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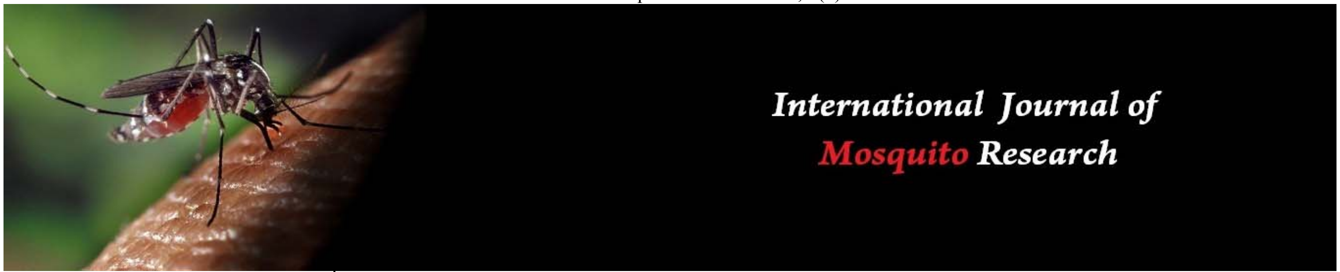

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Retrospective analysis of malaria transmission patterns and its association with meteorological variables in lowland areas of Plateau state, Nigeria

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Abstract
Malaria is a major public health problem in the remote areas of lower Plateau state. This study described malaria transmission patterns and analysed the impact of meteorological variables on the disease transmission in the study area. The study was a retrospective study, which involved the use of archival data relating to rainfall, temperature, relative humidity and malaria case reports. Data on climatic factors and malaria cases were obtained from the Nigeria Meteorological Agency and the general hospitals from selected areas of Langtang North, Mikang and Shendam from 2003-2015. Estimated smoothed trend line series for climatic factors were obtained based on structural time-series models in combination with the Kalman filter. Generalized Additive Models were used to model trends in malaria incidences over time and it's lagged association with meteorological variables. The results show a significant cyclical trend in malaria incidences in Langtang-North and Shendam ($p<0.001$) whereas the trend in Mikang was also significant ($p<0.001$) but an increasing linear one. The association between monthly malaria cases and mean monthly meteorological variables were significant ($p< 0.05$) at different time lags and locations. Our findings suggest that meteorological factors are among the major determinants of malaria transmission in the study areas. This will be informative in planning intervention strategies specific to each study area

Keywords: Malaria Transmission Trend, climate change, Plateau state, Nigeria

1. Introduction

Climate change, according to National Oceanic and Atmospheric Administration [NOAA] [1]. is a change in the statistics of the weather occurring over a long period of time for a particular place and time of year. Analysed data over the years have shown that the climate is indeed changing dramatically and its impacts on parasitology is obvious [2]. Malaria, a major parasitic disease is caused by *Plasmodium* species through the bites of infected female Anopheles mosquitoes is fast spreading into areas that were formally not conducive for its transmission due to climate change [3]. Most countries in sub-Sahara Africa are in suitable geographical locations for the spread of the disease and have poor health facilities to deal effectively with the effect of this spread [4].

The WHO report [5]. credited climate change with about 6% of malaria cases in some middle-income countries in the year 2000. This is because weather can influence the reproduction rate and life span of insect vectors thereby altering the dynamics of vector borne diseases [6,7].

Changes in relative humidity, temperature and precipitation exert a significant effect on the survival and distribution of malaria vectors and parasites and consequently influence the parasite by shortening the extrinsic life cycle [8,9].

The overall effect of the changing climate on malaria transmission has aroused intense debate and different researchers have come up with varying hypotheses [10].

Several studies have identified climate change as a major contributor to increased malaria transmission [11, 12, 13]. Bai *et al* reported that climatic factors are among the major determinants of malaria transmission on the China-Myanmar boarder [14]. Ermert *et al* forecasted that climatic changes driven by greenhouse gases and land use changes will sufficiently affect the spread of the disease in tropical Africa well before 2050 [11]. Whereas other studies have reported no association between climate change and malaria increase and/or transmission [15, 16, 17]. It has also been suggested that climatic factors and disease dynamics might complement each other and interact at different time scales to exacerbate malaria cases [18].

