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Vulnerability to epidemic malaria in the highlands of Lake Victoria basin: the role of climate change/variability, hydrology and socio-economic factors

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Abstract Endemic malaria in most of the hot and humid African climates is the leading cause of morbidity and mortality. In the last twenty or so years the incidence of malaria has been aggravated by the resurgence of highland malaria epidemics which hitherto had been rare. A close association between malaria epidemics and climate variability has been reported but not universally accepted. Similarly, the relationship between climate variability, intensity of disease mortality and morbidity coupled with socio-economic factors has been mooted. Analyses of past climate (temperature and precipitation), hydrological and health data (1961–2001), and socio-economics status of communities from the East African highlands confirm the link between climate variability and the incidence and severity of malaria epidemics. The communities in the highlands that have had less exposure to malaria are more vulnerable than their counterparts in the lowlands due to lack of clinical immunity. However, the vulnerability of human health to climate variability is influenced by the coping and adaptive capacities of an individual or community. Surveys conducted among three communities in the East African highlands reveal that the interplay of poverty and other socio-economic variables have intensified the vulnerability of these communities to the impacts of malaria.

1 Introduction

The Lake Victoria basin (0°21′ N–3°0′ S; E) has a catchment area of 181,000 km^2 and a total water area of 68,800 km^2. The catchment area is shared by Kenya, Uganda, Tanzania, Rwanda, Burundi while the lake itself is shared by Kenya, Uganda and Tanzania, with each owning 6%, 51% and 43% respectively. The human population, that is heavily concentrated near the lake (Cohen et al. 1996), is estimated to be about 30 million (World Bank 1996), growing rapidly at about an average of 3% per year, and is expected to double within the next two decades (World Bank 1996). The lake basin supports one of the densest (more than 100 persons/km^2, and up to 1,200 persons/km^2) and poorest rural populations in the world (Hoekstra and Corbett 1995; Cohen et al. 1996).

Invariably, in the tropical regions, maximum temperature (T_{max}) occurs during the day and minimum temperature (T_{min}) during the night/early morning, reflecting the dominance of diurnal fluctuations in temperature on the local to meso-scale 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). Rainfall variability is closely linked to many global and regional scale systems that include both El-Niño-Southern Oscillation (ENSO) and Sea-Surface Temperatures (SSTs) in the Indian and Atlantic Oceans (Ropelewski and Halpert 1987; Ogallo et al. 1989). The inter-annual variability of rainfall for the East African region is dominated by recurrences of above 10 to 11 years, 5 to 6 years, 3.5 and 2.3 years spectral peaks (Ogallo et al. 1989; Nicholson 1996). An example of the extreme variability of rainfall in individual years is during 1961 when Lake Victoria rose several metres and reached levels unattained since the nineteenth century (Nicholson 1996). The other extremely wet years in the region were the 1997/98 events that have traditionally been linked to El Niño. The 1961 episode was linked to Indian Ocean circulation anomalies, including strong influence by Indian Ocean SST dipole (Conway 2002; Mutemi 2003). The extremely dry years include 1984 and 2001–2002 that were linked to La Niña (Indeje et al. 2000). The inter-annual variability of rainfall is remarkably coherent throughout most of eastern Africa during the 'short rains' season of October–December (Ogallo et al. 1989; Nicholson 1996).

Since 1988 malaria epidemics have been reported with an increasing frequency in the highlands of Eastern Africa (Mouchet et al. 1998). Similar epidemics in the highlands were observed between 1920 and 1940 (Garnham 1945; Roberts 1964). Several factors account for these epidemics and this range from drug resistance, land use change, vector migration and poverty, to climate variability (Lepers et al. 1988; Khaemba et al. 1994; Loevinsohn 1994; Lindsay and Martens 1998; Malakooti et al. 1998; Mouchet et al. 1998; Some 1994; Matola et al. 1987; Fowler et al. 1993). Zones of unstable malaria are more sensitive to climate variability and environmental changes than those where the disease is endemic (Mouchet et al. 1998). El Niño events lead to elevated temperatures and enhanced precipitation in parts of Eastern Africa which increases malaria transmission (Kilian et al. 1999; Lindblade et al. 2000). On the other hand, Hay et al. (2002) dispute this claim, asserting that their climate data analysis showed no significant changes in temperature or vapour pressure at any of the highland sites reported to have had high malaria incidences. However, these views have been challenged by Patz et al. (2002) and Zhou et al. (2004, 2005) who have shown that climate variability contributes more variance to malaria patient numbers than autocorrelation and seasonality. They found highly significant nonlinear synergistic effects of the interaction between rainfall and temperature on malaria patient time series.

Globally, malaria causes about one million deaths annually out of which more than 90% occur in Africa. It is one of the major killers of infants, pregnant women and the elderly on the continent (World Malaria Report 2005; WHO 1996; Greenwood 2004; Greenwood and Mutabingwa 2002; McMichael et al. 1996). It constitutes 25–35% of all outpatients clinic visits, 20–45% of all hospital admissions in sub-Sahara Africa and 10% of the continent's overall disease burden (Africa Malaria Report 2003). The disease deprives Africa of US$ 12 billion every year in lost Gross Domestic Product (GDP) (Mocumbi 2004) and traps countries into poverty (Sachs and Malaney 2002). A significant proportion (15.5%) of East Africa's population is found in the highlands where the most severe forms of malaria occur within all age groups (Githeko et al. 2006; Lindblade et al. 1999).

In 2002 Kenya reported 124,197 malaria cases of whom 38,426 were infants (below 5 years) and 135 reported malaria deaths. In 2002 and 2003 in Uganda, there were 7,216,411 and 12,343,411 cases of malaria resulting in 6,735 and 8,500 deaths respectively (World Malaria Report 2005). In Tanzania, malaria causes between 70,000 and 125,000 deaths annually, and accounts for 19% of the health expenditure (De Savigny et al. 2004a, b). In East Africa malaria is the leading cause of morbidity and mortality in both children and adults. Malaria has been creeping upwards from the lowlands to the highlands in the Lake Victoria region in East Africa, and indications are that it has been aggravated by climate variability and change as well as poverty.

