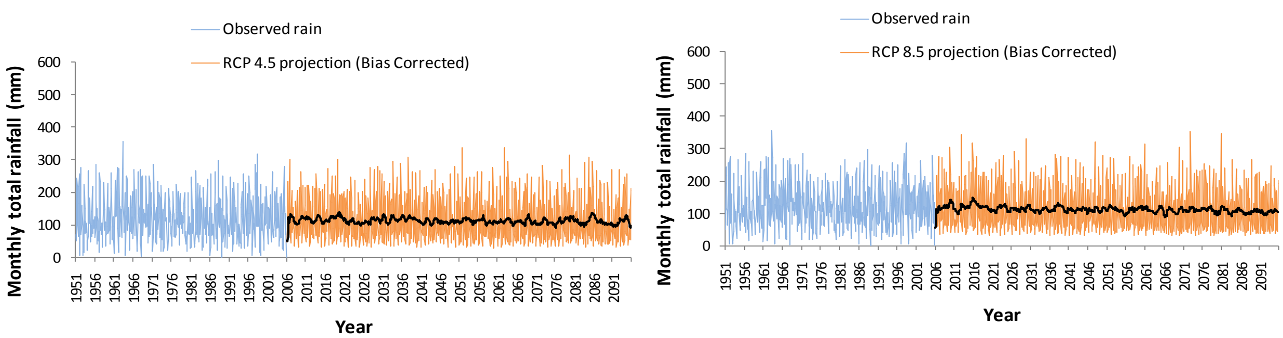
Historical (1951 to 2005: 55 years) climate model simulations, as well as a future (2006 to 2095: 90 years) climate model simulated projections are presented in this section. Rainfall and temperature projections for Tororo and Kabale districts are based upon two climate scenarios: under conditions of a high Carbon Dioxide (CO2) Representative Concentration Pathway (RCP 8.5) and a medium-to-low CO2 Representative Concentration Pathway (RCP 4.5). Additionally, climate change event history for both districts are included in this section, which were based upon qualitative interviews (key informant interviews and community focus group discussions).

4.1. Tororo

4.1.1. Rainfall scenarios

Figure 9 displays the observed and forecasted average monthly rainfall totals (mm) for Tororo District. The projections include bias corrections and show the projections under the RCP 4.5 (left) and RCP 8.5 (right) scenarios. The black lines represent 12-month running averages.

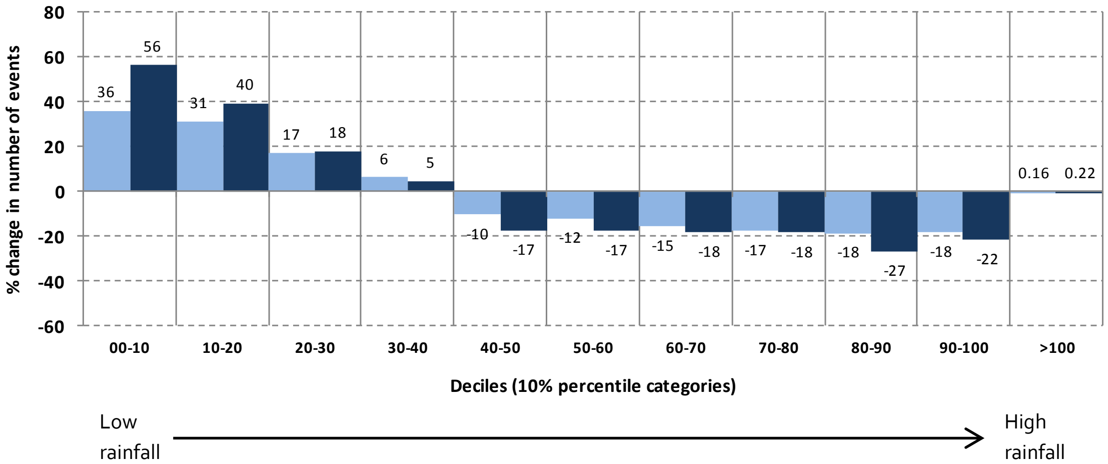
Figure 9: Tororo District domain area averaged observed GPCC monthly rainfall totals (mm) with bias corrected CCLM 4.8 RCM rainfall projections, under conditions of the RCM 4.5 (left) and RCM 8.5 (right) pathways



Current rainfall is approximately 100 mm per month. In both the RCP 4.5 and RCP 8.5 rainfall projections, future rainfall appears to reduce slightly, but this decrease is almost insignificant. In both the RCP 4.5 and RCP 8.5 it appears that future rainfall variability might be very similar to current trends.

Figure 10 gives the projected percentage change in the number of daily rainfall events over the 55-year period 2041-2095 for the RCP4.5 (light blue) and RCP8.5 (dark blue), relative to the number of daily rainfall events in historical deciles over the 55-year period 1951-2005. According to the figure, there are likely to be more days with lower amounts of rainfall and less days with heavy amounts of rainfall in future. A small, but increasing fraction (RCP 4.5 = +0.16%; RCP 8.5 = +0.22%) of days might receive more daily rain than ever recorded before (>100% percentile).

Figure 10: Projected % change in the number of daily rainfall events over the 55-year period 2041-2095 for RCP4.5 (light blue) and RCP8.5 (dark blue) concentration pathways, relative to the number of daily rainfall events in historical deciles over the 55-year period 1951-2005 in Tororo.

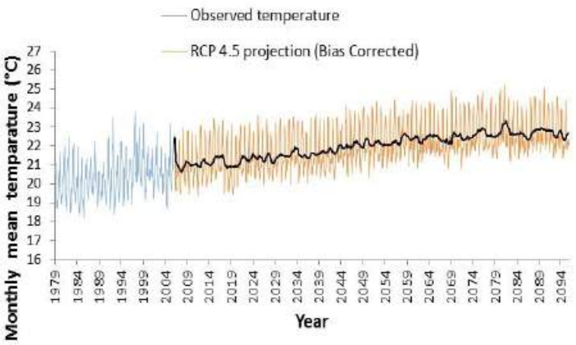


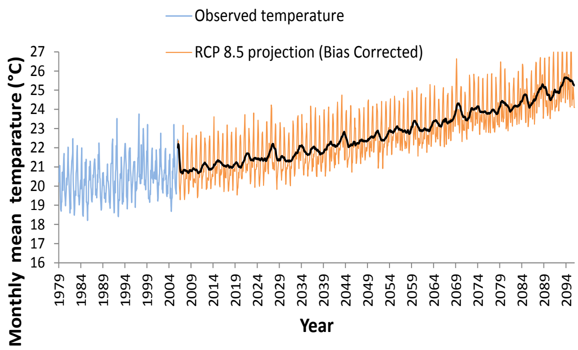
Note: Each decile represents 10% of the days over the 55-year period 1951-2005, ranked by daily amount of rainfall; i.e. decile 00-10 is the 10% days with the lowest rainfall whereas decile 90-100 is the 10% days with the most rainfall. The chart gives the percentage change of rainfall days in each decile; for example, under RCP4.5 there will be 36% more days with rainfall in the 00-10 decile (i.e. more days with low rainfall).

4.1.2 Temperature scenarios

Figure 11 provides Tororo District's observed monthly near-surface temperature averages (°C) with bias corrected near-surface temperature projections (orange), under conditions of the Representative Concentration Pathway (RCP) 4.5 (left) and RCP 8.5 (right). The black lines represent 12-month running averages.

Figure 11: Tororo District observed and bias corrected near surface temperature projections





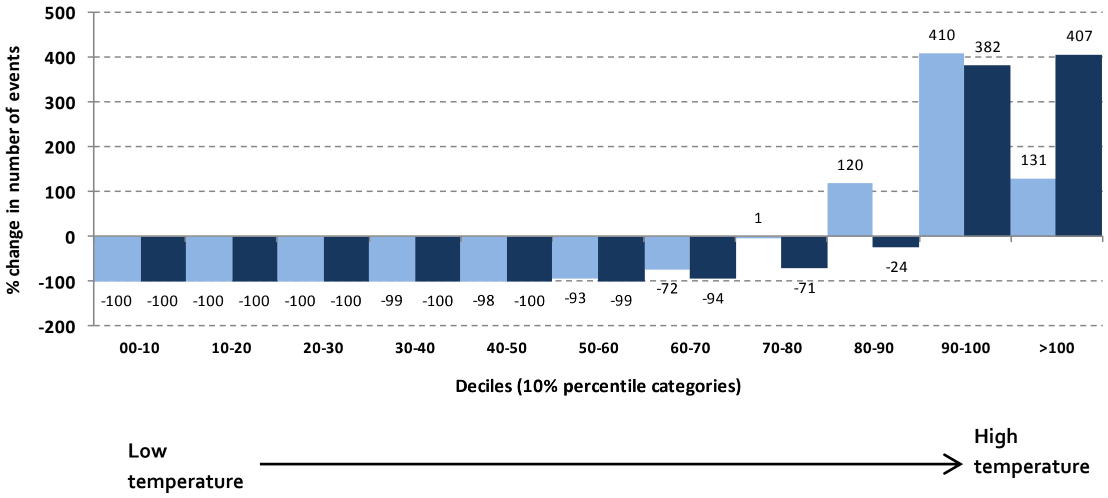
Near-surface temperatures are likely to increase by approximately 1.5°C and 3.5°C in the year 2095 for the RCP 4.5 and RCP 8.5, respectively.

Figure 12 gives projected percentage change in the number of daily near-surface temperature events over the 55-year period 2041-2095[14] for the RCP4.5 (light blue) and RCP8.5 (dark blue), relative to the number of daily near-surface temperature events in historical deciles over the 55-year period 1951-2005. The figure indicates that more extreme near-surface temperatures will most likely be observed in the future, and there are likely to

[14] Historical deciles are available over a 55 years period, so for comparison, the same range was be taken for future projections. It was decided to start in 2041 in order to get a picture in the long term, rather than in the short term.

be fewer days with lower temperatures and more days with higher temperatures. The number of daily events with low temperatures might decrease, while a significant increase might be expected in daily events with temperatures in the higher range (80% - 100% percentiles of current temperatures).

Figure 12: Projected percentage change in the number of daily near-surface temperature events over the 55-year period 2041-2095 for RCP4.5 (light blue) and RCP8.5 (dark blue) concentration pathways in Tororo, relative to the number of daily near-surface temperature events in historical deciles over the 55-year period 1951-2005.



4.1.3. Climate event history in Tororo

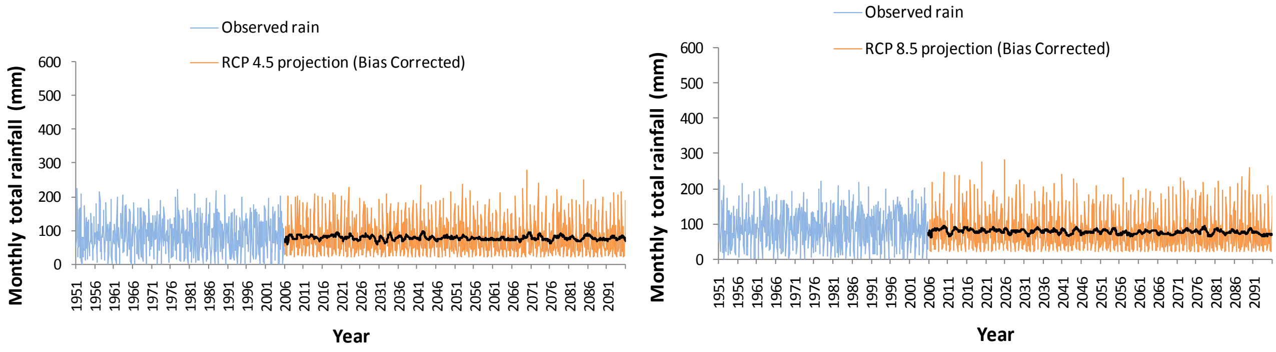
Tororo has a tropical monsoon climate with a short dry season. According to the individuals interviewed, the district is perceived to be experiencing climate change given the changes in both the timing and duration of the dry and rainy seasons, compared to previous years. The first rainy season used to occur from March to June while the second was from August to October; however over the last 5 years this is perceived to have had gradually changed. The rainy seasons now occur for longer periods - much more into the months that have been known to be in the dry seasons while the dry seasons have become hotter. This change has become more visible in the past two years, according to the interviewees, with rains starting earlier than usual, in August, and going on up to December, which was considered to be a dry season month. Such prolonged periods of rainfall are thought to have led to some areas flooding, especially the low-lying villages, while in other instances, the heavy rains have been accompanied by hail storms. These perceived changes are interesting and call for investments in meteorological data collection and monitoring in the region in order to build the evidence base. Such perceptions at local level may facilitate the implementation of appropriate adaptation strategies, but perceptions should not drive policy action on their own. Policy decisions should be based on robust evidence and analysis, in the absence of which no or low regrets options should be prioritised. Further work is needed in terms of capacity building in the regions.

4.2. Kabale

4.2.1. Rainfall scenarios

Figure 13 displays the observed and forecasted averaged monthly rainfall totals (mm). The projections include bias corrections and show the projections under the RCP 4.5 (left) and RCP 8.5 (right) scenarios. The black lines represent 12-month running averages.

