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Consequences of Climate Variation on Malaria Incidence in Uganda

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Abstract

Introduction: Temperature and rainfall are assumed to play an important role in the transmission of malaria. According to Zhou simultaneous analysis of the long-term time series of meteorological and parasitological data are critically needed to understand the effects of climate on malaria incidence. However, it would be more plausible to assess the effect of climate variation on the malaria incidence since increase or decrease in the number of malaria cases does not quantify the disease frequency.

Objective: This study therefore, seeks to examine the consequences of variation in climatic factors such as temperature and rainfall on the malaria incidence among the Ugandan population.

Methods: To account for variation and dynamics in monthly malaria incidence among the Ugandan population, data on environmental factors like minimum and maximum temperature, and rainfall were obtained from Uganda National Meteorological Authority (UNMA) while monthly malaria counts for the period (2006-2016) were obtained from Ministry of Health (MoH). Dynamically complete models were used to simultaneously investigate the impact of environmental factors on monthly malaria incidence in the population.

Findings: Findings revealed that the long-run impact of three months successive one percent increase in maximum temperature would result into an 8.1% reduction in monthly malaria incidence. Similarly, three months successive one percent increase in minimum temperature would increase monthly malaria incidence by about 16.7% in the long-run. The impact of rainfall was also significant in that successive one percent three months increase in rainfall would reduce malaria incidence by about 14% in the long-run.

Conclusion: Increasing maximum temperature is associated with a reduction in malaria incidence while increasing minimum temperature is associated with an increase in monthly malaria incidence. Lastly, increasing amount of rainfall is associated with a reduction in monthly malaria incidence.

Recommendations: In order to lower the incidence of malaria among the population, it's imperative that malaria control and preventive interventions consider environmental modifications that lower minimum temperature and increase the amount of rainfall. These interventions include land use methods such as conversion of land from forests to settlements and agricultural activities, wetlands for settlements and other economic activities.

Introduction

Uganda experiences stable endemic malaria in 95 % of the areas of altitude 1200 to 1600 m. Malaria transmission is perennial with two peaks, after the rainy season, (April-May) and the period between October-November. Temperatures between 20 and 30 degrees centigrade and relative humidity of 60% provide optimal conditions for malaria transmission. Hence, the temperatures in Uganda which range between 16-36 degrees centigrade provide ideal conditions for malaria transmission. This implies that understanding the malaria dynamics in the country requires understanding its link with temperatures and rainfall in a given month. Therefore, a model that links the monthly malaria cases with rainfall and temperature could be more accurate since these two factors have high correlation with increased disease burden, not only for malaria but also some other diseases. Previous studies have attempted to link malaria transmission to temperature based on clinical trials mainly in efficacy studies. According to

MacDonald, Bruce-Chwatt and Molineaux suggested that understanding the association between malaria incidence and environmental factors might be the most effective way of predicting changes in malaria transmission dynamics and thus improve the impact of control efforts [1-3]. Furthermore, many studies have attempted to analyze seasonality in malaria incidence and environmental factors using different approaches although there has not been a convincing approach that could be used across the continent including Uganda [4-8]. Therefore, there is limited literature on the dynamics of malaria burden based on routine data obtained in normal health setting that could be used to improve the design of control interventions based on environmental factors in the communities.

In the Eastern part of Africa especially Uganda where malaria is more prevalent during seasons of peak agricultural activities, the disease not only excludes the sick ones from daily agricultural activities

but also the healthy ones who have to take care of their sick family members and relatives. According to UBOS over 80% of the Ugandan population is still employed in agricultural sector. Agriculture in most parts of the country still depends on natural climatic conditions of rainfall and environmental temperature [9]. Increased burden of malaria does not only affect their health but also their incomes as well as food security at household level. It is estimated that workers suffering from a malaria bout can be incapacitated for 5-20 days. The lack of adequate manpower during the peak of agricultural activities decreases productivity and hence, lowers income and aggravates food insecurity [10]. A poor malaria-stricken family may spend up to 25% of its income on malaria prevention and treatment. It is estimated that 40% of health expenditures in Sub-Saharan Africa are spent on malaria treatment [11]. Understanding the dynamics between rainfall and environmental temperature over time will not only help in their forecast but also accurately predict the burden of malaria. This study therefore, attempts to assess the variation in environmental factors and their consequences on observed malaria incidence in the population.

