The Causal Relationship between Anopheles Mosquito Population and Climatic Factors in Makurdi- Nigeria: An Empirical Analysis

Kuhe, David Adugh[1] and Jenkwe, Elizabeth D[2]

[1]Department of Mathematics/Statistics/Computer Science, Federal University of Agriculture, Makurdi, Benue State-Nigeria.
[2]Department of Geography and Environmental Management, University of Abuja, Abuja-Nigeria.
Corresponding Author: Kuhe, David Adugh. Department of Mathematics/Statistics/Computer Science, University of Agriculture, P.M.B. 2372, Makurdi, Benue State-Nigeria.
Tel: +2348064832229. E-Mail: davidkuhe@gmail.com

***Abstract*: This paper investigates the causal relationship between Anopheles Gambiae and Anopheles Funestus species of mosquito population and weather parameters such as mean temperature, mean rainfall and mean relative humidity in Makurdi, the metropolitan city of Benue State in Nigeria. The study uses monthly data obtain for the period February, 2014 to July, 2015 on the study variables. Simple correlation and linear regression analyses are employed to determine the degree and direction as well as the effect and short run relationship among the study variables. Johansen co-integration test is employed to investigate the long-run dynamics while Granger causality analysis is then applied to examine the causal relationship between Anopheles mosquitoes' population and weather parameters. The correlation result shows that Anopheles gambiae and Anopheles funestus have strong negative and significant relationship with mean temperature. Whereas a positive and significant correlation exists between Anopheles gambiae and Anopheles funestus with mean rainfall and mean relative humidity. The regression result reveals that mean monthly temperature is negatively and statistically significantly related with Anopheles mosquito population in the study area. While mean rainfall and mean relative humidity are positively and statistically significantly related with Anopheles mosquito population. Johansen cointegration test results show the existence of long-run relationship among the variables under study. The Granger causality analysis result indicates that Anopheles mosquito species population is Granger caused by mean rainfall, mean temperature and mean relative humidity and that mean rainfall Granger causes mean temperature and mean relative humidity which favoured the increasing number of Anopheles mosquito population in the study area. The study recommends strong preventive and control measures against malaria in the study area.**

***IndexTerms*: Anopheles mosquitoes, mean temperature, mean rainfall, mean relative humidity, cointegration, Granger causality.**

I. INTRODUCTION

Malaria is considered the most detrimental mosquito-borne disease worldwide. Because of the Climate-sensitivity of the mosquito vector, malaria is strongly influenced by climatic factors. Climate variables could play an important role in the geographic distribution and seasonal occurrence of these vector species (Hopp & Foley 2001, Martens & Thomas 2005, and Kearney *et al.* 2009). Although the relationship between malaria and climate variables has been assessed in many regions, few studies have addressed the relationship between the vector species and climate variables. In addition, since there are many species of malaria vector mosquitoes in Africa which occurs in various climates, such as cool- and warm-temperate, subtropical and tropical, the relationship between vectors and projected climate conditions is quite complex, depending on the type of species (Paing *et al.* 1989, Chow 1991, Garros *et al.* 2008, Manguin *et al.* 2008, Barik *et al.* 2009, Ndoen *et al.* 2010).

In particular, little is known about the broad-scale impact of variations in climate on the vector species distributions in these regions. Recent studies that have mapped vector species have attempted to explain the geographic distribution of Anopheles and Aedes mosquitoes by analysing the climate variables of mosquito observation sites using niche-based distribution models (Foley *et al.* 2008). These studies have generated high resolution maps of the present distributions of these vectors over large areas using climate data. The ecophysiological and entomological approaches have also been employed in a number of studies to explain the temporal occurrence of vectors, by describing their life cycles and addressing climate factors (Patz *et al.* 1998, Hopp & Foley 2001, Depinay *et al.* 2004, and Pascual *et al.* 2006). Apart from simple climatic variables, the activities of the mosquitoes depend on variables related to their native habitats, such as water and soil conditions.

Precisely, population of malaria is influenced by weather, which affects the ability of the main carrier of malaria parasites, anopheles mosquitoes, to survive or otherwise. Tropical areas including Nigeria have the best combination of adequate rainfall, temperature and humidity allowing for breeding and survival of anopheles mosquitoes. Country-specific evidence shows that Nigeria has the largest population at risk of malaria in Africa and therefore most vulnerable to the risk of missing MDGs target. The disease, malaria, is a major health problem in the country, with stable transmission throughout the country. It accounts for about 50% of out-patient consultation, 15% of hospital admission, and also prime among the top three causes of death in the country (National Malaria Control Plan of Action 1996 to 2001). Approximately 50% of the Nigerian population experience at least one episode per year. However, official estimate suggests as much as four bouts per person per year on the average (WHO, 2002).The rate of malaria infection across space depends on dynamic processes involving complex climatic, environmental, physical, and social variables operating differently in space. This complexity makes the analysis of the causal relationship between anopheles mosquito population and climatic factors in Nigeria important. This analysis can explain the relationship, thereby providing a basis for policy intervention. Makurdi metropolitan city of Benue State is one of the areas infested by mosquitoes and no research information is available on the issue in the study area. In this regard, it becomes imperative to conduct a phased enquiry on the causal relationship between anopheles mosquito population and climatic factors in Nigeria using Makurdi metropolitan city of Benue State as a case study

