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Vulnerability to Climate-Induced Highland Malaria in East Africa[1]

Shem O. Wandiga, Maggie Opondo, Daniel Olago, Andrew Githeko, Faith Githui, Michael Marshall, Tim Downs, Alfred Opere, Pius Z. Yanda, Richard Kangalawe, Robert Kabumbuli, Edward Kirumira, James Kathuri, Eugene Apindi, Lydia Olaka, Laban Ogallo, Paul Mugambi, Rehema Sigalla, Robinah Nanyunja, Timothy Baguma and Pius Achola

1. Introduction

In tropical and subtropical countries, malaria continues as a leading cause of morbidity and mortality. Out of the 1 million annual malaria deaths, approximately 90 percent occur in Africa and nearly three-quarters of these are children under the age of five (WHO, 1996; McMichael et al., 1996;), making it one of the most common causes of morbidity and mortality among children. In Kenya, Uganda, and Tanzania malaria is endemic in most regions, accounting for one-third or more of outpatient morbidity in the population. In 2002 and 2003, there were 5.7 and 7.1 million cases of malaria in Uganda, resulting in 6,735 and 8,500 deaths, respectively. Whereas, in Tanzania, malaria causes between 70,000 and 125,000 deaths annually, accounting for 19 percent of the health expenditure (De Savigny et al., 2004). Recent increased frequency of malaria in the highlands is a matter of serious concern. Fifteen percent of the African population lives in

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the highlands and is at high risk from the impacts of epidemic malaria particularly in the eastern and southern African regions (Worrel et al., 2004). Complications due to malaria such as severe anemia (especially in children and pregnant women) and cerebral malaria are widespread posing a major health risk. Low birth weight caused by malaria is responsible for about 6 percent of infant mortality; for instance, in Kenya, malaria accounts for 40,000 infant deaths annually. Malaria is also an economic burden, as it deprives Africa of U.S$ 12 billion every year in lost Gross Domestic Product (GDP) (Greenwood, 2004).

Because of climatic and ecological diversity, there is variation in the epidemiology of transmission, ranging from negligible to high risks in high-altitude areas, low but stable transmission along the Indian Ocean, and intense, high transmission around the Lake Victoria basin. Its eradication is linked to poverty alleviation despite the fact that it is at the same time a medical challenge. The impacts of malaria epidemics have been devastating and are increasingly exposing vulnerable groups to the adverse effects of climate change, as well as challenging their ability to cope. One of the critical factors influencing the vulnerability of human health to climate change is the extent to which the health and socio-economic systems are robust enough to cope (WHO, 2003).

Climate variability and change combined with anthropogenic factors (such as land use change, population increase, and poverty) have aggravated malaria in the highland areas in the Lake Victoria region. Private expenditures for treatment and prevention, increased urbanization, and increased funding for government control can reduce malaria

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transmission; however, economic development alone without breakthroughs in medical prevention and treatment cannot eradicate the disease (Sachs and Malaney, 2002).

Malaria is transmitted by mosquitoes, especially *Anopheles gambiae* in East Africa, although other species are also able to transmit the disease. Distribution of infectious diseases like malaria in space and time is related to climate. Climate changes with altitude and latitude. Cold weather can stop transmission of some diseases, e.g., malaria. Sensitivity of diseases' transmission to weather and climate depends upon the reproductive rate of the vector, reproductive rate of the reservoir, and rate of development of the pathogen in the vector or in the environment, preference for human blood feeding, and suitability and availability of disease habitat. Rainfall, in general, affects the availability and suitability of disease habitats, while temperature affects the rate of vector and pathogen development and also the vector blood-feeding rates. Temperature also affects the suitability of habitats for disease reservoirs. A study of three communities living at high altitudes above 1,100 meters (above sea level) in Kenya, Uganda, and Tanzania was conducted to ascertain the relationship between climate change and weather variability and malaria. The disease is endemic in the lowland, and dwellers in such places have developed immunity to it and hence such communities were not studied.

Highland malaria in East Africa has a long recorded history dating back to the 1920s and 1950s when it was first reported (Garnham, 1945; Fontaine et al., 1960; Roberts, 1964; Githeko and Clive, 2005). The early highland malaria epidemics were not as severe or as frequent as they have been within the last two decades. For instance, from the 1960s to the early 1980s, there were virtually no recorded malaria epidemics in the East African highlands. The resurgence of highland malaria epidemics in the last two decades has been closely associated with the frequency of climate variability (Matola et al., 1987; Lepers et al., 1988; Fowler et al., 1993; Khaemba et al., 1994; Loevinsohn, 1994; Some, 1994; Lindsay and Martens, 1998; Malakooti, et al., 1998; Mouchet et al., 1998; Githeko and Ndegwa 2001;, Zhou et al., 2004). On the other hand, Hay et al., (2002) has disputed this claim, asserting that their climate data analysis showed no significant changes in temperature or vapor pressure at any of the highland sites reported to have had high malaria incidences. They used data for diurnal temperature range spanning the 1950–1995 period.

Zones of unstable malaria, such as the East African highlands are more sensitive to climate variability and environmental changes (Mouchet et al., 1998). Temperature and precipitation in the highlands, as a result of predicted climate change, are expected to rise above the minimum temperature and precipitation thresholds of malaria transmission in various parts of the region (Githeko et al., 2000). Other studies point to the fact that to a larger degree, short-term climate extremes, such as El Niño, lead to elevated temperatures and high precipitation, which increase malaria transmission (Kilian et al., 1999; Lindblade et al., 1999). In addition to temperature and precipitation, other physical variables, such as soil moisture or its proxies (e.g., streamflow), improve transmission modeling, as they explain the interaction between precipitation, temperature, and the ground (Patz et al., 1998). Increases in human population density in the highlands have led to deforestation and swamp reclamation (Mouchet et al., 1998, Afrane et al., 2005; Minakawa et al., 2005). Puddles and elevated temperatures resulting from land cover change provide ideal breeding sites for mosquitoes (Walsh et al., 1993; Minakawa et al., 2005; Munga et al., 2006). Papyrus, found in many of the swamps in valley bottoms of the East African highlands, excrete oil and provide shade, which inhibit *Anopheles gambiae* reproduction (Mouchet et al., 1998; Lindblade et al., 2000).

A time series of the inter-annual variability of precipitation in East Africa from 1901 to 1985 shows that most of the peaks in rainfall correspond to El Niño Southern Oscillation (ENSO) years, (e.g., 1941, 1951, 1957, 1963, 1968, 1972, 1978 and 1982) (Nicholson, 1996). One characteristic of the inter-annual variability is its extreme magnitude in individual years, for example, the conditions of 1961, a year in which Lake Victoria rose several meters and reached levels unattained since the nineteenth century (Nicholson, 1996). The spectrum for rainfall for the East African region is dominated by a strong peak at 5 to 6 years, but significant peaks at about 3.5 and 2.3 years are also evident (Nicholson, 1996). In relation to malaria, such climate variability may have an influence on the availability of breeding grounds for the mosquitoes and indicate repeatability of malaria epidemics in time and space with respect to climate and weather.

Although malaria is one of the most climate-sensitive vector-borne diseases (Epstein, 1995; Morse, 1995; Githeko and Ndegwa 2001), several other factors have been identified as contributing to its emergence and spread. These include environmental and socio-economic change, deterioration of health care and food production systems, and the modification of microbial/vector adaptation (Epstein, 1992, 1995; Morse, 1995; McMichael et al., 1996).

The relationship between climate variability and the incidence of malaria in the highlands of the Lake Victoria region was examined. The relationship between precipitation and temperature to malaria was explored by using available climate, health, and hydrological data dating from 1960 to 2001. The study encompassed an integrated vulnerability mechanism assessment of the affected communities. The analyses of how the sources of vulnerability are differentiated within the population of the affected region are carried out, while, at the same time, identifying the coping and adaptive capacities of those affected.

Therefore, the study seeks to address the following research questions:

1. Which target groups are most vulnerable, that is, how are sources of vulnerability differentiated within the population of the Lake Victoria region?
2. What excess risk (the added risk above the normal malaria incidence in a community/household) could be attributable to climate variability?