Therefore, the assessment of the impact of climate change on the incidence of malaria remains inadequately addressed, have received little attention and therefore an area of significant research interest. The information gained from present research work will help to improve future malaria control programmes by linking climate variables with the disease transmission.

Materials and Methods

Research Design

This study employed a retrospective survey design which involved the use of archival data of climate parameters (temperature, rainfall and relative humidity) and medical case records on malaria from selected hospitals in three (3) local government areas on the lowlands of Plateau state Central, Nigeria. The archival data on climatic factors were obtained from the Nigeria Meteorological Agency in Jos and Abuja and National Remote Sensing Centre in Jos, Plateau state for a period of thirty one (31) years from 1985-2015.

Medical records of Malaria cases were obtained from the general hospitals in the selected Local Government Areas (LGAs) for the study for a period of thirteen (13) years from 2003-2015.

Description of the Study Area

This study was conducted in Plateau state, Nigeria. It is located in North-Central Nigeria and lies between latitudes 80º24'N and longitudes 80º32' and 100º38' east. Plateau state has a total land area of 26,899 square kilometers. Three (3) local government areas namely: Langtang-North, Mikang and Shendam LGAs were selected from the lowlands (altitudes ≤400m above sea level) areas for this study

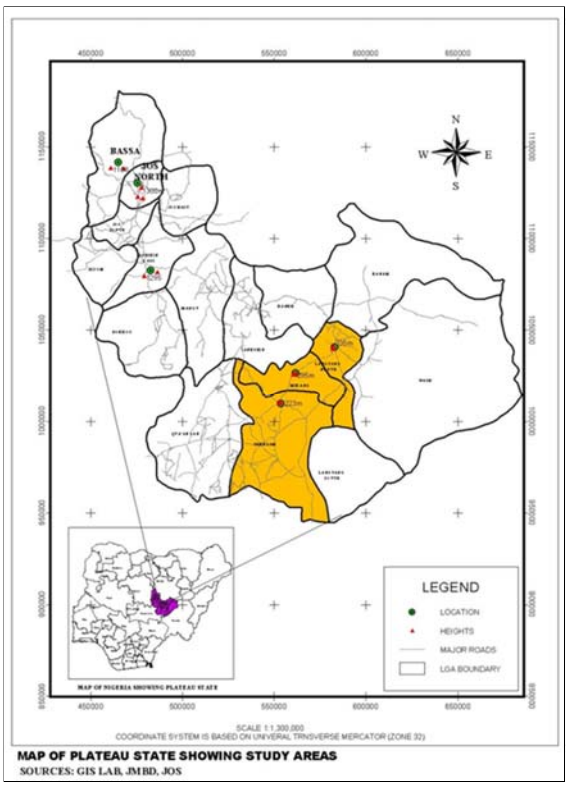


Fig. 1: Map of Plateau State Showing Study Areas.

Data Analysis

Generalized Additive Models (GAMs) were used to model trends in malaria incidences over time. GAMs are used to model trends as smooth, nonlinear function of time, and to also provide a framework for testing the statistical significance of changes in malaria incidence over time [19]. Mean monthly temperature, rainfall, and relative humidity were included as covariates in the models and the significance of each was given. The mgcv package version 1.8-7 for the R statistical package was used for the GAM analysis [20]. For modelling malaria incidences at the different sites, several GAM models were considered. The first model tested the immediate effect of mean monthly temperature at time t, rainfall at time t, and relative humidity at time t on malaria cases at time t. In alternate models, the relationships between malaria cases with up to six months' lag (i.e. t-1 to t-6 months) of the covariates were also tested. Smoothing term was applied to all covariates.

Model diagnostics

The informal verification of the goodness-of-fit of the GAM was obtained through plots of residuals and standard errors.