II. DATA AND STUDY AREA

This study is conducted in Makurdi, the metropolitan city of Benue State of Nigeria. Makurdi is the capital of Benue State in Nigeria. The city is located in central Nigeria along the banks of River Benue, a major tributary of the Niger River. Makurdi has an estimated population of 500,797. Makurdi is situated at 7.74° North latitude, 8.51° East longitude and 104 meters elevation above the sea level. Owing to its location in the valley of River Benue, Makurdi experiences warm temperatures most of the year. The period from November to January, when the harmattan weather is experienced is, however, relatively cool. Monthly data on Anopheles gambiae and Anopheles funestus mosquito population, mean temperature, mean rainfall and mean relative humidity for the time period from February, 2014 to July, 2015 were collected making a total of 18 months.

III. MATERIALS AND METHODS

3.1 Simple Correlation

Two variables are said to be correlated if the change in one variable results in a corresponding change in the other variable. A mathematical method for measuring the intensity of the magnitude of linear relationship between two variable series was suggested by Karl Pearson (1867-1936). Pearson Correlation Coefficient between two variables x and y, usually denoted by $r(x,y)$ or r_{xy} or simply r, is a numerical measure of linear relationship between them and is defined as the ratio of the covariance between x and y, written as $Cov(x,y)$, to the product of the standard deviations of x and y. Symbolically:

$$r = \frac{Cov(x,y)}{\sigma_x \sigma_y} = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2]\left[n\sum y^2 - (\sum y)^2\right]}} \qquad (1)$$

Equation (1) is known as Karl Pearson's coefficient of correlation or product moment correlation coefficient. Pearsonian correlation coefficient lies between -1 and $+1$.

3.2 Simple Linear Regression

A Simple linear regression equation is one that involves one dependent variable and one independent variable. The relationship between the dependent variable and the independent variable can be expressed in a linear additive model as:

$$Y = \beta_0 + \beta_1 X + \varepsilon \qquad (2)$$

Where Y is the response (dependent) variable; X is the controlled (independent) variable; β_0 is the intercept of the vertical axis; β_1 is the slope or gradient of the line. β_0 and β_1 are called the regression parameters or coefficients. ε is unknown error component that is super imposed on the true linear relation. This error is undesirable random variable which we assume is dependent and normally distributed with mean zero and variance σ_ε^2. The parameters β_0 and β_1 which together locate the regression line are unknown. The $\hat{\beta}_0$ and $\hat{\beta}_1$ are the least squares estimators of the regression coefficients. Thus the least regression equation is:

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X \qquad (3)$$

and for any fixed value of the control variable x, the value of the response variable y can be predicted using the equation (3).

3.3 Coefficient of Determination

The coefficient of determination denoted by r^2measures the proportion of the total variations in the data that is explained or accounted for by the regression model. Clearly $0 \leq r^2 \leq 1$ and is usually expressed as a percentage. It is denoted as follows.

$$r^2 = \frac{Explained\ sum\ of\ squares}{Total\ sum\ of\ squares} = \frac{\beta_1^2\left[n\sum X_i^2 - \left(\sum X_i\right)^2\right]}{n\sum Y_i^2 - \left(\sum Y_i\right)^2} = \frac{\sum(\hat{Y}-\bar{Y})^2}{\sum(Y-\bar{Y})^2} \qquad (4)$$

If the explained sum of squares is much greater than the unexplained sum of squares, the r^2 will be close to one and the more precise the fit. This indicates how useful the regression line will be as a predictor. When r^2 is close to one, the regression model is adequate or a good fit for the data. The coefficient of determination can also be obtained as the square of the correlation coefficient.

3.4 Ramsey RESET Test

The Ramsey Regression Equation Specification Error Test (RESET) test is a general specification test for the linear regression model. It tests whether non-linear combinations of the fitted values help explain the response variable. The intuition behind the test is that if non-linear combinations of the explanatory variables have any power in explaining the response variable, the model is mis-specified, (Ramsey, 1969).Consider the model

$$\hat{y} = E\{y/x\} = \beta x \qquad (5)$$

The Ramsey test then tests whether $(\beta x)^2$, $(\beta x)^3$, $(\beta x)^4$, …, $(\beta x)^k$ has any power in explaining y**.** This is executed by estimating the following linear regression:

$$y = \alpha x + \gamma_1 \hat{y}^2 + \cdots + \gamma_{k-1}\hat{y}^k + \varepsilon \qquad (6)$$

and then testing by means of F-test using the following hypotheses:

$\boldsymbol{H_0}$: the model is well specify against $\boldsymbol{H_1}$: there is mis-specification of the model

Decision Rule: If p-values of t-statistic, F-statistic or likelihood ratio are greater than $\alpha = 0.05$, accept H_0, otherwise reject H_0, and accept H_1.

