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Variability Effects of Meteorological Factors on Reported Malaria Cases in Kano and Lagos States of Nigeria

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Abstract: Malaria is one of life's threatening disease that contributed significantly to morbidity and mortality in Nigeria. The variability effects of meteorological factors between the Northern and Southern region of Nigeria on malaria transmission remain unclear and not well researched. This research was aimed at comparing the non-linear effects of seasonal, trend and meteorological variables on monthly malaria cases in Kano and Lagos State of Nigeria. The monthly malaria cases for age group above 5-year for Kano and Lagos State were obtained from DHIS for the period of January, 2016 to December, 2022. Also, the predictors/meteorological variables (Rainfall, Relative Humidity, Minimum Temperature and Maximum Temperature) were obtained from Nigeria Meteorological Agent. Generalized Additive Model was fitted using Negative Binomial to apply smooth function to estimate and compare the effects of the selected predictors on the malaria transmission in Kano and Lagos States. Rainfall and Maximum temperature were found not significant in explaining the effect of malaria transmission. Malaria transmission was found to be seasonal and varying in Kano State with highest transmission between September and October while the seasonal effect was reduced to linear in Lagos State. The long term trend had a significant increasing effect on malaria transmission in Kano Sate compared to non-significant effect in Lagos State. The effect of Relative Humidity was reduced to linear and increasing in the both State. Paying attention to the variability in the influence of season, trend and meteorological variables on malaria transmission will enhance respective State Government to develop an early warning and awareness that will help in controlling the malaria outbreak in their State.

Keywords: Malaria Transmission, Meteorological Factors, Negative Binomial Model, Generalized Additive Model, Repeated Measures Correlation

I. Introduction

Malaria remains a significant public health challenge in Nigeria, with the country accounting for a staggering 25% of global malaria cases and 30% of malaria-related deaths [10]. The transmission of this debilitating disease is influenced by various environmental and ecological factors, with meteorological variables playing a crucial role [3]. Temperature, rainfall, and humidity have been identified as key determinants that affect the survival, development, and distribution of the Anopheles mosquito vector, as well as the parasite's reproduction and transmission dynamics [7]. Ultimately, the significance of this research lies in its potential to contribute to the ongoing fight against malaria in Nigeria, a country that bears a disproportionate burden of the disease. By providing a deeper understanding of the meteorological drivers of malaria transmission in Kano and Lagos States, this study can pave the way for more effective and sustainable malaria control strategies, ultimately improving public health outcomes and contributing to the achievement of the Sustainable Development Goals related to combating malaria and other neglected tropical diseases.

Research in Nigeria has consistently demonstrated a seasonal variation in malaria cases, with studies highlighting the impact of meteorological factors on disease transmission. [8] found that the highest parasite densities occurred in September, while [6] reported that mosquito densities and malaria transmission risks peaked during the rainy season. [9] also noted a surge in asymptomatic parasitaemia in July, corresponding to the wet season. Furthermore, there have been emphases on the role of seasonal variations in malaria infection, with recommendations targeted interventions in affected states. This studies collectively underscore the need for season-specific malaria control measures in Nigeria. [1] highlighted, rainfall as a chief factor influencing the transmission of malaria, as it provides breeding sites for mosquito vectors. Temperature, on the other hand, determines the duration of development of mosquito larvae in the environment, while precipitation, directly related to rainfall, is an essential factor influencing the bionomics of malaria-transmitting mosquito vectors.

Despite the evidence of the impact of meteorological variables on malaria transmission in Nigeria, limited research has been conducted on the specific effects of these factors along the climatic variation like the Sahelian Climate prevalent in the North-East and North-West regions Kano state inclusive, and the Tropical Rainforest Climate of the South-South and South-East regions covering the coastal states including Lagos state, which have distinct climatic conditions and malaria burdens [5]. This study aims to bridge this gap by investigating the relationship between meteorological variables (temperature, rainfall, and humidity) and malaria transmission along these climatic

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variations within Nigeria. Understanding these relationships can inform the development of targeted interventions and early warning systems for malaria control in these regions, ultimately contributing to the ongoing efforts to combat this persistent public health challenge.

