WIDER Working Paper 2014/111

Changes in climatic factors and malaria in Uganda

Bruno Lule Yawe*

September 2014

Abstract: The study examines the relationship between climatic factors and reported malaria cases using data from 12 districts in Uganda over the period 2000-2011. A panel dataset comprising temperature, temperature standard deviation; minimum humidity; maximum humidity; precipitation; precipitation standard deviation; malaria cases; health facilities; hospital beds; health workers; per capita health expenditure and gross domestic product per capita. The Fixed Effects Model was found to be preferable. Health facilities, per capita GDP, the interaction of temperature and precipitation, the interaction of precipitation and variability in precipitation, maximum and minimum humidity have a significant positive effect on malaria cases. Hospital beds and health workers are significant and negatively related to malaria cases while per capita health expenditure, temperature, precipitation and variability in temperature have no effect.

Keywords: climate change, malaria, health, ecological economics
JEL classification: Q54

---

*School of Economics, Makerere University; e-mail: byawe@yahoo.com; byawe@fema.mak.ac.ug

This study has been prepared within the UNU-WIDER project 'Development under Climate Change', directed by Channing Arndt, James Thurlow, and Finn Tarp.

ISSN 1798-7237 ISBN 978-92-9230-832-2

Typescript prepared by Lisa Winkler at UNU-WIDER.

UNU-WIDER gratefully acknowledges the financial contributions to the research programme from the governments of Denmark, Finland, Sweden, and the United Kingdom.

The World Institute for Development Economics Research (WIDER) was established by the United Nations University (UNU) as its first research and training centre and started work in Helsinki, Finland in 1985. The Institute undertakes applied research and policy analysis on structural changes affecting the developing and transitional economies, provides a forum for the advocacy of policies leading to robust, equitable and environmentally sustainable growth, and promotes capacity strengthening and training in the field of economic, and social policy-making. Work is carried out by staff researchers and visiting scholars in Helsinki and through networks of collaborating scholars and institutions around the world.

UNU-WIDER, Katajanokanlaituri 6 B, 00160 Helsinki, Finland, wider.unu.edu

1 Introduction

It has been known for thousands of years, at least since the time of Hippocrates that climate has wide ranging impacts on health. Increasing recognition of the process of climate change has led to a growing interest by health researchers in assessing the potential mechanisms by which changes in climate could influence health. Such health effects will be modulated by factors such as socioeconomic development and by the degree to which effective adaptation measures are implemented. Although most studies have assessed the potential impacts of climate change in isolation from other environmental changes, in reality, climate change will be experienced against a background of other global changes such as population growth, urbanization, land use changes and depletion of fresh water resources that themselves have implications for health and which could, in some instances interact with climate change to magnify the impacts (Haines et al. 2006).

Malaria remains one of the most important diseases in Uganda in terms of morbidity, mortality and economic losses. Uganda has also experienced the negative consequences of climate change on the health of the people of Uganda for example floods in Eastern Uganda in 2007 resulted in a humanitarian crisis. Higher temperatures and rainfall associated with El Nino increase the transmission of malaria leading to epidemics in highland areas of Uganda. Conversely, prolonged drought leads to food insecurity and malnutrition, thereby further predisposing populations to illnesses (Republic of Uganda 2010).

Despite considerable progress in the last decade in our understanding of the link between climate change and the consequences for human infectious diseases (and other health risks) (McMichael et al. 2006) considerable work remains, particularly in better understanding the role of environmental drivers versus other epidemiological factors known to drive the transmission of malaria. Current uncertainties may be categorized as those related solely to epidemiological aspects independent of climate, those related to uncertainties associated with climate models themselves and those related to the interaction between disease and climate.

Generally, this study examines the relationship between climatic factors and vector-borne diseases in Uganda. Specifically, the study examines the relationship between climatic factors and reported malaria cases using data from 12 districts in Uganda over the period 2000-2011. This study was guided by the following hypothesis. Generally, we conjectured that climate change is associated with increased malaria cases. Specifically, increased humidity; rainfall and temperature are postulated to lead to increased incidence of malaria and consequently increased economic burden to society.

Understanding the climate change-malaria transmission nexus is of great policy relevance due to amongst others: (i) Malaria is a main cause of mortality and morbidity among both infants and adults; and (ii) A direct relationship has been demonstrated between poverty and incidence and prevalence of malaria, dysentery and diarrhoea as they are more prevalent among the poor compared to the rich. Additionally, communicable diseases account for 54 percent of the total burden of disease in Uganda with HIV and AIDs, tuberculosis (TB) and malaria, being the leading causes of ill health (Republic of Uganda 2010).

This study is organized into nine sections. The next section presents the status of malaria in Uganda while section 3 reviews previous studies on the relationship between malaria and climatic factors.

Model specifications and empirical model specifications are presented in section 4. Section 5 covers the unit of analysis, data type, sources and sample size. Empirical results including descriptive statistical analysis; correlation analysis; as well as econometric analysis are presented in section 6. Preliminary discussion and further research and preliminary policy implications, are respectively presented in sections 7 and 8 while section 9 concludes.

2 Status of malaria in Uganda

Malaria continues to be a major public health problem and the most frequently reported disease at both public and private health facilities in Uganda. Clinically-diagnosed malaria is the leading cause of morbidity and mortality, accounting for 25-40% of outpatient visits at health facilities, 15-20% of all hospital admissions, and 9-14% of all hospital deaths. Nearly half of inpatient deaths among children under-five years of age are attributed to clinical malaria. A significant percentage of deaths occur at home and are not reported by the facility-based Health Management Information System (HMIS). The current estimated annual number of deaths from malaria ranges from 70,000 to 110,000 (USAID 2011).