3.5 Johansen Cointegration Test

Two or more time series are said to be cointegrated if they share a common stochastic drift. If two or more series are individually integrated but some linear combination of them has a lower order of integration, then the series are said to be cointegrated, (Engle, Granger, and Clive ,1987). The Johansen test is a test for cointegration that allows for more than one cointegrating relationship. A Vector Autoregressive based cointegration test methodology developed by Johansen (1991, 1995) is as follows: Consider a Vector Autoregressive (VAR) of order p:

$$y_t = \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + \cdots + \Phi_p y_{t-p} + Bx_t + \varepsilon_t \qquad (7)$$

where $y_t =$ k-vector of non-stationary I(1) variables, $x_t =$ d-vector of deterministic variables and, $\varepsilon_t =$ a vector of innovations. We may rewrite this VAR as:

$$\Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + Bx_t + \varepsilon_t \qquad (8)$$

where

$$\Pi = \sum_{i=1}^{p} A_i - \boldsymbol{I},\ \Gamma_i = -\sum_{j=i+1}^{p} A_j \qquad (9)$$

Granger's representation theorem asserts that if the coefficient matrix Π has reduced rank $r < k$, then there exist $k \times r$ matrices α and β each with rank r such that $\Pi = \alpha\beta'$ and $\beta' y_t$ is I(0). r is the number of cointegrating relations (the cointegrating rank) and each column of β is the cointegrating vector. Johansen cointegration test computes two statistics: trace statistic and maximum eigenvalue statistic.

The trace statistic for the null hypothesis of r cointegrating relations is computed as:

$$\lambda_{trace}(r|k) = -T\sum_{i=r+1}^{k} \log(1-\lambda_i) \qquad (10)$$

The maximum eigenvalue test statistic is computed as:

$$\lambda_{max}(r|r+1) = -T\log(1-\lambda_{r+1}) = \lambda_{trace}(r|k) - \lambda_{trace}(r+1|k) \qquad (11)$$

Where$\lambda_i = i$-th largest eigenvalue of the Π matrix in (9), $r =$ 0, 1, 2, …, k-1.

3.6 Granger Causality Test

A variable x is said to Granger-Cause another variable y if y can be better predicted using the histories of both x and y than it can by using the history of y alone.We can test for the absence of Granger Causality by estimating the following vector Autoregressive (VAR) equation:

$$Y_t = \sum_{i=1}^{n} a_i Y_{t-i} + \sum_{i=1}^{n} b_j X_{t-j} + \varepsilon_t \qquad (12)$$

$$X_t = \sum_{i=1}^{n} a_i X_{t-i} + \sum_{i=1}^{n} b_j Y_{t-j} + u_t \qquad (13)$$

where a_i and b_j are coefficients.Then testing $H_0: b_1 = b_2 = \cdots = b_p = 0$ against $H_1: b_1 \neq b_2 \neq \cdots \neq b_p \neq 0$ is the test that x does not Granger-Cause y. Similarly H_0: $a_1 = a_2 = \cdots = a_p = 0$ against $H_1: a_1 \neq a_2 \neq \cdots \neq a_p \neq 0$ is the test that y does not Granger-cause x. In each case, a rejection of H_0 implies there is Granger causality.

IV. RESULTS AND EMPIRICAL FINDINGS

4.1 Simple Correlation Analysis

To investigate the degree and direction of relationship between Anopheles mosquito species and weather parameters, we employ simple correlation analysis. The result of correlation is reported in Table 1.

Table 1: Correlation between Anopheles Species and Weather Parameters

Correlations	Correlation Coefficient	P-value
Anopheles *Gambiae* and Mean Temperature (^{O}C)	-0.710**	0.001
Anopheles *Gambiae* and Mean Rainfall (mm)	0.706**	0.001
Anopheles *Gambiae* and Mean Relative Humidity	0.669**	0.002
Anopheles *Funestus* and Mean Temperature (^{O}C)	-0.745**	0.000
Anopheles *Funestus* and Mean Rainfall (mm)	0.730**	0.001
Anopheles *Funestus* and Mean Relative Humidity	0.675**	0.002

Note: ** means correlation is significant at 0.01 level

The result of Table 1 depicts the monthly relationship between weather parameters and Anopheles mosquito population at High level Makurdi, the Benue State capital-Nigeria. The result shows that *Anopheles gambiae* and *Anopheles funestus* have strong negative and significant relationship with mean temperature measured in (^{O}C). This means that an increase in mean temperature will decrease Anopheles mosquito population in the study area while a decrease in mean temperature will lead to a corresponding increase in Anopheles mosquito population. There also exist positive and significant correlations between *Anopheles gambiae* and *Anopheles funestus* with weather parameters such as mean rainfall and mean relative humidity. This means that increasing mean rainfall or mean relative humidity lead correspondingly to increase in Anopheles mosquito population in the study area.

4.2 Simple Linear Regression Result

To determine the effect of the short-run relationship among study variables, we apply simple linear regression discussed in the methods. The result is presented in Tables 2-4.