Temperature plays an important role in the survival of the parasites in the anopheles mosquito vector. A study by Crag established that these parasites have a short development cycle which lasts between 8 to 21 days. The parasites require an optimum temperature ranging between 27-31°C [12]. Furthermore, it was also established that temperatures below 19°C does not favor the *Plasmodium falciparum* species to complete their cycle and propagate malaria. This implies that in a country like Uganda with an average annual temperature ranging from 17°C to 36°C provides the best environment for the *Plasmodium falciparum* species to complete its cycle and propagate malaria in the population. Therefore, any model to predict malaria incidence in the population need to incorporate the effect of temperature over time [13].

Temperature and rainfall are assumed to play an important role in the malaria transmission. It has been established that rainfall influences the availability of mosquito larval habitats and thus mosquito demography. According to Zhou simultaneous analysis of the long-term time series of meteorological and parasitological data are critically needed to understand the effects of climate on malaria cases [14]. However, it would be more plausible to assess the effect of climate variation on the malaria incidence since increase or decrease in the number of malaria cases does not quantify the disease frequency. Patz reaffirms that climate variability is epidemiologically more relevant than the mean temperature increase [15]. This implies that the use of the epidemiological measure of disease frequency like malaria incidence in studying the effect of temperature and rainfall through an appropriate model will shade some insights on how climate variation is affecting malaria transmission in Uganda. This study therefore, seeks to examine the consequences of variation in climatic factors such as temperature and rainfall on the malaria transmission among the Ugandan population [16].

Methods and Materials

Data sources

To account for variation and dynamics in monthly malaria incidence among the Ugandan population, data on environmental factors like minimum temperature, maximum temperature, and rainfall were obtained from Uganda National Meteorological Authority (UNMA). UNMA collects daily maximum and minimum temperatures as well as rainfall from the different weather stations across the districts in Uganda. Monthly malaria counts for the period (2006-2016) were obtained from Ministry of Health (MoH). MoH through its health facilities collects routine data using a standard Health Management Information System (HMIS) form. The HMIS 105 form is provided at all the health facilities across the country.

Data management and analysis

To explore the variation of malaria incidence and environmental factors, mean and standard deviations of each of the variables were computed. Furthermore, graphs of minimum temperature, maximum temperature, and rainfall and malaria incidence over time were plotted.

Test for stationarity

Each of the variables monthly malaria count, minimum temperature, maximum temperature, and rainfall were assessed to establish whether they were stationary before they were in the model. Augmented Dickey-Fuller test was used to test for stationary in the variables and establish the number of lagged variables in the model.

Multivariate analysis

To simultaneously estimate the effect of environmental factors and monthly malaria incidence in the population, dynamically complete models were used. This framework was adopted to investigate the dynamics in both malaria incidences as well as in the environmental factors in predicting monthly malaria incidence among the population in Uganda because both malaria incidence and climate factors vary with time.

Model specification

where, A(L) is defined as the lagged values of monthly malaria incidence, B(L) is the lagged values of minimum temperature, C(L) is the lagged values of maximum temperature, D(L) is the lagged values of rainfall respectively.

Model diagnostics

The dynamically complete model was assessed for normality of the errors, serial correlation and model inadequacies. For normality of the errors, a plot of the residuals against the fitted values of monthly malaria incidence was done. A random scattering of the points above and below the line with nearly all the data points being within the band defined by 2-standard deviations is expected if the assumptions are satisfied. The model inadequacies are identified if the plot of the residuals against the fitted values gives asymmetric shape about zero. The presence of a serial correlation in the residual was assessed using the run test. The test involved counting the number of runs or sequence of positive and negative residuals and comparing this result to expected number of runs under the null hypothesis of independence.