Significance of the Study

Malaria remains a significant public health burden in Nigeria, with substantial socioeconomic and human costs [10]. Despite progress in malaria control efforts, the disease continues to pose a significant challenge, particularly in regions with diverse climatic conditions and varying transmission dynamics. Kano and Lagos States, two distinct regions in Nigeria, have different malaria burdens and climatic patterns, necessitating tailored interventions and control strategies [5].

The motivation behind this study lies in the need to understand the in the variability in the effect and relationship between meteorological variables and malaria transmission in these two states. Previous research has established the influence of factors such as temperature, rainfall, and humidity on the life cycle and behavior of the Anopheles mosquito vector, as well as the development and transmission of the malaria parasite [3]. However, the effects of these variables can vary depending on the local environmental conditions and climatic patterns.

By investigating the impact of meteorological variables on malaria transmission in Kano and Lagos States, this study aims to provide valuable insights that can inform the development of targeted and effective malaria transmission awareness and control strategies. Identifying the specific meteorological drivers of malaria transmission in these regions and how the effect of these drivers varies between the regions can aid in the planning of early public warning systems, enabling their respective State Government and authorities in public health to anticipate and prepare for potential malaria outbreaks.

II. Methodology

This study considered a retrospective panel data analysis using secondary data of monthly malaria cases in Kano and Lagos States of Nigeria for the period of January 2016 to December 2022 among age group above 5-year. The monthly malaria incidence for the considered states were retrieved from DHIS. The monthly climate data for Lagos, Kano and Rivers State were also derived from the relevant government agency in Nigeria for the period of January 2016 to December 2022. The considered meteorological variables were Rainfall, Relative Humidity (RH), Minimum Temperature and Maximum Temperature.

Generalized Additive Model

Let consider X_{i1} to be log-transformation and X_{i2} to be a reciprocal transformation in a linear model,

Then the resulting model is given as

$$Y_i = \beta_0 + \beta_1 \log(X_{i1}) + \beta_2 / X_{i2} + e_i \quad (1)$$

$$Y_i = \beta_0 + g\beta_1(X_{i1}) + g\beta_2(X_{i2}) + e_i \quad (2)$$

Where $g\beta_1(X)$ and $g\beta_2(X)$ are two functions specified by β_1 and β_2

The transformation for the jth predictor is given as

$$g_j(X) = \sum_{k=1}^{K_j} \theta_{jk}\psi_{jk}(X) \quad (3)$$

Where $\left[\psi_{jk}(.)\right]_{k=1}^{K_j}$ are B-spline basis functions,

Let $\left\{(x_i, y_i)\right\}_{i=1}^{n}$ be considered as simple regression data

Then cubic spline smoother $g(x)$ that minimizes the above is given as

$$\sum_{i=1}^{n}\left(y_i - g(x_i)\right)^2 + \lambda\int_{-\infty}^{\infty} g''(x)^2 dx \quad (4)$$

$$\lambda \geq 0$$

And good fit is achieved by minimizing the sum of squares

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$$\sum_{i=1}^{n}\left(y_i - g(x_i)\right)^2 \qquad (5)$$

Where $\int_{-\infty}^{\infty} g''(x)^2\,dx$ measures how wiggly $g(x)$ is

And $\lambda \geq 0$ is how much we will penalize $g(x)$ for being wiggly

The monthly malaria incidence is considered as the response variable and meteorological factors as the explanatory variables. The effect of seasonal, trend and meteorological variables on monthly malaria cases were assessed using Negative Binomial Generalized Additive Model. The predictor variables effect on malaria cases was compared between two states in Nigeria (Kano and Lagos). Lagos State is considered to represent Southern region and Kano for Northern region.

Poisson, Negative Binomial, quasi-Poisson distributions among others are different distributions suitable for modelling count response variable. However, negative binomial is more suitable for over-dispersed data [11].[4] shows that Negative Binomial provided a better fit to modelling monthly malaria incidences with respect to climate variables.

The expected malaria cases count is specify as follows:

$$g\left(E(Y_{ij})\right) = \beta_0 + \sum_{i=1}^{k}\beta_i I\left(State = i\right) + \sum_{i=1}^{k} f_i\left(predictor_j\right) I\left(State = i\right) \qquad (6)$$

Where, g is the link function, $\left(E(Y_{ij})\right)$ is the expected value of malaria cases, β_0 is the overall intercept, β_i are the coefficients of the State indicator variables, $f_i\left(predictors_j\right)$ are the smooth function of the selected predictors specific to each $State = i$ and $I\left(State = i\right)$ are indicator functions for each State, which are 1 if the observation belongs to State i and 0 otherwise.