Table 2: OLS Parameter Estimates of Total Anopheles and Mean Temperature

Dependent variable: Total Anopheles				
Variable	Coefficient	Std. Error	t-statistic	P-value
Intercept	2002.462	376.7715	5.314791	0.0001
MTempt.	-48.50391	11.17867	-4.338971	0.0005
R-squared				0.540582
Adjusted R-squared				0.511868
DW statistic				0.778069
F-statistic	18.82667		Probability	0.000508

The result of Table 2 shows the output of a simple linear regression model describing the relationship between mean temperature and Anopheles mosquito population at High level Makurdi, the Benue State capital in Nigeria. The result of the table shows that the intercept of the regression line is positive and statistically significant at 1% marginal significance level. This means that the total Anopheles mosquito population in the study area will be approximately 2002 with a standard error of 376.7715 when the independent variable (mean temperature) is held constant. The slope coefficient of the independent variable is -48.50391, which is negative and statistically significant with a standard error of 11.17867. The implication is that a 1 ^{o}C rise in mean temperature will reduce Anopheles mosquito population in the study area by approximately 49 units. The value of R^2 is 0.540582 meaning that about 54.06% of the variations in the dependent variable have been explained by the regression model. The 45.94% unexplained variations are being accounted for by the error term or by factors not included in the model. The Durbin Watson (DW) statistic is 0.778069, which is greater than R^2-adjusted indicating that the model is non-spurious. The F-statistic which measures the overall significance of the regression model has a significant p-value of 0.000508 meaning that our model is a good fit.

Table 3: OLS Parameter Estimates of Total Anopheles and Mean Rainfall

Dependent variable: Total Anopheles				
Variable	Coefficient	Std. Error	t-statistic	P-value
Intercept	235.2416	44.91875	5.237047	0.0001
MRainfall	1.139415	0.269879	4.221951	0.0006
R-squared				0.526975
Adjusted R-squared				0.497411
DW statistic				1.095242
F-statistic		17.82487	Probability	0.000648

The result of Table 3 depicts the estimates of a linear regression model describing the relationship between mean rainfall and Anopheles mosquito population at High level Makurdi, the Benue State capital in Nigeria. The result shows that the constant parameter is positive and statistically significant at 1% significance level. This implies that the total Anopheles mosquito population in the study area will be approximately 235 when the independent variable (mean rainfall) is kept constant. The slope coefficient of the independent variable is 1.139415, which is positive and significant with a standard error of 0.269879. This implies that for every 1mm increase in mean rainfall, Anopheles mosquito population in the study area is predicted to increase by approximately 1 unit. The R^2 in the model indicates that about 52.70% of the variations in the dependent variable have been explained by the independent variable. The Durbin Watson (DW) statistic value of 1.095242 is greater than R^2-adjusted indicating that the model is not spurious. The F-statistic, which measures the overall significance of the regression model is F=17.82487 with a significant p-value of 0.000648 meaning that our model is a good fit.

Table 4: OLS Parameter Estimates of Total Anopheles and Mean Relative Humidity

Dependent variable: Total Anopheles				
Variable	Coefficient	Std. Error	t-statistic	P-value
Intercept	-182.9748	153.6610	-1.190770	0.2511
MRH	7.775872	2.099165	3.704269	0.0019
R-squared				0.461671
Adjusted R-squared				0.428026
DW statistic				0.544022
F-statistic		13.72161	Probability	0.001925

The result of Table 4 shows the output of a simple linear regression model describing the relationship between mean relative humidity and Anopheles mosquito population at High level Makurdi, the Benue State capital. The result shows that the intercept of the regression line is negative and statistically insignificant. The implication of this is that the total Anopheles mosquito population in the study area will be less than unity when the independent variable (mean relative humidity) is held constant. The slope coefficient of the independent variable is 7.775872, which is positive and significant. This shows that for every 1% increase in mean relative humidity Anopheles mosquito population in the study area is predicted to increase by approximately 8 units. The R^2 value of 0.461671 indicates that about 46.17% of the variations in the dependent variable have been explained by the regression model. The Durbin Watson (DW) statistic value of 0.544022, which is greater than R^2-adjusted indicates that the model is non-spurious. The F-statistic measures the overall fitness of the regression model with a significant p-value of 0.001925 shows that our model is a good fit.

4.2.1 Models Stability Diagnosis

To check whether the regression models presented in Tables 2-4 are not mis-specified, we use Ramsey Regression Equation Specification Error Test (RESET). The result is reported in Table 5.

Table 5: Ramsey RESET Test

Dependent Variable: Total Anopheles				
Independent Variable	Test statistic	Value	Degree of freedom	P-value
Mean Temperature	t-statistic	0.534341	15	0.6009
	F-statistic	0.285520	(1, 15)	0.6009
	Likelihood Ratio	0.339404	1	0.5602
Mean Rainfall	t-statistic	0.748003	15	0.5349
	F-statistic	0.551522	(1, 15)	0.5349
	Likelihood Ratio	0.339542	1	0.5767
Mean Relative Humidity	t-statistic	0.584924	15	0.5673
	F-statistic	0.342136	(1, 15)	0.5673
	Likelihood Ratio	0.405951	1	0.5240

The result of Table 5 shows the Ramsey Regression Equation Specification Error Test (RESET). For this test the probability value to be used is either t-statistic, F-statistic or the Likelihood ratio. The results of the test fail to reject the null hypotheses that the models are well specified since all the p-values are greater than $\alpha = 0.05$ significance level. We therefore conclude that there are no misspecifications for the regression models presented in Tables 2-4.

4.3 Johansen Cointegration Test Results

To investigate the long run relationship among total Anopheles mosquito population in the study area and weather parameters, we employ Johansen cointegration rank test. The result is reported in Table 6.