Figure 2 is an example of the diagnostic plot generated by R

(Core Team, 2013), the package used for the analyses [21].
These are diagnostic plots for the analysis of malaria incidences in Langtang- North Local Government Area with mean annual temperature, precipitation, and relative humidity as covariates.
Top left plot: Partial deviance residuals (black dots) lie along the straight quantile line
Bottom left plot: Residuals follow a normal distribution
Top right plot: Even variance of the residuals

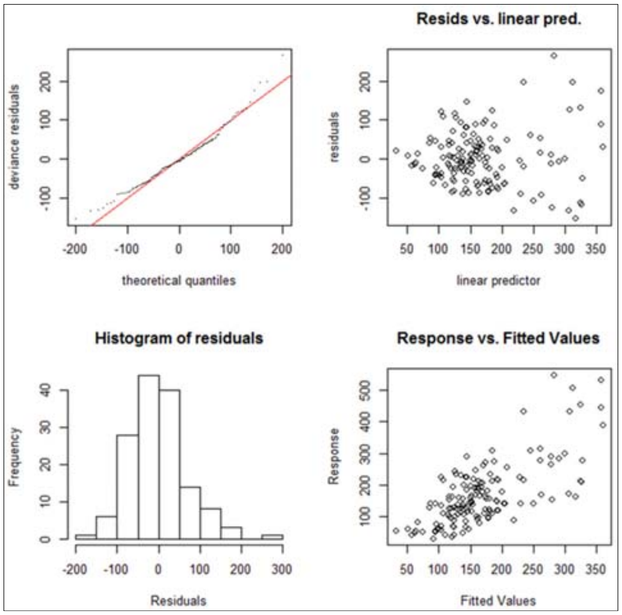


Fig 2: Diagnostic plots for malaria incidence in Langtang- North LGA

Results

Malaria trends in Langtang-North, Mikang and Shendam LGAs from 2003-2015

The results clearly show that there was a significant trend in malaria occurrence in Langtang-North LGA between 2003 and 2015 ($F= 12.8$, $p< 0.001$). The trend in malaria incidence between 2003 and 2015 was non-linear as indicated in figures 3. There was a steady increase in malaria cases from 2003 to 2010. Year 2011-2012 witnessed a gradual decline. This fall was not sustained as malaria cases began to rise again till 2015.

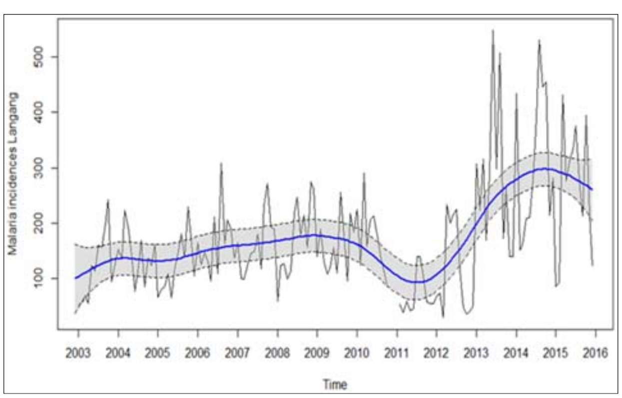


Fig 3: Non-linear malaria trend in Langtang-North LGA from 2003-2015

In Mikang LGA the trend was also significant between 2003 and 2015 ($F= 24.3$, $p< 0.001$). The trend was an increasing linear one as shown in figure 4.

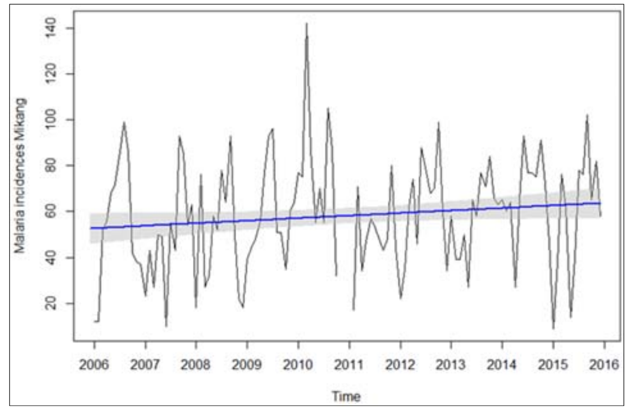


Fig 4: Increasing linear malaria trend in Mikang LGA from 2006-2015

The trend in malaria occurrence in Shendam LGA between 2003 and 2015 was significant ($F= 11.1$, $p< 0.001$) and cyclical as shown in figure 5. It reveals a sharp decline around 2005-2006 and another fall around 2011-2012