For more comprehensive review on Generalized Additive Model for monthly malaria incidence, please refer to [2] and [12]

III. Results and Discussion

Overall, 10,515,037 malaria confirmed cases among age category five years and above were reported in all considered states in the study, in Nigeria between 2016 to 2022 with highest number of cases from Kano State (6,716,089) and Lagos State (3,798,948). Table 1 revealed that high malaria transmission occurred in the state that represent northern sub region, compared to Lagos State that represent South sub region in the study.

Table 2 contains the repeated measures correlation coefficients (r) and their significant values (p-values) for malarial cases and meteorological variables. Malaria cases were found to have significant correlation with Rainfall, Relative humidity (RH) and Maximum Temperature, though the strength of their correlation were seen to be from weak to moderate. Repeated correlation coefficient revealed a weak and non-significant correlation between malaria cases and Minimum Temperature (r = -0.1159 and p-value = 0.1357). The table further revealed that there will be no fear of multi-collinearity in including all the meteorological variables in the model as there is no perfect correlation within the variables.

The selection of variables that will be considered for comparing the variation in the trend of malaria incidence between Lagos and Kano was done by setting “select = TRUE” in the gam function of R package. Table 4 revealed the contributions and significant of meteorological variables in explaining malaria incidence in the region. Season, Long term trend, RH and Minimum temperature were found to have smooth relationship with malaria incidence, since their p-values were less than 0.05 while rainfall and maximum temperature were found non-significant in explaining the effect of malaria. 79% of variation in malaria case was predictable using model that consist of main effect of seasonal, trend, RH, Rainfall, Maximum temperature, Minimum temperature variables and 73.3% percentage deviance explained while the model that exclude Rainfall and Maximum temperature accounted for the same variation and percentage deviance explained. Furthermore, fig. 1 revealed the flat shapes of rainfall and maximum temperature on the vertical axis. Hence, rainfall and minimum temperature will be excluded in the further analysis to compare geographical variation in malaria transmission in Nigeria.

Table 1: Yearly Malaria cases according to States

Malaria cases among age category five and above by State			
Year/State	Lagos	Kano	Total
2016	511450	500881	1012331
2017	537876	664447	1202323

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2018	580744	796470	1377214
2019	596318	1013154	1609472
2020	472992	1067160	1540152
2021	539027	1295066	1834093
2022	560541	1378911	1939452
Total	3798948	6716089	10515037

Table 2. Correlation coefficients between Malaria cases and Meteorological Variables

FACTORS	MALARIA CASES	RAINFALL	RH	MAX TEM	MIN TEMP
MALARIA CASES	1.0000 0.0001***	0.1915 0.0313*	0.4252 0.0001***	-0.2571 .0007**	-0.1159 0.1357
RAINFALL	0.1915 0.0313*	1.0000 0.0001***	0.5806 0.0001***	-0.2417 .0016**	0.0313 0.6876
RH	0.4252 0.0001***	0.5806 0.0001***	1.0000 0.0001***	-0.1791 0.0205*	0.4002 0.0001***
MAX TEMP	-0.2571 0.0007**	-0.2417 .0016**	-0.1791 0.0205*	1.0000 .0001***	0.5444 0.0001***
MIN TEMP	-0.1159 0.1357	0.0313 0.6876	0.4002 .0001***	0.5444 .0001***	1.0000 0.0001***

Table 3. Contributions of seasonal, trend and meteorological variables on the combined States

Factor	Estimate	P – value
Intercept	10.9503	<0.0001
Smooth Terms	edf	P - value
S(Month)	4.0529	<0.0001
S(Year)	1.6849	<0.0001
S(Rainfall)	0.0005	0.3814
S(RH)	2.2035	<0.0060
S (Max Temp)	0.0006	0.2268
S (Min Temp)	4.9721	0.0001
R-square(adj) = 0.79, Percentage of Deviance Explained = 73.3%		