Table 6: Johansen Cointegration Test Results

Trace Test					
Hypothesized No. of CE(s)	H_0	H_1	Trace statistic	Critical Value	P-value**
None *	$r = 0$	$r \geq 1$	100.9014	47.85613	0.0000
At most 1 *	$r \leq 1$	$r \geq 2$	52.68751	29.79707	0.0000
At most 2 *	$r \leq 2$	$r \geq 3$	17.81652	15.49471	0.0220
At most 3 *	$r \leq 3$	$r = 4$	7.607766	3.841466	0.0058
Maximum Eigenvalue Test					
Hypothesized No. of CE(s)	H_0	H_1	$\lambda_{\max}$ statistic	Critical Value	P-value**
None *	$r = 0$	$r = 1$	48.21387	27.58434	0.0000
At most 1 *	$r \leq 1$	$r = 2$	34.87098	21.13162	0.0003
At most 2	$r \leq 2$	$r = 3$	10.20876	14.26460	0.1986
At most 3*	$r \leq 3$	$r = 4$	7.607766	3.841466	0.0058

Note: Trace test indicates 4 cointegrating eqn(s) at the 0.05 level. Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level. * denotes rejection of the null hypothesis at the 0.05 level. ** denotes MacKinnon-Haug-Michelis (1999) p-values. Variables included in the vectors are Total Anopheles, Mean Temperature, Mean Rainfall, and Mean Relative Humidity.

The results of Table 6 rejects the statistical hypotheses of no cointegration at $r = 0, r \leq 1, r \leq 2$ and $r \leq 3$ for trace test and at $r = 0, r \leq 1$ and $r \leq 3$ for maximum Eigenvalue test statistics. The null hypothesis of no cointegration is not rejected at $r \leq 2$ in the maximum eigenvalue test. The trace test indicates four cointegrating equations at the 0.05 significance level while the maximum Eigen value test indicates two cointegrating equations at the 0.05 significance level. The trace test and maximum Eigenvalue test thus indicate that there is a long run relationship among the variables under study. What this long run relationship means is that the variables under study share a common stochastic drift.

4.4 Granger Causality Test Result

To determine the causal relationship among study variables, we employ pairwise Granger Causality test. The result is documented in Table 7.

Table 7: Pairwise Granger Causality Test Results

Null Hypothesis	F-Statistic	P-value
MEAN RAINFALL does not Granger cause TOTAL ANOPHELES	0.91252	0.3557
TOTAL ANOPHELES does not Granger cause MEAN RAINFALL	5.70031	0.0316*
MEAN RELATIVE HUMIDITY does not Granger cause TOTAL ANOPHELES	8.44390	0.0115*
TOTAL ANOPHELES does not Granger cause MEAN RELATIVE HUMIDITY	19.6322	0.0006*
MEAN TEMPT. Does not Granger cause TOTAL ANOPHELES	6.29546	0.0250*
TOTAL ANOPHELES does not Granger cause MEAN TEMPT.	33.0818	0.0000*
MEAN RELATIVE HUMIDITY does not Granger cause MEAN RAINFALL	0.01467	0.9053
MEAN RAINFALL does not Granger cause MEAN RALATIVE HUMIDITY	6.42268	0.0238*
MEAN TEMPT. Does not Granger cause MEAN RAINFALL	0.01008	0.9215
MEAN RAINFALL does not Granger cause MEAN TEMPT.	6.81022	0.0206*
MEAN TEMPT. does not Granger cause MEAN RELATIVE HUMIDITY	1.81022	0.2009
MEAN RELATIVE HUMIDITY does not Granger cause MEAN TEMPT.	0.22464	0.6428

The result of Table 7 shows that there is a one-way causality between mean rainfall and total Anopheles mosquitoes in the study area. This means that total Anopheles mosquitoes are Granger caused by mean rainfall but not the other way round. There also exist two-way causality between mean relative humidity and total Anopheles and between mean temperature and total Anopheles. What this two-way causality means is that total Anopheles mosquitoes are Granger caused by mean relative humidity and vice versa. Also mean temperature Granger causes total anopheles mosquitoes and total anopheles mosquitoes in turn Granger causes mean temperature. The result of Table 7 also shows that mean relative humidity and mean temperature in the study area are Granger caused by mean rainfall. That is, mean rainfall causes mean relative humidity and mean temperature.