In most parts of Uganda, temperature and rainfall allow intense, perennial malaria transmission. Malaria is highly endemic in 95 percent of the country, covering approximately 90 percent of the population of 33 million. The remaining 5 percent of the country consists of unstable and epidemic-prone transmission areas in the highlands of the south- and mid-west, along the eastern border with Kenya, and the North Eastern border with South Sudan. In some areas of northern Uganda, the entomological inoculation rates (infective biting rates by the mosquitoes that transmit malaria) are among the highest recorded in the world. The most common malaria vectors are *Anopheles gambiae s.l.* and *Anopheles funestus*. *A. gambiae* is the dominant species in most places, while *A. funestus* is generally found at higher altitudes and during the short dry seasons (September through November), when permanent water bodies are the most common breeding sites. In some areas of northern Uganda, such as Apac and Oyam, *A. funestus* is the most common vector which feeds primarily on humans and also takes blood meals from other domestic animals. The Uganda Malaria Indicator Survey, conducted in late 2009, showed that *Plasmodium falciparum* is responsible for 99 percent of malaria cases. *P. malariae,* accounts for 0.2 percent of cases as a mono-infection but is more commonly found as a mixed infection with *P. falciparum* (up to 2.7 percent of childhood infections in highly endemic areas). Both *P. vivax* and *P. ovale* are rare and do not exceed 1-1.6 percent of malaria cases in Uganda (USAID 2011).

Table 1 shows malaria as the highest ranked cause of morbidity for children below five years of age in Uganda over the period 2007-2011, followed by Cough or Cold without Pneumonia. In 2011, these two accounted for over 56 percent of all cases of morbidity down from 72 percent in 2010. The proportion of persons presenting with intestinal worms, skin diseases and pneumonia causes of morbidity slightly decreased in 2011.

Table 1: Proportion of cases among the leading causes of morbidity, 2007-2011 for children below five years of age in Uganda

Type of Illness	2007	2008	2009	2010	2011
Malaria	33.6	26.1	48.5	48.2	36.2
No pneumonia-cough or cold	15.6	12.2	15.5	24.1	19.3
Intestinal worms	5.3	4.0	4.4	6.5	5.2
Skin diseases	3.3	2.7	2.9	3.8	3.2
Pneumonia	2.9	2.2	2.4	3.2	2.4
Other diseases	39.3	52.8	26.3	14.2	33.7

Source: Uganda Bureau of Statistics (2012).

In terms of health centre-based mortality for all by age group, a total of 13,761 health centre deaths were reported mortality for 2010/11. Malaria was the top (20.9 percent) cause of mortality followed by AIDS (9.4 percent), Pneumonia (7.8 percent), Anaemia (7.6 percent), and tuberculosis (3.9 percent) among the top five. The highest number of mortality was among males above 5 years (36.1 percent) followed by females above 5 years (25.1 percent), males under 5 (20.2 percent) and females under 5 (18.5 percent) as indicated in Table 2. Among children under 5 years, malaria is the highest (27.2 percent) cause of mortality followed by anaemia (12.1 percent), pneumonia (11.4 percent), perinatal conditions (7.8 percent) and septicaemia (5.0 percent), among the top five causes of mortality.

Table 2: Top ten causes of hospital-based mortality for all ages in Uganda for fiscal year 2010/11

Diagnosis	Under Five Years	Above Five Years
Malaria	27.16	16.99
AIDS	2.61	13.67
Pneumonia	11.37	5.58
Anaemia	12.10	4.74
Tuberculosis	0.90	5.74
Perinatal conditions (in new borns 0-28 days)	7.78	na
Septicaemia	4.99	1.42
Other types of meningitis	0.96	2.40
Respiratory infections (other)	2.72	1.26
Injuries -road traffic accidents	0.49	2.55
All others	28.93	45.66
Total	100.00	100.00

Source: Uganda Bureau of Statistics (2012).

The proportion of pregnant women who reported receiving a second dose of Fansidar for Intermittent Presumptive Treatment (IPT) of malaria has been increasing over time. A proportion of 43 percent was recorded for 2011 as compared to 40 percent recorded in 2010.

In what follows we provide the status of the following malaria control tools: (i) vector control; (ii) malaria case management; (iii) malaria in pregnancy; (iv) epidemiologic preparedness and response; (v) procurement and supply management; (vi) advocacy communication and social mobilization; and (vii) surveillance, monitoring, evaluation and operations research.

(i) Vector control. Vector control is among the key strategies that are widely promoted by the World Health Organization (WHO) and the Roll Back Malaria Partnership (RBM) for prevention and reduction of malaria. However, Republic of Uganda (2011) notes that vector control in Uganda combines the use of Indoor Residual Spraying (IRS), Long Lasting Insecticidal Nets (LLINs) and on a limited scale, larval source management. With support from partners, IRS was reintroduced in 2006 and has been expanded to ten districts thereby protecting approximately three million people. The National Malaria Control Programme (NMCP) started promoting Insect Treated Nets (ITNs) as a major vector control tool in 1998 initially targeting pregnant women and children under five years of age and changed to universal access targets in 2009. In 2010, the program distributed more than 7.2 million LLINs. An additional 10 million LLINs was planned for distribution to achieve universal coverage by 2012. As of May 2011, there was limited routine distribution of LLINs to pregnant women and children under five years of age. Additionally, IRS was implemented in ten districts. IRS and LLINs still remain largely donor-dependent. It should be noted that infrastructure for effective and routine entomological monitoring on mosquito bionomics is inadequate. Additionally, there are no policy guidelines for integrated vector management.