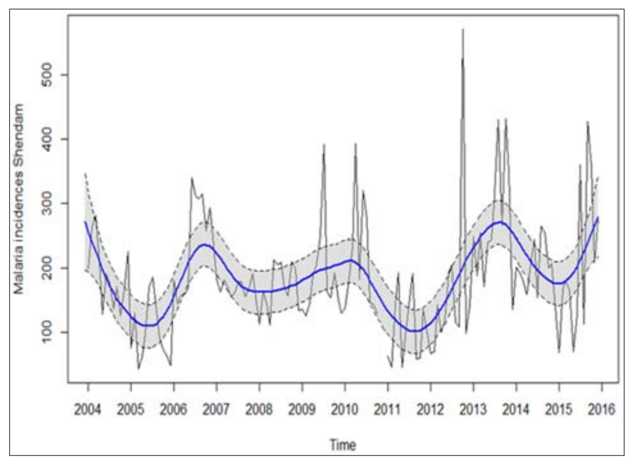


Fig 5: Cyclical malaria trend in Shendam LGA from 2004-2015

Malaria incidences in relation to temperature, rainfall and relative humidity in Langtang-North, Mikang and Shendam LGAs

Malaria occurrence in Langtang-North LGA was significantly affected by 1-month lagged average monthly temperature and 2-month lagged relative humidity (table 1). The deviance explained 54.6% of the association between malaria incidences with temperature, precipitation and relative humidity in this LGA.
In Mikang LGA, malaria cases were significantlyaffected by 3-month lagged precipitation and 2-month lagged relative humidity (table 1). The deviance explained 58.9% of the association between malaria cases with temperature, relative humidity and precipitation.
In Shendam LGA, malaria cases were significantly affected by 3-month lagged precipitation and 2-month lagged Relative humidity (Table: 1). The association between malaria cases with temperature, relative humidity and rainfall was explained by 65.8% deviance.

Table 1: Lagged association between meteorological variables and malaria cases

LGAs	Langtang-North				Mikang				Shendam			
Factors	**Lag**	**df**	**F**	**P**	**Lag**	**Df**	**F**	**P**	**Lag**	**df**	**F**	**P**
Yearly trend		8	12.8	<0.001		7	24.3	<0.001		9	11.1	<0.001
Temperature	1	1	4.4	0.037	1	1	3.1	0.080	2	3	1.3	0.237
Precipitation	3	5	1.5	0.167	3	1	4.2	0.042	3	7	2.1	0.041
Relative Humidity	2	1	7.7	0.006	2	1	8.7	0.004	2	7	2.1	0.042
Deviance explained				54.6%				58.9%				65.8%

Discussion

Malaria trends in Langtang-North, Mikang and Shendam LGAs from 2003 -2015

Malaria trend in Langtang-North LGA show steady increase from 2003 to 2015 with a temporary dip around 2011 and 2012. This steady increase is consistent with similar study in the northern Anhui Province of China by Gao *et al* [22]. Where they reported an increase in malaria incidence after 2000 with annual incidence peaked in 2006. The increase recorded in our study coincided with the period when malaria control in Nigeria witnessed challenges of exceptional increase in malaria cases due to drug resistance by the parasites [23]. Another major setback in the fight against malaria during this period was non availability of Insecticide Treated Nets (ITN) with ownership restricted to few households that could afford to purchase [24]. Further to this, the increase could also be as result of a corresponding steady increased in annual average temperature and rainfall during the same period (Appendices I&II). On the other hand, malaria control initiatives undertaken by the Government agencies and partners might have led to the temporary decline from 2011 to 2012 [25]. The Carter Center reported increased ownerships of LLIN after mass distribution campaigns in Langtang-North LGA during this period [26].