2. Selection of Study Sites

One characteristic of highland malaria epidemic is that the affected communities have not yet developed resistance/immunity in their systems. This is due to the fact that the disease has not been endemic to the area since it was formerly a high-altitude cold region. Therefore, high altitude formed one of the criteria for site selection. The communities selected were located at altitudes higher than 1,100 meters above sea level, an altitude at which the existence of malaria vectors is limited because of cold temperatures.

The communities selected were located at various altitudes (valley bottom, hillside, and hilltop) but higher than 1,100 meters above sea level. It was important to include households from different elevations because previous studies (Githeko, et al., 2006) have shown that prevalence of highland malaria is differentiated by elevation, with 68, 40, and 27 percent in valley bottom, hillside, and hilltop, respectively. Other factors considered in the selection of sites were proximity to a hospital(s) and a meteorological station with reliable data.

Availability of reliable health and weather data at a nearby hospital and or meteorological station were necessary conditions for selection. All of the three sites selected have reliable government or missionary hospital records and a nearby meteorological station with good weather/climate data. Kabale, Kericho, and Muleba were selected as study sites (Figure 1). These sites not only have a recorded history of malaria epidemics in the last two decades but also have been experiencing climate variability and change since the turn of the 20th century.

2.1 Data Collection and Analysis

In order to establish the association between climate variability and malaria epidemics, climate data (temperature and rainfall) were collected from meteorological stations that were nearest to the study sites in the Lake Victoria basin for Kenya, Uganda, and Tanzania. The meteorological stations used were Kericho in Kenya, Kabale in Uganda, and Bukoba in Tanzania. This data were collected for the period of 1961 to 2001, except for Kericho, where the temperature data were from 1978 to 2001. The data were first analyzed for consistency and treatment of gaps, according to the methods of Kemp et al. (1983) and Tabony (1983). Linear regression and locally weighted scatterplot smooth (LOWESS) methods (Helsel and Hirsch, 2002) were used to determine trends.

Streamflow data, covering the period from 1961 to 2001 was obtained from National Water Ministries or Meteorological Agencies, for rivers crossing in or close to the study sites in Kenya and Uganda. Streamflow data were obtained as follows: Sondu-Miriu and Yurith Rivers for the Kericho (Kenya) site, and Kiruruma North and South

Rivers for the Kabale (Uganda) site. Because of significant quality assurance and quality control problems with the Kabale River data, it was omitted from further analysis. Rivers at or near the Tanzanian sites are ungauged, and therefore, no streamflow data were available. Thus, only streamflow data from the Kenya sites (Rivers Sondu and Yurith), covering the period 1961 to 1991, were used for analysis (Table 1). The data had some gaps that were filled in using the MOVE1 (moment of variance extension) method of flow estimation (Hirsch, 1982), based on a matching data set of three years' length to determine the relationship between the two stations' data. Single- and cross-spectral analyses were also performed to see whether there were significant cycles in the time series.

An integrated approach using both quantitative and qualitative techniques was employed in assessing the vulnerability and adaptability of the highland communities to malaria epidemics. A household survey of 150 semistructured interviews (SSIs)[1] was conducted in each study site at Kabale, Kericho, and Muleba. The survey sought to establish the health, demographic and socio-economic characteristics of the affected communities. The key variables collected include location (valley bottom, hillside, and hilltop); socio-demographic data (gender, age, level of education, marital status, and household composition); incomes (sources and monthly totals); household food security (types and regularity of meals, subsistence, and cash crop farming); wealth indicators (ownership of livestock, land, radio, bicycle, house type, and ability to buy newspapers); health issues (distance and frequency of visits to health facilities and type of facility); knowledge of disease (causes, prevention, treatment, and relationship to weather); and coping mechanisms.

Hospital records of the number of monthly cases of malaria (both in- and out-patient) were collected for Kabale, Kericho, and Muleba over a 30-year period (1971–2001). However, analysis of the health data was carried out for a six-year period (1996–2001), this is because the data before 1996 had gaps that could not be corrected. At the same time, trial check on some of the earlier data indicates that it does not vary with seasons. An alarming 750 percent increase in malaria cases in Kericho was observed over a 13-year period from 1986 to 1998 (Shanks et al., 2000). Similarly, in Kabale, malaria cases increased from 17 to 24 per 1,000 cases per month between 1992 and 1996 and 1997 and 1998, respectively (Kilian et al., 1999; Lindblade et al., 1999), and yet this is not reflected in the health data collected. This is an indication of poor records, because it is only in the last decade that highland malaria epidemics have been recognized as a national health concern by the East African governments. Health data were collected from Kabale Regional Referral Hospital, Litein Mission Hospital (Kericho), and Rubya District hospital (Muleba), respectively.

The first level of quantitative analysis involved the development of a coding scheme, which was used to transform and store the data into an electronic format. This database was consequently analyzed using SPSS for Windows Version 10.0. The first round of analysis involved the generation of frequency tables. Cross-tabulation of the key variables (e.g., use of **insecticide-treated nets** (ITNs) by income) was subsequently done to establish existing correlations and to identify vulnerable groups. The secondary health data were analyzed statistically using normalized standard deviation of mean cases of malaria patients against temperature anomalies.

The SSIs were complemented with qualitative data derived from focus group discussions (FGDs) and participatory stakeholder meetings held with primary stakeholders such as the community and, health and local administrative officials. A total of 12 FGDs (four in each study site) were conducted with communities where the household interviews had been conducted. Although deliberate efforts were made to have same-sex FGDs a few of the FGDs comprised both male and female participants. The interaction and group dynamics of the participants appeared to enhance group cohesiveness, which is an important step toward encouraging community-based adaptation strategies. Two participatory stakeholder meetings each were conducted in Kabale, Kericho, and Muleba. In these forums, the stakeholders were encouraged to play an active role and articulate their knowledge, values, and preferences regarding vulnerability and adaptation to malaria epidemics. Focus group discussions provide a good complement to semi-structured interviews (SSIs) because the information derived from SSIs can be used as a springboard to more extensive discussions in focus groups. The issues discussed included indicators of wealth, knowledge of disease, attitude, practice and impact of disease, coping mechanisms, and interventions. A combination of participatory exercises such as mapping, wealth ranking, role play, and participatory monitoring and evaluation by the communities of the efficacy of governance and civil institutions were employed.

3. Results for Climate and Hydrological Data

3.1 Climate and Hydrology of the Study Sites

(a) Temperature

Invariably, in the tropical regions, $T_{\max}$ occurs during the day and $T_{\min}$ during the night, reflecting the dominance of diurnal fluctuations in temperature on the local to mesoscale regional climate and weather in the tropics, in contrast to the higher latitudes, where diurnal cycles are much less pronounced than seasonal fluctuations (Hastenrath, 1991; Indeje et al., 2000). Both lowland and highland sites show increases in $T_{\max}$ and $T_{\min}$ over the various period lengths of the temperature data sets (Table 2). Of note is the marked increase in $T_{\max}$ (3.6ºC) in Kericho (a highland site). The temperature change (increase in $T_{\max}$ and $T_{\min}$) has generally been greater in the highlands than in the lowlands. There has been an increasing trend in $T_{\max}$ and $T_{\min}$ for the lowland sites of Kisumu and Kampala, but Mwanza showed the converse, where there has been a declining trend. The maximum temperatures ($T_{\max}$) increase from 1978 to 1999 by about 0.6ºC for Kisumu and Entebbe but remain constant for Mwanza. The minimum temperatures ($T_{\min}$) likewise show an increase of about 0.6ºC for Kisumu and Entebbe but register a decrease of slightly over 2.0ºC for Mwanza. This has probably enabled malaria vector mosquitoes to find new habitats in the highlands; hence, the creeping altitudinal ascent of unstable malaria epidemics.

The ranked $T_{\max}$ and $T_{\min}$ values (Table 3) indicate those high $T_{\max}$ years within the Lake Victoria region as a whole are associated with El Niño occurrences and concomitant high streamflow and flooding in the Lake Basin area.