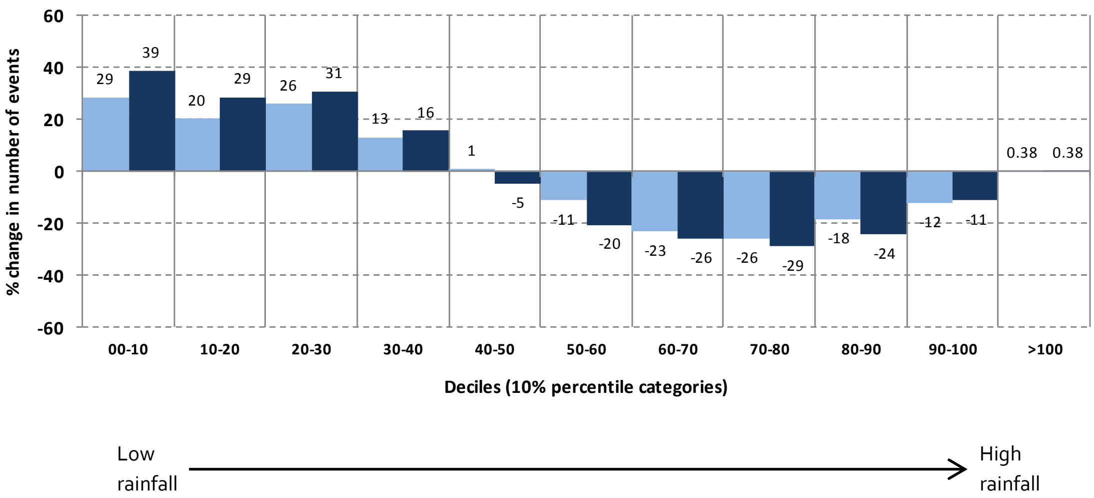
Figure 13: Kabale district domain area averaged observed GPCC monthly rainfall totals (mm) with bias corrected CCLM 4.8 RCM rainfall projections, under conditions of the RCM 4.5 (left) and RCM 8.5 (right) pathways



In both the RCP 4.5 and RCP 8.5 rainfall projections, future rainfall appears to be become slightly less than current rainfall of approximately 100mm per month, but this decrease is almost insignificant. In both the RCP 4.5 and RCP 8.5, but especially for the RCP 8.5, it appears that rainfall extremes of up to 300 mm per month might occur on a more regular basis.

Figure 14 gives projected percentage change in the number of daily rainfall events over the 55-year period 2041-2095 for the RCP4.5 (light blue) and RCP8.5 (dark blue), relative to the number of daily rainfall events in historical deciles over the 55-year period 1951-2005. According to the figure, there are likely to be more days with lower amounts of rainfall and fewer days with heavy amounts of rainfall in future. A small, but increasing fraction (RCP 4.5 = +0.38%; RCP 8.5 = +0.38%) of days might receive more daily rain than ever recorded before (>100% percentile).

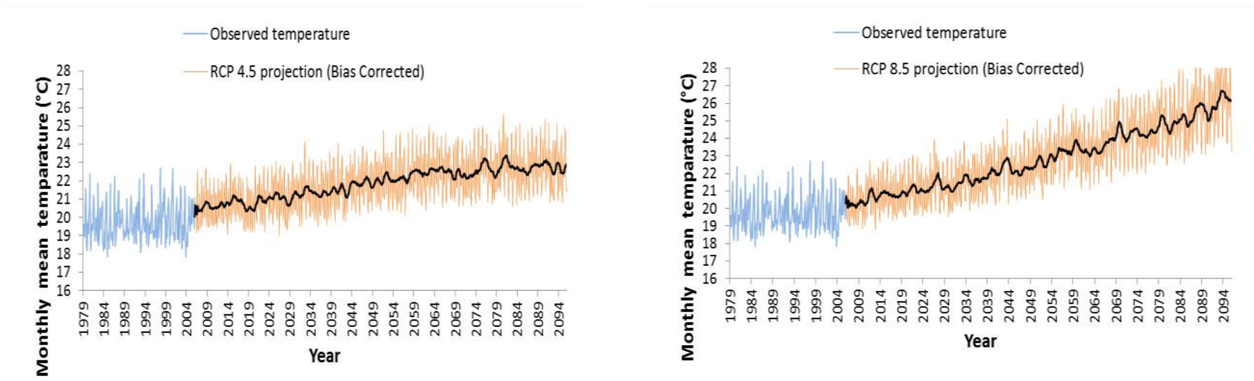
Figure 14: Projected % change in the number of daily rainfall events over the 55-year period 2041-2095 for RCP4.5 (light blue) and RCP8.5 (dark blue) concentration pathways in Kabale District, relative to the number of daily rainfall events in historical deciles over the 55-year period 1951-2005.



4.2.2. Temperature scenarios

Figure 15 shows the Kabale District domain area averaged observed monthly near-surface temperature averages (°C) with bias corrected near-surface temperature projections (orange), under conditions of the Representative Concentration Pathway (RCP) 4.5 (left) and RCP 8.5 (right). The black lines represent 12-month running averages.

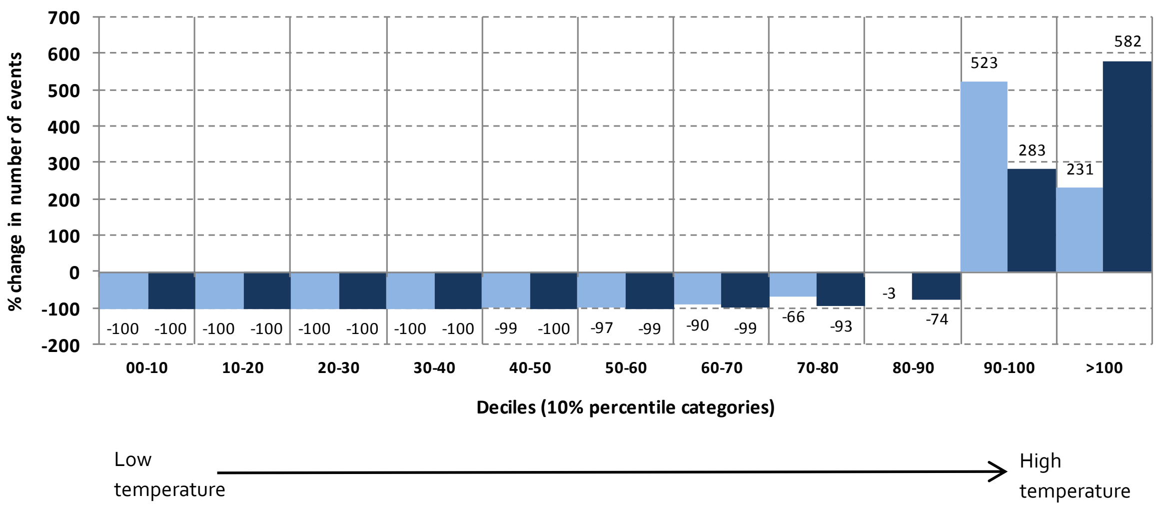
Figure 15: Kabale District observed and bias corrected near surface temperature projections



Near-surface temperatures are likely to increase by approximately 3°C and 4.5°C in the year 2095 for the RCP 4.5 and RCP 8.5, respectively.

Daily temperatures in the lower range might decrease, while a significant increase might be expected in daily temperatures in the higher range (20% - 100% percentiles of current temperatures). Figure 16 gives the projected percentage change in the number of daily near-surface temperature events over the 55-year period 2041-2095 for the RCP4.5 (light blue) and RCP8.5 (dark blue) in Kabale District, relative to the number of daily near-surface temperature events in historical deciles over the 55-year period 1951-2005. It indicates that more extreme near-surface temperatures will most likely be observed in the future.

Figure 16: Projected % change in the number of daily near-surface temperature events over the 55-year period 2041-2095 for RCP4.5 (light blue) and RCP8.5 (dark blue) concentration pathways in Kabale District, relative to the number of daily near-surface temperature events in historical deciles over the 55-year period 1951-2005.



4.2.3. Climate event history

According to those interviewed in Kabale, the district has experienced warmer weather than before. This change is estimated to have started in the late 1970s, with areas that previously used to be very cold and covered with mist becoming warmer. These changes have been perceived to have led to a number of other climatic events. For example, in 1975 two villages in Buhanga sub-county were flooded and submerged after heavy rainfall and in 1997 the district experienced significant flooding, which was said to have been due to the El Niño phenomenon (Republic of Uganda, 2007). Kabale was one of the districts highlighted in Uganda's National Adaptation Programme of Action (NAPA) as having experienced significant increases in malaria during the 1997-98 El Niño event (Republic of Uganda, 2007).

Kabale district has also experienced a number of significant destructive landslides in recent years all caused by heavy rainfall, although other factors certainly influenced the landslides (e.g. deforestation). A number of these resulted in deaths (New Vision, 2009, 2010).

Interviewees also observed that there has been a change in rainfall characteristics, with rains appearing more intermittent than torrential, and the rainy season lasting longer than in previous years.

5. Impacts of climate change on malaria prevalence in Tororo and Kabale

5.1. Climate and malaria in Tororo and Kabale

The future monthly levels of rainfall under both RCP4.5 and RCP8.5 are expected to be almost the same as experienced today.

With regards to daily rainfall, it is only the distribution of rainfall that is expected to change. More days, in comparison to present, will experience "light" rain (below the daily average), while fewer days might experience more extreme rainfall. Extremes that have never been recorded before might also occur in future, but for only a few cases.

The implications for the incidence of malaria have to be seen in relation to more days with light rain (less extreme with dry days in between) and some increase in temperatures. The more continuous rainfall with water kept in and above the soil might lead to an increase in malaria cases. The same applies to the expected increase in temperatures, which in the likely range would lead to a higher incidence of malaria.

5.2. Climate and malaria: Evidence from the literature

Table 3 presents a summary of the limited literature that has examined the relationship between climate and malaria, based on a database search using relevant key words, such as climate, climate change, malaria, risk, and prediction. **There were no consistent findings. In some studies, there were significant associations between malaria and rainfall and/or temperature; with other studies, the associations were not significant.** Additionally, if significant, the associations also differed in terms of magnitude (size) and direction of association (negative or positive association). **There is no simple relationship between climate and malaria – the relationship differs between geographic and environmental contexts**. In addition, studies use a range of climate variables and the source for the climate data can be based upon ground observations or remote sensing data. For example, rainfall could be measured as total rainfall, average rainfall, or maximum rainfall (among other variations). Rainfall could also be measured directly through meteorology stations or estimated through remote sensing data based upon infrared technology, both of which are subject to measurement error. The climate variable measurement and source, in addition to the methods used in the analysis, have implications when attempting to draw inference from previous studies.

There is one completed environment and malaria study for Uganda (Yawe, 2014) with another study in progress Kigozi (2015). Yawe assessed the effects of climate and other variables on malaria cases across several districts in Uganda. There are some weaknesses in the study, most notably there seem to be issues in the econometric analysis in terms of the appropriate development of the models[15]. However, Yawe (2014) does find the following relationship between climate and malaria:

- A statistically significant relationship between cases of malaria and rainfall;
- A positive but not statistically significant relationship between cases of malaria and temperature.

Again, Yawe's findings are an average across several districts, which creates difficulties in inferring the results to specific geographic regions given the importance of the local environment on malaria incidence/prevalence.

The Kigozi study is a work in progress which assesses the associations between climate variables and malaria cases using simple cross-correlations. They have found a significant negative association between rainfall and malaria for Kabale, meaning as total rainfall increases the number of malaria cases decreases. They also found a significant positive association between night time temperature and malaria for Kabale, meaning that higher the night time temperature was associated with more cases of malaria. Night time temperature is a proxy for minimum temperature and one would expect that in the highland regions with sporadic malaria such as Kabale, night time or minimum temperature is a limiting factor for malaria transmission.

Given the simplicity of the Kigozi study and the lack of regression coefficients, we have decided to base the malaria projections on Yawe's findings: taking the lower and upper bounds of the range of coefficient estimates that he provides. To test for the sensitivity of the results we also looked at non-Ugandan studies that were estimated with sound statistical methods, but the results were not easily transferable because they do not give a coefficient for temperature on its own. Thus we worked with the Yawe study and used the range of coefficients to give upper and lower bound estimates.

We note also that we have not been able to estimate the effect of an increase in the altitudinal incidence of malaria in Uganda. This would require a significant modelling effort, which is beyond the scope of the current project. We note, however, that this impact has been shown in Ethiopia and Colombia (Sinaj et al., 2014). Hence, estimates presented here are likely to underestimate the interaction between climate and altitude on malaria.

Another major limitation is that the precipitation measures examined in these studies do not consider the distribution of rainfall across days – thus it is difficult to assess the impact on malaria of this change. Further work would be needed to assess this, for example through a mathematical modelling process.

Table 4: Summary of literature on climate and malaria

Study	Location	Temperature	Rainfall	Notes
Komen et al., 2014 Ecohealth	South Africa	0.5212 (r^2) 4.56 (coeff)	0.2810 (r^2) -0.37 (coeff)	Long-term mean of temperature and rainfall
Craig et al., 2004 Trop Med and Int Health	South Africa	0.155 (r^2) 0.432 (coeff)	0.196 (r^2) -0.00091 (coeff)	Mean temperature during previous season; total rainfall during previous season. Regression is for the change in cases, which makes coefficients specific to the location
Krefis et al., 2011	Ghana		0.022 (coeff)	Included a 2 week lag between rainfall and malaria

[15] For example, there is weak justification of the development of the model – both GDP per head and number of medical facilities are included in the models, with the coefficient on GDP per head being positive. This suggests that increased development leads to more malaria, but it is likely that GDP per head rises with time and this does not appear to have been taken into account in the analysis. In addition, the number of medical facilities is included as an explanatory variable – this is perhaps not surprising to be positive as the dependent variable is number of cases in medical facilities – so the more medical facilities there are, the higher the number of reported cases.

Am J Trop Med Hyg				
Ceccato et al., 2007 Am J Trop Med Hyg	Eritrea	0.01-0.7 (r^2)		Findings variation depending on location (subcounty). Lagged by 2 months
Abeku et al., 2004 Parasitology	Ethiopia	0.19 (coeff)	4.12 (coeff)	Min temperature in previous month, rainfall 2 month lag
Yawe Working paper	Uganda	-0.1255 (r^2) 0.0253-0.0743 (coeff)	0.2338 (r^2) 0.0008-0 (coeff)	Pooled across several districts. OLS coefficient with outcome of malaria per capita and coefficients varied across regression models
Kigozi et al. In progress	Uganda	Kamwezi daytime temp -0.0495 (r^2); -0.0084 nighttime temp Tororo daytime - 0.0979 nighttime 0.1648	Kamwezi -0.224 (r^2) Tororo -0.0959 (r^2)	Mean correlation coefficient across years, based on weekly observations

Notes: r^2 reflects the proportion of variation in malaria cases explained by the climatic variables. An r^2 of 0.155, as in the case of the Craig study, suggests that 15.5 percent of the variation is explained by the climate variable. Coeff represents the correlation coefficient.