V. CONCLUSION

This paper attempted to investigate the causal relationship between Anopheles Gambiae and Anopheles Funestus species of mosquito population and climatic factors such as mean temperature, mean rainfall and mean relative humidity in Makurdi metropolitan city of Benue State in Nigeria. The study uses monthly data obtain for the time period February, 2014 to July, 2015 on the study variables. Simple correlation and linear regression analyses are employed to determine the degree and direction as well as the effect and short run relationship among the study variables. Johansen cointegration test was employed to investigate the long-run dynamics while Granger causality analysis was applied to examine the causal relationship between Anopheles mosquitoes' population and weather parameters.The correlation result shows that Anopheles gambiae and Anopheles funestus have strong negative and significant relationship with mean temperature meaning that increase in mean temperature decreases Anopheles mosquito population in the study area while a decrease in mean temperature will lead to a corresponding increase in Anopheles mosquito population. Whereas a positive and significant correlation exists between Anopheles gambiae and Anopheles funestus with mean rainfall and mean relative humidity meaning that increasing mean rainfall or mean relative humidity lead correspondingly to increase in Anopheles mosquito population in the study area. The regression result reveals that mean monthly temperature is negatively and statistically significantly related with Anopheles mosquito population in the study area. While mean rainfall and mean relative humidity are positively and statistically significantly related with Anopheles mosquito population. Johansen cointegration test results show the existence of long-run relationship among the variables under study. The Granger causality analysis result indicates that Anopheles mosquito species population is Granger caused by mean rainfall, mean temperature and mean relative humidity and that mean rainfall Granger causes mean temperature and mean relative humidity which favoured the increasing number of Anopheles mosquito population in Makurdi the metropolitan city of Benue State in Nigeria. The study therefore recommends that the Government of Nigeria and Benue State in particular should employ strong preventive and control measures against malaria in the study area and beyond in order to reduce the rate of malaria infection caused by abundant Anopheles mosquitoes in the area.

REFERENCES

1. Barik, T. K., Sahu, B. and Swain, V. (2009). A Review on Anophelesculicifacies: From Bionomics to Control with Special Reference to Indian Subcontinent. Acta Trop 109: 87−97.
2. Chow, C.Y. (1991). Malaria Vectors in China. Chin J EntomolSpec Publ 6: 67−79.
3. Depinay, J. M. O., Mbogo, C. M., Killeen, G., Knols, B., and Others (2004). A Simulation Model of African Anopheles Ecology and Population Dynamics for the Analysis of Malaria Transmission. Malaria Journal, 3: 29.

4. Foley, D. H., Rueda, L. M., Peterson, A. T., Wilkerson, R. C. (2008). Potential Distribution of Two Species in the Medically Important Anopheles Minimus complex (Diptera: Culicidae).Journal of Medical Entomology, 45: 852−860.
5. Garros, C., Van Nguyen, C., Trung, H. D., Van Bortel, W., Coosemans, M., Manguin, S. (2008). Distribution of Anopheles inVietnam, with Particular Attention to Malaria Vectors ofthe Anopheles minimus complex. Malaria Journal, 7: 11.
6. Hopp, M. J., Foley, J. A. (2001). Global-Scale Relationships between Climate and the Dengue Fever Vector Aedesaegypti. Clim Change, 48: 441−463.
7. Kearney, M., Porter, W. P., Williams, C., Ritchie, S., Hoffmann, A. A. (2009). Integrating Biophysical Models and Evolutionary Theory to Predict Climatic Impacts on Species' Ranges: The Dengue Mosquito Aedes aegypti in Australia. Funct Ecol, 23: 528−538.
8. Johansen, S. (1991). Estimation and Hypothesis Testing for Cointegration Vectors in Gausian Vector Autoregressive Models. Econometrica, 59, pp 1551-1580.
9. Johansen, S. (1995), Likelihood-Based Inference in Cointegrated Vector Autoregressive Models, Oxford University Press, Oxford.
10. MacKinnon, J. G. (1991). Numerical Distribution Functions for Unit Root and Cointegration Tests. Journal of Applied Econometrics. 11: 601–618.
11. Manguin, S., Garros, C., Dusfour, I., Harbach, R. E, Coosemans, M. (2008). Bionomics, Taxonomy, and Distribution of the Major Malaria vector Taxa of Anopheles subgenus Celliain Southeast Asia: an updated review. Infect Genet Evol, 8: 489−503.
12. Martens, P., Thomas, C. (2005). Climate Change and Malaria Risk: Complexity and Ccaling. In: Takken W, Martens P,Bogers R. J (eds) Environmnetal change and malariarisk: global and local implications. Springer, Dordrecht,p3–14.
13. Ndoen, E., Wild, C., Dale, P., Sipe, N., Dale, M. (2010). Relationships between Anopheline Mosquitoes and Topographyin West Timor and Java, Indonesia. Malaria Journal, 9: 242.
14. Paing, M., Sebastian, A. A., Lin, T. (1989). Anopheline Mosquitoesof Myanmar. 1. Anopheles (Cellia) dirus Peyton andHarrison, 1979. Myanmar Health Sci Res J 1: 122−129.
15. Pascual, M., Ahumada, J. A., Chaves, L. F., Rodó, X., Bouma, M. (2006). Malaria Resurgence in the East African highlands: Temperature Trends Revisited. Proc Natl Acad Sci USA103: 5829−5834
16. Patz, J. A., Strzepek, K., Lele, S., Hedden, M., and Others (1998). Predicting Key Malaria Transmission Factors, Biting and Entomological Inoculation Rates, using Modeled Soil Moisture in Kenya. Trop Med Int Health 3: 818−827
17. WHO (2002). Malaria Entomology and Vector Control: Learners guide, social Mobilization and Training. Available at www.malaria.org.zw/vector/vc24.pdf.

APPENDIX

TABLE A: Monthly Number of Anopheles Mosquito Population and Weather Data in High Level, Makurdi, Benue State-Nigeria.