Mutero et al. (2012) used a structured questionnaire to interview 34 individuals working at technical or policymaking levels in health, environment, and agriculture and fisheries sectors about integrated vector management (IVM) in Uganda. All participants were familiar with the term integrated vector management and knew various conventional malaria vector control (MVC) methods. Only 75 percent thought that Uganda had a MVC policy. Eighty percent (80%) felt there was intersectoral collaboration towards integrated vector management, but that it was poor due to financial constraints, difficulties in involving all possible sectors and political differences. The health, environment and agricultural sectors were cited as key areas requiring cooperation in order for integrated vector management to succeed. Sixty-seven percent (67%) of participants responded that communities were actively being involved in MVC, while 48% felt that the use of research results for evidence-based decision making was inadequate or poor. A majority of the participants felt that malaria research in Uganda was rarely used to facilitate policy changes. Suggestions by participants for formulation of specific and effective IVM policy included: revising the MVC policy and IVM-related policies in other sectors into a single, unified IVM policy and, using legislation to enforce IVM in development projects. The authors concluded that integrated management of malaria vectors in Uganda remains an underdeveloped component of malaria control policy. Cooperation between the health and other sectors needs strengthening and funding for MVC increased in order to develop and effectively implement an appropriate IVM policy. Continuous engagement of communities by government as well as monitoring and evaluation of vector control programmes will be crucial for sustaining IVM in the country.

(ii) Malaria case management. Uganda's malaria case management policy evolved from chroloquine (CQ) monotherapy to CQ+SP to ACTs in the last decade. Similarly, the policy on the diagnosis of malaria has evolved from clinical to parasitological based diagnosis. Home based management of fever (HBMF) introduced in 2002 has now been incorporated into the integrated community case management. Nevertheless, there are frequent stock-outs of antimalarial medicine and supplies at health facilities and community level. Although the national malaria control programme has conducted trainings of health workers in 21 districts on the Rapid Diagnostic Tests (RDTs), its implementation is hampered by the non-availability of RDT kits. Integrating private sector providers into national case management programmes remains a challenge. In addition, there are weak services for the management of severe malaria below Health Center IV level (Republic of Uganda 2011).

(iii) Malaria in pregnancy. With regard to managing malaria during pregnancy, in 2001, the national malaria control programme commenced the implementation of intermittent preventive treatment in pregnancy as a strategy which was earlier on adopted in 1998. Nevertheless, routine distribution of ITNs remains limited. Poor coordination between the reproductive health division and the national malaria control programme has hampered progress in the implementation of malaria in pregnancy activities (Republic of Uganda 2011).

(iv) Epidemic preparedness and response. Since 2000, six epidemics have occurred in Uganda with the most recent epidemic in 2009/10 in Mubende District. The national malaria control programme has established a malaria surveillance system using weekly data generated from all health facilities. Epidemic thresholds have been developed in epidemic prone districts and health workers were trained in the use of the thresholds. Two centres of excellence have been established in early detection of epidemics. The current malaria epidemic threshold values are based on the clinical diagnosis of malaria. There is need to regularly review and update the thresholds to take into account the introduction of malaria diagnostics (Republic of Uganda 2011).

(v) Procurement and supply management. All anti-malarial medicines and laboratory commodities are listed on the essential medicines list of Uganda and are available through the National Medical Stores, Joint Medical Stores and the private sector. The public procurement and disposal of public assets act is being revised to address delays in medicines procurement. However, the availability of malaria commodities at service delivery points remains a problem largely due to poor coordination between the national malaria control programme, pharmacy division, procurement unit and the national medical stores. There is a lack of up-to-date data on the country malaria burden to guide forecasting and quantification (Republic of Uganda 2011).

(vi) Advocacy communication and social mobilization. The national malaria control programme has a focal point person, malaria communications strategy and guidelines for advocacy and social mobilization implementation. There is a functional advocacy and social mobilization working group at national level. However, the national malaria control programme had a malaria newsletter and notice board which are no longer functional. There is a parliamentary malaria subcommittee of the social services committee. Uganda commemorates the Africa Malaria Day/World Malaria Day annually with high level political participation. However, inadequate erratic funding and staffing still hampers this activity (Republic of Uganda 2011).

(vii) Surveillance, monitoring and evaluation, and operations research. The national malaria control programme over the past ten years has implemented two malaria strategic plans 2000/1-2004/5 and 2005/6-2009/10. There has been increased support from partners in strengthening capacities for monitoring and evaluation (M&E). In 2008, the national malaria control programme developed the first ever M&E plan. In addition, a national malaria research centre was established in 2004 and the first malaria indicator survey was conducted in 2009. Nevertheless, malaria data remains inadequate, untimely and incomplete due to the weaknesses in the Health Management Information System (HMIS). Data on inpatient malaria admissions and deaths are not systematically collected. No system exists for collecting and integrating data from the private sector (which provides services to more than 50 percent of the population) into the HIMS. Additionally, there is no functional malaria database within the national malaria control programme. A clear research agenda to guide programmatic implementation has not been outlined (Republic of Uganda 2011).

3 Previous studies on the relationship between malaria and climatic factors

A number of researchers have investigated the relationship between malaria and climatic factors. Githeko (2009) noted that all the drivers of malaria transmission are found in abundance of Africa and climate change is a new addition. Since the late 1980s there have been reports of malaria epidemics particularly in the East African Highlands. In many of these regions there was widespread parasite resistance to chloroquine and in addition there was virtually no vector control. At that time it was not clear whether the epidemics were as a result of environmental change or due to the effects of drug resistance and lack of vector control. He notes that a detailed study of climate and malaria epidemics indicated that the epidemics were associated with incidents of El Nińo. These events were characterized by abnormal warming and wetness. Weak and late interventions failed to contain the outbreaks leading to severe health outcomes. Kenya, Uganda, Burundi, Tanzania, Eritrea, Ethiopia and Rwanda reported severe malaria epidemics in the late 1980s to 2003. This period had two very strong El Nińos and a number of weak events (1982, 1988, 1990-1994, 1997-98, 2003).