5.3. Tororo

To understand how climate affects malaria incidence in Tororo, it is necessary to first get insights from stakeholders in the region. Box 1 gives some insights from qualitative interviews with stakeholders – showing that little is known of the exact climate-malaria relationship by those on the ground.

Box 1: Malaria and Climate in Tororo: Stakeholder views

According to stakeholder interviews the exact impact of prolonged rainy seasons on malaria is not adequately documented in Tororo. However, there are events that can be directly linked to increased rainfall. This weather change is known to create a favourable environment for mosquito breeding resulting in an increased malaria burden. Tororo has been known to be an area of high malaria transmission, with some of the highest rates of malaria infection in Uganda, and increased rainfall would further exacerbate this situation. However, this has not been the case, instead the stakeholders interviewed perceive that there has been a reduction in malaria burden, which is largely attributable to the increasing malaria related intervention coverage for example the universal coverage of long lasting insecticide nets (LLINs), diagnosis and prompt treatment of malaria patients and intermittent preventive therapy. Efforts to decrease the impact of malaria should not be reduced – anecdotal evidence collected by the study team following the stakeholder workshops suggests that the number of children affected by malaria in Tororo may be now increasing.

Given the limited understanding on the ground, it is necessary to use a modelling approach to evaluate the extent to which a changing climate may impact on malaria incidence. As explained in the previous section, to estimate the impact of future climate change on malaria in Tororo, we take the coefficients from Yawe (2014). There are some difficulties in doing this:

- The temperature coefficient for Yawe (2014) was shown to be insignificant – but this is based on a rather limited dataset;
- Rainfall in both case study locations is likely to be almost insignificantly impacted by climate change – as such we focus solely on temperature.

We also take into account the effect of socioeconomic change based on the relevant socioeconomic scenarios – assuming that all regions of Uganda grow with the national average[16]. The results are shown in Table 5, where it can be seen that the population effect due to increasing populations significantly outweighs the climate effect. The base case is taken to be the average of cases in 2010 to 2014, the years for which data are felt most reliable. Under the RCP4.5/SSP1 scenarios, the estimated additional cases using both socioeconomic change and the Yawe study are between 5,599 to 5,866 additional cases in 2025 and between 15,323 to 16,404 additional cases in 2050. The climate effect amounts to between 96 to 362 cases in 2025 and 383 to 1,464 cases in 2050. Under the RCP 8.5/SSP5 scenarios, the estimated additional cases are between 5,481 and 6,270 in 2025, and between 15,310 and 17,899 in 2050. The climate effect amounts to between 65 and 853 cases in 2025 and between 884 and 3473 cases in 2050.

The total number of cases by 2050 may be in the range of 26,951, to 28,032 cases under RCP4.5/SSP1 and between 26,938 and 29,527 cases under RCP 8.5. An interesting observation is that the difference between the two scenarios is relatively small in terms of total cases for Tororo. This is because in SSP1 the population increase is greater than that in SSP5, but this is counter-balanced by the higher climate effect of RCP 8.5. This is illustrated by the table and the figure below.

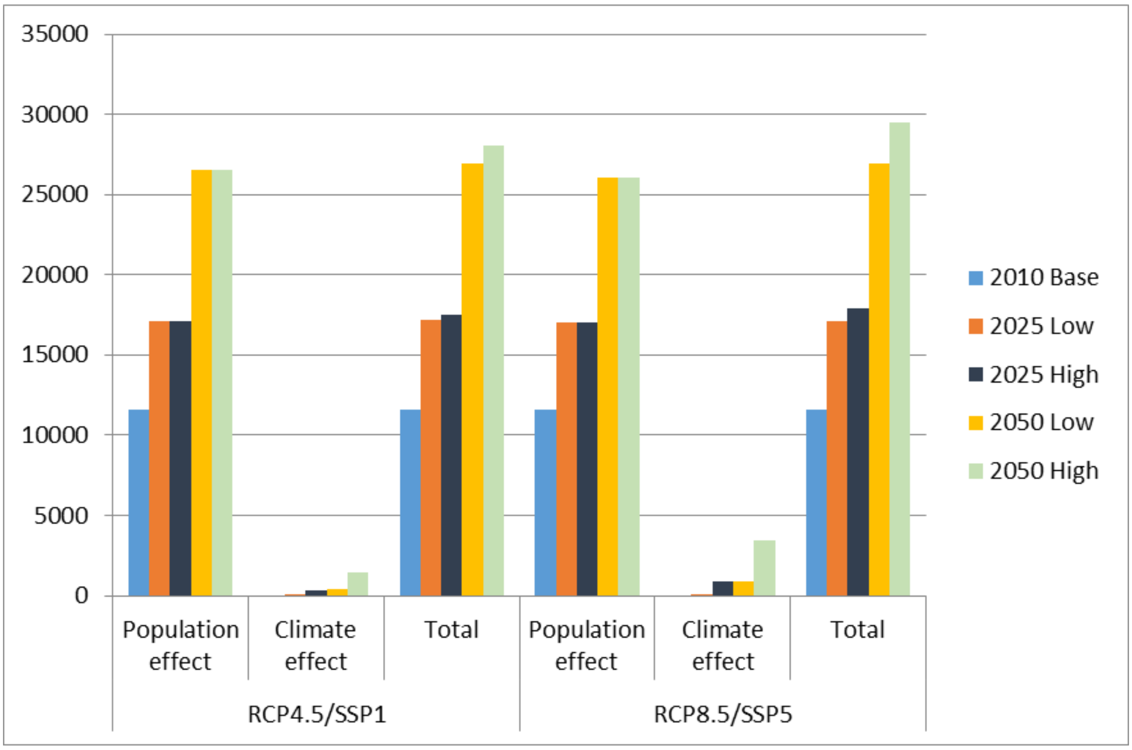
Table 5: Cases of Malaria in Tororo due to changing population and temperature

Scenario	Impact		2025		2050	
		Base	Low	High	Low	High
RCP4.5/SSP1	Population effect	11,628	17,131	17,131	26,568	26,568
	Climate effect	0	96	362	383	1,464
	Total	11,628	17,227	17,494	26,951	28,032
RCP8.5/SSP5	Population effect	11,628	17,045	17,045	26,054	26,054
	Climate effect	0	65	853	884	3473
	Total	11,628	17,109	17,898	26,938	29,527

Note: Estimates are based on the parameters from Yawe (2014) for Uganda

[16] The SSP scenarios give figures for future population and GDP at the national level. In this study we have downscaled these to the districts under analysis, assuming that percent changes at the district level will follow the national pattern. We also do not assume a decline in the number of cases of malaria as a result of the expected increase in real per capita income to 2050. One may get some decrease as a result of better sanitary conditions but a preliminary examination of trends of incidence of the disease in Uganda did not pick up a decline following the growth in per capita incomes we have witnessed in the last decades.

Figure 17: Cases of Malaria in Tororo due to changing population and temperature



5.4. Kabale

Qualitative interviews with stakeholders in Kabale (Box 2) suggest that an increase in malaria in Kabale was in part linked to climatic events, though there has been a reduction in cases due to adaptation measures.

Box 2: Malaria and Climate in Kabale: Stakeholder views

The increase in temperature and rainfall results in a favourable environment for mosquito breeding. Subsequently, Kabale, a previously malaria-free district, witnessed a sharp increase in malaria cases and outbreaks, especially in the 1990s. These outbreaks claimed many lives irrespective of age, as these communities had low levels of immunity to malaria. However, the malaria burden has been reduced, largely because of the indoor residual spraying conducted in 2006, and the now universal LLIN coverage, in addition to the other malaria interventions like diagnosis and prompt treatment and the use of intermittent preventive therapy. The effectiveness of the scheme to provide LLINs is affected by behavioural factors. Fortunately, there has been no other significant reported disease outbreak from the onset of this weather change.

To estimate the impact of climate change on malaria incidence, the same modelling approach is used as in the Tororo case. This leads to the results in Table 6. In the case of Kabale, the climate effect is likely to be more significant than the population effect – but the overall number of cases is still relatively small compared to Tororo. Under the RCP4.5/SSP1 scenario the estimated additional cases using both socioeconomic change and the Yawe study are between 1,649 to 1,805 additional cases in 2025 and 4,548 to 5,196 additional cases in 2050. The climate effect amounts to between 56 to 212 cases in 2025 and 223 to 871 cases in 2050 under the same scenario. Under the RCP 8.5/SSP5 scenarios, the estimated additional cases are between 1,700 and 1,888 in 2025, and between 4,399 and 5,493 in 2050. The climate effect amounts to between 83 and 320 cases in 2025 and between 223 and 1,317 cases in 2050.

The total number of cases by 2050 may be in the range of 7,914, to 8,562 cases under RCP4.5/SSP1 and between 7,765 and 8,859 under RCP 8.5.

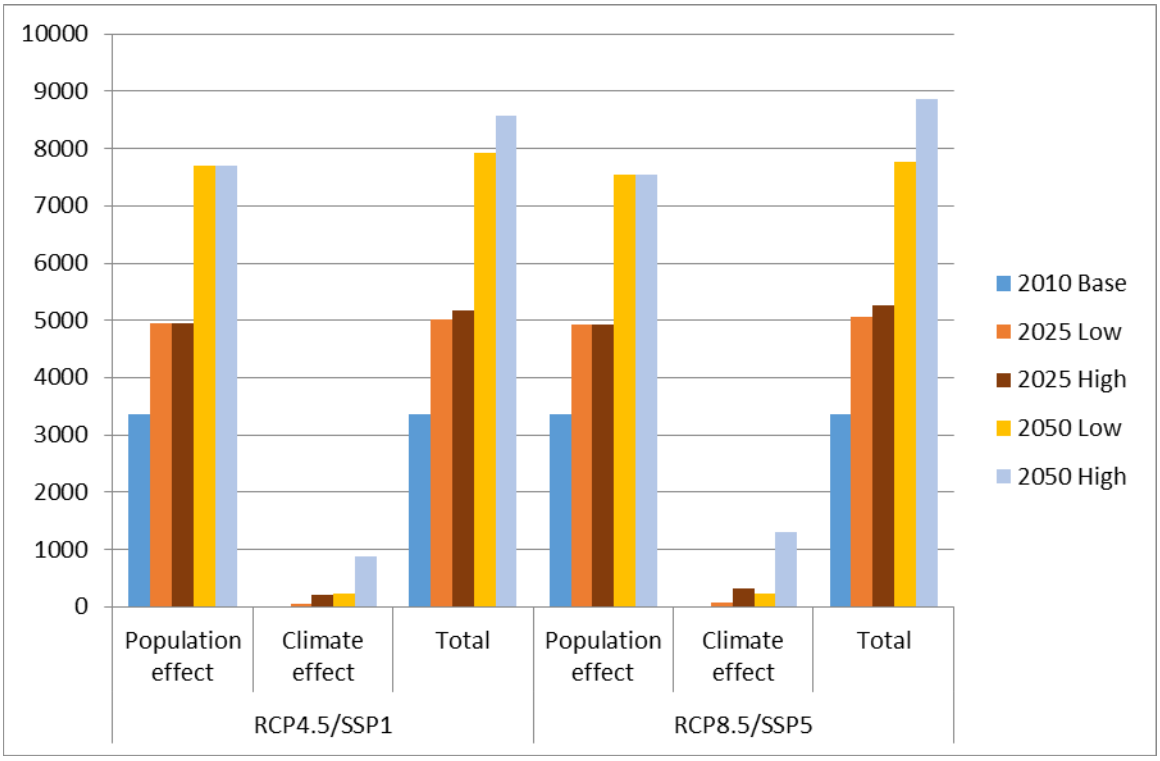
The importance of the climate effect differs between Kabale and Tororo – in part because Kabale is expected to experience warming of between 3°C and 4.5°C by 2095, which is greater than the anticipated change in Tororo. Socioeconomic change in terms of increased population is the most important driver of increased malaria cases – and the proportion of additional cases that are caused by the climate effect varies between the socioeconomic scenarios. For RCP 4.5/SSP1 in Tororo between 2.5% and 8.9% of the additional cases by 2050 are due to climate change, whereas for Kabale climate change leads to 4.7% to 14.4% of the additional cases. For RCP8.5/SSP5 in Tororo 5.8% to 19.4% of additional cases by 2050 are due to climate change, compared to 5.1% to 24% of cases in Kabale.

Table 6: Cases of Malaria in Kabale due to changing population and temperature

Scenario	Impact		2025		2050	
		Base	Low	High	Low	High
RCP4.5/SSP1	Population effect	3,366	4,959	4,959	7,691	7,691
	Climate effect	0	56	212	223	871
	Total	3,366	5,015	5,171	7,914	8,562
RCP8.5/SSP5	Population effect	3,366	4,934	4,934	7,542	7,542
	Climate effect	0	83	320	223	1,317
	Total	3,366	5,066	5,254	7,765	8,859

Note: Estimates are based on the parameters from Yawe (2014) for Uganda.

Figure 18: Cases of Malaria in Kabale due to changing population and temperature



6. ECONOMIC IMPACTS OF MALARIA

6.1. Current economic burden of malaria

In this section, we attempt to place a monetary value on the current burden of malaria in Uganda. We estimate in particular:

- Morbidity costs – based largely on an earlier study in the region, including:
    - Treatment costs;
    - Time losses, including travel and treatment time; and
    - Productivity losses.
- Mortality costs – based on estimates of the value of a statistical life.