Malaria is most prevalent in the typically wet and humid tropics. This being the case, it is of great concern that the changing climate may affect the transmission intensity and geographic distribution of the disease and thus affects vulnerable populations with a low coping capacity (Martens et al. 1999). Documentation of socio-economic impact of malaria in Africa has recently been reported by Spielman and Seiguer (2003) for Ethiopia and the methodology validated for Kenya, Uganda and Tanzania. That frequent malaria epidemics have been observed in the warmest decades of the twentieth century is consistent with the biology of its transmission. It is thus prudent to determine to what extent the densely populated highlands of East Africa are vulnerable to malaria as a result of climate variability and change. Temperature and precipitation in the highlands are expected to rise above the minimum temperature and precipitation thresholds of malaria transmission in various parts of the region as a result of predicted climate change (Githeko et al. 2000).

In addition to temperature and precipitation, other physical variables, such as soil moisture or its proxies (e.g. streamflow), improve modelling of malaria transmission, as they explain the interaction between precipitation, temperature, and the ground (Patz et al. 1998).

This paper explores the interplay between climate variability and change, hydrology, socio-economic factors, and the incidence of epidemic malaria in target populations living in the highlands of Lake Victoria basin. In addition, the paper examines the vulnerability and coping strategies of these target populations, as well as the excess risk to which they are exposed as a result of climate change. According to IPCC Fourth Assessment Report (IPCC 2007), climate change can manifest itself as changes in mean patterns of climate, or in the magnitude and frequency of extreme events. Examples include increases in the frequency of El Niño/La Niña episodes or floods and droughts.

One of the main findings of the IPCC TAR (McMichael et al. 1996) was that changes in climate, including changes in climate variability, would affect many vector-borne infections. Populations at the margins of the current distribution of diseases might be particularly affected.

The transmission of some mosquito-borne diseases is affected by drought events. During droughts, mosquito activity is reduced and, as a consequence, the population of non-immune persons increases. The incidence of mosquito-borne diseases such as malaria decreases because the mosquito vector lacks the necessary humidity and water for breeding.

The spatial distribution, intensity of transmission, and seasonality of malaria is influenced by climate in sub-Saharan Africa; socio-economic development has had only limited impact on curtailing disease distribution (Hay et al. 2002; Craig et al. 2004). Rainfall can be a limiting factor for mosquito populations and there is some evidence of reductions in transmission associated with decadal decreases in rainfall. Interannual malaria variability is climate-related in specific ecoepidemiological zones (IPCC 2007). However, the attribution of changes in human diseases to climate change must first take into account the considerable changes in reporting, surveillance, disease control measures, population changes, and other factors such as land use change.

2 Methodology

In order to study the linkage between malaria and climate, relevant climate and malaria data were collected from meteorological stations and hospitals in several study sites. The climate data used had missing records which were filled using standard statistical methods as described under Section 2.2.1. However, only health data without gaps were used in the analysis due to lack of long term health records required for data extrapolation. Basic statistics were derived from the collected data. This included mean, variance, standard deviation and correlation coefficients and regression analysis. While correlation coefficients examined the degree of relationship between the variables, regression analysis provided a simple mathematical formulation for cases with significant relationships. Time series were also plotted for anomalous rainfall, temperature (maximum and minimum) and malaria cases. The association between climate and malaria data anomalies were determined from these statistics. Socio-economic data was collected from selected households in the study villages using semi-structured interviews. Focus group discussions were used to validate observations from the questionnaire data. This study took a multidisciplinary approach involving meteorologists, hydrologists, health experts and social scientists.

2.1 Selection of study sites

Three criteria were used to select the study sites and populations. First, at each study site, communities living at various altitudes (valley bottom, hill side and hill top) but higher than 1,500 m above sea level (ASL) in the Lake Victoria basin and with a history of epidemic malaria were selected (Fig. 1). The second criterion was the presence of a government or a missionary hospital with well maintained and credible accessible malaria data. Finally, the sites were required to have a meteorological station with long term data located nearby and the station must be within the same climatological zone as the study site.

2.2 Data collection and treatment

2.2.1 Climate data

Temperature and rainfall data were collected from three meteorological stations that were closest to the study sites - Kericho, Kabale and Bukoba in Kenya, Uganda and Tanzania respectively. Although the data was collected for the period 1961–2001, the period selected for site comparison of the climate datasets was from 1978 to 1999. This was based on the shortest record, primarily due to the need to compare the datasets from the three sites without any temporal biases, such as in the determination of the magnitude of change. Data gaps were treated according to the methods outlined in Kemp et al. (1983) and Tabony (1983).

2.2.2 Malaria data

In- and out-patient malaria data were collected from Litein, Kabale and Muleba hospitals in Kenya, Uganda and Tanzania respectively. Data from Tanzania was categorized into age groups under 5 years and those above 5 years and were thus suitable for analysis of the impacts of malaria on children. Blood transfusion data associated with malaria induced anaemia were also available from the Tanzania data set. Data on the incidence of malaria during pregnancy was not available.

2.2.3 Hydrological data

The only co-located stream flow gauges are for the Yurith (station 1JD03, 35°00′ E, 0°39′ S) and Sondu-Miriu (station 1JG01, 35°04′ E, 0°28′ S) rivers in Kericho