Zhou et al. (2003) work on African highlands indicates that climatic factors such as temperature and precipitation play an important role in explaining the variation in malaria cases but that the studies were conducted on a small scale (in a specific region of a country) creating a need for larger scale investigation. The role of climate change in the increase of malaria incidence in African highlands has particularly been controversial (Pascual et al. 2006) but it is difficult to totally deny the fact that climatic factors play an important role in the incidence of malaria (Parham and Michael 2010). Most of the economic analyses have been oriented toward cost effectiveness analysis of anti-malaria drugs (World Health Organization 2009) and available treatment options. Goodman et al. (2000) reviewed literature on the measurement of the economic impact of malaria in sub-Saharan Africa and concluded that the few available studies are less reliable and there is a need of more sophisticated research in the area.

Egbendewe-Mondzozo et al. (2011) use a semi-parametric econometric model to study the relationship between malaria cases and climatic factors in 25 African countries (including Uganda). Results show that a marginal change in temperature and precipitation levels would lead to a significant change in the number of malaria cases for most countries by the end of the century. The study by Egbendewe-Mondzozo et al. (2011) investigates the link between climate change and malaria at the country level which clouds the district-specific picture.

In Uganda, malaria epidemics have partly coincided with periods of El Nino occurrence which are characterized by high rainfall, flooding and landslides. The apparently worsening malaria situation is attributed to a number of factors: epidemiological shifts due to climate change, environmental factors increasing breeding sites for mosquitoes, increasing resistance to anti-malarial drugs, weak health system, late treatment seeking behavior, inadequate knowledge on the disease, costly preventive interventions and the high prevalence of low quality treatment outlets both formal and informal. Malaria epidemics have increased in areas originally considered malaria-free zones like the South Western and Eastern highlands. The most affected districts include Kisoro, Kabale, Rukungiri, Bushenyi and Mbarara. Epidemics of varying severity and extent occurred in these areas in 1992, 1994, 1997/98 and 2000/2001. In these areas all age groups are at equal risk of catching and dying of malaria. The cycle of epidemics in the past seem to suggest an epidemiological transition from lower to higher malaria endemicity which may be associated with climate change (Namanya 2009).

Niringiye and Douglason (2010) attempted to establish the relationship between malaria prevalence and environmental and socio-economic variables in Uganda. They assert that an understanding of the factors that are associated with malaria prevalence is critical for the design of policies aimed at reducing malaria prevalence. Their regression results using Ordinary Least Squares indicate no relationship between malaria prevalence and environmental and socio-economic variables. They recommend that there is need for further study using disaggregated data, panel data, and adding more control variables to the health production model to identify the factors that are associated with malaria prevalence in Uganda.

Empirical evidence suggests that malaria varies seasonally in highly endemic areas and is probably the vector-borne disease more sensitive to long-run climate changes. For example, the comparison of monthly climate and malaria data in highland Kakamega, Western Kenya, highlights a close association between malaria transmission and monthly maximum temperature anomalies over the years 1997-2000. The effects of soil moisture to determine the causal links between weather and malaria transmission has also been studied. For the most common mosquito species Anopheles gambiae, the soil moisture predicts up to 45 percent and 56 percent of the variability of human biting rate and entomological inoculation rate, respectively (Grasso et al. 2010).

4 Model specifications

The basic dataset was a panel with repeated observations at 12 sites. To carry out the statistical analysis a semi-parametric panel model was specified and estimated. Such a model allows us to simultaneously handle nonlinearity in the relationships along with the effects of districts and time (years). Pooling the data across districts and years allows us to capture the likely impact that we might expect to see in a longer, but unavailable, time series for the individual district. The estimated coefficients ptovide information on the relationship between observed malaria cases, temperature and precipitation. The theoretical model follows the analysis in Egbendewe-Mondzozo et al. (2011) and is specified as follows:

$$y_{it} = f(X_{it}) + \beta Z_{it} + \alpha_i + u_{it},\ i = 1,...,N \ and \ t = 1,...,T \tag{1}$$

where y_{it} is the natural log of the number of reported malaria cases per 1,000 people in district i at time period t; X_{it} is a vector of climate variables that includes temperature, precipitation and a measure of climate variability; Z_{it} is a vector of socio-economic control variables that includes population density, per capita gross domestic product, inequality index, per capita healthcare expenditure and number of hospital beds per 1,000 people; α_i are unobserved individual district effects and u_{it} is an idiosyncratic error term. The function f, the coefficients β and the unobserved district effects α_i are all parameters to be estimated. Note that climate variables are assumed to affect the number of malaria cases per 1,000 people through an unknown function to be estimated while the socio-economic variables affect malaria cases linearly.

4.1 Empirical model specifications

This study adapts Egbendewe-Mondzozo et al. (2011) empirical model specification by assuming and estimating two specifications of the nonlinear function f. The first functional form assumes an additive form while the second assumes a complex function of an unknown form of f. The first functional form is smooth in the climate variability index measured by monthly standard deviation in precipitation. In this functional form, climate variability influences the number of malaria cases through the intercept (α_0) as well as through the slope of temperature (α_1) and precipitation (α_2). In other words, the influence of precipitation and temperature on the number of malaria cases will depend upon how precipitation variability evolves. Put differently, the size of the impact of temperature and precipitation on malaria prevalence is contingent upon fluctuations in climate measured by the standard deviation in precipitation. Thus, the empirical statistical relationship between malaria cases, climatic and socioeconomic variables can be presented as:

$$Log[MCASES_{it}] = \alpha_0[STDPRECIP_{it}] + TEMP_{it} * \alpha_1[STDPRECIP_{it}] + PRECIP_{it} * \alpha_2[STDPRECIP_{it}] + \beta_1 GDP_{it} + \beta_2 EXP_{it} + \beta_3 BED_{it} + \beta_4 HF_{it} + \beta_5 HW_{it} + \varepsilon_i \quad (2)$$

where α_i, for i = 0, 1, 2 are smooth coefficients (of functions of climate variability) and β_j are the coefficients of the linear socioeconomic control variables. In this functional form, the interaction between temperature and precipitation is established through the variability of precipitation.