(b) Precipitation

For the entire series of record that we have for the various sites (1961-2002), the rainfall analyses show that Kericho (annual rainfall range from 897 to 2420mm) and Bukoba

(884-2736mm) receive relatively high amounts of rainfall with relatively higher coefficients of variation, while Kabale (755-1282mm) receives the lowest. Generally, annual time series analysis for the period 1961-2001/2 shows a decreasing trend in rainfall at all the stations except Kabale. In all the stations, March to May (MAM) receives more rainfall than September to December (SOND). Seasonal rainfall analysis for the study sites, for the different time series, indicates that Kericho has a downward trend except in January and February (JF), while the other seasons show an almost constant trend. On the other hand, Bukoba shows a downward trend for all the seasons. Kabale is unique in that it shows a decreasing trend in the seasons of JF and MAM and an increasing trend in June, July and August (JJA) and SOND. Only Bukoba showed a statistically significant downward trend for the JF, MAM, and JJA seasons.

The ranked mean monthly cumulative precipitation data (1978-1999) show that in Kericho, wet years occur either during El Niño and La Niña years (Table 4). While the strong El Niño of 1982-83 affected Kericho, the one of 1997-98 was not significantly wetter than other years in the period of analysis. In Kabale, wet years appear to be more associated with La Niña and El Niño, but more consistently with La Niña. This may indicate the much stronger coupling of Kabale area to Atlantic airstreams and a relatively weaker influence from the southwest Indian monsoon that appears to predominate in Kericho. In Bukoba, wet years are associated with El Niño and there is one occurrence of high rainfall during a non-El Niño/La Niña year (1985). The response to El Niño at this site is, however, more erratic and more widely spaced in time. Dry years in Kericho occur during El Niño and non-El Niño/La Niña years. In Kabale, dry years occur during El Niño, and there are single occurrences of such dry years during a La Niña and non-El

Niño/La Niña year. In Bukoba, dry years are associated with non-El Niño/La Niña years, but it is of significant note that during the strong El Niño of 1982-83, Bukoba was dry, but experienced a 'normal' rainfall season in SOND.

While rainfall in East Africa tends to be above normal during EÑSO years and rainfall deficits tend to occur in the EÑSO (+1) years, the highlands often experience deficits during the boreal summer on into the short-rain season of EÑSO years and above normal rainfall during these months in EÑSO (+1) years (Indeje et al. 2000). The observed heterogeneity in the rainfall patterns around Lake Victoria may be partly accounted for, to varying degrees, by a combination of factors such as differences in topography and aspect, changes in land use, the influence of Lake Victoria, and land-ocean interaction (cf. Ogallo et al., 1989; Ropelewski and Halpert, 1987).

(c) Hydrology

There are no significant trends in the annual flows for the Sondu-Miriu and Yurith Rivers during the period of analysis (1961-1990). Moving averages, however, show that flow in the early sixties was above normal, was normal or near normal from mid-1960s to mid-1970s, above normal in the late 1970s, below normal in the mid-1980s, and normal to above normal in the early 1990s. The high flows coincide with the Uhuru Rains of 1961 to 1963, as well as the El Niño years (1968, 1970, 1978-79, 1982, 1988 and 1990). These high flows are at least one standard deviation higher than the mean flows (mean – 46.89m^3/s for Sondu-Miriu River and 31.68m^3/s for Yurith River). The mean and median flows for the Sondu and Yurith Rivers show that highest flow occurs in the MAM "long rains” season, and declines gradually through JJA with a subdued peak in August to September, and rises in the SOND “short rains” season with a peak in November. The peak river flow lags behind two of the three observed rainfall peaks (April and August) by one month, but is coincident with the rainfall peak in November.

The El Niño years exert a strong influence on the regions hydrologic balance; leading to abnormally high flows in either or both MAM and SOND. Flood frequency analysis on the Sondu-Miriu River indicates that the return period for maximum flow is between 2 to 5 years, which suggests that not only El Niño, but other mesoscale climate and weather systems in tandem can account for all the flooding events. Spectral analysis of the streamflows and cross-spectral analysis of streamflows and rainfall have a six month cycle which reflects the biannual wet seasonal cycle that characterises the Lake Victoria basin, and demonstrates that the precipitation and resulting flow in rivers within the area are a tightly coupled system.

3.4 Possible Links Between Climate, Hydrology and Malaria Outbreaks

There were some constraints in relation to the analyses of the climate and hydrological data from the three study sites. Precise location of the datasets within the study sites was constrained by the pre-determined location of the closest meteorological and hydrological stations, which in many cases did not lie within the geographical boundaries where the household surveys were conducted. In addition there was the problem of scaling for hydrology, as the gauging stations cover a much wider area of the drainage basin than the size of the study sites. However, the similarities in flow for the two different rivers (Kericho site) that were analyzed give confidence that the climatology and hydrology of the region is fairly homogenous and therefore representative of the site which is nested within the area of data coverage. Lack of high-resolution spatial and time-series datasets on land features within the area inhibited a quantitative evaluation of flooding extent and duration of floodwaters (a critical factor for the malaria vector's growth and development) within the study area during the wet seasons. This bottleneck has been circumvented by carrying out a qualitative and hypothetical analysis of the flow data in terms of relative soil moisture saturation. The lack of hydrological data for the Tanzania site and data inconsistencies for the Uganda site, mean that they could not be included in the hydrological analysis. The climate of the Lake Basin region is, however, broadly similar across the chosen sites, and the tight coupling between rainfall and hydrology as demonstrated by the cross-spectral analysis indicates that changes in rainfall can be taken as a good proxy for hydrological change. This latter case similarly applies to the current disjoint between the available malaria (1995-2002) and hydrological (1961-1991) data sets.

Despite the above constraints, the climate and hydrological data give some insights into the links between vulnerability to malaria and climate. Positive excursions in maximum temperature are significantly linked to El Niño Southern Oscillation (ENSO) (Table 3), which, in turn, has been associated with serious malaria epidemics in the Lake Basin. These results indicate that the malaria exposure risk of the highland lake communities is dramatically increased during ENSO when anomalously high temperatures and widespread flooding favors the proliferation of *A. gambiae*. Secondly, anomalously wet years are not always necessarily accompanied by anomalously high temperatures (see Tables 3 and 4), which indicates that other mesoscale climate or weather patterns, such as the Indian Ocean dipole reversal (cf. Conway, 2002) that can generate heavy precipitation events equaling or even exceeding ENSO effects, do not necessarily increase the risk of epidemic malaria in the highlands. This notwithstanding, the increasing trend in mean temperatures across the study sites in the Lake basin region over the past three decades or so suggests that perhaps a critical threshold in this relationship could be breached in the near future if the warming trends continue, and could therefore lead to increased non-ENSO related malaria epidemics in the highlands. From the flood frequency analysis, it can be deduced that the frequency of occurrence for conditions conducive to highland malaria epidemics could double in the future, assuming that the global warming trends do not significantly disrupt the current prevailing weather patterns in the region.

3.2 Results for malaria data

In East Africa, malaria represents 30–40 percent of all hospital admissions. In all the three study sites, the most reliable hospital-based morbidity data records were from 1996 on wards, as explained above. The data were reanalyzed to indicate departure of mean monthly inpatient admissions from long-term means (6 years) obtained from inpatient cases from 1996 to 2001 (Figure 2). The results were then expressed as a percent departure from the long-term mean. The data were assessed for seasonal departures from the long-term mean and for long-term trends from 1996 to 2001. Although these data are not the standard 30 year long-term[2] they, nevertheless, capture the effects of climate variability during the El Niño periods, and this gives insights into possible future scenarios under climate change. A monthly increase of 50 percent in malaria admissions above the long term mean from the respective study sites was taken as a threshold for malaria epidemic outbreaks. The first upsurge in malaria cases in Muleba was observed in May to July, and in Litein from June to July 1997. In Kabale, the number of cases during this period remained below normal (Figure 2).

Trends in malaria cases for children under five years old and individuals over five years old indicated that children under five years old were highly susceptible to malaria attacks compared to older individuals (Figure 3). Children less than five years old were 1.5 times more likely to be admitted than older individuals. This statistic correlates with the fact that younger children have lower immunity.