The trend was an increasing linear one in Mikang with a gradual increase from 2006 to 2015. This could be as result of less attention received by this LGA from the malaria control initiatives of government agencies and partners. The Carter Center, in her annual report show that Mikang LGA cumulative ITN distribution between 2004 and 2010 stood at 43,356 nets. This is far below the 92,456 and 88,596 nets received by neighbouring Shendam and Langtang-North LGAs respectively [27]. In addition, factors such as limited number of health facilities where residents can readily seek treatments and denser vegetation cover in Mikang LGA could have contributed to the increased trend.

It is also possible that the increasing trends in climatic factors had influence on malaria transmission in the LGA. This is because malaria transmission, mean annual temperature and rainfall showed similar trends (Appendices III&IV).

Malaria trend in Shendam LGA showed a cyclical pattern (Fig.5). The fluctuations reveal a decline around 2005-2006 and another fall around 2011-2012 a situation similar to that reported in Langtang-North LGA. This could also be attributed to malarial intervention strategies put in place by the government [26].

Malaria incidences in relation to temperature, rainfall and relative humidity in Langtang-North, Mikang and Shendam LGAs from 2003 -2015

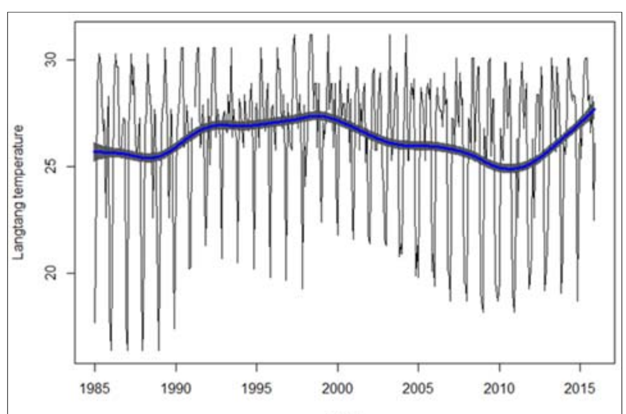
The relationship between monthly malaria cases and mean monthly temperature, rainfall and relative humidity for Langtang-North, Mikang and Shendam LGAs show significant association at different time lags. In Langtang-North LGA, mean monthly temperature and relative humidity were significantly associated with malaria cases at 1and 2-months lag respectively. This finding is in consistent with that of related study in India [28]. They reported a positive correlation between monthly malaria prevalence with average monthly temperature. This is consistent with the fact that there was approximately one month period in the course of the malaria infection cycle from female Anopheles mosquito larvae developing into an infectious *Anopheles* mosquito that can bite human and human manifesting malaria symptoms [29]. On the other hand, related studies have reported no evidence of association between malaria incidences, rainfall, relative humidity and temperature [30]. The findings in Langtang-North LGA further emphasize the influence of climatic variables on malaria transmission.

In Mikang and Shendam LGAs, average monthly relative humidity and precipitation were both significantly associated with the occurrence of malaria parasites at 2-month lag and 3-month lag respectively. This is not surprising because these LGAs border each other having similar ecology and human behaviours. A positive correlation between monthly malaria incidences with average monthly rainfall and average monthly relative humidity at 2 to 3 months lags have also been reported in Ethiopia [31]. Also consistent with this finding is the significant effects of relative humidity and rainfall that were observed at a lag of 8 weeks and 10 weeks respectively in Yunnan, province in China [14]. The effect of Relative humidity on *Plasmodium* species development seems to be indirect. This is because average relative humidity less than 60% shorten the life cycle of the Anopheles mosquito to less than the extrinsic incubation period (about 2 weeks) so that there is no malaria transmission [32]. It has also been shown that relative humidity at <60% limit the distribution and abundance of *anopheles* species in China [33].