In the second expression where the nonlinear functional form is unknown, the empirical formulation of the empirical model can be expressed as:

$$Log[MCASES_{it}] = f[PRECIP_{it}, STDPRECIP_{it}, TEMP_{it}] + \beta_1 GDP_{it} + \beta_2 EXP_{it} + \beta_3 BED_{it} + \beta_4 HF_{it} + \beta_5 HW_{it} + \varepsilon_i \quad (3)$$

Equation (3) is the most attractive for empirical investigations because it nests all possible functional forms of the effect of climatic factors on malaria prevalence. Nevertheless, it comes with the cost that higher dimensionality of the function f might weaken the correct estimation of the marginal effects given the actual sample size. Since we are fitting a three dimensional function with fewer data points (our current sample size is 132 observations) we can run into the risk of not having enough data points in some neighbourhoods for a good fit. Yatchew (2003) refers to this problem as the '*curse of dimensionality*' in nonparametric estimations. When more data become available for instance at least 500 observations, more general nonparametric models with fewer assumptions could be tested.

5 Unit of analysis, data type, sources and sample size

For the following districts: Arua, Entebbe, Gulu, Jinja, Kabale, Kampala, Kasese, Lira, Masindi, Mbarara, Soroti, and Tororo, data were gathered on the following: malaria cases; population; health facilities; per capita health expenditure; number of hospital beds; number of health workers; average temperature; Average Mean Maximum Humidity; Average Mean Minimum Humidity; and Annual Rainfall. Table 1 presents the variable definitions and data sources.

Table 1: Variable definitions and data sources

Climatic variables		
Variable	Definition	Data source
Temperature	Temperature is the degree of hotness or coldness of a body or environment. Average monthly temperature is, therefore, the monthly mean of the daily (24 hour) temperature.	Uganda Bureau of Statistics Statistical Abstracts
Temperature standard deviation	Temperature standard deviation	Uganda Bureau of Statistics Statistical Abstracts
Minimum humidity	Average minimum ratio of the partial pressure of water vapour in a parcel of air to the saturated vapour pressure of water vapour at a prescribed temperature.	Uganda Bureau of Statistics Statistical Abstracts
Maximum humidity	Average maximum ratio of the partial pressure of water vapour in a parcel of air to the saturated vapour pressure of water vapour at a prescribed temperature.	Uganda Bureau of Statistics Statistical Abstracts
Precipitation	Falling products of condensation of atmospheric water vapour that is pulled down by gravity and deposited on the Earth's surface as snow, hail or rain within a given period.	Uganda Bureau of Statistics Statistical Abstracts
Precipitation standard deviation	Precipitation standard deviation	Uganda Bureau of Statistics Statistical Abstracts
Socioeconomic variables		
Variable	Definition	Data Source
Malaria cases	Malaria cases per 1,000 people	Ministry of Health, Malaria Department
Health facilities	Number of health facilities per 1,000 people	Uganda Bureau of Statistics Statistical Abstracts
Beds	Number of hospital beds per 1,000 people	Uganda Bureau of Statistics Statistical Abstracts
Health workers	Number of health workers per 1,000	Uganda Bureau of Statistics Statistical Abstracts
Per capita health expenditure	Average health expenditure per person	Ministry of Finance, Planning and Economic Development
Gross domestic product per capita	Gross Domestic Product divided by the population size.	Ministry of Finance, Planning and Economic Development

Source: Literature review.

6 Empirical results

The empirical results are categorized under the following headers: descriptive statistical analysis; correlation analysis; and econometric analysis.

Descriptive Statistical Analysis: The means of the variables incorporated in the analysis for each the twelve (12) districts over the 2000-2011 period are presented in Table 2.

Table 2: Means of variables by district for the pooled dataset (2000-2011)

District	Malaria Cases	Health facilities	Hospital Beds	Health Workers	GDP Per capita	Temperature	Precipitation	Max Humidity	Min. Humidity
Arua	196,375	96	756	382	37,982	29	1,427	69	46
Entebbe	na	na	na	na	na	26	1,562	74	60
Gulu	218,783	139	736	187	27,599	30	1,404	65	42
Jinja	205,768	98	859	415	28,633	28	1,290	72	50
Kabale	171,588	83	382	227	34,747	24	1,053	82	52
Kampala	281,150	723	3,301	893	22,448	28	1,290	68	50
Kasese	209,787	96	489	298	26,763	30	872	71	46
Lira	191,527	71	590	250	28,073	31	1,471	63	39
Masindi	154,514	66	344	351	22,905	27	1,273	69	48
Mbarara	161,278	82	710	351	38,558	27	937	72	46
Soroti	305,150	64	392	199	42,373	31	1,322	65	42
Tororo	305,911	86	556	349	31,168	30	1,576	68	51

Source: Descriptive statistical analysis of panel data set.

It is clear from table 2 that districts with mean temperatures of at least 30 degrees on the Celsius scale (for instance, Gulu, Kasese, Lira, Soroti and Tororo), respectively have a high number of malaria cases (218,783; 209,787; 191,527; 305,150; and 305,911). It is also worth noting the close association between mean precipitation on the one hand, mean temperature on the other, and malaria cases. It is worth noting that districts with mean temperatures of at least 30 degrees and mean precipitation of at least 1,300 millimetres [Gulu (1,404 mm); Lira (1,471 mm); Soroti (1,322 mm); and Tororo (1,576 mm)] have average malaria cases of at least 190,000. Additionally, districts with mean maximum humidity of at least 60 (Gulu; Lira; Soroti and Tororo) have average malaria cases of at least 190,000.

Table 3 presents the mean, standard deviation, minimum and maximum for the variables in the sampled districts for the pooled dataset (2000-2011).