	Number of Anopheles species collected			Data on weather parameters		
Sample Months	Anopheles Gambiae	Anopheles Funestus	Total	Mean Tempt (°C)	Mean rainfall (mm)	Mean RH (%)
Feb., 2014	98	83	181	36.9	0.75	51
Mar.,2014	121	129	250	37.6	0	49
April., 2014	209	189	398	35.7	135.7	65
May 2014	292	301	593	33.5	150.5	78
Jun., 2014	267	282	549	31.2	172.9	82
Jul., 2014	291	295	586	31.4	128.5	89
Aug., 2014	342	303	645	30.3	251.7	93
Sept., 2014	296	281	577	29.8	276.3	91
Oct.,2014	174	168	342	29.9	286.9	90
Nov., 2014	99	102	201	33.7	2.5	85
Dec., 2014	72	82	154	34.6	0	81
Jan.,2015	69	57	126	35.2	0	52
Feb., 2015	81	63	144	35.9	0	48
Mar., 2015	106	99	205	37.6	0.5	54
April 2015	186	161	347	36.7	148.5	60
May 2015	112	206	318	33.1	170.8	65
Jun., 2015	258	264	522	31.8	360.2	71
Jul., 2015	291	285	576	29.8	90.5	83
Total/Mean	**3,364**	**3,350**	**6,714**	**33.6**	**120.9**	**71.5**