The most significant change in seasonal outbreaks was observed from January to March 1998 in Tanzania and Kenya, but the trends extended to May of the same year in Kabale, Uganda. The extended departure implies that the epidemic lasted for six months. In Tanzania, the epidemic caused a peak increase in cases of 146 percent, while in Kenya and Uganda the increase was 630 percent and 256 percent, respectively. The peak month for admissions in all countries was March. It should be noted that in Kenya, the government hospitals workers were on industrial strike so most of the cases were treated in Mission hospitals. The Kenyan hospital used in this study is a Mission hospital, and the cases reported include those that should have been admitted to a government one, the Kericho District Hospital. It is more likely that the increase in malaria cases in Tanzania and Uganda reflects the true trends.

Uganda had further malaria cases outbreaks in November–December 1999 (with epidemic increase of 63 percent) and again in December 2000 through February 2001 when the outbreak peaked at 312 percent in January. A small outbreak was observed in Kenya (with an increase of 78 percent) in February 2001. Data from Uganda indicate that outbreaks are more common after the short rainy season in September through November.

The most significant anomalies in temperature and rainfall were observed during the El Niño period of 1997/1998, after which there were severe malaria outbreaks. In all cases, seasonal malaria outbreaks were associated with anomalies in temperature. This observation is consistent with the well-established biology of malaria transmission. For example, anomalies at Kericho in the mean monthly maximum of 2.2-4.5°C were observed between January and March 1997 and 1.8-3.0°C in February through April 1998.

The data did not show significant annual trends in malaria cases over the period 1996–2001. However, the data from Litein, Kenya, and Muleba, Tanzania, showed a declining trend in malaria cases, while data from Kabale showed a slightly increasing trend. Data from the three study sites were compared by regression analysis to determine the degree of association among sites. Data of Tanzania and Kenya had the best association of ($R^2 = 0.59$) while R^2 for Kenya and Uganda was 0.3 and for Uganda and Tanzania was 0.29. These results indicate that there was a common effect modulating the outbreaks and this is most likely a climate phenomenon.

3.2.1 Self-medication. Up to mid-1980s, chloroquine was the drug of choice in East Africa, but by 1990, 70 percent of the parasites were showing resistance to the drug. Thereafter, in the early 1990s, sulfadoxine pyremithamine (SP) combinations replaced chloroquine as the first line of treatment for malaria. However, in the late 1990s, resistance to SP drugs significantly increased, and artemisinin-based drugs were recommended, but these were too expensive for most people. Quinine, which is still very effective, is a third-line prescription drug that is only used under hospitalization.

In Kericho, Kenya residents were asked which drugs they used for malaria treatment at home. The majority of the people (49 percent) used chloroquine, a drug for which 85 percent of the malaria parasites are resistant. The next most popular drug used by 39 percent of the people was Fansidar (sulfadoxine pyrimethamine, SP). The parasite resistance level for Fansidar is about 50 percent. Other drugs used were quinine and antibiotics, and these are prescription drugs. These data indicate that people treating themselves in Kericho are at a high risk of developing severe and complicated malaria due to drug failure or under dosage. This can result in high morbidity and mortality, particularly in populations with low immunity.

3.2.2 Knowledge of disease. Knowledge of disease was surveyed because it is essential in early detection and prevention of malaria epidemics. The study revealed that the knowledge of malaria among the communities and local health officials is couched in myths. For example, the Public Health Act requires clearing of bushes around houses to prevent yellow fever. Recent studies have demonstrated that such bush clearing creates a favorable microclimate for anopheles mosquitoes that spread malaria (Walsh et al., 1993). A second misconception was the role of climate in triggering the outbreak of malaria epidemics. For example, the year 2002; which was a relatively hot year, had a malaria epidemic episode. In 2003, the temperature was 2ºC cooler than the previous year, and there was no malaria outbreak. The Clinical Officer at Litein in Kericho attributed the low incidences of malaria in 2003 to the effectiveness of the campaign promoting the use of ITNs. However, the campaign to use ITNs has not been as successful as claimed - there is lack of supply of ITNs in the shops, and cost is also a prohibitive factor. Although the use of bed nets (treated or not) may have contributed to the low-recorded incidences of malaria in 2003, the fact that the low incidence was associated with a lower temperature suggests that climate variability may have an impact on malaria transmission in these highland areas.

Public perception and awareness on extreme weather events and disease are among the critical factors determining the prevention and adaptive capacity of individuals and communities to the impact(s) of climate-sensitive diseases such as malaria. Generally, a significant proportion of the respondents (83.2, 94.5, and 52.7 percent in Kabale, Kericho, and Muleba, respectively) could establish a link between the health of household members and weather conditions. The level of awareness of symptoms of malaria is also high. However, the level of knowledge regarding the causes and prevention of malaria is similarly widespread. For instance, different communities have developed myths around malaria. One such myth from Kenya supposes that if one eats food cooked with an edible oil called “Chipsy,” it activates malaria immediately (“*ukikula mafuta ya chipsy inaamusha malaria mara moja*”). This brand of edible oil was introduced in 1990, a year that coincided with the El Niño rains and the malaria epidemics. Another myth was that drinking water from a spring or stream source different from the one normally used causes malaria. In Muleba, Tanzania, people believe that eating maize meal instead of bananas cause malaria. Coincidentally, maize meal is usually consumed only during periods of food shortages that usually result from above- and/or below-average rains (e.g., the El Niño rains and/or La Niña droughts). These are also the periods when malaria is more rampant. Similarly, in Uganda, malarial complications, such as convulsions (neuropsychiatric events), are attributed to supernatural forces, and hence best treated with traditional medicine (Nuwaha, 2002). This often leads to delays in medical care and in many instances resulting in cure failure, thereby increasing malaria morbidity, severity, and mortality. Regarding the prevention of malaria, 62.7, 40.1, and 24.7 percent, in Kabale, Kericho, and Muleba, respectively, of people still clear bushes in the hope of eradicating malaria. Monthly household income, gender, or levels of education had a significant correlation with the level of awareness on prevention of malaria.

3.2.3 Socio-economic analysis. The surveys do reveal that the interplay of poverty and other variables intensify the vulnerability of a population to malaria's impact. This is because of a lack of economic resources to invest in health-coping mechanisms that can offset the costs of adaptation. The characteristics of the local environment in Kabale, Kericho, and Muleba indicate that variability of the climatic signals of temperature, precipitation, and hydrology trigger malaria epidemics in the East African highlands of the Lake Victoria Basin.

The socio-economic characteristics suggest certain poverty indices that reflect the vulnerability of these communities to malaria epidemics. Most of the households in the survey area live below the poverty line (on less than one dollar a day), relying predominantly on either farming or self-employment (Table 5). Formal employment that is a source of steady income is the privilege of only a few, with 19, 15, and 2 percent relying on this source of income in Kabale, Kericho, and Muleba, respectively. Indeed, when disaggregated by income group, formal employment is the most common source of income for the households found in the higher income bracket (U.S.$ 91–100 and U.S.$

101+). In addition to having poor incomes, these communities also experience household insecurity, further increasing their vulnerability. The type of food and frequency of meals that a household has is a good measure of household food security. Although most of the households reported having a fairly well-balanced diet of proteins and carbohydrates, a significant proportion of the households in the study areas indicated days of household food shortages. The poorer households are more likely to experience food shortages; for instance, 50 percent of the households with a monthly income of less than U.S.$ 30 experience days of food shortages (Table 5). Kabale and Muleba have a significantly higher proportion (54.5 and 46.7 percent) of households experiencing food shortages than Kericho (20.5 percent).

Lack of adequate health care systems coupled with persistent poverty greatly compromises the adaptive capacity of individuals and communities to take advantage of opportunities and cope with the consequences of malaria epidemics. Most households surveyed in Kericho indicated that they often visit the local dispensaries when they have malaria and not the provincial or district hospitals that are better equipped and have professional staff and inpatient facilities, but Kabale reported more use of the district hospital (59.2 percent) and private clinics (28.7 percent). Reliance on local dispensaries and private clinics for treatment often results in misdiagnosis due to lack of qualified staff or self-medication by the respondents. Table 6 indicates the types of health facilities visited by the respondents in all the three East African countries. However, respondents report that they sometimes prefer private clinics because they provide a quicker service, unlike public health facilities that are often overcrowded and have long queues of patients. The medical and support staff in the public facilities are also considered generally unfriendly by the patients. The predominant mode of transport used to get to medical health facilities is a bicycle for all income groups apart from the highest income group (Table 5). Most respondents indicated that this was due to the high cost of motorized transport. The inaccessibility of health facilities is also reflected in the low frequency of visits to health facilities (Table 7). In addition, the malaria mortality rate appears to be more prevalent among the low-income households; indeed, 30 percent of households living below the poverty line had lost a household member in the past five years (Table 5). Coping mechanisms that increase accessibility of the local health infrastructure need to be developed to reduce the vulnerability of these communities. Generally, the poverty indices indicate that vulnerability increases as monthly household incomes decrease and days of food shortages and household mortality increase, while proportion of bed nets in use decrease (Table 5).