Table 3: Mean; standard deviation; minimum and maximum of variables pooled dataset (2000-2011)

Variable/Statistic	Mean	Standard deviation	Minimum	Maximum
Malaria cases	219,193.6	142,675.1	15,465	1,087,962
Temperature	28.62	2.25	17.9	31.4
Temperature std	1.50	0.88	0.2	6.8
Maximum humidity	70.18	21.22	24.2	95.9
Minimum humidity	47.93	16.64	11.3	69.8
Precipitation	1,287.76	302.18	532	2,062
Precipitation Std	69	20	33	132
Health facilities	145.7	371	25	3,572
Health workers	354.6	374.8	80	2,628
Hospital beds	827.8	838.1	81	3,563
GDP/head	31,088	24,924	0	277,958

Source: Descriptive statistical analysis of panel data set.

The mean temperature for the twelve districts over the period 2000-2011 stood at approximately 29 degrees on the Celsius scale, with a minimum of 17.9 degrees and a maximum of 31 degrees and a standard deviation of 2.3. Maximum humidity had a mean of 70, standard deviation of 21 as well as a minimum of 24 and a maximum of 96. Minimum humidity had an average of about 48, standard deviation of 17, minimum of 11 and a maximum of about 70. Average precipitation stood at about 1288 millimetres, with a standard deviation of 302, minimum of 532 and a maximum of 2,062.

Correlation Analysis: Table 3 presents the Pearson correlation matrix of the variables for the pooled dataset (2000-2011). Some correlation coefficients are significant while others are not. We report both the significant and insignificant correlation coefficients especially those with policy implications for the sampled districts.

Table 3: Pearson correlation matrix of malaria cases and climatic variables, pooled dataset (2000-2011)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Malaria cases	1.0000						
(2) Temperature	-0.1255	1.0000					
(3) Temperature standard deviation	-0.1261	0.1360	1.0000				
(4) Maximum humidity	0.0466	-0.0182	-0.3475*	1.0000			
(5) Minimum humidity	0.2244	-0.1023	-0.4168*	0.9610*	1.0000		
(6) Precipitation	0.2338*	0.0774	0.1331	-0.1101	0.0300	1.0000	
(7) Precipitation standard deviation	-0.0015	0.0127	0.2404*	-0.1578	-0.0624	0.6773*	1.0000

Source: Correlation analysis of panel data set.

From Table 3, the Pearson correlation coefficient between malaria cases and precipitation is positive and is significant (0.2338). The correlation coefficient between maximum humidity and temperature standard deviation is negative and is significant (-0.3475). The correlation coefficient between minimum humidity and temperature standard deviation is negative and is significant (-0.4168). The correlation coefficient between precipitation standard deviation and temperature standard deviation is positive and is significant (0.2404). The correlation coefficient between maximum humidity and minimum humidity is positive and is significant (0.9610). The correlation coefficient between precipitation and precipitation standard deviation is positive and is significant (0.6773).

Table 4: Pearson correlation matrix of malaria cases and socioeconomic variables, pooled dataset (2000-2011)

	(1)	(2)	(3)	(4)	(5)
(1) Malaria cases	1.0000				
(2) Health facilities	0.1509	1.0000			
(3) Hospital beds	0.0935	0.5122*	1.0000		
(4) Health workers	0.0756	0.0681	0.5012*	1.0000	
(5) Per capita GDP	-0.0565	0.0415	-0.1048	-0.1144	1.0000

Source: Correlation analysis of panel data set.

From Table 4, the Pearson correlation coefficient between hospital beds and health facilities is positive and significant (0.5122). The Pearson correlation coefficient between health workers and hospital beds is positive and is significant (0.5012).

Econometric analysis

The dataset was transformed by removing Entebbe which only had data on climatic variables and no data on socioeconomic variables. Table 5 presents the estimates of the pooled ordinary least Squares, the Random Effects Model (REM) and the Fixed Effects Model (FEM). The results in Table 5 provide a benchmark from which the preferred estimation technique was selected.

Table 5: Regressions for per capita malaria cases (Benchmark Regression)

Malaria cases per capita	Pooled OLS	Random Effects Model	Fixed Effects Model
Health facilities	0.2226**	0.2610**	0.3434***
	(0.1033)	(0.1091)	(0.1259)
Per capita GDP	0.4781***	0.4699**	0.4452**
	(0.1822)	(0.1840)	(0.1937)
Temperature	0.0253	0.0419	0.0743
	(0.0344)	(0.0389)	(0.0555)
Rainfall	0.0008***	0.0005*	0.0000
	(0.0003)	(0.0000)	(0.0003)
Constant	-2.9092	-3.1702	-3.5193
	(2.1903)	(2.2400)	(2.5541)
R^2	0.15	0.14	0.14
Chow test P-value			0.0067
Hausman test P-value			0.0100
LM test P-value		0.1038	
Joint significance test P-value	0.0005	0.0007	0.0013
N	132	132	132

Notes: Figures in parentheses are standard errors and ***, **, and * denote levels of significance at 1%, 5% and 10%, respectively.

Source: Econometric analysis of panel data set.

The test statistics displayed in Table 5 show that the Chow test of the pooled model (OLS) against the FEM indicates the rejection of the null hypothesis at 1 percent and the conclusion is that the preferred model is the FEM. Breusch and Pagan LM test of pooled (OLS) against the REM, rejects the null hypothesis at 10 percent and thus the preferred model is the REM. The Hausman specification test that compares the FEM versus REM under the null hypothesis that the individual effects are uncorrelated with the other regressors in the model shows that the FEM is preferred since the null hypothesis is rejected at 1 percent. All regressions pass the joint significance test for overall model specification at 1 percent level. Thus the results presented in this paper (see Table 6) are based on fixed effects estimation technique. In order to investigate a variety of malaria determinants identified in the literature, this paper adopted a reduced form approach rather than adhering to one particular, narrow structural model.