Results

Descriptive analysis

Table 1 shows the annual average malaria cases, rainfall, maximum temperature and minimum temperature observed across Uganda for the period 2006-2016. The average monthly malaria cases observed for

the period 2006-2016 was about 1.1 million cases. The average monthly amount of rainfall observed was 117.6 mm. The average observed monthly minimum and maximum temperature were 17.3°C and 28.7°C respectively as seen in Table 1.

Variables	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
Malaria cases (000,000)	0.8	1	1.01	1.04	1.11	0.98	1.14	1.38	1.15	1.12	1.34	1.1
Rainfall	127.2	127.2	121.7	123.4	128	104.4	123.6	120.3	112.7	108.1	96.9	117.6
Maximum temperature (°C)	27.9	28.1	28.9	29	29.1	28.9	28.3	28.9	28.5	28.5	29.8	28.7
Minimum temperature (°C)	16.1	16.5	17.6	17.8	18.2	17	16.8	17.6	17.2	17.1	18.4	17.3
Relative humidity at 06.00	77.1	77.1	77.2	79.5	81	77.3	70.8	73.9	81.8	80.7	81	77.9
Relative humidity at 12.00	55.7	55.7	55.8	56.2	56.6	56.5	55	56.5	57.1	57.4	54	56.1

Table 1: Average Monthly malaria and environmental factor.

Figure 1 shows that there is a trend in both malaria incidence and environmental factors. Furthermore, the observed monthly malaria incidence was increasing with fluctuations. This implies that the monthly malaria incidence might be exhibiting trend stationarity.

Moreover, the observed monthly maximum and minimum temperatures were also gradually increasing in a similar trend to malaria incidence. On the other hand, the observed average rainfall seems to be stable with no trend.
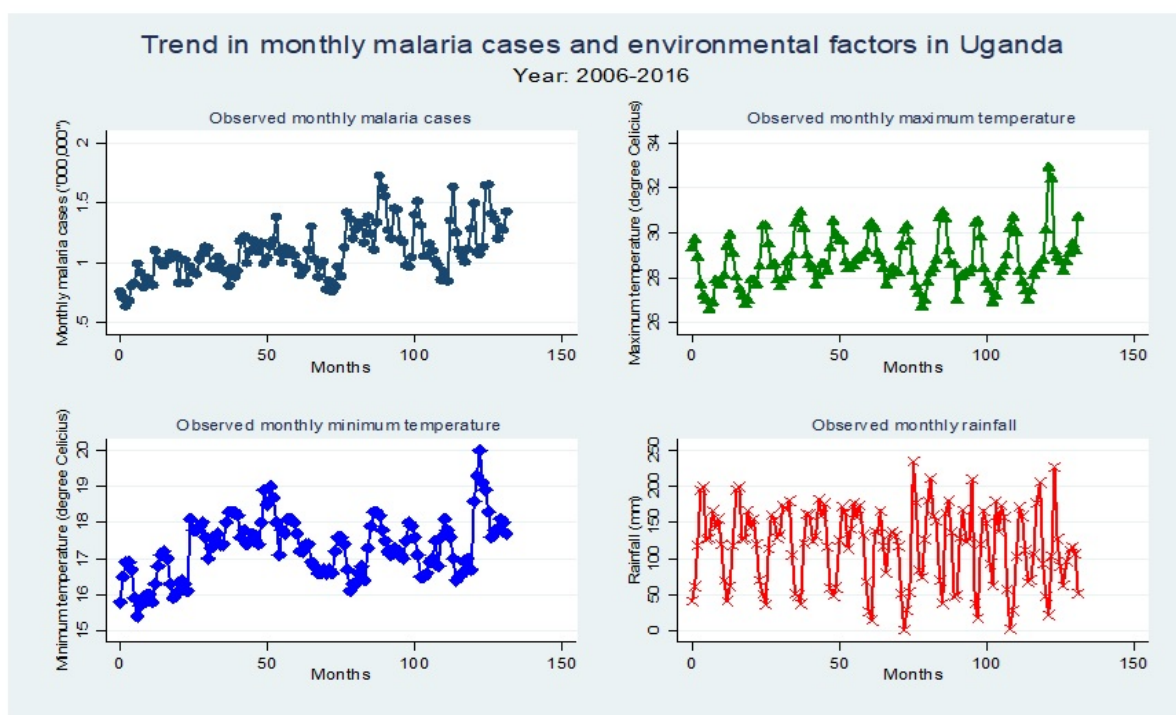