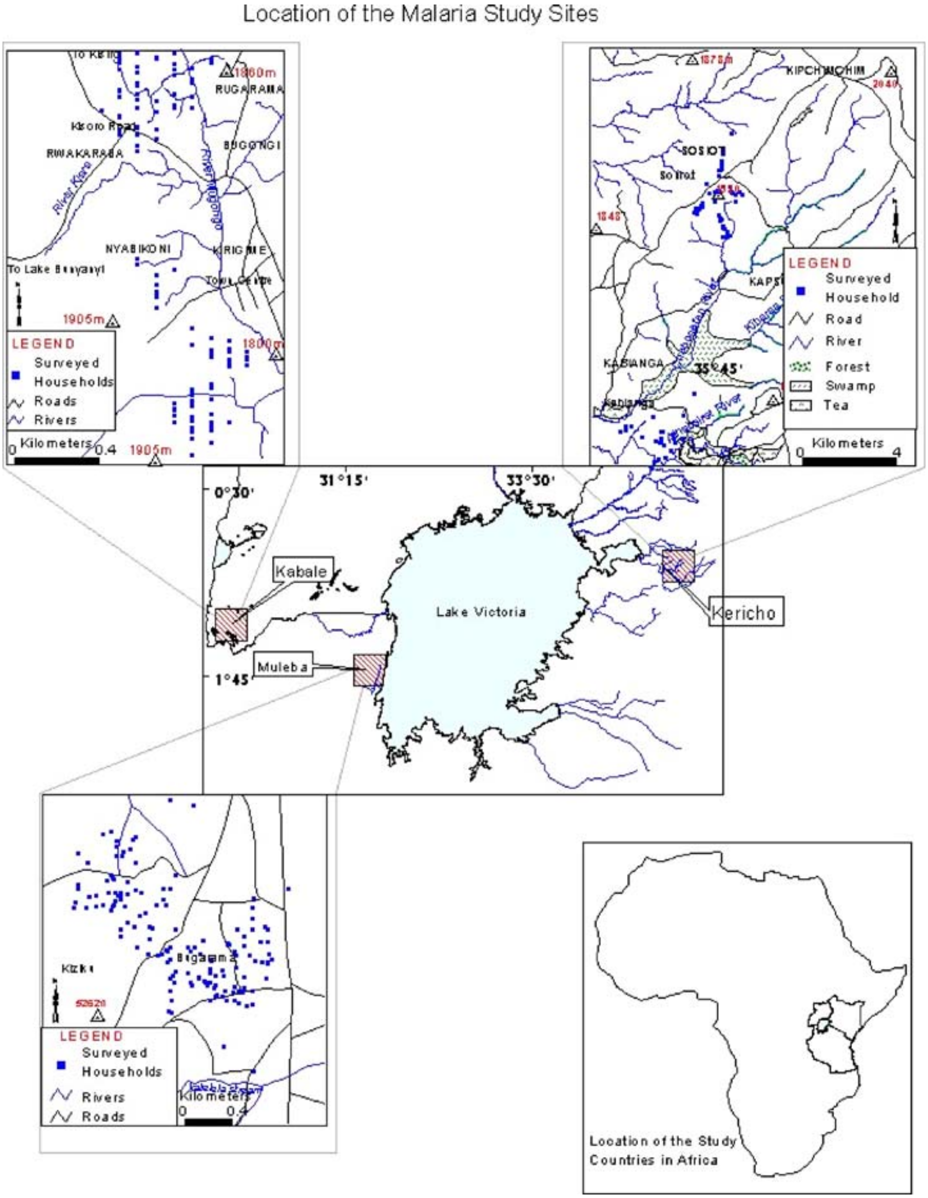


Fig. 1 Location of study sites in Lake Victoria basin

(Kenya). Rivers in or close to the other study sites are either ungauged, inaccessible (Bukoba, Tanzania) or have unreliable data (Kabale, Uganda). Stream flow data, covering the period from 1961 to 1991 was obtained from Ministry of Water and Irrigation in Kenya. Data gaps were filled in using the MOVE1 (moment of variance extension) method of flow estimation (Hirsch 1982), based on a matching dataset of 3 years length with a correlation of 0.97.

2.2.4 Socio-economic data

An integrated approach, using both quantitative and qualitative methodologies, was used to gather both health and socio-economic data from the target populations. A household survey of 450 semi-structured interviews was conducted at the three malaria sites in Kenya, Uganda and Tanzania. The survey sought to establish the health, demographic and socio-economic characteristics of the affected communities. The health and socio-economic data derived from this survey was subjected to statistical analyses. Secondary socio-economic and health data was obtained from national statistics and local hospitals with reliable patients' health records respectively. Qualitative data was derived from focus group discussions with the communities and stakeholder meetings with opinion leaders from the selected sites.

3 Results from the study

3.1 Climate and hydrology

The annual cycle of temperature patterns for T_{max} for the three highland sites generally depicts distinct seasonal variability in all locations (Fig. 2). The sites are characterised by two rainfall peaks in March–May and October–November. The driest period occurs in December–January while the coolest months are June–August. The seasonal temperature range is generally lower at Bukoba, and highest at Kericho and Kabale in the highlands. This may be attributed to the fact that Bukoba is located on the shores of Lake Victoria while the other two are much further away from the Lake.

The peaks in T_{max}/T_{min} occur during the peaks of the dry/wet seasons respectively. For the period 1978–1999, regression analysis indicates significant changes in T_{max} for Kericho, and Tmin for Bukoba and Kabale (Table 1).

Figure 3 shows three seasonal variation of maximum temperature for Kericho site between 1978 and 2004. A linear annual correlation curve shows a clear rise in temperature during the years of study.

Over the period 1978 to 1999, there are no significant trends in the wet/dry seasons, except for Bukoba during March–May (MAM) rainfall season where a decline in rainfall is observed as is shown in Fig. 4.

The characteristic annual cycle of flow indicates that the highest flow occurs in the MAM long rains season, and declines gradually through JJA with a subdued peak in August to SOND short rains season with a peak in November (Fig. 5). 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 dataset shows that the high flows coincide with the heavy 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 is 46.89 m^3/s for Sondu-Miriu River and 31.68 m^3/s for Yurith River).

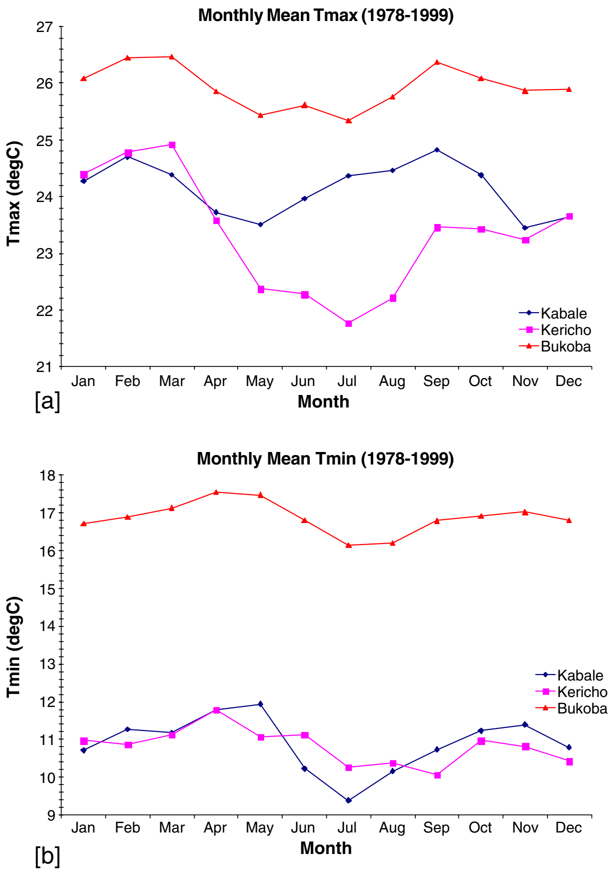


Fig. 2 Monthly variation of maximum (**a**) and minimum (**b**) temperatures over the three locations between 1978 and 1999