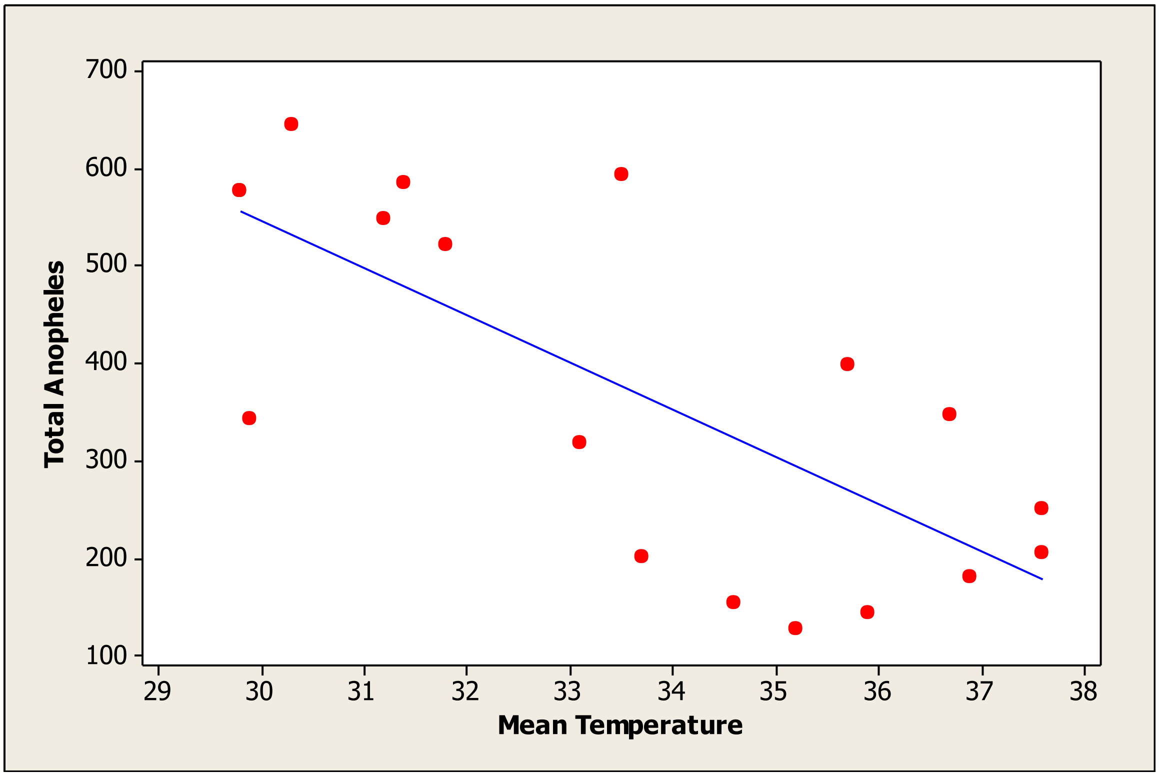

Figure A: Scatter Plot of Total Anopheles and Mean Temperature

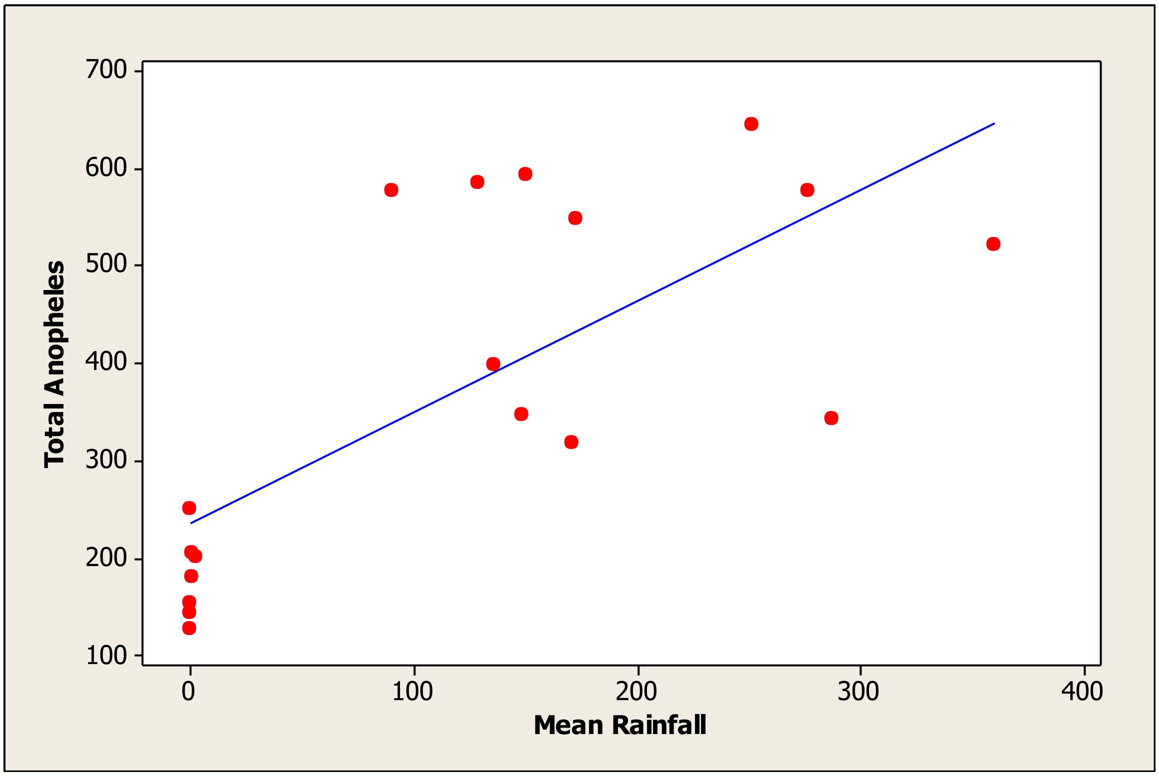

Figure B: Scatter Plot of Total Anopheles and Mean Rainfall

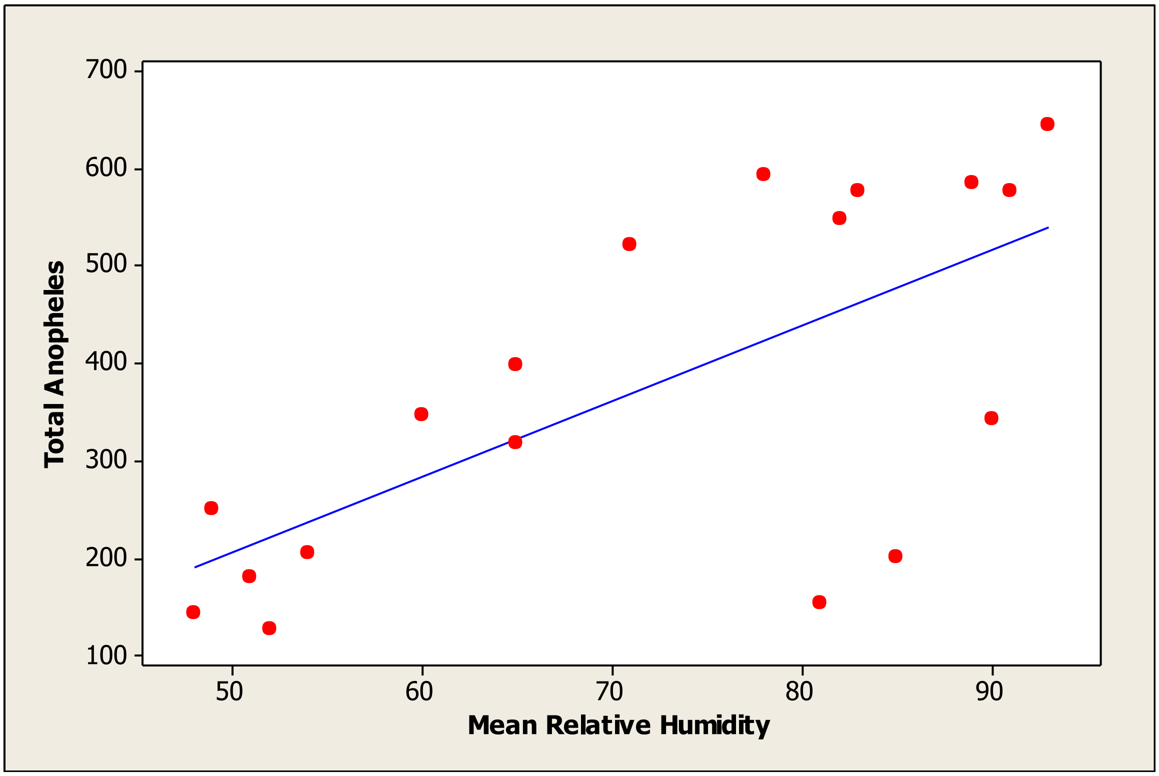

Figure C: Scatter Plot of Total Anopheles and Mean Relative Humidity