The morbidity costs of malaria in Tororo and Kabale have been estimated drawing on a study of the costs of illness of malaria conducted by Nabyonga-Orem et al. (2011). This study was based on a survey conducted as part of an international study in 2004 and presents a breakdown of different elements of the morbidity cost of malaria – for those in hospital and those who self-medicate.

Previous cost-benefit analysis of malaria control have used different methods to place a monetary valuation on health, derived from estimating the Disability Adjusted Life Years and placing a monetary value on these derived from per capita incomes, such an approach was used in the business case for UKaid's malaria control strategy (UKaid, 2013). The approach taken here is more detailed in that the different cost elements are investigated and the valuation of mortality is based around contingent valuation of mortality risk rather than more "human capital" type approaches.

6.1.1. Treatment costs

To cost this, we need to first identify the treatment costs. Nabyonga-Orem et al. (2011), based on surveys of 973 households in four districts in Uganda including Tororo and Kabale in 2004, identify cost elements as shown in Table 7. We have adjusted for inflation using the consumer price index (CPI) for Uganda and arrive at a total cost of US$2.32 for self-medication and US$11.11 for clinically treated malaria. Multiplying this by the total number of cases gives a current cost for treatment costs, based on average annual cases, of US$96,934 in Tororo and US$31,445 in Kabale. This data, collected as part of an international study, seems robust – treatment costs may have changed to a certain extent outside of inflation but this is difficult to measure.

Table 7: Costs of illness in Uganda for malaria (per case)

	Cost (US$2004)	Cost (US$2014)
Self-medication		
Transport	0.06	0.14
Medication	0.62	1.44
Other	0.32	0.74
Total	***1***	***2.32***
Clinic/Hospital		
Transport to and from clinic	0.73	1.69
Registration fee	0.11	0.26

Consultation fee	0.18	0.42
Lab cost	0.18	0.42
Total drug cost at clinic	1.1	2.55
Treatment cost	2.1	4.87
Total drug cost at drug store	0.36	0.84
Transport to and from drug store	0.03	0.07
Total	***4.79***	***11.11***

Source: Based on Nabyonga-Orem et al. (2011)

6.1.2. Time losses

To estimate the total number of adult cases, which may incur some additional costs, we make the assumption that 40.6% of outpatients patients were adults, based on the observation from Nabyonga-Orem et al. (2011) that 59.4% of patients were accompanied by parents.

For travel time losses, we employ the standard approach – using estimates of time lost and multiplying by wages. We estimate the cost based on average Ugandan wages of 1,121 shillings per hour (Besamusca and Tijdens, 2012). Total clinic time is given by Nabyonga-Orem et al. (2011) at 80 minutes in Kabale and 84 minutes in Tororo. Travel time can be estimated at 77 minutes in Kabale and 45 minutes in Tororo for a one-way trip to the clinic, based on the Nabyonga-Orem et al. study. Assuming all children are accompanied and 41% of adults are accompanied based on the same study, this means that an average of 1.17 adults travel to the clinic. This implies an average time loss of 275 minutes in Kabale and 205 minutes in Tororo. The total value of time losses can be estimated at US$4,878 in Kabale and US$10,751 in Tororo. Note that here we only value the time of adults. The loss of time for children is also valuable – either in terms of lost time in education or possibly productive (e.g. working in the fields). Hence this is likely an underestimate of the true value of time lost.

6.1.3. Productivity losses

For productivity losses, following Nabyonga-Orem et al. (2011), we assume that 52.4% of cases are severe enough to limit work, with 8.4 days lost per case of where the symptoms are severe enough to limit work on average. This leads to a total wage loss of US$38,738 in Tororo and US$18,221 in Kabale, based on average Ugandan wages of 1,121 shillings per hour (Besamusca and Tijdens, 2012). We are unable to account for losses to carers.

6.1.4. Mortality

The valuation of mortality requires particular attention when it comes to the valuation of the impacts of malaria. Mortality has a significant cost for society – and different approaches exist to value or consider mortality in analysis. The main focus of this study has been to attempt to develop cost-benefit analysis of adaptation, hence we take a valuation approach rather than simply reporting mortality endpoints. Different techniques can be used to value mortality – some focus on the disability adjusted life year and the monetary valuation of this using different techniques including willingness to pay or human capital approaches, others employ the value of a statistical life. The data available lends itself to the use of the value of a statistical life – given that the impacts to be valued are deaths and not morbidity (these being valued by other methods above), and in that the impacts are largely on children (and hence human capital approaches could be controversial).

The welfare losses due to mortality are valued based on transfer of the value of a statistical life from a developed country (the US) to the Ugandan context. To take into account uncertainty, we use a range of US$81,256 to

US$2.1 million[17]. This is consistent with the approach taken to value health in other parts of the current study and is similar to that applied in other studies on health impacts in Uganda (e.g. Laxminarayan et al., 2007). We note that other approaches to value mortality, e.g. using GDP per capita as a proxy would likely result in estimates towards the lower bound – but these do not capture the full welfare effect.

Expert opinion suggests that most of the malaria-related mortality in Uganda relates to children. Studies on valuing child mortality suggest that the value of a statistical life should rise by up to a factor of 2 to account for parents' altruistic concerns for their children (OECD, 2004)[18]. This leads to an overall cost of mortality in the range of US$487,326 to US$5.9 million for the 3 child deaths reported in Kabale and US$12.7 million to US$152.3 million for the 36 child deaths reported in Tororo.

6.1.5. Summary of costs

A summary of the overall costs is given in Table 8. Mortality is shown to dominate the economic costs.

Table 8: Summary of yearly average costs of malaria in baseline (US$ thousand, 2014 values)

	Mortality		Treatment costs	Time losses - Travel and Treatment	Work loss	Total cost	
	Low	High				Low	High
Tororo	5,850	152,300	97	11	39	5,997	152,447
Kabale	488	12,692	31	5	18	542	12,746

Note: Low and high values for mortality reflect different values for the value of a statistical life

6.2. Future economic burden of malaria

Based on the above analysis, we can estimate the future economic burden of malaria under climate change. Assuming constant prices in real terms, and that the percentage of mortality does not decrease, Figure 19 and Figure 20 show the future possible burden. It can be seen that the impacts increase in all cases:

- In Tororo, the cost of malaria may rise from US$8.7 million (mn) to US$221mn in the current period to US$20.1mn to US$560.5mn in 2050.
- In Kabale, malaria is expected to increase in cost from between US$0.7mn to US$15.8mn in the base case to between US$1.55mn and US$41.7mn in 2050.

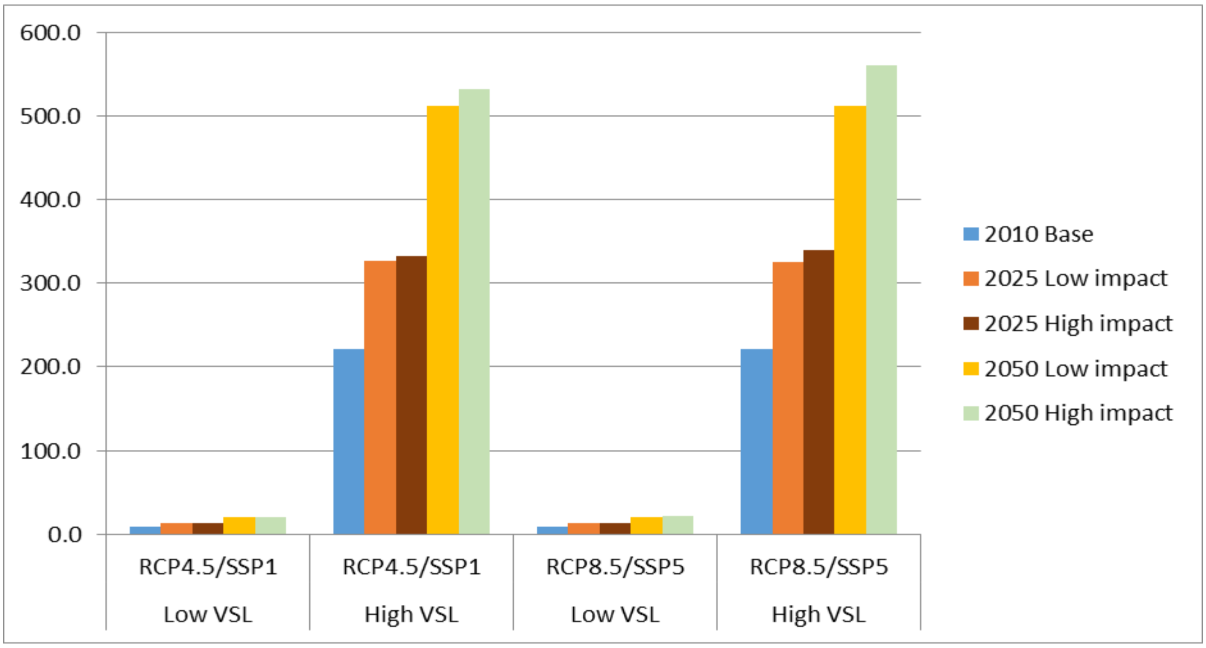
Morbidity costs amount to between 0.1% to 2.44% of the value in Tororo and 0.4% to 10% of the value in Kabale.

It can be seen there is **quite some uncertainty** in the impact, in part due to the lack of Uganda specific studies on the **monetary valuation of mortality risk, which means that a significant range is used for this value,** and in part due the variation in climate and socioeconomic scenarios. Perhaps the most significant source of uncertainty is the response function between temperature and malaria – which is particularly important in the Kabale case where temperature is anticipated to increase more significantly. It should be noted that we have

[17] To our knowledge, no primary study of the Value of a Statistical Life (VSL) exists for Uganda. Hence we transfer values from the US case to the Ugandan context, adjusting for income and income elasticities between 0.3 and 1. Taking the USEPA value of US$7.4 million, inflating using the US CPI and adjusting for PPP GNI per capita leads to estimates of a VSL for Uganda in 2013 of between US$81,256 (e=1) to US$2.1 million (e=0.3).
[18] Note that OECD (2011) suggests a multiplier in the range of 1.5 to 2, when a policy affects mainly children, as in this case.

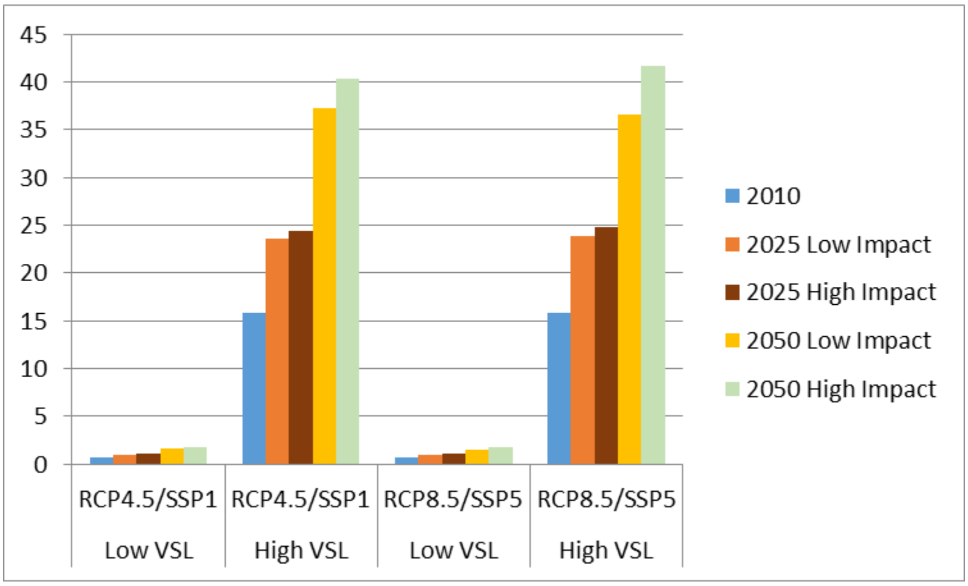
also assumed that what has happened in the past will continue to happen in the future – we have not estimated the impact of advances in medicine or in environmental control. We also do not adjust for income increases which may increase the value of a statistical life in the future.