3.2.4 Existing coping and adaptation mechanisms. The use of ITNs is one of the preventive measures advocated by the Malaria Global Control Strategy, as well as the national malaria control programs in East Africa[3]. However, the survey revealed that the use of ITNs is not very widespread, particularly among the poorer households with monthly incomes of less than U.S.$ 30 and U.S.$ 31–40, in which 76.2 percent and 69 percent do not have bed nets (Table 5). A further illustration of the possible influence of income on bed net use is derived from Kabale, where the proportion of household members sleeping under a bed net increases with the increase in average income. Farming and self-employment were the most common source of income generation, but these are largely unpredictable and unreliable, especially in the context of the East African rural communities that are characterized by a weak economic base. Such sources of income leave the communities vulnerable to external shocks and to seasonal and climatic variability and change[4]. In such circumstances, it is formal employment that can guarantee an income to the household even in times of sickness. Therefore, this means that the poor groups, who also have poor nutrition, are more vulnerable to malaria than the well-off households.

The World Health Organization's (WHO, 2002) program on "Roll back malaria" has been adopted by most countries in Africa. The three East African governments actively promote this program, whose objectives toward malaria eradication are increase in the use of ITNs, early diagnosis and treatment of malaria, and use of effective antimalarial drugs. This program has attracted several local and international civil societies. One such nongovernmental organization active in East Africa is the Population Services International (PSI), which receives financial support from both the British and U.S. Governments. Its stated objective is to increase the use, ownership, and availability of ITNs in Kenya, Uganda, and Tanzania, to be within reach (i.e. a 15 minute-walk distance) in the malaria-endemic areas. As such, marketing promotion of ITNs is prevalent in most market centers in East Africa. However, the cost of a subsidized ITN, which is U.S.$ 1.50 is beyond the reach of those households living below the poverty line (Table 5).

Despite the widespread promotion of the use of bed nets, the survey revealed that the majority of households do not use ITNs. This has implications for the effectiveness of the "Roll back malaria" program for two reasons. First, the size of the household and the number of mosquito nets available may affect the effectiveness of ITNs in rolling back malaria. Secondly, those using bed nets tend not to treat the nets with insecticides (75 percent) and if they do treat the nets, it is likely to be once or twice a year (25 percent). Therefore, the treatment of nets with insecticides is clearly not a common practice. A household may have as many as 16 persons with an average size of 3–7 persons. The number of bed nets on the other hand, may range from 1 to 6 and out of those who use these nets, only 28.1 percent treat them with insecticides twice a year. For example, in Kabale, Uganda, only 39 percent of households had at least one net in the house. For these households, not everyone has the chance to sleep under a bed net. The analysis showed that for those who have nets, only 37 percent could afford to have more than three quarters of the household members sleeping under nets.

The survey reveals that there are very few coping mechanisms available for the households. The respondents indicate that in the likely event that a malaria epidemic does occur, the majority (75.5 percent) sell their food crops in order to cover the cost of treatment. Other ways of coping include borrowing or relying on remittances from relatives. In Kabale, focus group discussions revealed that a number of people have resorted to selling land in order to cope with malaria. Out of the 30 participants in the group, 13 reported to have sold land at some stage in the last eight years in order to cope with malaria in the family. The stated coping mechanisms deplete respondents' resources and may lead to increased food shortage, debts, and poverty.

Among the adaptations to highland malaria has been the use of traditional curative measures (using local herbs as insect repellents or antimalarial treatments). It appears that this is a crucial adaptation strategy in Muleba, Kericho, and Kabale, particularly given the high poverty levels in the area. Surveys carried out by the National Institute for Medical Research (NIMR) in Tanzania noted that traditional healers have knowledge and skills useful for malaria disease management (diagnosis, treatment, and prevention). Further, NIMR laboratory analyses of traditional herbs established their efficacy and safety. Toxicity varied from low to very high (Mwisongo and Borg, 2002).

Another adaptation measure concerns the increasing use of bed nets and, more recently, the use of insecticides-treated nets. However, the biggest concern is that not many people can afford buying bed nets for the entire household. Rarely, do local communities use hospital-administered medicines for treatment of malaria. However, given the high costs involved and often long distances to health facilities, many people in the vulnerable areas resort to self-treatment.

4. Predicting malaria epidemics using climate data

The observed increase in maximum or both minimum and maximum temperatures and the relatively higher temperature variability in the highlands, as compared to the lowlands, have probably increased the mosquito productivity in vector habitats, thus increasing vector populations and, in turn, increased malaria transmission. This would partly explain why episodic malaria outbreaks have been increasing at higher altitudes. Githeko and Ndegwa (2001) have found several lines of evidence to support this view. For example, vector larval survival is very low in low-temperature regimes, but this improves at higher water temperature. Also, mosquito biting frequency increased in deforested areas compared to a forested area due to temperature change of 2°C in the western Kenya highlands Githeko et al., 2006).

The period March-April-May (MAM) receives more rainfall than the September-October-November (SON) or September-October-November-December (SOND) season throughout the three study sites. During MAM, when the highest rainfall in the year occurs, rivers overflow their banks and flood their basins, while in much wider areas, the soils get saturated, encouraging retention of standing water on land. There is a one-month lag between the peak rainfall and the peak river flow, as the rivers are largely recharged by land runoff and groundwater flow from its drainage basin. The malaria epidemics tend to occur from July to September; since peak rainfall occurs in April, there is a minimum two-month lag between the peak rainfall and the epidemics: this is related to a one-month lag between peak rainfall and peak streamflow, and a further one-month lag related to the ontogeny of the malaria vector. During El Niño years, when the short rains (SOND) are anomalously heavy and temperature is high, there exists the potential for malaria epidemics in January-February (JF) as the characteristic conditions of MAM season are replicated.

Figures 4 and 5 indicate that malaria outbreaks are sensitive to maximum temperature with a lag of one to four months after the maximum peak to the onset of malaria episode (Githeko and Ndegwa, 2001), which agrees with the hydrological data. However, recent ecological data, (Githeko and Ndegwa, 2001) clearly indicate that transmission intensities and malaria prevalence can vary up to fivefold in sites at the same altitude due to the shape of the valleys, which determine the availability and stability of mosquito breeding habitats. Thus, although the general principal of the model is valid, there is a need to fine-tune it to specific ecological zones. Furthermore, changes in malaria treatment policies can affect the outcome of the model, as the use of effective antimalaria in primary health care levels can dramatically reduce the number of cases in hospitals. Analysis of trends in temperature data indicated that in Kabale, Uganda, there has been an increase of 1.17°C in mean annual minimum temperature between 1960 and

2001. In Kericho, Kenya, the mean annual maximum increased by 3.5°C. In Bukoba, Tanzania, the mean annual maximum and minimum temperatures were found to have increased by 0.21 and 0.49°C, respectively, between 1960 and 2001, adding up to 0.70 °C over the period. However, Bukoba lies on the shores of Lake Victoria, at an altitude of 1,100 meters above sea level. Whereas climate data are collected on a regular basis, this has not been the case for malaria data, with the exception of a few privately owned hospitals in some tea estates. The long-term climate data demonstrated a trend toward warming in the highlands, an observation that suggests improved transmission conditions. Although the five-year malaria data cannot be used to detect long-term trends in transmission, it nevertheless demonstrated that malaria cases are associated with climate variability. A 1ºC increase in temperature is equivalent to a reduction of 154 meters in altitude. For example, the transmission conditions at 1,500 meters above sea level would become equivalent to conditions at approximately 1,200 meters above sea level for an increase of 2ºC, thus making malaria at 1,200 meters above sea level to be considered stable and hyperendemic.