3.2 Malaria

3.2.1 Malaria epidemics

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 (Fig. 6a). Correlation analysis was used to compare data from the three countries to determine the degree of association. Data for Tanzania and Kenya had

Table 1 Direction of trend for temperature

Station	Temperature	Change (°C)	*P*-values
Kericho	Max	3.48	0.006[a]
	Min	No trend	
Kabale	Max	No trend	
	Min	1.17	0.02[a]
Bukoba	Max	0.21	0.56
	Min	0.49	0.36

[a]Denotes significant trends, with p-values ≤0.05

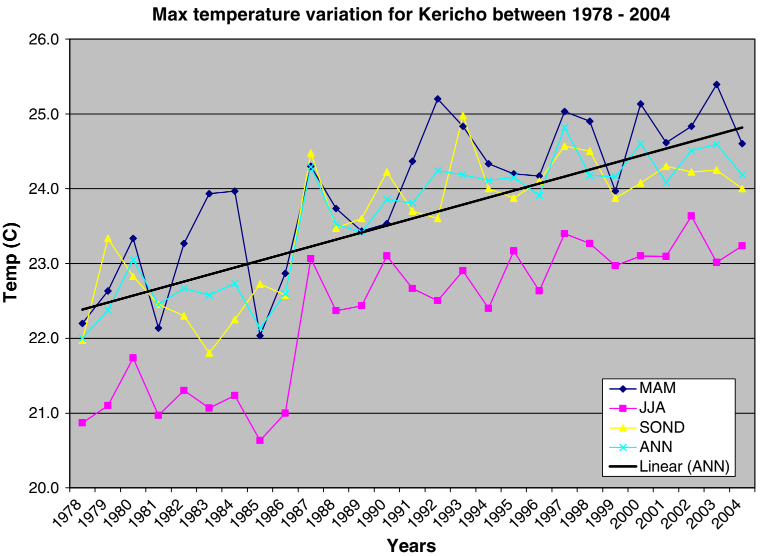
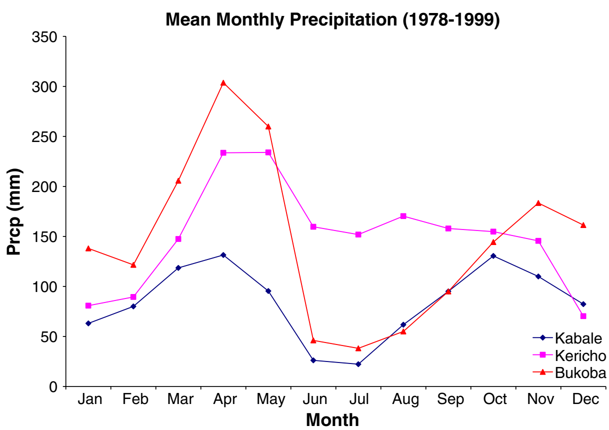


Fig. 3 Variation of maximum temperature for Kericho site between 1978 and 2004

the best association ($R^2 = 0.59$) while R^2 for Kenya and Uganda was 0.3 and for Uganda and Tanzania was 0.29. This association is a reflection of similar temporal regimes in malaria outbreaks since the three sites had similar climate seasons. Trends in malaria cases for children under 5 years old and those over 5 years old indicated that children under five were more highly susceptible to malaria attacks than those above five (Fig. 6b). Children less than 5 years were one-and-half times more likely to be admitted than those above 5 years. This is consistent with the fact that young children have lower clinical immunity.

The first upsurge in malaria cases in Tanzania was observed in May to July, and in Kenya from June to July in 1997. In Uganda the number of cases during this period

Fig. 4 Mean monthly precipitation for Kabale, Kericho and Bukoba during 1978–1999 period



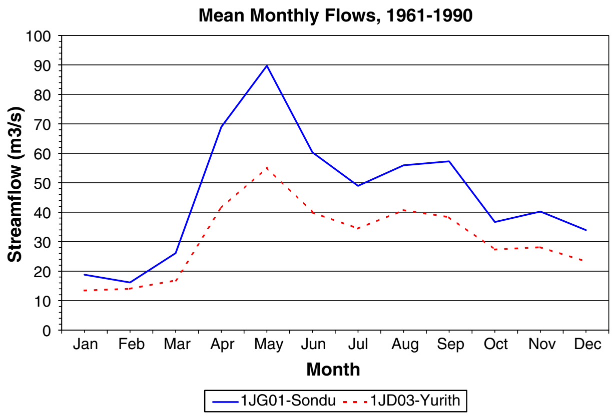


Fig. 5 Temporal variation of the flows of Sondu-Miriu and Yurith Rivers: Mean monthly flows for the two rivers between 1961 and 1990

remained below normal (Fig. 6a). The most significant change in seasonal outbreaks was observed from January to March in 1998 in Tanzania and Kenya but the trends extended to May of the same year in Uganda. The extended departure implies that the epidemic lasted for six months. In Tanzania the epidemic caused a peak increase in cases of 146% while in Kenya and Uganda the increase was 630% and 256% respectively. The peak month for admissions in all countries during 1998 was March. It should be noted that in Kenya the government hospitals workers were on strike and so most of the malaria cases were treated in Mission hospitals. The Kenyan hospital used in this study is a Mission hospital and therefore the cases reported include those that should have been admitted at the Kericho District Hospital. It is more likely that the increase in malaria cases in Tanzania and Uganda reflect the true trends.

Uganda had further cases of malaria outbreaks in November and December 1999 (with an epidemic increase of 63%) and again in December 2000 to February 2001 when the outbreak peaked at 312% in January. A small outbreak was observed in Kenya (with an increase of 78%) in February 2001. Data from Uganda indicates that outbreaks are more common after the short rain season in September to November. The epidemics were associated with El Niño events in 1997/8 and 2001.

3.2.2 Self medication for malaria

In Kericho, households were asked which drugs they used for malaria treatment at home. About half the households (49%) (Table 2) used chloroquine, a drug to which 89% of the malaria parasites are resistant. The next most popular drug used by 39% of the households was Fansidar (Sulfadoxine pyrimethamine). The parasite resistance level for Fansidar is about 50%. Other drugs used were quinine and antibiotics and yet these are prescription drugs. The data indicates 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.