Figure 19: Estimated cost of malaria in Tororo over time and under different climate scenarios, including population change and climate change (US$mn, 2014 prices, no discounting)



Note: Low and high impact relates to assumptions on the strength of the causal relationship between climate and malaria, high and low VSL reflects differing values for the value of mortality (value of a statistical life) in Uganda

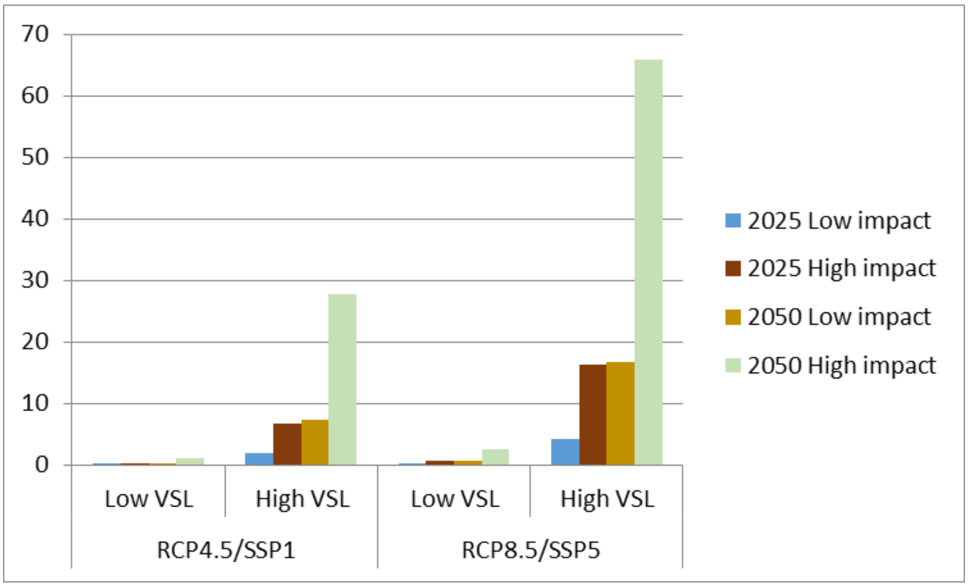
Figure 20: Estimated cost of malaria in Kabale over time and under different climate scenarios, including population change and climate change (US$mn, 2014 prices, no discounting)



Note: Low and high impact relates to assumptions on the strength of the causal relationship between climate and malaria, high and low VSL reflects differing values for the value of mortality (value of a statistical life) in Uganda

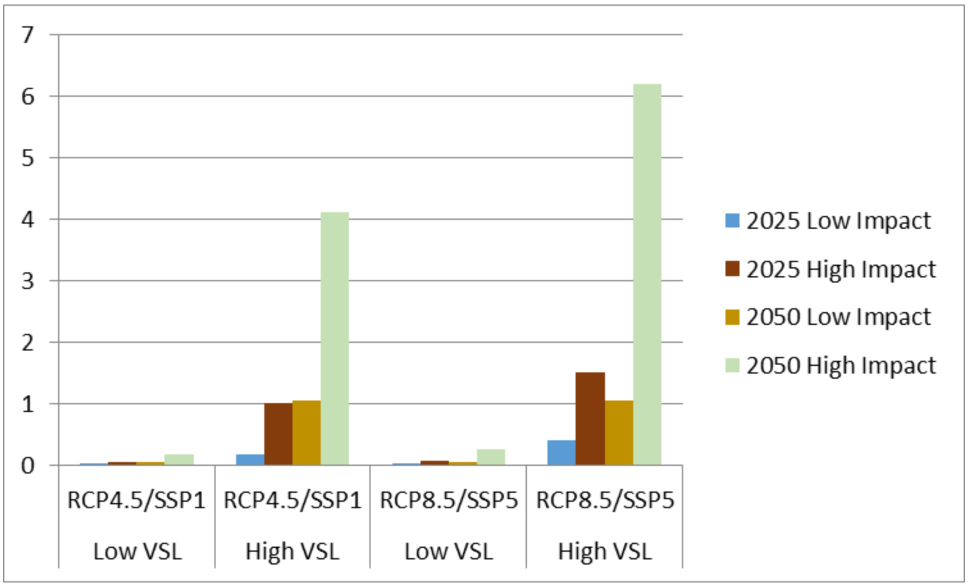
Isolating the impact of climate change is rather artificial, as any policy to respond to malaria in Uganda will be faced with both the climate and socioeconomic changes (and other changes not addressed in this report including behaviour change). However, it is useful in highlighting the differing degree of likely importance of climate change in driving the spread of malaria into different districts, and so for completeness the figures below report the climate change costs of malaria in Uganda in isolation from the socioeconomic change. The strength of the effect depends on whether the climate impact on malaria is low or high. For Tororo, the climate change associated costs range from $0.66mn to $65.9mn in 2050, depending on the scenarios used. For Kabale, the climate change associated costs range from $0.04mn to $6.2mn in 2050, depending on the scenario.

Figure 21: Estimated cost of malaria in Tororo over time and under different climate scenarios, climate effect only (US$mn, 2014 prices, no discounting)



Note: Low and high impact relates to assumptions on the strength of the causal relationship between climate and malaria, high and low VSL reflects differing values for the value of mortality (value of a statistical life) in Uganda

Figure 22: Estimated cost of malaria in Kabale over time and under different climate scenarios, climate effect only (US$mn, 2014 prices, no discounting)



Note: Low and high impact relates to assumptions on the strength of the causal relationship between climate and malaria, high and low VSL reflects differing values for the value of mortality (value of a statistical life) in Uganda

7. IDENTIFICATION OF ADAPTATION OPTIONS

7.1. Identification of adaptation options: National Policy

In 2012, Uganda published the National Climate Change Policy (NCCP) document on specific sectors including health. The NCCP policy priority in the health sector is to strengthen adaptive mechanisms and preparedness for climate change–related diseases, which include malaria.

Specific NCCP strategies for tackling this sectoral policy priority that are relevant for malaria include the following:

- Assess the impacts of climate change on human health and wellbeing
- Conduct vulnerability assessments of health sector to climate change impacts
- Heighten the surveillance of disease outbreaks and provide subsequent rapid responses to control epidemics
- Improve the capture, management, storage and dissemination of health information
- Strengthen public health systems by building hospitals and supplying them with medicine, equipment and well-trained personnel
- Develop and implement contingency plans for climate change–resilient health systems
- Increase the health workforce's awareness of the relationship between climate change and human health
- Make provisions for safe water and sanitation facilities to limit outbreaks of water-borne diseases, and implement strong public awareness programmes to promote better hygiene.

One key issue is the weak implementation of these strategies, which will hamper the adaptive capacity of Uganda in the future. Further work is needed to reduce malaria in Uganda and to mainstream climate change into the health care system.

Additionally, the National Adaptation Programme of Action (NAPA) for Uganda has two projects which specially name malaria:

- The Community, Water and Sanitation Project
- The Vectors, Pests and Disease Control Project.

In this NAPA, some of the proposed activities of the proposed Community, Water and Sanitation Project include:

- Sensitize communities on health impacts due to climate change
- Establish emergency and disaster management plans and enhance strategic planning for disaster preparedness and response
- Formulate appropriate policies and strategies, legislation, standards
- Scale up preventive public health programmes including vector control e.g. mosquito control and
- Management of malaria
- Special assistance to vulnerable people
- Scale up hygiene & sanitation activities

- Improve on safe water supply through construction of more protected water sources and gravity flow schemes
- Household sanitation promotion
- Strengthen school sanitation
- Strengthen water quality surveillance
- Scale up capacity building initiatives

Another project proposed in the NAPA is the Vectors, Pests and Disease Control Project, which proposed activities include:

- Investigate the relationships between climate change and disease, vector and pest outbreaks (e.g. termites) including biodiversity loss
- Develop and implement strategies for effective control of climate change-related vector and pest outbreaks
- Conduct monitoring and evaluation of effectiveness of vectors, pests, and disease control strategies
- Implement effective programs for treatment of diseases
- Investigate the use of herbal plants in the management of these outbreaks
- Verify alternative technologies for management of disease pests and vectors.

According to USAID (2014), despite the NAPA, Uganda has not successfully implemented these health programmes because of a lack of resources.

At the Ministerial level, existing programmes include the National Malaria Control Programme (NMCP) which promotes:

- Sleeping under long lasting insecticide nets (LLINs)
- Indoor residential spraying
- Early diagnosis and prompt treatment of malaria
- Intermittent preventive therapy for pregnant mothers using Fansidar medication.

Actions taken under the NMCP have included the following:

- Free universal distribution of LLINs (one net for every two people) and continuous distribution to pregnant women through antenatal care visits
- Provision of subsidised nets through the private sector
- Sale of full cost nets through the private sector (USAID, 2014)
- Provision of free malaria laboratory diagnostics (RDTs and microscopy) and treatment using artemisinin-based combination therapies
- Free distribution of Fansidar medication at antenatal clinics.

USAID (2014), in a recent study in Uganda, proposed a number of adaptation actions and key recommendations that are relevant for malaria and climate change including:

- Improve strategic planning for the prevention and/or mitigation of health issues relating to climate change by conducting comprehensive disease vulnerability assessments at the sub-national level by appropriate organisations and personnel
- Improve monitoring and surveillance of disease and mortality in regions at-risk for increased disease burden, epidemics and/or emergence
- Develop early warning systems including an early warning system within the National Malaria Control Programme
- Consider source reduction of vector habitat as part of the malaria control strategy
- Invest in drainage systems for sanitation and disease prevention purposes
- Strengthen Village Health Teams by developing their capacity to identify and manage climate related health risks
- Train local communities on the impacts of climate change and adaptation with respect to health issues.

7.2. Identification of adaptation options: Regional Stakeholders

Interviews in the districts enabled the identification of existing adaptation options and possible future adaptation options.

Long Lasting Insectide treated Nets (LLINs)

In Tororo and Kabale, all of those interviewed mentioned LLINs. The government campaign to increase LLIN use was highlighted, alongside some barriers such as reports of the nets leading to itching.

Indoor Residual Spraying (IRS)

IRS was particularly identified in Kabale, where there was a significant IRS programme in 2006 that, it was felt, led to significant reduction in mosquito populations. Some advocated for further IRS deployment given the reduction in malaria when it was applied.

Treatment

Treatment, and particularly early diagnosis, was frequently mentioned. Several respondents highlighted the intermittent use of preventive therapy during pregnancy (e.g. Fansidar). One respondent highlighted the use of co-trimoxazole among the HIV positive as prophylaxis for malaria and other diseases. The availability of government resources to provide treatment was noted, with treatment being free of charge in public hospitals.

Improved hygiene and sanitation

The clearing of breeding sites including bushes and the disposal of broken containers that can catch water were highlighted as existing actions.

Smoke

The use of smoke to disperse mosquitoes was mentioned by some. However, health impacts in terms of increased cough incidence were highlighted. In addition, one respondent suggested that this took place prior to 2013 and the LLIN campaign – with the implication that smoke may be used less in the period after the nets were distributed.

Coils and sprays

Coils and sprays were noted to be used by some individuals as an option to reduce the impact of mosquitoes.

Education campaigns

It was noted by several of the respondents that educational campaigns, including radio shows and plays, have increased awareness of malaria.

Research and Surveillance

Research and surveillance was only mentioned by one of the respondents in Tororo, who highlighted the role of the Health Management and Information System. One respondent also mentioned surveillance in Kabale, highlighting its use in targeting of IRS before 2006.

Housing Standards

One respondent suggested that the setting of standards by the Tororo district may have had an impact – with enforcement actions for those without a kitchen or latrine.

Future options

Future options identified by stakeholders include:

- Elimination of breeding sites, including stagnant water and bushes
- Enhanced community awareness is still regarded as a future option by stakeholders, including education campaigns around LLINs
- Improving the housing stock
- New drugs for malaria
- Improved regulation of construction – including avoiding construction in swampy areas and resettlement
- Improved agricultural practice including the planting of crops away from houses
- Terracing of agricultural land to prevent erosion was identified in Kabale only
- Improved infrastructure - the construction of latrines and stronger roads
- Tree planting
- Improved drainage
- Preparedness in terms of the planning of amount of antimalarial demand when rainy season is near.

Particular options may exist for certain sectors, for example respondents highlighted the need for hospitals to properly adapt and the potential for subsidies on building materials to encourage appropriate adaptation. Improved monitoring of health by Village Health Teams was also highlighted as a potential action.

7.3. Costing of adaptation options

The adaptation options for the health sector identified in 7.1 and 7.2 can be broadly classified in three categories:

- Primary interventions – before damage occurs to minimise exposure (e.g. a number of public health interventions)
- Secondary interventions – aim to prevent disease before it becomes manifest (e.g. screening tests)
- Tertiary interventions – applied once impacts occur

Table 9 gives an overview of different options for adaptation to malaria.

Table 9: Examples of primary, secondary and tertiary types of adaptation options for Malaria

Primary	Secondary	Tertiary
Vector control (vector habitat destruction, bednets, change in agricultural practices). Information and health education.	Disease surveillance and monitoring Vaccination, when available	Diagnosis and treatment (early detection, drugs)

Some options are difficult to cost due to either the lack of data or their indirect effects on malaria prevalence; we have costed those for which existing data was sufficient.

Primary – Vector control

Previous studies have costed LLINs and IRS. The average cost of delivering LLINs is approximately US$6.20 per net (Kolaczinski et al., 2010, cited in Kasirye and Ahaibwe, 2011). Kasirye and Ahaibwe use a cost of delivering IRS per household of US$15.60 per household based on a study by Research Triangle International (2008). More recent estimates in the President's Malaria Initiative Malaria Operational Plan 2014 suggests costs per household of US$5.84 to US$7.30 for the period September 2009 to May 2011.

Health sector based options are not the sole adaptation options available – actions by other sectors are likely to have a significant impact on malaria. It is likely that some actions may have a very low cost. This may include the inclusion of appropriate drainage at the time of the construction of new roads – drainage designed with anticipated changes in rainfall patterns in mind (note in this study the anticipated change in rainfall is relatively low, but we do not consider extreme events – and the rainfall in other districts of Uganda may be anticipated to increase more significantly). In the case of the water sector, there are likely to be impacts on malaria as well, with appropriate design of water infrastructure assisting in the reduction of breeding habitats. Other sectors including agriculture and education will also be important. For agriculture, training farmers in appropriate skills to manage crops alongside the reduction of health risks may yield benefits (see below). Mainstreaming of malaria and climate change in education may also help increase adaptive capacity.

Primary – Information and Health Education

Health education is relatively inexpensive to provide – for example the use of social marketing was shown to be a cost-effective intervention, alongside the use of insecticide treated nets in Tanzania (Hanson et al., 2003). It may be possible to reduce costs by linking health education in with other programmes, e.g. Wielsgosz et al. (2013) describe the linkage of malaria education into education programmes for farmers - linking with Integrated Pest and Vector Management. They suggest that such programmes may be cost-effective, with costs of US$800 for two seasons and 25 farm families involved in Farmer Field Schools and Integrated Pest and Vector Management.

Secondary – Surveillance and Monitoring

The total budget for entomological surveillance and monitoring in Uganda amounts to US$600,000 annually according to the President's Malaria Initiative Malaria Operational Plan 2014. Using population statistics and assuming the surveillance is equally distributed, this means costs in Tororo of US$9,053 and Kabale of US$9,187. Surveillance is important for appropriate planning and monitoring the effectiveness of interventions.

Tertiary – Diagnosis and Treatment

The current budget for the entire primary health care system in Kabale district amounts to approximately US$1.9 million in 2013/14. In the cost calculations above we have considered treatment costs. Under the most extreme estimate above for the case of Kabale costs of registration, lab tests and treatment rise by only US$43,300 per year – an increase of 2.3% of the current budget. The treatment cost itself represents an adaptation to a certain extent, if current levels of treatment were continued and budgets were limited to current levels then the burden of malaria would likely be greater in terms of mortality.