The risk of a malaria epidemic is associated with positively anomalous temperatures in the months preceding and during the rainy season. Temperature controls the rate of larval and parasite development. Higher temperatures shorten the development time of the larvae and parasites in the mosquitoes. The logistic model for the effects of temperature and rainfall (Githeko and Ndegwa, 2001) indicates that the rate of growth of a mosquito population is dependent upon the initial population size before the rainy season. Climatic events that create this condition can precipitate epidemics. Rainfall increases the availability of mosquito breeding habitats and thus the size of the mosquito population. The intensity of malaria transmission is proportional to the size of the mosquito population.

The original model (Githeko and Ndegwa, 2001) only took into consideration precipitation and temperature in predicting malaria epidemic outbreak. However, recent studies (Zhou et al., 2004) indicate that the availability and stability of mosquito breeding habitats and the initial vector population size before the rainy season are also a function of drainage efficiency and epidemic propagation and intensity. Rainfall increases the availability of mosquito breeding habitats and thus the size of the mosquito population.

Githeko and Ndegwa (2001) showed that malaria epidemics in Kakamega district in western Kenya could be predicted using a simple temperature and rainfall data. The model was able to identify climatic conditions that were permissive to the mosquito population in rapid growth leading to epidemics one or two moths later. One of the problems with the model is incidence of temperature and precipitation anomalies, usually occurring in January and February, which did not coincide with wet periods. The JF rains are associated with the Indian Ocean dipole reversal episodes that cause off-El Niño rains in East Africa (Nicholson, 1996; Conway, 2002). The model does not take these unpredictable off-seasons rains into account, and hence, the discrepancy. In the case of the El Niño period, rainfall continued from November of 1997 into January and February of 1998, thus creating perfect breeding habitats for malaria vectors.

Zhou et al. (2004) further attributed a significant variability in malaria incidence to climate in several sites in East Africa. We used the data from the three sites to determine whether the model of Githeko and Ndegwa was applicable to other sites in East Africa. Our preliminary results show that with a slight modification the model was able to identify major epidemics in Kericho, Kabale and Muleba (Figure 4). In all cases the epidemics were associated with anomalies in the mean monthly maximum temperature one or two months before the epidemic. The other necessary condition was significant increase in rainfall one month before the peak of the epidemic. The model is being further refined to take into consideration the drainage characteristics of individual sites as this affects the rainfall thresholds used in the model. The ability to forecast an epidemic with a time lag of about two months prior to the event is critical in decision making and logistics of putting preventative and curative measures in place in timely fashion.

5. Conclusion

There have been changes in climate at the three study sites, and these changes are consistent with what has been observed and documented by previous research in other parts of the highlands of East Africa. The maximum and minimum temperatures have changed, with significant increases generally recorded at all sites. The temperature change has been more pronounced at the higher altitudes than in the lowlands. The observed temperature increase has enabled malaria vector mosquitoes to find new habitats in the highlands. Similarly, the rainfall pattern has changed. Generally, time series analyses for the 1961–2001 period show decreasing trends in rainfall for all of the stations except Kabale. Hydrological data show that for the Kericho site, the peak river flow lags behind two of the three observed rainfall peaks (April and August) by one month, but is coincidental with the rainfall peak in November.

The malaria epidemics often occur from the months of July to September; since peak rainfall occurs in April, there is a minimum two-month lag between the peak rainfall and the epidemics. If, for a given year, the maximum and minimum temperatures are consistently conducive for development and growth of the malaria vector, then the two-month lag between peak rainfall and the onset of the epidemics can largely be accounted for by the one-month lag in peak stream flow.

During the 1997/1998 El Niño, malaria admission data indicated that the epidemic months corresponded with the onset of abnormally high-elevation short rains, or El Niño years preceded with a season of abnormally high maximum temperatures. This was confirmed with the observation of anomalies in the mean monthly maximum of 2.2–4.5°C between January and March in 1997 and 1.8–3.0 °C between February and April in 1998. Other cases of malaria epidemics follow the trends described above, with the highest incidents in March, April, and May and July, August, and September during the long and short rainy seasons, respectively.

Poverty seems to play a very big role in the vulnerability of the communities to climate change and variations in the social system. Communities lack effective strategies for coping with climate-induced shocks such as disease and weather extremes, especially because of poverty and inadequate early warning mechanisms. There is also lack of a good information system to communicate predictable effects of climate change. With early warning systems and good communication, the management of malaria epidemics in the East African Highlands could be geared toward anticipatory adaptation measures, which are more sustainable.

The communities in this study are susceptible to malaria attacks. Household incomes, for instance, are low and derived from largely insecure and uncertain sources. Self-employment is the major source of income. This exposes people to external shocks. The majority hold employment as petty traders, taxi/cycle transporters, casual workers, and subsistence farmers. Those who may be employed as unskilled workers have no work contracts, and hence, are quickly and easily replaced. Therefore, members of the communities are unable to build capacity to counteract climatic extremes. The East African governments have no comprehensive programs or fiscal facilities to deal with climate variability and extremes. Malaria programs run by civil societies or governments receive assistance from major external resources. Therefore, the local capacity to develop adaptive strategies to cope with climate variations and extremes is still very poor, at all levels, and remains a big challenge.

Future adaptation programs should take into account the diversity of factors that influence a society's capacity to cope with the changes. Such programs should have as major components the demographic trends and socio-economic factors, since these have an effect on land use, which may, in turn, accelerate or compound the effect of climate change. Trends in demographic, economic, and social development would definitely have a dampening effect on the potential consequences of climate change. HIV/AIDS, malaria, diarrheal diseases, respiratory diseases, and others are very big factors in the people's health, productivity, and responsiveness to external threats. The trends in dealing with these diseases must therefore be factored into the analysis of the future effects of climate change on the vulnerable system.

Findings from this study show that malaria is closely associated with socio-economic factors. However, climatic variability plays an important role, in that it contributes to the increasing frequency of extreme wet and dry periods, thus leading to crop failure, associated with either excessive rains or drought. Shortage of food contributes to malnutrition, particularly, in poor households resulting in ill health that makes individuals vulnerable to diseases such as malaria. These poor families cannot afford preventive and curative measures and have high malaria mortality rates. Although there is an increase in the use of bed nets, many households are unable to buy sufficient mosquito nets for all household members, because of large household sizes and the low incomes of the households.

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Endnotes

[1] This sample represents 4, 5, and 7 percent of the total number of households in the lowest level of administrative unit in Kabale, Kericho, and Muleba.

[2] Standard long-term data refer to a mean of 30 years climate data, and the long-term trend is the regression analysis of this data.

[3] Malaria programs and strategies in East Africa are guided by the overall health policy whose goal is to provide universal primary health care. Such strategies seek to reduce malaria through the promotion of primary health care, increasing access to health care services and encouraging the private sector to play a greater role in the delivery and financing of health care services. Coexisting with national health policies are international ones such as the Global Malaria Control Strategy that advocates four technical measures:

- Sustainable preventive measures such as the use of ITNs;
- Early diagnosis and treatment;
- Early detection and prevention of epidemics; and
- Strengthening local research capacities.

[4] Subsistence farmers in Kabale, for instance, are worried that they can no longer accurately predict the onset of rains and that even the rains have reduced in amount. This is affecting their agricultural productivity, income, and nutritional status, hence, their increased vulnerability to climate-related diseases.