In Table 6, column 1 is the benchmark regression (FEM in Table 5) with which we start to investigate the various malaria determinants in Uganda. In this column, both health facilities and per capita GDP have a significant positive effect on malaria cases. While per capita health expenditure was found to have no effect on malaria cases (see column 2, Table 6).

The different roles played by hospital beds, health workers and health facilities in determining malaria cases are investigated in columns 3, 4, 5 and 6 (see Table 6). Both hospital beds and health workers are significant and negatively related to malaria, while in column 6 we investigate the individual effect of all the three covariates and find them to be individually statistically significant with the expected sign.

In all the different regression specifications, temperature and precipitation have no effect on malaria cases. In column 7, we find variability in temperature to also have no effect on malaria in Uganda. While the interaction of temperature and precipitation was found to have a significant positive effect on malaria cases (see column 8). This implies that high temperature and precipitation create favourable conditions for mosquitoes causing malaria and thereby increase malaria cases in Uganda. In column 9 we investigate the effect of the interaction of precipitation and variability in precipitation and find a significant positive effect. This implies that high precipitation and its variability create conditions that increase malaria cases. In columns 10, 11, 12 and 13, we find both maximum and minimum humidity to have a positive significant effect on malaria cases.

Below is the summary of major findings. Health facilities, per capita GDP, the interaction of temperature and precipitation, the interaction of precipitation and variability in precipitation, maximum and minimum humidity have a significant positive effect on malaria cases in Uganda. Both hospital beds and health workers are significant and negatively related to malaria cases in Uganda. Per capita health expenditure, temperature, precipitation and variability in temperature have no effect on malaria cases in Uganda.

Table 6: Determinants of malaria in Uganda using the fixed-effects model (2000-2011)

Explanatory Variables/equation	1	2	3	4	5	6	7	8	9	10	11	12	13
Constant	-3.5193 (2.5541)	0.4799 (2.1953)	0.7601 (3.0902)	0.3185 (2.9070	5.3249 (3.3159)	4.7914 (3.2717)	6.5202 (2.7769)	4.3980 (3.2489)	4.3551 (3.2516)	5.4326 (2.7191)	5.5433 (2.7177)	4.1883 (3.1988)	4.4682 (3.1960)
Temperature	0.0743 (0.0555)	0.0658 (0.0568)	0.0778 (0.0555)	0.0796 (0.0551)	0.0676 (0.0536)	0.0578 (0.0530)		0.0733 (0.0532)	0.0493 (0.0528)			0.0592 (0.0516)	0.0527 (0.0518)
Temperature Std							0.0769 (0.1037)			0.1724 (0.1059)	0.1665 (0.1056)		
Maximum humidity											0.0150*** (0.0053)		0.0132** (0.0051)
Minimum humidity										0.0199*** (0.0069)		0.0174* (0.0066)	
Precipitation	0.0000 (0.0004)	0.0000 (0.0004)	-0.0000 (0.0004)	0.0002 (0.0004)	0.0000 (0.0003)	0.0000 (0.0004)		0.0004 (0.0004)	0.0009 (0.0006)			0.0000 (0.0003)	0.0000 (0.0003)
Precipitation Std							-0.0078 (0.0049)			-0.0072 (0.0048)	-0.0068 (0.0048)		
Health facilities	0.3433*** (0.1259)	0.4054*** (0.1277)				0.2741** (0.1249)	0.3428*** (0.1289)	0.3159** (0.1259)	0.3058** (0.1251)	0.2441* (0.1296)	0.2387* (0.1304)	0.1687 (0.1282)	0.1671 (0.1287)
Per capita health expenditure		0.0560 (0.2063)											
Health workers				-0.4929*** (0.1695)	-0.5168*** (0.1647)	-0.4121** (0.1689)	-0.3831** (0.1673)	-0.3923** (0.1677)	-0.4012** (0.1675)			-0.2529 (0.1755)	-0.2556 (0.1756)
Hospital beds			-0.5503*** (0.2099)		-0.5824*** (0.2027)	-0.5978*** (0.1996)	-0.6099*** (0.1967)	-0.5810*** (0.1979)	-0.5748*** (0.1982)	-0.4370** (0.1999)	-0.4453** (0.1996)	-0.4527** (0.2023)	-0.4597** (0.2020)

Per capita GDP	0.4452** (0.1937)		0.5183*** (0.1896)	0.4501** (0.1919)	0.3876** (0.1875)	0.3109* (0.1878)	0.3093* (0.1859)	0.2883 (0.1865)	0.2971 (0.1863)	0.1351 (0.1902)	0.1213 (0.1923)	0.1427 (0.1939)	0.1282 (0.1965)
Temperature*precipitation								0.0004* (0.0002)					
Precipitation*precipitation Std									0.7030* (3.9900)				
R^2	0.14	0.10	0.14	0.15	0.20	0.24	0.25	0.26	0.26	0.30	0.30	0.28	0.28
Joint significance test P-value	0.0013	0.0128	0.0017	0.0009	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Chow test P-value	0.0067	0.0047	0.0035	0.0501	0.0036	0.0133	0.0010	0.0062	0.0100	0.0018	0.0012	0.0123	0.0121
N	132	132	132	132	132	132	132	132	132	132	132	132	132

Notes: Figures in parentheses are standard errors and ***, **, and * denote levels of significance at 1%, 5% and 10%, respectively
Source: Econometric analysis of panel data set.

.

7 Discussion and further research

It is widely acknowledged that climate changes are only one of many important factors influencing the incidence of infectious diseases and that their effects are very unlikely to be independent of socio-demographic factors (e.g. human migrations, transportation, nutrition), or of environmental influences (e.g. deforestation, agricultural development, water projects, urbanization). While malaria transmission increases with temperature and humidity, the decrease in disease incidence seen with prolonged drought may negate these effects (Environmental Health Perspectives and the National Institute of Environmental Health Sciences 2010).