7.4. Evaluation of benefits of adaptation – effectiveness of interventions

One recent study estimates that despite the increased use of Insectide Treated Nets and anti-malaria therapy in Tororo, there has been an increase in incidence of malaria among children in Tororo (Jagannathan et al., 2012). The study suggests that interventions by the distribution of bednets alone may not be effective – a broader strategy may be needed. This shows the complexity of the determinants of malaria.

Kasirye and Ahaibwe (2011) compared the cost-effectiveness of LLINs to indoor residential spraying. Using two "representative districts" in Uganda they estimate the following:

a. Number of malaria cases averted at 8,783 for LLINs and 33,625 for IRS

b. The estimated difference in deaths avoided through the use of IRS was 1,000
c. The use of IRS instead of LLNs would cost an additional US$28 per case
d. The gross incremental cost per death avoided would be US$702
e. If costs of illness are considered, the additional costs of IRS fall to US$5.80 per case and the gross incremental cost per death avoided would be US$660 per death.

In cost-benefit terms, the use of IRS would be justified given that the value per death avoided is between US$162,000 and US$4.2 million (assuming that mortality is experienced only in children) – meaning a benefit-cost ratio of between 1:232 and 1:6,026 depending on which value we take for a death avoided. This shows the significant benefits of action to control malaria. More recent estimates suggest that the cost of IRS has fallen so the benefits would be even greater.

The benefits would also likely be greater as the study by Kasirye and Ahaibwe (2011) did not consider climate change – with changes in climate leading to increased potential cases of malaria. This would particularly be true in Kabale district, where climate is likely to have a greater impact.

To compare the different adaptation options, it is useful to examine the relative reduction in the costs of malaria in Tororo and Kabale that would be needed to cover the costs of the interventions in question. Taking a very simple approach, we estimate these values for both the current period and for 2050 under different climate and socioeconomic scenarios. We use the most recent values for IRS, monitoring and surveillance and LLINs. To estimate costs for 2050 we adjust only for population.

Table 10 gives an overview of the analysis for the current period, where it can be seen that:

- Surveillance and monitoring would have to reduce the damage by a relatively small amount to be cost-beneficial in both Tororo and Kabale.
- The same is not true for a universal IRS or the distribution of LLINs, where in the current situation such measures would have to reduce damage in Tororo by between 0.1% and 8.8% to be cost beneficial depending on the assumptions used, whereas in the case of Kabale - if we take the low damage estimates - such measures would not be cost-beneficial on average.

It is important to note that the assumptions here are that LLINs only last for 1 year and that IRS has no benefit beyond the year of application. **Given these assumptions and the assumptions on costings of benefits, care should be taken in their application for direct policy action.** However, the results do indicate the need for careful analysis to ensure appropriate action is taken.

Table 10: Analysis of costs and benefits of different interventions, current period

	Costs (US$)	% current damage reduction needed for positive cost-benefit (no discounting)		Assumptions
		Low damage estimate	High damage estimate	
Tororo				
Surveillance and monitoring	9,053.0	0.1	0.0	Scaling of national cost according to population
IRS - low cost estimate	609,497.4	7.0	0.3	No residual effect beyond 1 year
IRS - high cost estimate	761,871.8	8.8	0.3	No residual effect beyond 1 year
LLINs	647,069.2	7.5	0.3	1 net per household delivered, lasting 1 year
Kabale				
Surveillance and monitoring	9,187.0	1.4	0.1	Scaling of national cost according to population
IRS - low cost estimate	698,645.0	103.6	4.4	No residual effect beyond 1 year
IRS - high cost estimate	873,306.3	129.6	5.5	No residual effect beyond 1 year
LLINs	741,712.2	110.0	4.7	1 net per household delivered, lasting 1 year

If we consider the situation in 2050, the picture changes somewhat, as shown in Table 11.

- For Tororo, all options become more viable with reductions of damages needed of between 0.2% and 8.6% for IRS and 0.3 to 7.3% for LLINs for these to be viable under RCP4.5 and SSP1, with the relative reduction in damage to justify cost being lower in RCP8.5/SSP5.

For Kabale, climate change has a more significant impact hence the adaptation options become more viable, but still the benefits do not exceed costs. These findings of this preliminary analysis suggest that:

- Some interventions are cost effective under current climatic conditions, and become even more viable with projected climate change under the two climate scenarios analysed.
- Care may be needed in the blanket implementation of IRS, particularly in areas where malaria is less prevalent.
- Disease surveillance may be needed to inform to IRS usage/intervention usage.
- These findings should be interpreted with extreme care, as there are a number of assumptions that would affect this analysis. For example, we have assumed no residual effect of IRS beyond the year of spraying and assumptions on both the value of a statistical life used to value mortality and the exact relationship between climate change and malaria mean **there is a significant amount of uncertainty**

in these results. Further work is certainly merited, particularly on the climate-malaria linkage and on the valuation of mortality risk in Uganda.

Table 11: Analysis of adaptation options in 2050, single year, no discounting

	Costs (US$)	% 2050 damage reduction needed for positive cost-benefit		Assumptions
		Low damage estimate	High damage estimate	
Tororo				
RCP4.5/SSP1				
Surveillance and monitoring	20,684.7	0.1	0.0	Scaling of national cost according to population, costs increase with population
IRS - low cost estimate	1,392,608.2	6.9	0.3	No residual effect beyond 1 year
IRS - high cost estimate	1,740,760.2	8.6	0.3	No residual effect beyond 1 year
LLINs	1,478,453.9	7.3	0.3	1 net per household delivered, lasting 1 year
RCP8.5/SSP5				
Surveillance and monitoring	20,284.4	0.1	0.0	Scaling of national cost according to population, costs increase with population
IRS - low cost estimate	1,365,657.2	6.8	0.2	No residual effect beyond 1 year
IRS - high cost estimate	1,707,071.5	8.5	0.3	No residual effect beyond 1 year
LLINs	1,449,841.5	7.2	0.3	1 net per household delivered, lasting 1 year
Kabale				
RCP4.5/SSP1				
Surveillance and monitoring	20,990.9	1.3	0.1	Scaling of national cost according to population
IRS - low cost estimate	1,596,296.8	100.7	4.0	No residual effect beyond 1 year

IRS - high cost estimate	1,995,371.0	125.9	5.0	No residual effect beyond 1 year
LLINs	1,694,698.7	106.9	4.2	1 net per household delivered, lasting 1 year
RCP8.5/SSP5				
Surveillance and monitoring	20,584.7	1.3	0.0	Scaling of national cost according to population
IRS - low cost estimate	1,565,403.8	100.7	3.8	No residual effect beyond 1 year
IRS - high cost estimate	1,956,754.8	125.8	4.7	No residual effect beyond 1 year
LLINs	1,661,901.3	106.9	4.0	1 net per household delivered, lasting 1 year

7.5. Barriers and enabling factors for adaptation

Qualitative interviews with stakeholders enabled the identification of a number of barriers and enabling factors for adaptation. These include both institutional and social barriers.

- **Low income levels and poverty** were felt to be significant barriers. Poor households lack the resources needed to reduce the impact of climate variability and so may be disproportionately impacted by malaria presently and hence also by climate change induced malaria.
- There is generally felt to be a **lack of information and awareness about climate-health linkage and education on bednet usage.** Most community members are not aware of the impact of climate change on malaria and therefore do not consider it a problem. More generally, people are unaware of the effects of climate change and its relationship to health. Therefore, there is need for education on vector control and prevention, which may also consider the influence of climatic variation on malaria risk. There is also a lack of information on why people should use the bednets all the time, whether it is hot or cold. There is also a lack of awareness of the effects of increasing rainfall and its relationship to malaria. Some report the need for awareness of the consequences of deforestation and swamp land reclamation.
- **Behavioural aspects** are important to the implementation of actions to respond to the malaria threat. When it is hot, some people do not use the bednets, exposing themselves to mosquitoes. There are reports of some selling bednets or using bednets for other purposes which may reduce effectiveness of bednet distribution as an intervention. **Gender issues were also identified,** with one respondent reporting disputes between husbands and wives over the use of bednets – with refusal by men to use the nets. As a consequence, it is reported that some women have now created two beds. This suggests it may be necessary to provide women with additional nets to give them protection. In addition, women, who are the primary care takers, bear a number of the costs of malaria as they have to look after the sick children while at the same time farming the land.
- **The challenge of facing an expanding population, with a limited supply of land, is one facing a number of countries and Uganda is no exception.** With a growing population, land becomes scarce,

leading to encroachment of wetlands, which can be breeding sites for mosquitoes. . Those living in these areas are at greater risk of being bitten by a mosquito carrying malaria. In addition, it is difficult to displace people who settle in these areas.

- Another barrier is a **lack of adequate infrastructure**, including access to boreholes. There are few protected water sources and stagnant water can be a breeding ground for *Anopheles* mosquitoes (malaria vectors).
- **Institutional barriers** also exist**.** Some suggested that there is weak leadership that does not recognise the effects of climate change and strongly act on preventing its consequences. Others argued that there is no serious political willingness to fight wetland encroachers. Stakeholders report the need for further government support to implement some of these adaptations.
- **Nomadic populations** were highlighted by one respondent in Kabale, with populations from Rwanda being felt as posing difficulties in terms of education regarding protection of the land. There is need for particular outreach efforts with these groups to inform them of better land management practices that may reduce malaria risk.
- **Some stakeholders suggest there is insufficient current action.** One respondent suggested that bednets alone are not enough to deal with the malaria problem. Some individuals in the communities do not take some of the health workers recommendations seriously and continue engaging in risky behaviours.

Potential enabling factors include:

- **Better weather forecasting information** – better information will enable increased preparedness in terms of public warnings regarding climate related health risks such as malaria. This will likely need significant action in terms of education campaigns to help the uptake of information.
- **Better understanding of the weather-malaria linkage** is crucial to aid better policy.
- Increasing levels of **awareness about climate impacts, malaria and need for early treatment** – increasing levels of awareness enable the uptake of early treatment and likely reduced mortality risk from malaria.
- **Disease surveillance** – which may provide an "early warning" of emerging epidemics and allow the effective mobilisation of resources.
- **Improved interaction between government departments in mainstreaming health across all policies**, this may be particularly important in terms of land use and water regulation.

8. KEY FINDINGS, POLICY IMPLICATIONS AND RECOMMENDATIONS

The key findings of this report are as follows:

1. **The number of cases of malaria are likely to significantly increase in Uganda due to population growth and climate change**. However, data is limited and work on the analysis of **climate-malaria linkages in Uganda is needed**. Recent efforts to improve data reliability are noted, and further effort is needed to improve the quality of data. In particular, better weather data is needed to allow for better modelling of the climate-malaria relationship. Based on the best data available, we estimate that the number of cases will more than double in both districts by 2050. In Tororo cases are expected to increase from 11,628 cases annually at the current time to between 26,938 and 29,527 by 2050, and in Kabale from 3,366 cases annually at the current time to between 7,765 to 8,859 cases by 2050. Most of the increase in cases is expected to be due to population increase. Climate change induced increases in malaria may be particularly important in Kabale – where temperature is likely to increase more significantly than in Tororo. This suggests that further efforts may be needed to monitor malaria in Kabale and assess the impact of temperature on malaria incidence in that context – as further resources may be needed to reduce climate induced malaria

2. **The significant cost of inaction in response to socioeconomic and climatic change is shown** in this report. The analysis of the economic impact of inaction is complex, and a number of assumptions need to be made to enable the quantification of costs. Our estimates suggest that under socioeconomic and climatic change the costs of malaria will at least double by 2050. In Tororo, the cost of malaria may rise from US$8.7 million(mn) to US$221mn in the current period to US$20.1mn to US$560.5mn in 2050. In Kabale, malaria is expected to increase in cost from between US$0.7mn to US$15.8mn in the base case to between US$1.55mn and US$41.7mn in 2050.A large proportion of the costs are associated with population increase. It is possible to separate the climate change associated costs – but this does not make sense in terms of policy analysis. For Tororo, the climate change associated costs range from $0.66mn to $65.9mn in 2050, depending on the scenarios used. For Kabale, the climate change associated costs range from $0.04mn to $6.2mn in 2050, depending on the scenario. To improve on this analysis, further work is needed on the quantification of the valuation of a statistical life in the Ugandan context in particular and on measuring the physical impacts of malaria across Ugandan society.

3. There are a number of actions that can be taken at different levels to reduce the risk of the disease. These include measures that reduce the impact of driving forces including water management, agricultural practices and urban development on vector populations. There are also actions that can reduce the impact of changes in breeding grounds on vector populations – such as environmental manipulation (e.g. land use management). Another group of actions may affect the exposure of the affected population – including clothing, and the use of nets and sprays. The final group of actions can reduce the effects on the population through prompt treatment – thus reducing the risk of mortality. **There is a need for concerted action across a number of sectors to address this issue. The appropriateness of the different responses varies on a case by case basis: there is no 'one size fits all' response to malaria.**

4. The range of possible actions to combat malaria suggest the **need to mainstream climate change adaptation and particular consideration of the health co-benefits of adaptation into infrastructure investment**. The "adaptation deficit" is significant, and ongoing investments in a number of sectors including water, agriculture, transport and health are needed. Avoiding maladaptation is particularly important – for example the construction of appropriate drainage systems for roads may reduce possible breeding grounds. There is also likely a strong role for planning in ensuring urban development does not

encroach on wetlands and so exacerbate the existing issues. Improving access to potable water and management of water resources in such a way as to minimise malaria are also important

5. **Actions have been shown in previous studies to be generally cost-effective even without changes in climate.** Action to adapt to climate change in the form of providing long lasting insecticide nets (LLINs) and indoor residential spraying is strongly justified in economic terms. Drawing on previous studies **we estimate that for every US$1 of expenditure on IRS the benefits in terms of mortality alone amount to US$232 and US$6,026**. However, this is strongly dependent on assumptions of the benefits of such measures. We have attempted a simple analysis which shows that in the case of Kabale IRS and LLINS may not necessarily be cost-beneficial under all conditions – but climate change may make such measures more viable. This suggests that action to monitor for potential outbreaks and then taking action may be more appropriate in Kabale, though it does depend largely on the value placed on a statistical life. For Tororo, the benefits of IRS and LLINs are more likely to outweigh the costs in the present period, given the prevalence rate, and even more so under future climate scenarios.