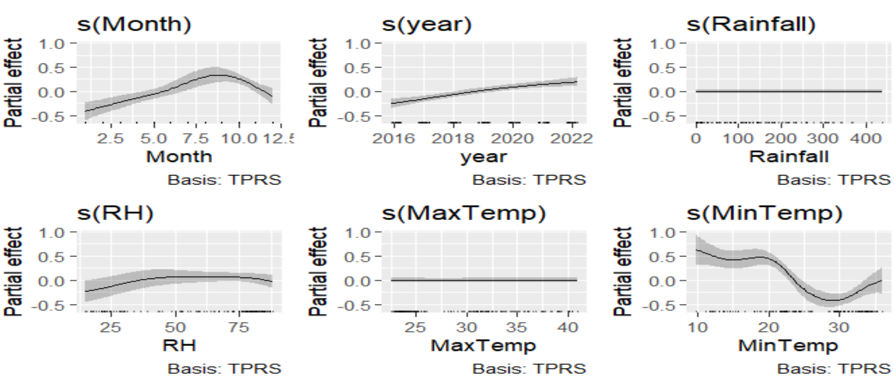

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Figure 1: effects of seasonal, trend and meteorological variable on the combined states

State Differences in Malaria Transmission

Generalized Additive Model was fitted using Negative Binomial to apply smooth function to estimate the effects of the selected meteorological variables (Seasonal, Trends, RH and Minimum Temperature) on the malaria cases in Kano and Lagos State.

Table 4(Month) revealed that monthly malaria cases had a significant smoothed (non-linear) relationship with season with the edf of 5 in Kano State while malaria cases had non-significant linear relationship with season in Lagos State. The effect of season with malaria cases was reduced to linear in Lagos State and Figure 2(Month) further revealed that it had an increasing linear effect on the Log-link scale of the monthly malaria cases in the State while there was a sharp increase in malaria cases around the month of May and peaked between September and October and then decreases after October in Kano State.

The effective degree of freedom from Table 4(Year) revealed that trend had a significant smoothed relationship with malaria transmission in Kano State with higher malaria transmission from the year 2019 and above. However, the long term trend had a non-significant smoothed relationship with malaria transmission and almost a flat linear shape on the vertical axis in Lagos State. Figure 2(RH) shows that malaria cases had an increasing linear relationship with RH in the both states and the effects was found to be significant in Kano State compare to Lagos State. There is higher malaria transmission in Kano State than Lagos State at RH that is above 60. Also a lower RH between 20 to 40 was found favorable for malaria transmission in Lagos State than Kano State. There is varying and significant in the effects of malaria cases with the minimum temperature in Kano State has shown in Table 4(Minimum Temperature). Minimum temperature between 12 to 17 were found to neither increase or decrease the malaria transmission in the State. Minimum Temperature above 17 to 22 had higher malaria transmission while the transmission was lower between 23 to 34 in Kano State. However, the relationship between malaria cases and minimum temperature was reduced to a linear and decreasing in Lagos State. There is lower malaria transmission with minimum temperature less than 25 in Lagos State.

Table 4: Smoothed effects of Seasonal, long term trend, relative humidity and minimum temperature in Kano and Lagos states

Month		
Smooth Terms	Estimate	P-value
Intercept	10.7182	0.0001
Kano	0.4906	0.0001
Smooth Terms	edf	P-value
S(Lagos)	1.0000	0.1420
S(Kano)	5.5640	0.0001
Year		
Smooth Terms	Estimate	P-value
Intercept	10.7194	0.0001
Kano	0.5155	0.0001
Smooth Terms	edf	P-value
S(Lagos)	1.0000	0.876
S(Kano)	2.1900	0.0001
RH		
Smooth Terms	Estimate	P-value
Intercept	10.6421	0.0001
Kano	0.7884	0.0001
Smooth Terms	edf	P-value
S(Lagos)	1.0000	0.5910
S(Kano)	1.0000	0.0001
Minimum Temperature		
Smooth Terms	Estimate	P-value

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Intercept	10.8497	0.0001
Kano	0.3164	0.7520
Smooth Terms	edf	P-value
S(Lagos)	1.0000	0.2720
S(Kano)	4.837	0.0001