Figure 1: Variation in malaria incidence, temperature and rainfall for the period 2006-2016.

Variation in malaria incidence and environmental factors

Figure 2 shows the variation in monthly malaria incidence over the last seven years. The results revealed that malaria incidence is highest in the month of January during the dry season and starts to reduce in the moths of February and March. Malaria incidence is observed to be on the rise in the months of April and May during the rainy season. There is observed decline in malaria incidence in the months of August and September followed by an increase in the months of October and November with a decline in December. The observed variation of

malaria incidence between dry and wet seasons does not clearly show its variation with environmental factors in Uganda.

Figure 2 shows the annual cycle of the variation in monthly maximum temperature in Uganda in 2010-2016. The reduction in the monthly maximum temperature is associated with the rains that start in the month of April. Therefore, December-March is the dry season while April-May is the rainy season. Variation of maximum monthly temperature over the years show temperatures begin to rise in the month of December and remain high till the month of April when they start to reduce till the month of November. The behavior in the minimum temperature is not different from the maximum temperature already discussed above. The yearly cycle observed in the maximum monthly temperature still is exhibited by the minimum temperature as seen in Figure 2. This implies that in a country like Uganda with an average annual temperature ranging from 15.4°C to 32.9°C provides the best environment for the *Plasmodium falciparum* species to complete its cycle and propagate malaria in the population.

The maximum monthly rainfall is was experienced in the months for April and October. For example, the average monthly rainfall in April was about 149.5 mm while that in October 159.3 mm. The minimum amount of rainfall was experienced in the month of January with only 1.2 mm in the period 2010-2016. The average monthly rainfall in the period 2010-2016 had great variability. High variability was experienced in the months of January and December with 84% and 80.3% relative variability respectively. This variability is an indication of unexpected rains in these months when they are largely believed to be dry months. The variability in the amount of expected rains are important for the breeding of mosquitoes that are responsible for the spread of malaria. Furthermore, unexpected rains most cases come as erratic rains which in turn result into warm temperatures and hence, can facilitate the fast maturity of the mosquitoes. As observed for the maximum and minimum temperature, the average monthly rainfall also has a cycle that repeats every year.
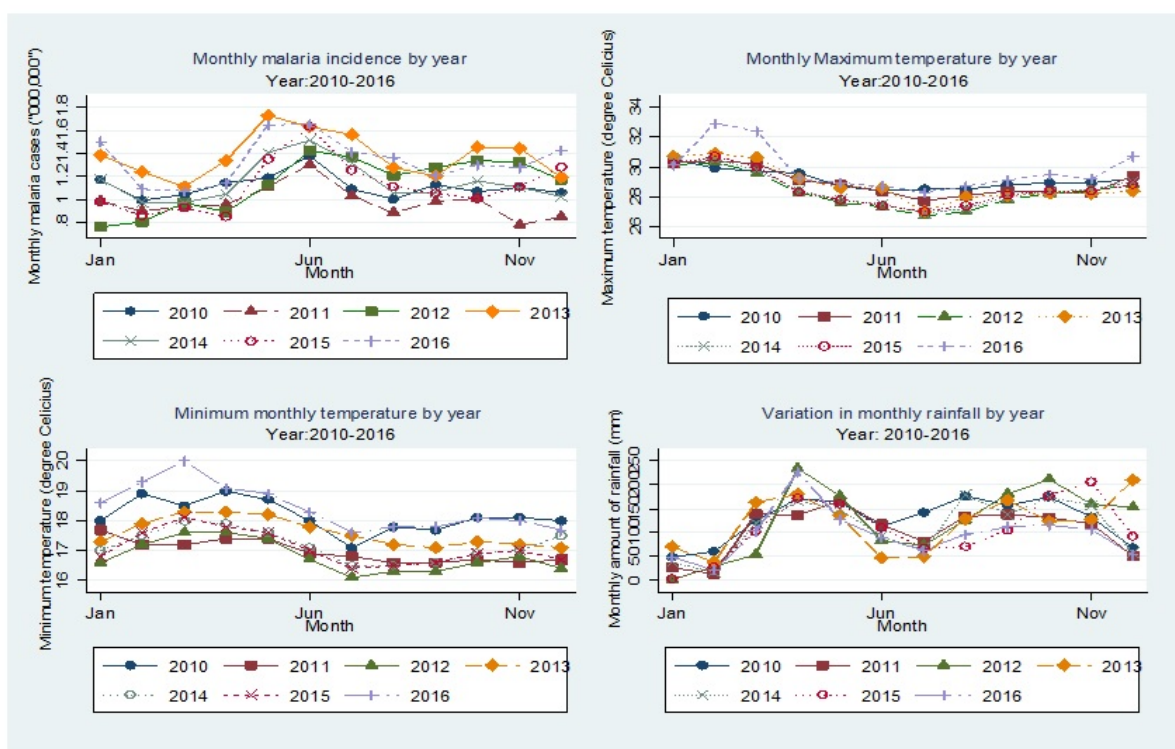