6. Appropriate investment to facilitate adaptation will include investment in **better weather forecasting**, with potential benefits for a range of sectors (e.g., agriculture, health and energy). Further investment in disease surveillance will assist in the better understanding of malaria risk in Uganda and aid better policy action. Linking timely and accurate weather data with malaria surveillance data will enable a better understanding of the climate related risks for malaria and potentially lead to improved early warning for malaria risk (e.g., through the creation of a malaria risk index). There have been attempts to understand the relationship between climate and malaria, and to apply this to seasonal forecasting of malaria in some countries, for example in India (Lauderdale et al., 2014).

   There is evidence that **education campaigns are starting to raise awareness, however further work is needed to ensure the dissemination of information about malaria risk and the appropriate use of bednets.** Those on the ground suggest that messages about when nets should be used are not necessarily getting through and that there may also be issues with gender equality – so actions to provide additional nets for women may be fruitful. Education across sectors may also be important – for example building messages around the need to avoid planting crops near houses to reduce the risk of malaria into farming education may lead to reduced costs and better outcomes than standalone health campaigns. **Action is needed at all levels**. National level actions are underway in terms of the National Malaria Control Programme and the National Climate Change Policy, but there is need to ensure there is effective implementation with strong leadership. **Climate change is one of many factors influencing the spread of malaria.** At local level, further action is needed in terms of educating communities about malaria risk and in developing appropriate infrastructure.

Based upon our analysis and USAID 2014 report, the following recommendations can be made:

National policy and programme development

Short-term

1. **Conduct comprehensive malaria vulnerability assessments at the sub-national level** (e.g., district level) for all regions of Uganda by the appropriate organizations and personnel (e.g., Ministries of Health, Water and Environment, Agriculture, Lands, Housing and Urban Development and Works and Transport; National Malaria Control Program; Vector Control, health and climate change experts, etc.). This analysis needs to consider both current conditions and future projections of climate change and socioeconomic change.

Intermediate-term

2. **Increase collaboration across government departments and organizations in strategic planning and policy development for climate change and malaria**, including prevention and mitigation, and ensure the

inclusion of the appropriate organizations and personnel (e.g., Ministries of Health, Water and Environment, Agriculture, Lands, Housing and Urban Development and Works and Transport; National Malaria Control Program; Vector Control, health and climate change experts, etc.).

This study is one example of a subnational study of the type that can be conducted with existing data. Further work may be needed to improve data availability. In the overall Economic Assessment study there has been significant collaboration on the issues relating to climate change between certain departments, but there is need for cross-collaboration bringing together different ministries to ensure the health co-benefits of actions to adapt to climate change are maximized and maladaptation is avoided.

National sector programming

Intermediate-term

1. **Develop an early warning system for extreme weather events and malaria risk predictions** within the National Malaria Control Programme.

2. **Develop emergency plans** for extreme weather events (e.g., flooding, drought) focusing on improved early warning, effective contingency planning, and identification of the most vulnerable and exposed communities.

Long-term

3. **Improve access to potable water** through increased number of potable water sources and improved protection of current sources.

4. **Support the conservation of wetlands**.

A number of these issues were highlighted in this case study – from the need to reduce potential breeding grounds to the need for better drainage. Emergency planning was not raised by stakeholders, but is an important area for action for adaptation to extreme events which we have not addressed here. The need for monitoring of malaria is clear to enable fast action to respond to increased cases in the face of climatic variation.

Knowledge generation

Short-term

1. Support the Department of Meteorology to improve the **accuracy and timeliness of temperature and rainfall data**.

Intermediate-term

2. Support the **timely dissemination of weather data** by the Department of Meteorology; to researchers and policy makers to enable better analysis and preparation.

3. **Improve the understanding of how climate change is related to malaria** through increased research.

Data from the Department of Meteorology is likely to be important to assist in the development of better weather forecasting. This may assist a number of sectors – including water, energy and agriculture – in planning responses to climate variation. Improving data on malaria is crucial to improve predictive models and planning actions.

Community capacity building and involvement

Short-term

1. Provide **education** sessions to communities on bednets (e.g. why, how they work, when they should be used, etc.).

Intermediate-term

2. Strengthen the **Village Health Teams** by developing their capacity to identify and manage climate-related health issues.

3. Establish **community-wide campaigns** to impart climate change knowledge (e.g., malaria, early climate warning signs, and early actions).

Long-term

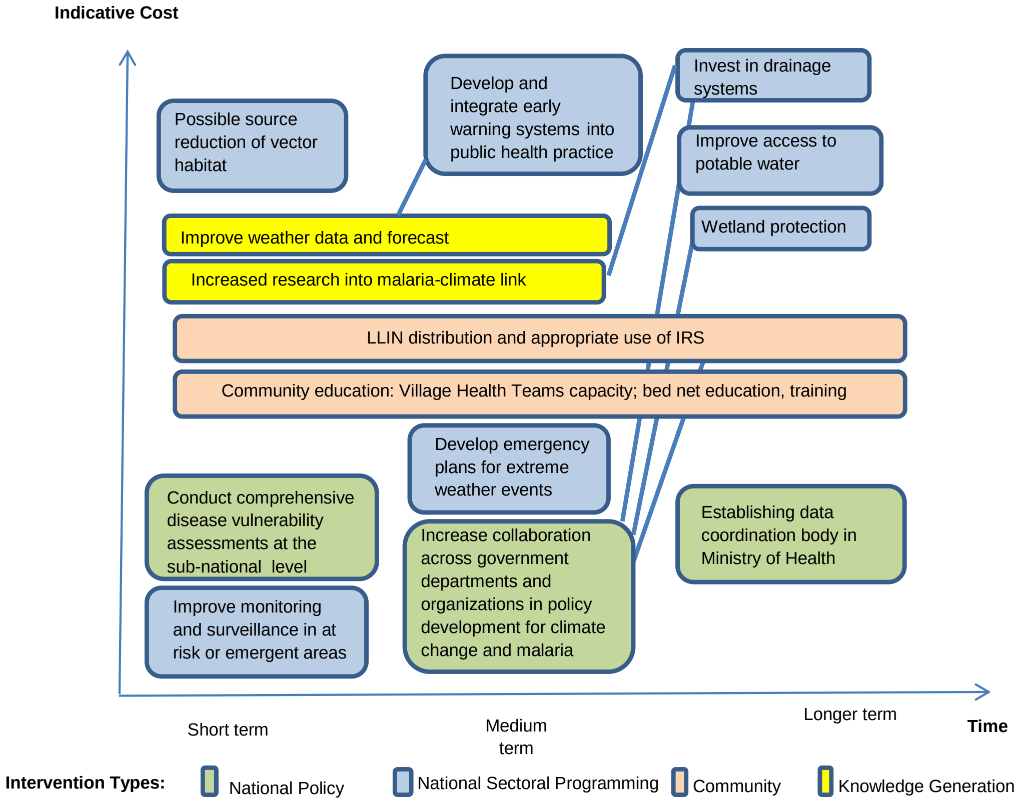
4. **Train local communities** on the impacts of climate change and adaptation/mitigation with respect to malaria.

A number of these actions respond to barriers highlighted in the case study in Tororo and Kabale – and other studies reviewed as part of this study. Coupling bednet distribution, noting that universal distribution of LLINs has recently taken place, with education on bednet use is clearly important to ensure the effectiveness of the distribution of bednets. Strengthening village health teams will improve the adaptive capacity of the health system. Again the need for integration of actions across sectors is raised – and the need for better water resource management to improve malaria control is clear.

Summary

The potential actions can be categorized based on some evidence of the costs of such policies and the linkages between them. Some policies are likely to have more significant costs than others – e.g. source reduction of vector habitat is likely to cost more than improving monitoring and surveillance, given the low costs of monitoring shown above. Some policies require other actions identified to be undertaken first – for example an integrated early warning system for public health risks related to malaria would require both better weather forecasting and a greater understanding of the malaria-climate link in Uganda. In Figure 23 below we attempt to bring together these factors – highlighting that some actions identified may have significant non-health related benefits and so will require health sector actors to work with those in other sectors to ensure malaria risk reductions are integrated into such policies. The below is only indicative – **a full analysis of the adaptation pathways would require further work at national level on health**, which was not possible in the current project. It should also be noted that although a policy may be considered to have a higher relative cost this does not necessarily imply that the policy will not be viable – as shown above **a number of policies working together are likely to be needed to adapt to the malaria threat**.

Figure 23: Overview of selection of potential adaptation measures for malaria (colours represent different intervention types)



9. Conclusions

This study has investigated the potential impact that climate change may have on malaria in Uganda. It looks at two regions, Tororo and Kabale. Climate change may lead to significant increases in temperature – between 1.5°C and 3.5°C by 2095 in Tororo and 3°C to 4.5°C in Kabale, depending on the climate change scenario used. Precipitation may change by an insignificant level in these regions in terms of average monthly precipitation, though there may be other changes in precipitation, for example daily rainfall patterns, that may affect malaria that cannot be considered in this study given the current state of scientific knowledge.

It can be seen there is considerable uncertainty around the impact that this would have, in part due to the issues involved in monetary valuation of mortality and in part due the variation in climate and socioeconomic scenarios. A significant amount of the variation is due to uncertainty in the response function between temperature and malaria – further work is needed to establish the relationship between climatic factors and malaria internationally and in the specific context of Uganda. Evidence on the precise nature of the relationship is mixed, but it is felt by the study team to be likely that climate change will lead to changes in the incidence of malaria; increases in the two case study areas (Kabale and Tororo), and likely increases in other areas of Uganda where there will be increases in minimum temperature and increasing days with rainfall (more continuous moisture). We present first quantitative estimates based on the available evidence – but note that these studies are either weak in design or based outside Uganda. Care should hence be taken in applying the results for policy analysis.

Malaria is not, however, only likely to increase due to climate change. Socioeconomic drivers, notably population growth, are likely to lead to increased levels of malaria as the exposed population increases. Based on the best data available, we estimate that the number of cases will increase in Tororo from 11,628 cases annually to between 26,938 and 29,527 by 2050, and in Kabale from 3,366 cases annually at the current time to between 7,765 to 8,859 cases by 2050. Most of the increase in cases is due to population increase.

Again, we highlight the uncertainties in this analysis – further work is needed to further examine and verify the climate-health linkage in Uganda.

The findings suggest that the increase in malaria will bring significant economic costs, especially due to premature mortality among children. There will also be losses in terms of productivity, treatment costs and time losses for individuals seeking treatment or accompanying those needing treatment. In Tororo, the cost of malaria may rise from between US$8.7mn and US$221mn annually in the current period to between US$20.1mn and US$560.5mn in 2050. In Kabale, malaria may increase in cost from between US$0.7mn and US$15.8mn annually at present to between US$1.55mn and US$41.7mn in 2050. It is important to note that these ranges are large, in part due to differences in the climate-malaria linkage assumed and in part due to the value of mortality risk applied – further work on both of these is needed to narrow these costing bands and allow for better informed policy. However even if the lower estimates are taken, these indicate at least doubling of costs associated with malaria in the two case study areas.

A number of options for adaptation are identified. These range from individual actions to actions at the national level. It is clear that a concerted effort will be needed to reduce the overall burden of malaria in Uganda in the face of climatic and socioeconomic change. This will require action across a number of different sectors and by different government departments. For example, improved planning policy to reduce encroachment on wetlands may be merited – involving the Ministry of Lands, Housing and Urban Development. Actions in the agriculture sector may also affect the spread of malaria, so the Ministry of Agriculture may need to be engaged. **The need for application of a 'health in all policies' approach is clear.**

In terms of local actions this preliminary analysis suggests that implementing better surveillance and monitoring of malaria and providing LLINs and indoor residential spraying may be strongly justified in economic terms currently in Tororo and in the future in Kabale. The extent of benefits differs by location (Tororo shows a much higher benefit to cost ratio than Kabale for example). **Yet it is clear that in all cases climate change may make such measures more economically viable.**

The spatial differentiation in climate and malaria risk suggests there may be no "one size fits all" policy for malaria across the different districts. There is clear need for comprehensive disease vulnerability assessments – taking into account differences in malaria prevalence, climate change projections and likely socioeconomic change. **Better data is also needed to support these assessments, which would help improve decision making.** Engagement with local stakeholders is important to ensure the uptake of results – so action is needed to support adaptive capacity at local level.

A number of actions are ongoing in Uganda to address malaria risks. The findings of this report suggest that **malaria has a significant economic burden on Ugandan society and that efforts need to be increased to reduce this in the face of climate change and population growth. The costs of inaction across Uganda may be very significant indeed – and there are a number of low cost actions that may be taken to reduce this burden.**

References

Abeku, T., De Vlas, S., Borsboom, G., Tadege, A,, Gebryesus, Y., Gebreyohannes, Y, Gebreyohannes, H. et al. (2004) Effects of Metreorological Factors on epidemic malaria in Ethiopia: a statistical modelling approach based on theoretical reasoning. *Parasitology* 12 (6) pp585-93.

Alonso D, Bouma MJ, Pascual M. (2011) Epidemic malaria and warmer temperatures in recent decades in an East African highland. Proceedings of the Royal Society B: Biological Sciences. Apr 20;278(1712):1661–9.

Bescamusca, J. and K. G. Tijdens (2012) Wages in Uganda: Wage Indicator Survey 2012. Wage Indicator Foundation, Amsterdam. Available online at http://www.wageindicator.org/main/Wageindicatorfoundation/publications/2012/wages-in-uganda-wage-indicator-survey-2012

Ceccato, P, Ghebremeskel, T, Jaiteh, M., Graves, P., Levy, M., Ghebreselassie, S. et al., (2007) Malaria stratification, climate and epidemic early warning in Eritrea. Am J Trop Med Hyg 77 (6 Suppl) pp. 61-8.