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Tables

Table 1: Geographical Positions of Stream flow gauging Stations, Kericho Area

ID	**Longitude**	**Lattitude**	**Altitude**	**Name**
IJG01	35.008333	–0.393056	1500	Sondu
1JD03	35°04’45’’E	0°28’35’’S	>1500	Yurith

Table 2: The Long-Term Context of Temperature Changes in the Lake Victoria Basin, Showing Results for Highland Sites Based on Linear Regression

Station	**Period of analysis**	**Temperature change (ºC)**	
Kericho	1978–2001	Max	3.6
		Min	0.5
Kabale	1960–2003	Max	1.1
		Min	1.6
Bukoba	1960–2002	Max	0.7
		Min	1.1

Table 3: Ranked T_{max} and T_{min} with High T_{max} and Low T_{min} for the Period 1978 to 1999, Compared with Occurrence of El Niño and La Niña years

Site	**High T_{max} years**	**Low T_{max} years**	**High T_{min} Years**	**Low T_{min} years**	**El Niño years**	**La Niña years**
Kericho	1981, **1991**, **1994-1995**, **1997**, ***1999***	**1978**, 1985	**1987**, ***1989***	1981, **1991**	**1977-1978;** **1982-1983;** **1986-1987;** **1991-1992;** **1992-1993;** **1994-1995;** **1997-1998**	***1988-1989;*** ***1995-1996;*** ***1998-1999;*** ***1999-2000***
Kabale	**1982-1983**, **1995**, **1997**	-	**1983**, **1997**	**1978**, 1985, **1993**		
Bukoba	**1983**, **1987**, **1997**, ***1999***	1985	***1996***, **1997-1998**	**1987**, **1993**		

T_{max} ≥ 1 standard deviation from long-term mean. T_{min} ≤ 1 standard deviation from long-term mean. Bold, El Niño years; bold/italic, La Niña years; normal font, non-El Niño/non La Niña years.

Table 4: Ranked mean monthly cumulative precipitation with wet years (≥ 1 standard deviation from long term mean) and dry years (≤1 standard deviation from long term mean) for the period 1978 to 1999, compared with occurrence of El Niño and La Niña years

Site	Wet Years	Dry Years	El Nino years	La Nina years
Kericho	**1982**, ***1988-1989***, **1992**, **1994**, ***1996***	**1978**, 1980, 1984, **1986**, **1993**, ***1999***	**1977-1978;** **1982-1983;** **1986-1987;** **1991-1992;** **1992-1993;** **1994-1995;** **1997-1998**	***1988-1989;*** ***1995-1996;*** ***1998-1999;*** ***1999-2000***
Kabale	**1987**, ***1988***, ***1996***, ***1998***	1979, **1982**, **1993**, ***1999***		
Bukoba	1985, **1986**, **1994**	1980, 1981, **1982-1983**		

Note: Bold – El Niño years; bold/italic, La Niña years; normal font, non-El Niño/non La Niña years.

HIGH
VULNERABILITY

LOW
ERABILITY

Table 5: Selected Indicators of Vulnerability to Malaria Epidemics

Monthly household income (US$) [a]	**Proportion of households (%)**	**Predominant source of Income**	**Average household size**	**Days of food shortages (%)**	**Households without bednets (%)**	**Household malaria mortality (1998-2002) (%)**	**Most common mode of transport (%)**
<=30	47.8	Farming (54.5%)	8.0	50	76.2	30.0	Bicycle (46.7%)
31–40	12.2	Farming (73.5%)	7.4	47.2	69.0	16.7	Bicycle (32.4%)
41–50	7.1	Self employment (50%)	5.7	40	20.0	5.9	Bicycle (70.0%)
51–60	6.4	Farming (94%)	7.6	38.9	13.0	0	Bicycle (37.5%)
61–70	7.1	Farming (60%)	6.0	35	10.0	0	Bicycle (52.9%)
71–80	2.4	Farming (57.1%)	6.4	34.4	10.0	0	Bicycle (57.1%)
81–90	3.2	Self employment (66.7%)	5.3	23.5	3.0	0	Bicycle (100%)
91–100	2.0	Formal employment (60%)	7.6	14.3	1.0	1	Bicycle (80%)
101 [b]	11.8	Formal employment (54.5%)	7.0	0	1.0	1	Motor vehicle (56.3%)
Total	100.00 (*n* = 450)						

[a] The average monthly income is U.S.$ 50.2, whereas the most common income (mode) is U.S.$ 25.6.

[b] The highest monthly income in this class is U.S.$ 580.3.

Table 6: Type of Health Facility Visited

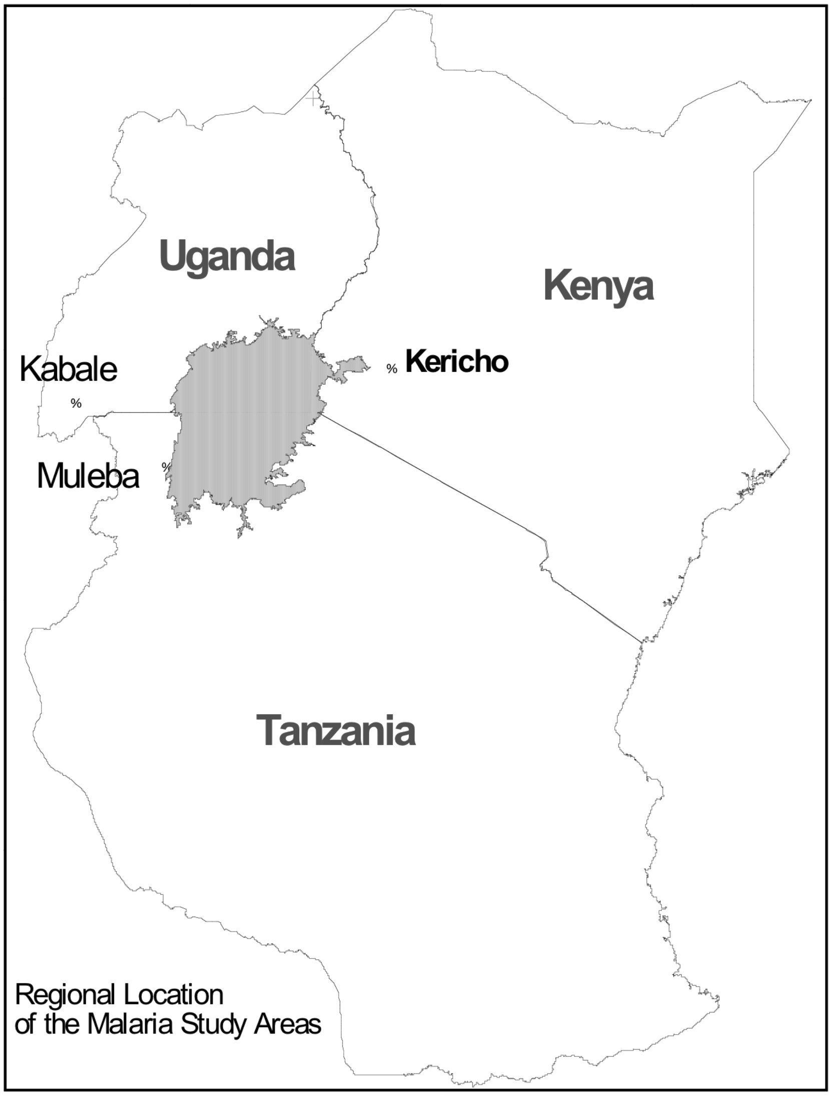
Health facility	**Kericho**	**Kabale**	**Muleba**
Provincial hospital		0.6%	0.7%
District hospital	1.0%	2.5%	11.7%
Health center	5.5%	59.2%	15.3%
Local dispensary	91.5%	20.3%	50.3%
Mobile dispensary			5.3%
Herbalist			10.0%
Private hospital	1.0%	6.4%	6.7%
Private clinic	1.0%	11.0%	
Total	**100%**	**100%**	**100%**

Table 7: Visits to Hospitals in the Last Three Months by Household Members

No of Visits	**Kericho**	**Kabale**	**Muleba**
0	44.4%	31.4%	28%
1	24.5%	37.1%	41.3%
2	15.9%	21.4%	16%
3	9.9%	7.5%	9.3%
4	2.0%	1.3%	2%
5	1.3%	0.6%	2%
6	1.3%		0.7%
9	0.7%		
			0.7%
Total	100%	100%	100%

Figures

Figure 1: Geographical Information System maps of the three study sites in Uganda, Kenya, and Tanzania