Figure 2: Variation and dynamics in malaria incidence and environmental factors (rainfall and temperature).

To assess the dynamics in malaria incidence and environmental factors, a distributed lag model was fitted. Coefficients, standard error, p-value and confidence intervals were estimated at different lags. The results of the estimation of the model are summarized in Table 2.

Maximum temperature and malaria incidence

Maximum temperature is one of the important factors that determine mosquito survival and completion of their reproductive cycle. Understanding the effect of maximum temperature on monthly malaria incidence gives insights on how the high temperature can affect the disease intensity in the population. Results of the analysis

revealed that an increase of about one percent in maximum temperature in the observation month would significantly reduce malaria incidence by about 23%. Similarly, an increase of about 1% in maximum temperature in the preceding month following a one percent increase in maximum temperature in the previous month would significantly reduce malaria incidence further by about 9.9%. Moreover, a one percent increase in maximum temperature two months following a one percent increase in maximum temperature in a previous month would result into a 24.7% increase in malaria incidence. Overall the long-run impact of three months successive one percent increase in maximum temperature would result into an 8.1% reduction in malaria incidence.

Minimum temperature and malaria incidence

Minimum monthly temperature significantly affects variation in monthly malaria incidence. Results of the analysis revealed that a 1% increase in monthly minimum temperature in the observation month would on average reduce monthly malaria incidence by about 36.2%. Similarly, a one percent increase in minimum temperature in the preceding month following a one percent increase in the previous month would result into a 22.2% reduction in monthly malaria incidence. Furthermore, a one percent increase in minimum temperature two months following a one percent increase in minimum temperature would significantly increase malaria incidence by about 2.8%. Overall, the long-run impact of three months successive one percent increase in minimum temperature would increase monthly malaria incidence by about 16.7%. Findings revealed that increasing monthly minimum temperature is associated with increasing monthly malaria incidence holding all other factors constant.

Malaria incidence and rainfall

Rainfall is one of the climatic factors that might affect malaria transmission in the population. Since rainfall provides water for the breeding of mosquitoes we assessed its impact on the monthly malaria incidence. The average monthly rainfall was estimated at about 117.6 mm. A One percent increase in rainfall in the observation month significantly reduced monthly malaria incidence by about 24.1%. Similarly, a one percent increase in rainfall in the preceding month following one percent increase in the observation month significantly reduced malaria incidence by about 2.1%. Furthermore, a one percent expected increase in rainfall two months following a one percent increase in rainfall in the previous month significantly increased monthly malaria incidence by about 12.3%. Overall, successive one percent three months increase in rainfall would reduce malaria incidence by about 14% in the long-run. Findings revealed that increasing rainfall is associated with long-term reduction in monthly malaria incidence.