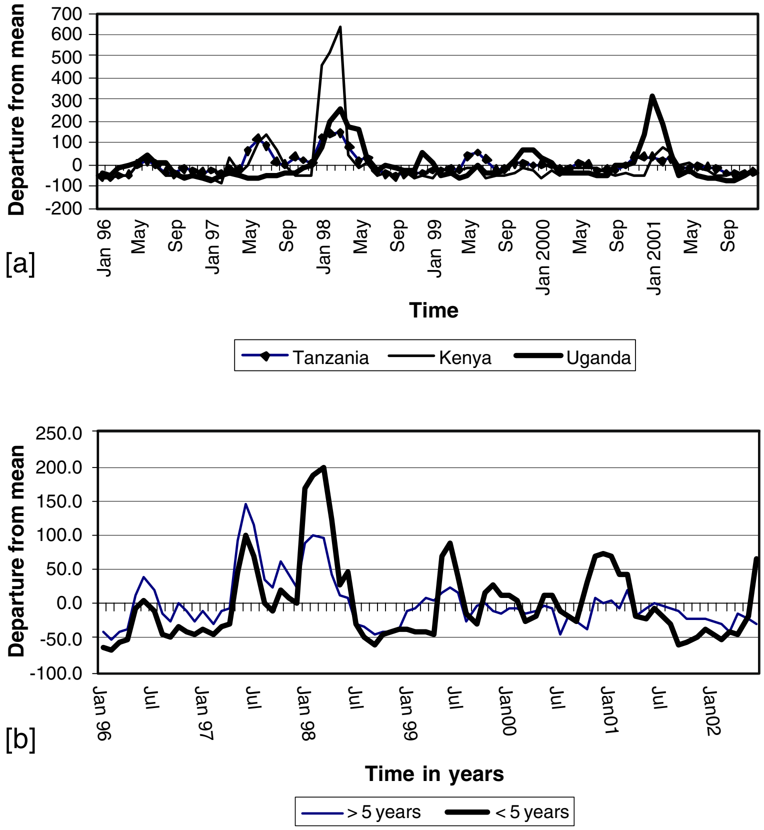


Fig. 6 Anomalies in Malaria Epidemics for Kenya, Uganda and Tanzania (**a**) and for infants and adults (**b**)

3.2.3 Knowledge of disease

The study revealed that the communities and local health officials were knowledgeable about malaria; however, there exist local beliefs and myths surrounding the causes of malaria. There is also confusion between general mosquito control and malaria control measures. For example, the Public Health Act requires clearing of bushes around houses to prevent yellow fever, a disease transmitted by outdoor resting *Aedes egypti*. *Anopheles gambiae,* the major vector of malaria in the highlands, always rests inside houses and so bush clearing has virtually no effect on this mosquito. And yet 62.7%; 40.1% and 24.7% in Uganda, Kenya and Tanzania respectively still clear bushes in the hope of eradicating the malarial habitat. Since health officials do not, in most cases, keep or refer to climate data, they are unable to associate malaria incidence with climate. Thus when asked why there were more malaria cases in 2002 than in 2003, the clinical officer at Litein Mission Hospital attributed the difference to increased use of insecticide impregnated bed nets, notwithstanding that in June and July 2003 during the main malaria transmission

Table 2 Drugs bought for self treatment

Drug type	Proportion	Resistance level
Chloroquine	49	89
Sulfadoxine pyrimethamine	39	50
Quinine	7	–
Others	5	–

season it was 2°C cooler than it was in 2002. Furthermore, the insecticide treated nets (ITNs) campaign had not been as successful as claimed—there was a lack of adequate supply of ITNs in the local shops and cost was also a prohibitive factor. While the use of bednets (treated or not) may have contributed to the low-recorded incidences of malaria in 2003, the role of climate should have been factored in.

Myths and folklore about malaria may be a barrier to its prevention and cure. For example, one community in Kenya believes 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 Kenya in 1990—a year that coincided with El Niño rains and malaria epidemics. Another myth was that drinking water from a different spring or stream causes malaria. In Tanzania, people believe that eating maize meal instead of bananas cause malaria. Incidentally maize meal is normally consumed only during periods of food shortages that coincide with above and/or below average rains (e.g. El Niño rains and/or La Niña droughts). Similarly, in Uganda, malarial complications such as convulsions are attributed to supernatural forces, and hence best treated by traditional medicines (Nuwaha 2002). This often leads to delays in medical care and in many instances results in no cure, thereby increasing malaria morbidity, severity and mortality.

3.3 Socio-economic analysis

The household surveys indicate an intricate relationship between socio-economic conditions and vulnerability of communities exposed to the risk of malaria. Since most of the households are poor, the economic resources for investing in health coping mechanisms that can offset the cost of adaptation are often lacking. Using primary data generated by the household surveys, frequencies and cross-tabulations were used to establish the correlation between poverty and vulnerability to malaria. Income was treated as the independent variable and cross-tabulated with selected socio-economic variables to generate a table of indicators of vulnerability to malaria epidemics (Table 3). More than half (54.5%) of the households who live on less than a dollar a day rely predominantly on farming.

Formal employment that is a source of steady income is the privilege of only a few—with 19%, 15% and 2% 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 (US$ 91–100 and US$101+). These low incomes are aggravated by household food insecurity which makes them even more vulnerable to malaria. Fifty percent of the households living below the poverty line experience days of food shortage (Table 3). Kabale and Muleba have a significantly higher proportion (54.5% and 46.7%) of households experiencing food shortages than

Table 3 Selected indicators of vulnerability to malaria epidemics

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

[a]The average monthly income is US$ 50.2 whilst the most common income (mode) is US$ 25.6

[b]The highest monthly income in this class is US$580.3

Table 4 Type of health facility visited

Health facility	Kericho (%)	Kabale (%)	Muleba (%)
Provincial hosp.		0.6	0.7
District hosp.	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 hosp.	1.0	6.4	6.7
Private clinic	1.0	11.0	
Total	100	100	100

Kericho (20.5%). It is also this income group that has a high proportion (76.2%) of households without bednets, and which also recorded the highest number of deaths due to malarial complications. Generally, the poverty indices indicate that vulnerability increases as monthly household incomes decrease and days of food shortages, household mortality and proportion of bed nets increase (Table 3).