8 Policy implications

The study has found that health facilities, per capita GDP, the interaction of temperature and precipitation, the interaction of precipitation and variability in precipitation, maximum and minimum humidity have a significant positive effect on malaria cases in Uganda. Since malaria may not be fatal in the initial stages, it is the case that some cases go unreported and are managed within the community through self-medication. The higher the number of health facilities and the belief that the community has in the facilities' capacity to manage malaria cases; the higher is the likelihood that more cases will be reported. Both hospital beds and health workers are significant and negatively related to malaria cases in Uganda. Poor staffing levels and bed occupancy levels beyond 100 percent reduce the number of malaria cases being reported. Ministry of Health, Health Systems 20/20, and Makerere University School of Public Health (2012) notes that the shortage of human resources for health and the pro-urban distribution of health workers (doctors, pharmacists, and other cadres) remain major obstacles to access to quality health care in remote and hard-to-reach areas. The percentage of filled public sector posts increased from 38 percent in 2006 to 56 percent in 2010, and 63 percent in 2011. However, public sector vacancy rates remain too high. The rapid increase in the number of districts has likely contributed to high vacancy rates in the districts, as the number of health facilities has increased without an increase in human resources for health.

The interaction of temperature and precipitation was found to have a significant positive effect on malaria cases. This implies that high temperature and precipitation create favorable conditions for mosquitoes causing malaria and thereby increase malaria cases in Uganda. This therefore implies that malaria vector control should be strengthened within the integrated vector management framework.

9 Conclusions

Whereas climatic factors are important in explaining the status of reported malaria cases, they singlehandedly cannot fully explain Uganda's malaria status. Socioeconomic factors are crucially important in fully explaining the status of reported malaria cases. The interaction of temperature and precipitation was found to have a significant positive effect on malaria cases.

References

Egbendewe-Mondzozo, A., Musumba, M., McCarl, B.A. and Wu, X. (2011), 'Climate Change and Vector-borne Diseases: An Economic Impact Analysis of Malaria in Africa', *International Journal of Environmental Research and Public Health,* Vol. 8, 913-30.

Environmental Health Perspectives and the National Institute of Environmental Health Sciences (2010), 'A Human Health Perspective On Climate Change; A Report Outlining the Research Needs on the Human Health Effects of Climate Change', available at: http://www.niehs.nih.gov/health/assets/docs_a_e/climatereport2010.pdf (accessed 04 March 2013).

Githeko, A.K. (2009), '*Malaria and Climate Change'*, available at: http://www.thecommonwealth.org/files/190385/FileName/Githeko_2009.pdf (accessed 04 March 2013).

Goodman, A.C.; Colman, P. and Mills, A. (2000), 'Economic Analysis of Malaria Control in Sub-Saharan Africa', World Health Organization: Geneva, Switzerland, pp. 1-182.

Grasso, M., Manera, M., Chiabai, A. and Markandya, A. (2010), '*The Health Effects of Climate Change: A Survey of Recent Quantitative Research'*, Basque Center for Climate Change BC3 Working Paper Series Number 2010-16.

McMichael, A., Woodruff, R. and Hales, S. (2006), 'Climate Change and Human Health: Present and Future Risks', *Lancet*, Vol. 367, No. 9513, 859-69.

Ministry of Health, Health Systems 20/20 and Makerere University School of Public Health (2012), 'Uganda Health System Assessment 2011', Kampala, Uganda and Bethesda, MD: Health Systems 20/20 project, Abt Associates Inc.

Mutero, C.M., Schlodder, D., Kabatereine, N. and Kramer, R. (2012), 'Integrated Vector Management for Malaria Control in Uganda: Knowledge, Perceptions and Policy Development', *Malaria Journal*, available at: http://www.malariajournal.com/content/pdf/1475-2875-11-21.pdf (accessed 04 March 2013).

Namanya, D. B. (2009), 'An Assessment of the Impact of Climate Change on the Health Sector in Uganda: A Case of Malaria and Cholera Epidemics and How to Improve Planning for Effective Preparedness and Response, available at: http://health.go.ug/docs/climate.pdf (accessed 04 March 2013).

Niringiye, A. and Douglason, O.G. (2010), 'Environmental and Socio-economic Determinants of Malaria Prevalence in Uganda', *Research Journal of Environmental and Earth Sciences,* Vol. 2 No. 4, 194-98.

Parham, P. and Michael, E. (2010), 'Modeling Climate Change and Malaria Transmission', *Advances in Experimental Medicine and Bioogy,* Vol. 673, 184-99.

Pascual, M., Ahumada, J., Chaves, L. and Bouma, M. (2006), 'Malaria Resurgence in the East African Highlands: Temperature Trends Revisited', Proceedings of the National Academy of Sciences, Vol. 103, 5829-34.

Republic of Uganda (2010), 'Health Sector Strategic Plan III 2010/11-2014/15', Ministry of Health, Kampala.

Republic of Uganda (2011), 'Uganda Malaria Performance Programme Review', available at: http://www.rbm.who.int/countryaction/aideMemoire/Uganda-The-malaria-program-performance-review-2011.pdf (accessed 04 March 2013).

Uganda Bureau of Statistics (2012) 2012 Statistical Abstract, available at: http://www.ubos.org/onlinefiles/uploads/ubos/pdf%20documents/2012StatisticalAbstract.pdf

USAID (2011), 'President's Malaria Initiative: Uganda Malaria Operational Plan for FY 2012', available at: http://www.pmi.gov/countries/mops/fy12/uganda_mop_fy12.pdf (accessed 04 March 2013).

World Health Organization (2009), 'World Malaria Report', Geneva: WHO.

Yatchew, A. (2003), '*Nonparametric Econometrics',* Cambridge: Cambridge University Press.

Zhou, G., Noboru, M., Githeko, A. and Yan, G. (2003), 'Association between Climate Variability and Malaria Epidemic in the East African Highlands, *Proceedings of the National Academy of Sciences*, Vol. 101, 2375-80.