Discussion

Findings revealed that two months successive increase in maximum temperature was associated with a reduction in malaria incidence while three months successive increase in maximum temperature was associated with increased malaria incidence. Therefore, increasing monthly maximum temperature in the long-run is associated with reducing monthly malaria incidence. Similarly, increase in minimum temperature was associated with long-term increase in malaria incidence. Increase in maximum and minimum temperature might be attributed to change of weather seasons or land use change. If the increases in maximum and minimum temperatures are attributed to weather changes, the malaria incidence might reduce and then increase because the optimal temperature range for the survival of mosquitoes might be exceeded. On the other hand, if the increases in both maximum and minimum temperatures are attributed to land use changes, malaria incidence might increase. For example, previous studies have established that deforestation to create new human settlements increases micro temperature as well as new breeding sites for malaria vector [17]. Therefore, for effective control of malaria incidence in Uganda, preventive measures that target land use changes like agricultural farming methods, settlements, deforestation, wetlands among others might provide a better approach in the reduction of malaria incidence in Uganda. Land use changes for example from forest land to settlements or agriculture might introduce mosquito breeding sites resulting into increased malaria incidences. Therefore, malaria prevention should be integrated with land use activities that alter the micro temperature leading to reduction in both minimum and maximum temperature.

Increasing amount of rainfall was associated with reducing malaria incidence. This finding might be attributed to the fact that too much rainfall results into a lot of run-off water that washes away most of the breeding sites for mosquitoes [18]. This implies that mosquito breeding requires little rainfall. Furthermore, activities by the population to the environment that result into increasing the amount of rainfall received in a month play an important role in the reduction of malaria incidence in Uganda. These activities are mainly on the land use change that alters the micro-environment and hence, the amount of rainfall. Therefore, restoration of wetlands, forests and better farming methods that affect land use might play an important role in the prevention and control of malaria incidence in Uganda.

Conclusions and Recommendations

Increasing maximum temperature is associated with reducing malaria incidence while increasing minimum temperature is associated with increasing malaria incidence. Lastly, increasing amount of rainfall is associated with reducing malaria incidence. Therefore, malaria control and preventive interventions should consider environmental modifications that lower minimum temperature and increase the amount of rainfall. These interventions include land use changes such as conversion of land from forests to settlements and to agriculture, wetlands for settlements and other economic activities.

Ln (Malaria cases)	Lags	Coefficients	Std. Err.	P>t	95% CI		B(L)/A(L)		
Ln (Malaria cases)_1	1	0.749	0.065	<0.001	0.62	0.878	Effect	95%CI	
Maximum temperature	0	-0.057	0.02	0.005	-0.097	-0.018	-0.229	-0.386	-0.072
	1	-0.025	0.025	0.319	-0.074	0.024	-0.099	-0.295	0.097
	2	0.062	0.019	0.002	0.024	0.1	0.247	0.094	0.399
Minimum temperature	0	0.091	0.027	0.001	0.037	0.144	0.362	0.148	0.575
	1	-0.056	0.036	0.126	-0.127	0.016	-0.222	-0.507	0.063
	2	0.007	0.031	0.827	-0.055	0.069	0.028	-0.22	0.275

	0	-0.06	0.015	<0.001	-0.091	-0.03	-0.241	-0.362	-0.12
	1	-0.005	0.016	0.743	-0.038	0.027	-0.021	-0.15	0.108
Rainfall	2	0.031	0.015	0.049	0	0.061	0.123	0.001	0.245
constant		3.341	1.026	0.001	1.31	5.372	13.308	5.217	21.399

Table 2: Dynamics in malaria incidence in Uganda; **significant at 5%.

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