Without adequate health care systems coupled with increasing poverty levels, the adaptive capacity of households is severely handicapped in taking advantage of opportunities to cope with the consequences of malaria epidemics. The district and provincial hospitals which tend to be better equipped and have professional personnel and in-patient facilities are rarely visited by the households when they are sick (Table 4). Majority of the households in Kericho (91.5%) and half (50.3%) of those in Muleba tend to visit the local dispensary. In Kabale, on the other hand, over half (59.2%) of the households prefer the health centre. Lack of qualified medical personnel and ill-equipped diagnostic laboratories in such health facilities increases the likelihood of misdiagnosis while reducing their capacity to cope with malaria epidemics. Distance to district and provincial health facilities could be one of the factors limiting their usage by rural-based communities. Given the underdeveloped road network, high transport costs and prohibitive treatment costs at health facilities, it is not surprising that the frequency of visits to health facilities is low (Table 5). The low frequency rate of visits to health facilities further compromises the accessibility of the households to health infrastructure.

Table 5 Visits to hospitals in the last 3 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

4 Discussion

4.1 Linkages between temperature and precipitation

The temperature results confirm previous studies that indicated increasing trends in T_{min} and T_{max} over many parts of East Africa, with a few stations along Lake Victoria shoreline (King'uyu et al. 2000). Locations along the lake have strong thermally induced meso-scale circulation, which together with local moisture sources can often modify large-scale circulation patterns, such as El Niño.

Table 6 examined T_{max} and T_{min} during some El Niño and La Niña events. It was noted in Section 3.1 that peaks in T_{max} and T_{min} occur during the peaks of the dry and wet seasons respectively. Table 6 indicates that inter-annual variability in both T_{min} and T_{max} years were associated with inter-annual patterns of extremely wet and dry years like those observed during El Niño and La Niña events. Thus ENSO events are associated with anomalies in T_{min} and T_{max} within the Lake Victoria Basin that can have significant impacts on malaria.

There are clear linkages between rainfall extremes over Lake Victoria region and El Niño/La Niña events (Table 7). These have been observed in many past studies (Ogallo et al. 1989; Indeje et al. 2000; Mutemi 2003).

4.2 Linkages between climate and hydrology

There were some limitations in relating results from climate and health to hydrological data. Precise co-location of the datasets within the study sites was constrained by the location of the meteorological and hydrological stations, thus the closest stations with available data were selected for analysis. In addition there was the problem of scaling for hydrology, since 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 in Kericho that were analysed 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

Table 6 Comparison of ranked Tmax and Tmin with El Niño and La Niña years

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

Normal font—non-El Niño/non La Niña years, bold font—El Niño years, bold/italic font—La Niña years

Table 7 Comparison of ranked mean monthly cumulative precipitation with 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**;	***1988–1989***;
Kabale	**1987**,***1988***, ***1996***, ***1998***	1979, **1982**, **1993**, ***1999***	**1991–1992**; **1992–1993**; **1994–1995**;	***1995–1996***;
Bukoba	1985, **1986**, **1994**	1980, 1981, **1982–1983**	**1997–1998**	***1998–1999***; ***1999–2000***

Normal font—non-El Niño/non La Niña years, bold font—El Niño years, bold/italic font—La Niña years

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 theoretical analysis of the flow data in terms of relative soil moisture saturation, as suggested in Section 4.4.

4.3 Linkages between climate, hydrology and malaria

Significant departures in malaria cases were preceded by positive anomalies in the maximum and minimum temperature. The minimum temperature showed a greater departure from the normal values than the maximum temperature. The epidemics only occurred when these temperature anomalies were followed by sustained rainfall 1 month later (Fig. 7). These conditions are permissive to the breeding of the malaria

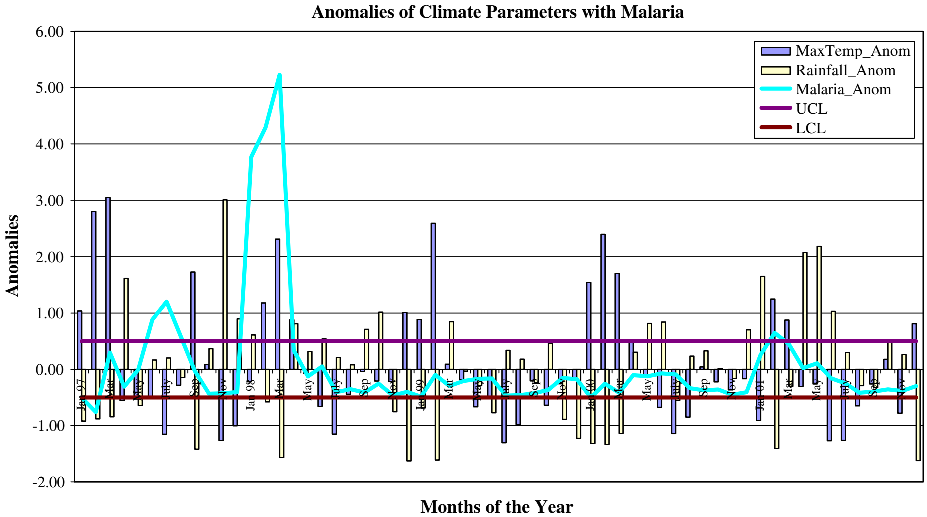


Fig. 7 Temporal variation of maximum temperature, rainfall and malaria epidemic anomalies between January 1997 and December 2001

vector and, indeed, high temperature accelerates the rate of larval development and shortens the parasite development period in the mosquitoes. Munga et al. (2006) showed that, in the western Kenya highlands, increase in temperature favours rapid larval development.

The most significant anomalies in temperature and rainfall were observed during the El Niño period of 1997/98 following which there were severe malaria outbreaks. In all cases seasonal malaria outbreaks were associated with anomalies in temperature. For example, at Kericho, anomalies in the mean monthly maximum of 2.2–4.5°C between January and March 1997 and 1.8–3.0°C between February and April 1998 were observed.

4.4 Relationship between climate change/variability, hydrology and malaria

The increases in T_{max} and T_{min} observed in the time series for Kericho, Kabale and Bukoba (Fig. 2 and Table 1) clearly indicate that these communities are facing an increasingly higher frequency of warmer temperature conditions that are conducive for the malaria vector to develop and multiply, and therefore need to develop mechanisms for adapting to the imposed malaria conditions.

Throughout the three study sites, the period MAM receives more rainfall than the SON (or SOND) season. During MAM, rivers overflow their banks and flood their basins. Soils also get saturated with water, encouraging standing water especially where land is flat. There is a one month lag between the peak rainfall and the peak river flow (see Figs. 4 and 5a), since the rivers are largely recharged by surface runoff and groundwater flow from the drainage basin. The malaria epidemics often occur from the months of July to September—since peak rainfall is centred around April, there is a minimum of a 2-month lag between the peak rainfall and the epidemics (see Fig. 7 and Table 8). If, for a given year the maximum and minimum temperatures are consistently conducive for development and growth of the malaria vector (see Table 8), then the 2-month lag between peak rainfall and the onset of the epidemics can largely be accounted for by the 1 month lag in peak stream flow, and the physiological factors related to the development of the malaria larvae into full grown adults (which require two to three weeks).