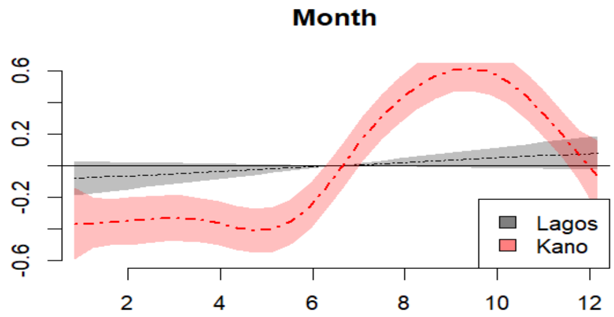

Figure 2(Month): Smoothed effects of Month on Malaria Transmission

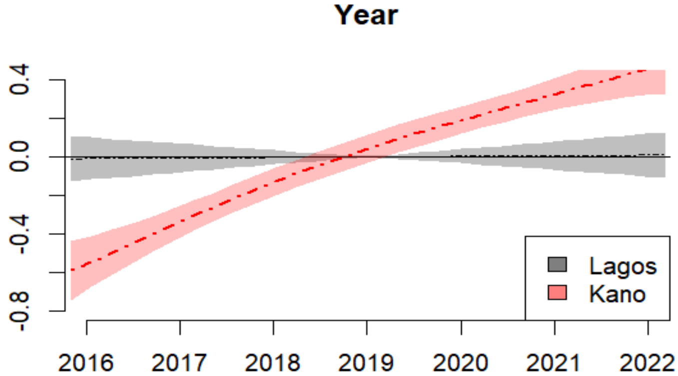

Figure 2(Trend): Smoothed effects of Trend on Malaria Transmission

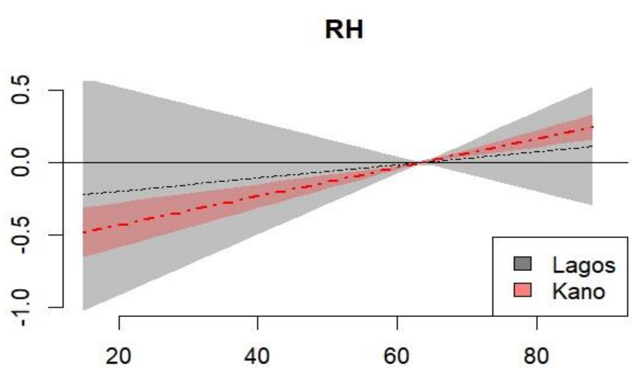

Figure 2(RH): Smoothed effects of Relative Humidity on Malaria Transmission

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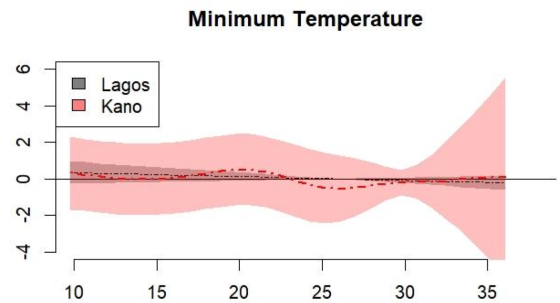

Figure 2 (Min Temp): Smoothed effects of Minimum Temperature on Malaria Transmission

IV. Conclusion

This research used a generalized additive model to estimate seasonal, trend, and smoothed effects of meteorological variables on malaria transmissions in Kano and Lagos State. Kano and Lagos state were on different geographical location in Nigeria. Seasonal, trend, Relative Humidity and Minimum Temperature were identified as factors that contribute to malaria transmissions in the two state. While there was a sharp increase in malaria transmission around the month of May and peaked between September and October in Kano state, Lagos state shows an increasing malaria transmission from January to December. There is high malaria transmission from year 2019 and low malaria transmissions below year 2019 in Kano state, while there is non-significant increase or decrease in malaria transmission in Lagos state. Relative Humidity was found to linearly increase malaria transmissions in both states. There is varying effect of minimum temperature on malaria transmissions in Kano state. Minimum temperature between 17 to 22 had higher malaria transmissions and lower transmissions in minimum temperature between 23 to 34 in Kano state, while the effect in Lagos state was found to be linearly decreasing.

Conflict Of Interest

The authors declare that there is no conflict of interest

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