Craig MH, Snow RW, Le Sueur D. A (1999) Climate-based distribution model of malaria transmission in sub-Saharan Africa. Parasitol Today (Regul Ed). Mar;15(3):105–11.

Craig, M, Kleinschmidt, I, Nawn, j., Le Sueur, D. and B. Sharp (2004) Exploring 30 years of case data in KwaZulu-Natal, South Africa: Part I: The impact of climatic factors. *Tropical Medicine and International Health* Vol 9, Issue 12, pp1246-1257.

de Walque, D. (2004) How does the impact of an HIV/AIDS information campaign vary with educational attainment? Evidence from rural Uganda. Policy Research Working Paper Series No 3289, The World Bank.

Gentry-Shields, J. and J. Bartram (2014) Human health and the water environment: Using the DPSEEA framework to identify the driving forces of disease. *Science of the Total Environment* 468-469: 306-14.

Hanson, K., Kikumbih, N., Armstrong Schellenberg, J., Mponda, H., Nathan, R., Lake, S., Mills, A., Tanner, M. and C. Lengeler (2003) Cost-effectiveness of social marketing of insecticide-treated nets for malaria control in the United Republic of Tanzania. *Bulletin of the World Health Organisation* 81 (4) pp. 269-276.

Hawkins, E., Osborne, T.M., Ho, C.K. and Challinor, A.J. (2013) Calibration and bias correction of climate projections for crop modelling: An idealised case study over Europe. *Agricultural and Forest Meteorology*, 170, 19-31.

Ho, C.K., Stephenson, D.B., Collins, M., Ferro, C.A.T. and Brown, S.J. (2012) Calibration strategies: a source for additional uncertainty in climate change projections. *Bull. Am. Meteorol. Soc*., 93, 21-26.

IPCC (2013) Summary for Policy Makers in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* [Stocker, T.F., Qin, D, Plattner, G.K., et al (eds)]. Cambridge University Press, Cambridge.

Jagannathan, P., Muhindo, M., Kakuru, A., Arinaitwe, E., Greenhouse, B., Tappero, J., Rosenthal, P., Kaharuza, F., Kamya, M., and G. Dorsey (2012) Increasing incidence of malaria in children despite insecticide-treated bed nets and prompt anti-malarial therapy in Tororo, Uganda. *Malaria Journal*. 11:435.

Kakaire O, Osinde MO, Kaye DK. (2010) Factors that predict fertility desires for people living with HIV infection at a support and treatment centre in Kabale, Uganda. Reprod Health. 7:27.

Kasirye, I, Ahaibwe, G. (2011) *Cost Effectiveness of Malaria Control Programmes In Uganda : the Case Study of Long Lasting Insecticide Treated Nets (llins) and Indoor Residual Spraying*. Kampala: Economic Policy Research Centre, 2011.

Kigozi R, Zinszer K, Mpimbaz A, Kizito F, Sserwanga A, Kigozi SP, et al. (in prep) Assessing temporal relationships between malaria morbidity and meteorological factors at varying transmission settings. Manuscript to be submitted to Malaria Journal.

Komen, K, Olwoch, J., Rautenbach, H., Botai, J. and A. Adebayo (2014) Long-Run Relative Importance of Temperature as the Main Driver to Malaria Transmission in Limpopo Province, South Africa: A Simple Econometric Approach. *Ecohealth* December 2014.

Krefis, A., Schwarz, N., Kruger, A., Fobil, J., Nkrumah, B,, Acquah, S., Loag, W., Sarpong, N., Adu-Sarkodie, Y., Ranft, U. and J. May (2011) Modelling the Relationship between Precipitation and Malaria Incidence in Children from a Holoendemic Area in Ghana. *Am J Trop Med Hyg* 84(2) pp. 285-291.

Lauderdale, JM, Caminade C., Heath A., Jones AE, MacLeod DA, Gouda KC, Murty US, Goswami P, Mutheneni, SR, Morse A (2014) Towards seasonal forecasting of malaria in India. *Malaria Journal*. Volume 13: 310.

Laxminarayan, R., Klein, E., Dye, C., Floyd, K., Darley, S., Adeyi, O. (2007) Economic benefit of tuberculosis control. Policy Research Working Paper No 4295, The World Bank, Washington DC.

Lindblade KA, Walker ED, Onapa AW, Katungu J, Wilson ML. (2000) Land use change alters malaria transmission parameters by modifying temperature in a highland area of Uganda. Trop Med Int Health. Apr;5(4):263–74.

Lindsay SW, Martens WJ. (1998)Malaria in the African highlands: past, present and future. Bull World Health Organ. 76(1):33–45.

Magona JW, Greiner M, Mehlitz D. (2000) Impact of tsetse control on the age-specific prevalence of trypanosomosis in village cattle in southeast Uganda. Trop Anim Health Prod. Apr;32(2):87–98.

Malaria Atlas Project, editor (2014). Uganda [Internet]. Malaria Atlas Project; [cited 2014 Mar 6]. Available from: http://www.map.ox.ac.uk/explore/countries/UGA/

MoH (2005) Uganda malaria control strategic plan [Internet]. Malaria Control Programme, Ministry of Health; 2005 Apr pp. 1–50. Available from: http://www.rbm.who.int/countryaction/nsp/uganda.pdf

Nabyonga-Orem, J., Muthuri Kirigia, J., Azairwe R., Muheki Zikusooka C., Bataringaya Wavamunno J., Ogwal Ogwang, P. (2011) Cost of Malaria Morbidity in Uganda. Journal of Biology, Agriculture and Healthcare. Vol 1, No 1, pp 35-38.Nabyonga-Orem

New Vision (2009) Landslide kills six in Kabale District. Published October 4th 2009. Available online at http://www.newvision.co.ug/D/8/12/696802.

New Vision (2010) Uganda: Kabale landslide kills University Student. Published 17th May 2010. Available online at http://allafrica.com/stories/201005180622.html.

OECD, 2004. The valuation of environmental heath risks to children: synthesis report. Working Party on National Environmental Policy. Environment Directorate, Report ENV/EPOC/WPNEP(2004)15. Organisation for Economic Co-operation and Development (OECD), Paris.

OECD, 2011. Valuing Mortality Risk Reductions in Regulatory Analysis of Environmental, Health and Transport Policies: Policy Implications. OECD, Paris.

Paaijmans KP, Wandago MO, Githeko AK, Takken W. (2007) Unexpected high losses of Anopheles gambiae larvae due to rainfall. PLoS ONE. Public Library of Science; 2(11):e1146.

Parham PE, Michael E. (2009) Modeling the Effects of Weather and Climate Change on Malaria Transmission. Environmental Health Perspectives. Dec 7;118(5):620–6.

Protopopoff N, Van Bortel W, Speybroeck N, Van Geertruyden J-P, Baza D, D'Alessandro U, et al. (2009) Ranking malaria risk factors to guide malaria control efforts in African highlands. PLoS ONE. Public Library of Science; 4(11):e8022.

Uganda Bureau of Statistics (UBOS) (2010), ICF Macro. Uganda malaria indicator survey 2009. Calverton, Maryland: UBOS and ICF Macro; Oct pp. 1–144.

UKaid (2013) Uganda Malaria Control: Supporting Uganda's largest malaria control programme to date. Business Case. September 2013. Report for DFID.

USAID (2014) An Overview of Climate Change and Health in Uganda. Report for African and Latin American Resilience to Climate Change Project. July 2014.

Usher, P K (2010) "Modelling Malaria Transmission Potential for Climate Change Scenarios in West Africa and Europe" *Earth & E-nvironment* Volume 5 pp40-65.

Wandiga, S., Opondo, M., Olago, D., Githeko, A., Githui, F., Marshall, M., Downs, T., Opere, A., Oludhe, C., Ouma, G., Yanda, P., Kangalawe, R., Kabumbuli, R., Kathuri, J., Apindi, E., Olaka, L., Ogallo, L., Mugambi, P., Sigalla, R., Nanyunja, R., Baguma, T., and P. Achola (2010) Vulnerability to epidemic malaria in the highlands of Lake Victoria basin: the role of climate change/variability, hydrology and socio-economic factors. *Climatic Change* 99:473-497.

Were, G. (1997) "Land Use and Land Degradation in Kabale District, Uganda" *East African Geographical Review* 19:1 pp9-13. Available online at http://www.macalester.edu/academics/geography/agr/journals/1997_19_2-1.pdf.

Wielgosz, B., Mangheni, M., Tsegai, D. and C. Ringler (2013) Malaria in Uganda: Improved Outcomes when the Health Sector joins forces with Agriculture. IFPRI project note. Available online at http://www.ifpri.org/sites/default/files/publications/pn_malariauganda.pdf.

World Health Organization (2012) World malaria report 2012. WHO Press; 2012.

Yawe, B. (2014) Changes in climatic factors and malaria in Uganda. WIDER Working Paper 2014/11. United Nations University. Available online at http://www.wider.unu.edu/publications/working-papers/2014/en_GB/wp2014-111/.

Yeka A, Gasasira A, Mpimbaza A, Achan J, Nankabirwa J, Nsobya S, et al.(2012) Malaria in Uganda: challenges to control on the long road to elimination: I. Epidemiology and current control efforts. Acta Trop. Mar;121(3):184–95.

Appendix: Interview Guide

Key Informant interview guide

Key Informant	Interview status	
	Yes	No
District Health Officer		
District Malaria Focal Personnel		
District Biostatistician		
District Hospital in-charge		
Health centre IV facility in-charge		
Two Village Health Team members		

Pre-amble

Introduce yourself.

I am Working on a CDKN/DFID project on Economic Assessment of the Impacts of Climate Change in Uganda. This assessment is structured around six work packages and this interview is focusing on the health sector and how climate change has impacted on disease burden, especially on malaria and the adaptation strategies in place.

There is growing concern that climate change will adversely impact the health of individuals in Uganda. The projected increases in temperature and the increasing variability of rainfall is likely to exacerbate diseases and other health determinants, such as socioeconomic status. The primary diseases of concern when looking at the effects of climate change in Uganda is malaria, given the risk of temperature and rainfall changes in the region coupled with the endemic nature of these diseases. Increases in temperature allow malaria to proliferate in regions where it previously was not established or where it occurred in a sporadic nature .

Semi-structured interview guide

Name, position, establishment?

What is your position/role in this establishment?

Describe the history and current malaria burden in your district?

Probe: *Any changes you've noticed in the malaria burden (different ages affected, certain populations/communities affected more than others, more resistant to treatment, etc.)? Number or proportion of population affected? For how long? is it a major public health issue?*

Have you experienced any recent climate change events that may have impacted on malaria in this district?

Probe: *Climate change event (e.g., flooding, increased rainfall/variability of rainfall, drought, increase/decrease temperature, etc.) with date of climate event and impact on;*

Malaria (probe: was there an outbreak, drastic increase/decrease in cases, duration?)

Population and health(water/food supply issues, other vector-borne disease, waterborne disease (such as cholera outbreak, mobility/transportation issues – affecting access to services/food/water

Income (work loss, damages – housing/infrastructure)

Do you have data on any of these events and impacts?

Climatic change event occurrence

Event	Date of event	Duration
Drought		
Flooding		
Increased rainfall		
Increased/decreased temp		
Others:		

<u>Impact of climatic change event</u>

Impact on	Impact	Date	Duration	Data available
Malaria				
Population and health				
Income				

What were/are the social/economic consequences of the increased prevalence of malaria?

Probe: *Could you comment on the social and economic impacts of malaria in your region*

The social consequences include socioeconomic status (education, income, occupation), how much disruption it causes in life, increased social vulnerability.

The economic consequences include direct cost of malaria such as treatment/diagnosis, or indirect such as work loss if ill or looking after someonewho is ill.

Do you have any data on any of these social and economic consequences?

Malaria prevalence on:	Consequence	Date	Durati on	Data available
Social				
Economic				

What are the existing malaria adaptation mechanisms in place in your region that may reduce the burden of disease?

***Probe**: The adaptation mechanism like bednets, indoor residual spraying, treatment and diagnosis, outbreak response from the Ministry or education campaigns*

Give examples of these and how you think they will reduce the malaria burden?

What are the current costs of malaria interventions?

Probe: Who bears the cost? (e.g. households/institutions)

What to focus on

***Institutional level**: cost of IRS/ITN/education campaigns/ACT, IV, quinine treatment/diagnostics RDT and smears??in study area; cost per IRS per household, number of households in district, cost of 1 ITN, number of individuals in district, cost of one education campaign.*

Personal/household level:** cost spent on ITN/nets/IRS/coils a year (for last 5 years)/anti-malarial drugs – **are these subsidized for individuals? By how much and by whom?

What are the administrative costs involved?

Cost of logistics(organizing campaign - transportation, personnel) and admin (printing, paper, pencils, etc) for IRS campaign, ITN campaign, education campaign

Intervention	*Cost bearer*	*Cost per year (Ug.sh)*				
ITN		2010	2011	2012	2013	2014
IRS						
LLINs						
AL (Coartem ACT)						
Artesunate						
Quinine						
Diagnosis- RDTs and microscopy						
Education campaigns						
Administrative						
Logistics						

Are there any other impacts of malaria interventions that we need to take into account? (e.g. impact on water supply, impact on environment, side-effects on health) Do you have any data on these?

What options exist for you to adapt to changes of climate especially due to malaria?

Probe: *Adaptation strategies (Flood protection measures such as reinforce housing/roads/waterways, water supply/sanitation systems, drinking water source protection (from mosquitoes), drainage systems or drainage of swamp lands, raising awareness, improved climate and malaria forecasting and monitoring, policy)*

In your view, what are the key barriers to adaptation to climate change especially related to malaria?

What would help facilitate adaptation to climate change especially that related to malaria?