During the months July to September, the flow of the rivers maintains a relatively steady tempo with muted variability after a rapid flow rate decline through the month of June (see Fig. 5), accounted for by reducing surface runoff. These characteristics are important, as they indicate that there is a high component of base flow contributing to the river recharge during the low rainfall months of July to September. The fact that the base flow is still relatively high means that MAM rainfall effect extends the saturation of soils in the immediate drainage basin close to the river course itself, and that it drives the persistent steady river flow (as opposed to the erratic and fast flow

Table 8 Correlation coefficients between malaria epidemics and weather parameters

Parameter	Rainfall	T_{max}	T_{min}
Malaria (Lag 0)	0.11868	**0.221189**	**0.338528**
Malaria (Lag1)	0.069701	0.014491	**0.348325**
Malaria (Lag2)	**0.331988**	−0.15049	**0.344429**

Bold numbers indicate that they were significant at 95% confidence level during rainfall periods). The flow remains higher than in the months SOND when wet conditions are again experienced through the short rains, suggesting that the land remains persistently wet enough from July to September to harbour breeding sites for mosquitoes. It also indicates that the short rains are not persistent enough to retain soil moisture at saturation levels for long enough periods sufficient for the development of *Anopheles gambiae* larvae (malaria mosquito). During El Niño years when the short rains (SOND) extend into January and February (JF) and are unusually heavy and temperature is high, there exists the potential for malaria epidemics in JF as the characteristic conditions of MAM season are replicated.

4.5 Excess risk attributed to climate change

It seems that there are possibilities of the epidemics continuing from the usual 2–3 months to 4–6 months as has been observed in Kabale, Uganda. Such conditions lead to very high mortality and morbidity rates. In comparison with temperature data from the lowland areas (Githeko and Ndegwa 2001; Olago et al. 2007) covering the past three decades, it is noted that the highlands are warming at a greater rate than the lowlands, and this has a significant effect on malaria transmission. A temperature change of 1°C would be equivalent to a reduction in altitude by 154 m. For example, the transmission conditions at 1,500 m asl would become equivalent to conditions at approximately 1,200 m asl for an increase of 2°C. This, therefore, makes malaria at 1,200 m asl be considered as stable and hyper-endemic.

4.6 Modelling malaria transmission

The risk of a malaria epidemic is associated with positively anomalous temperatures in the preceding and during the months of 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 (Zhou et al. 2005) indicates that the rate of growth of a mosquito population is dependent upon the initial population size before the rain 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.

Data from this study was used as an input in the epidemic prediction model (Githeko and Ndegwa 2001). This model uses simultaneously occurring anomalous temperatures and rainfall to calculate the risk of malaria epidemics. The two conditions must occur simultaneously for epidemic conditions to occur. The model output was compared to standardized case anomalies for data from Kenya (Fig. 8). The model output had a general agreement with trends in anomalies in malaria cases. However, for prediction purposes, the model needs to be modified to respond to site-specific conditions.

One of the problems with the model is its handling of incidents of temperature and precipitation anomalies, usually occurring in January and February, which do not coincide with wet periods. The JF rains are associated with Indian Ocean dipole reversal episodes that cause El Niño rains in East Africa (Nicholson 1996; Conway 2002). The model does not take these unpredictable off-season rains into account

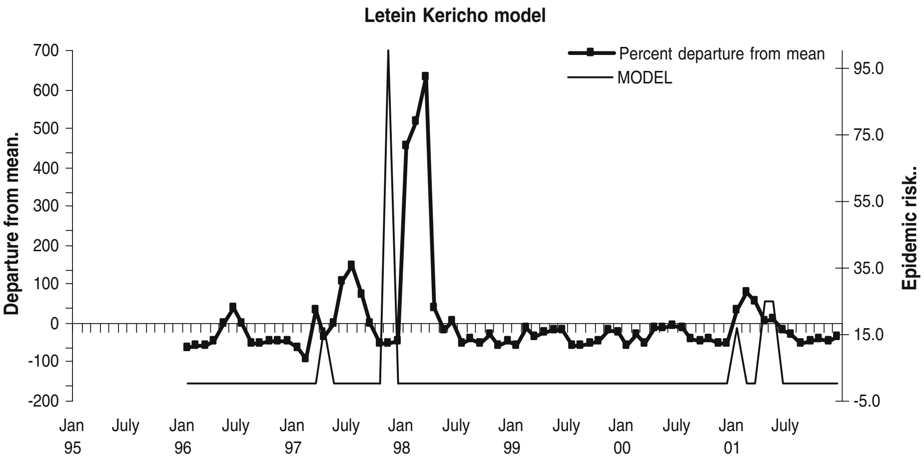


Fig. 8 Modeled climate and malaria data for Litein in Kenya

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.

4.7 Vulnerable communities

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 with demand (WHO 2003). Communities living at altitudes above 1,500 m asl have added risks of malaria disease due to climate variability and change, lack of immunity, and poverty. The observed climate trends and hydrologic patterns explained in the preceding sections indicate that the highland communities of East Africa have a higher disposition to malaria epidemics. Additionally, the poor are further disadvantaged by their inability to access medical treatment and the lack of health care facilities during such epidemics. There is, however, a need for a detailed explanation of how other socioeconomic indicators, including poverty, is linked to malaria incidences.

Poverty, however, seems to play a very big role in the vulnerability of the communities to climate variability and change. Due to poverty and inadequate, or lack of, early warning mechanisms, the communities lack effective strategies for coping with climate-induced shocks such as disease and weather extremes. Shortage of food resulting from frequent droughts and floods contributes to malnutrition; particularly in the poor households resulting in ill health that makes individuals easily succumb to diseases such as malaria.[1] Although there is an increase in the use of bednets, many households are unable to afford sufficient bednets for all household

[1]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 vulnerability to climate-related diseases.

Table 9 Household size and use of bednets

Household size	Common household size	Use of mosquito nets	Use of ITNs & treatment	No. of nets in household
1–16	3–7	32.2%	28.1% (2×/year)	1–6 nets

members, due to large household sizes and low incomes. It is these poor families that cannot afford preventive and curative measures that have high malaria mortality rates (see Table 9).