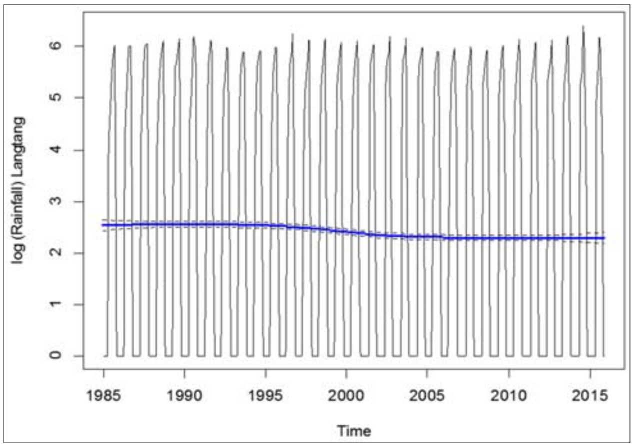
Though many studies have reported a complex relationship between rainfall and malaria transmission [34, 27, 32], rainfall appears to be the significant determinant of the completion of the life cycle of *Plasmodium* species [35]. This is consistent with the findings of this study where relative humidity and precipitation are the major determinants of malaria transmission in Mikang and Shendam LGAs.

Conclusion

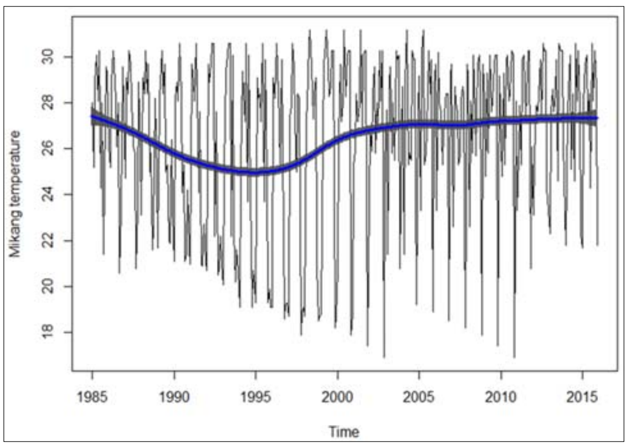
The study established a significant cyclical trend in reported malaria cases in all the LGAs except Mikang LGA, where the trend was linear between 2003 and 2015. Significant associations between mean monthly rainfall, temperature and relative humidity with malaria transmission at different time lags and locations were established. Our findings suggest that climatic factors are among the major determinants of malaria transmission in the lowland areas of Plateau state. This study has demonstrated a better understanding of the role of climatic variables in malaria transmission in the lowland areas of Plateau state. This knowledge can be helpful in formulation of better malaria surveillance system at the different micro-Eco epidemiological settings. This might help in predicting future malaria outbreaks for appropriate measures to be put in place before such occurrences.



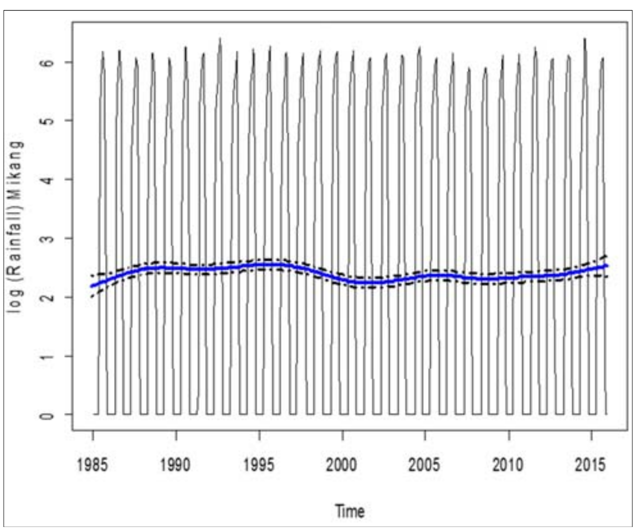
Appendix I: Annual temperature trend for Langtang-North LGA



Appendix II: Annual rainfall trend for Langtang-North LGA



Appendix III: Annual temperature trend for Mikang LGA.



Appendix IV: Annual rainfall trend for Mikang LGA.

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