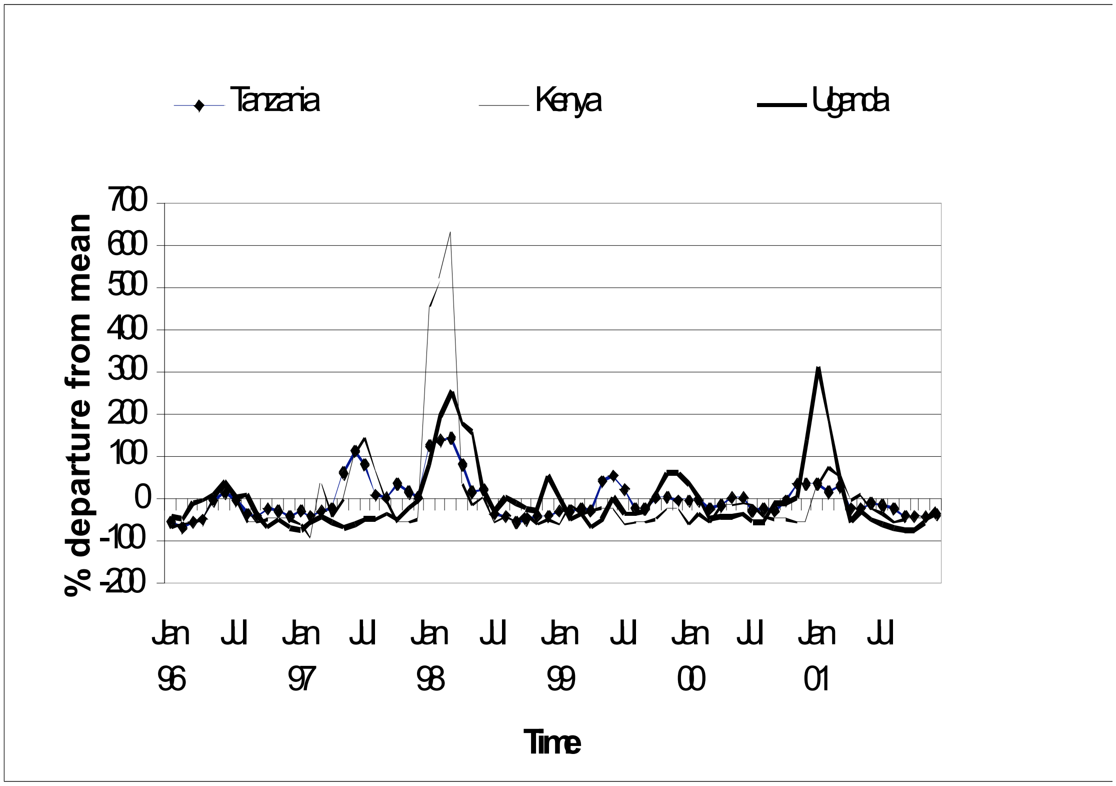


Figure 2: Trends in malaria hospital admissions in Kenya, Tanzania, and Uganda.

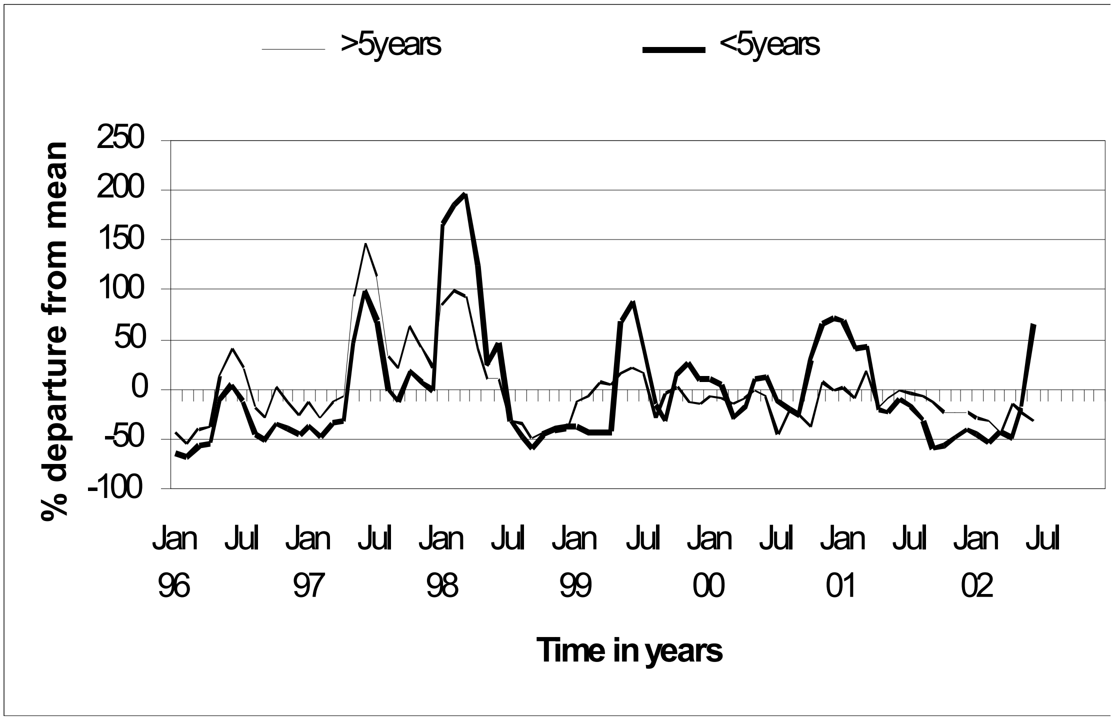


Figure 3: Trends in malaria in children < 5 years old in Muleba Tanzania.

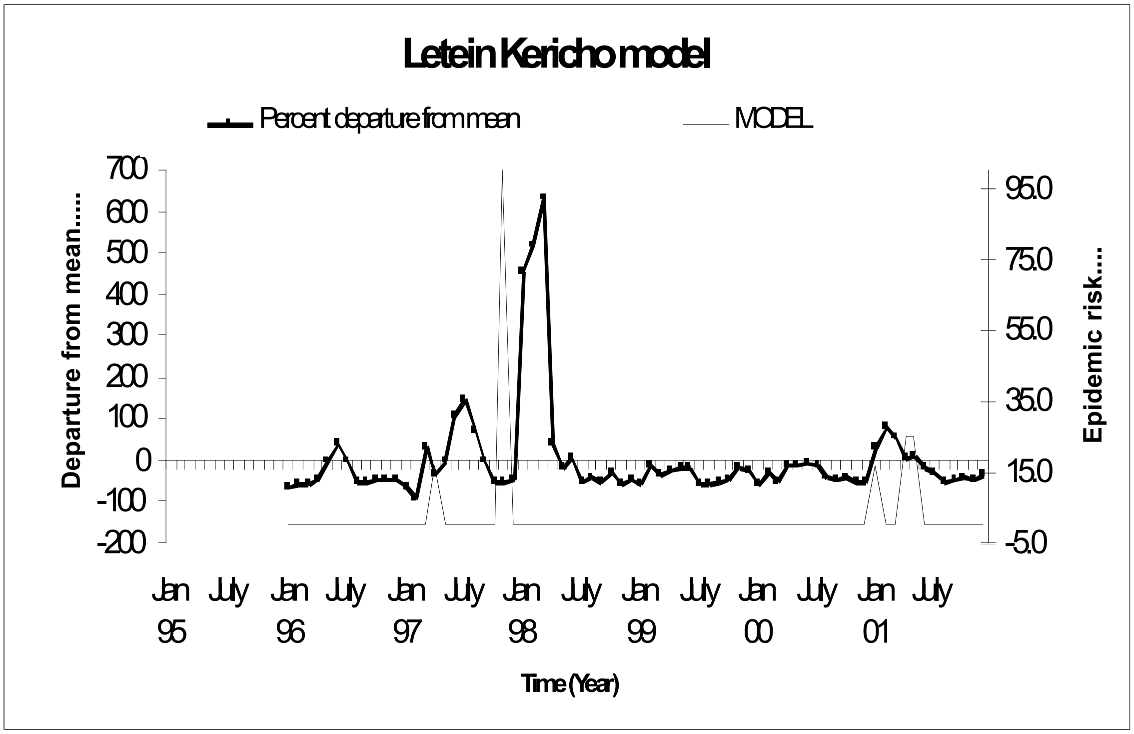


Figure 4: Modeled climate and malaria data for Litein in Kenya.