The East African governments have no comprehensive programs or fiscal facilities to deal with climate variability and extremes. Malaria preventive and curative programs run by civil societies or governments predominantly rely on external sources of assistance, whose long-term sustainability is not guaranteed. Therefore, the local capacity to develop adaptive strategies to cope with climate variations and extremes is still very low, at all levels, and remains a big challenge.

4.8 Existing and coping 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. However, the survey revealed that the use of ITNs is not very widespread due to high levels of poverty. For instance, poorer households with monthly incomes of less than US$ 30 and US$ 31–40 have the highest proportion (76.2% and 69% respectively) among those households which lack bed nets (see Table 9). Often children had no protective nets, and when available (usually only one in a household), the nets are more likely to be used by the parents. An illustration of the possible influence of income on bednet use is derived from the Uganda data, where the proportion of household members sleeping under bednets increases with the increase in average income, and only 39% of the households had at least one net. Therefore, this means that the poor groups, who also have poor nutrition, are more vulnerable to malaria than the well-off households. This implies that strategies aimed at rolling back malaria need to be specifically tailored to suit the varying needs of the affected communities.

Despite the widespread promotion of the use of bednets, e.g. through the World Health Organisation's (WHO) Roll Back Malaria Program,[2] the survey revealed that

[2]The World Health Organization's (WHO) program on 'Roll back malaria' has been adopted by most countries in Africa. The three East African governments actively promote this program whose objectives towards malaria eradication are:

- Increase the use of ITNs
- Early diagnosis and treatment of malaria
- Use of effective anti-malarial drugs

This program has attracted several local and international civil societies. One such non-governmental organization active in East Africa is Population Services International (PSI), which receives financial support from both the British and American Governments. Its stated objective is to increase the use, ownership and availability of ITNs in Kenya, Uganda and Tanzania within 15 min walk in the malaria endemic areas. As such marketing promotions of ITNs is prevalent in most market centers in East Africa.

the majority of households do not use ITNs. This has implications on 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%) and if there happens to be treatment, it is likely to be once or twice a year (25%). 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 (Table 9), while the number of bed nets may range from 1–6 and out of those who use these nets only 28.1% treat them with insecticides twice a year.

The household surveys and focus group discussions reveal 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 then in order to cover the cost of treatment, the majority (75.5%) sell their food crops. Other ways of coping include borrowing or relying on remittances from relatives. In Kabale a number of people have resorted to selling land in order to cope with malaria. These types of coping mechanisms deplete respondents' resources and may lead to increased food shortage, debts and poverty. It is, therefore, not surprising that nearly half of the respondents indicate that they find the cost of treating malaria exorbitant. Even in Kericho, an area which has a relatively high income per capita earned from cash crops like tea, about 72.7% of the households surveyed indicated that the costs for malaria treatment are prohibitive. Similar concerns were raised in Muleba where, despite the growing of coffee as a cash crop, people are very poor due to fluctuating coffee prices.

One of the objectives of the "Roll Back Malaria" program requires early disease diagnosis and treatment. This presupposes the availability of and accessibility of properly equipped and functioning health facilities, but this is not the case in the study sites. Thus increasing the adaptive capacity of these communities necessitates a robust health care system that is not only well-equipped but also accessible to the majority. The use of effective malarial drug is another policy strategy for controlling malaria. The results of the study indicate that the efficacy (see Table 2) of most of the drugs bought for self medication is wanting. Since, 2003 most public health facilities in East Africa—using donor funding—are providing free anti-malarial medication. Free ITNs are also provided to communities who have to continue treating them. But as the study showed only a small proportion of households treat the bed nets regularly (Table 9).

5 Conclusion

This study has shown that climate change has altered the climates of the highland areas 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 in the higher altitudes than in the lowlands. The observed temperature increase has enabled malaria vector mosquitoes to find new habitats in the highlands. This has resulted in a higher frequency and severity of malaria epidemics in the highland communities of East Africa. The major outbreaks are associated with the unusually wet and warm climate events related to El Niño and the Indian Ocean dipole reversals.

East African highland communities living at altitudes above 1,500 m asl are more vulnerable to malaria epidemics due to their lack of immunity. Poverty is an additional factor that enhances vulnerability to malaria in these communities, and the entire lake basin as a whole. The ability of these communities to cope is strongly challenged by these socio-economic factors. Since the effect and intensity of the disease is very closely associated with poverty, its reduction is essentially linked to poverty alleviation and thus in our view it deserves the unique title of a 'political disease' despite the fact that it is at the same time a medical challenge.

The adaptations to highland malaria commonly applied by communities in this study include traditional curative measures (using local herbs), the increasing use of bed nets and more recently the use of ITNs. One limitation for adaptation with respect to households is their inability to afford bednets for the entire household. Modern medical treatment, though an effective adaptation method, is out of reach of most households due to cost and distance to the nearest health centre. Strategies that reduce poverty will significantly enhance adaptation to malaria.

It has been proposed that private expenditures for treatment and prevention, increased urbanization, and increased funding for government control can reduce malaria transmission (Sachs and Malaney 2002). It is clear that under the current economic environment, the three East African countries are ill-placed to react in such a manner. Sachs and Malaney (2002) also note that economic development alone without breakthroughs in medical prevention and treatment cannot eradicate the disease. Due to poverty and lack of adequate early warning mechanisms, communities have limited capacity to respond to climate disasters and hence cannot develop effective strategies for coping with climate-induced shocks such as disease and weather extremes.

There is also lack of tested and reliable information systems to communicate predictable effects of climate variation. The East African governments have weak economies that are dependent on external assistance. In the face of recurrent climate disasters, the East African governments have been unprepared and are consequently reactive, slow and late in their response. Such strategies exacerbate the impact of climate-induced diseases such as malaria. There is an urgent need to develop sustainable adaptive strategies and early warning systems that will address future climate changes challenges. Combined efforts that improve adaptation to climate change, early warning systems, knowledge of disease, medical health infrastructure and provision of services, and socio-economic standards would reduce the existing malaria situation in East Africa.

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 take into consideration 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 demography and socio-economic development would definitely have a damping effect on the potential consequences of climate change. HIV/AIDS, malaria, diarrhoeal diseases, respiratory diseases and others play an important role in the people's health, productivity and responsiveness to external threats. The programs dealing with these diseases must therefore be factored into the analysis of the future effects of climate change on the vulnerable system.

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