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A COMPARATIVE ANALYSIS OF THE MALTHUSIAN GROWTH MODEL AND LINEAR REGRESSION APPROACH IN PREDICTING MALARIA INFECTION

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ABSTRACT: *The study shows a comparative analysis between the Malthusian growth model and the simple linear regression approach in predicting the outcome of malaria infection. These two models were applied in predicting the number of persons infected with malaria in Nigeria in the nearest future (2023 to 2030), using data from 2019 to 2022. The outcome revealed that at the end of 2030, the population of persons that would be infected with malaria using the regression model would be one hundred and five million (105,000,000) while that of the Malthusian model predicted ninety-one million, five hundred and thirty thousand (91,530,000). Furthermore, results gotten from the Malthusian model proved to be more reliable than the results gotten from the regression model because the coefficient of correlation and residual sum of squares for the Malthusian model was 0.999 and 1801670629370.527, with the data showing a level of statistical significance compared to the simple linear regression model approach, which was 1.00 and 0.00 respectively. This research will assist government organizations, non-government organizations, private and health organizations to apply a proactive measure and plan in dealing with the issue of malaria infection in the nation.*

KEYWORDS: Regression, Malthusian Model, Malaria, Comparative Analysis, Sum of Squares.

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INTRODUCTION

The World Health Organization [1] defines malaria as a disease caused by a parasite called plasmodium, which infects when the female anopheles mosquito bites a person and could lead to death. This disease can be prevented and controlled. Some of the symptoms of malaria include difficulty in breathing, convulsion, jaundice, bleeding through mouth or nose, etc. According to the 2020 world Malaria report [1], 27% of the world population infected with malaria is from Nigeria.

An assessment historically on the hazard associated with malaria and the mortality in Nigeria was done by [2]. The results from the research showed an increase in the prevalence of malaria for the period of five years. Many authors such as [3-4], Marcos and Gabriel, Hamid et al. and others have done research using models to predict the occurrence of malaria. [5] Yohana et al. carried out a study on the anti-mosquito properties of pelargonium Roseum and Juniperius Virginiana essential oils applied to curb the malaria vector, which is dominant in Africa. Some predictive models such as the Malthusian models and others have been applied by authors [6-14] in various research works to predict various outcomes, which proved successful.

MATERIALS AND METHODS

The simple regression statistical and Malthusian mathematical models were applied to predict the population of humans infected with malaria within the country with comparative analysis done for both models. The data used was obtained from the World Health Organization (WHO) report and the 2020 Severe Malaria Report for Nigeria. The Severe Malaria Report stated that the population of persons infected with malaria in Nigeria is 27% of the world population.

STATISTICAL MODEL FOR MALARIA INFECTION PREDICTION

From various studies as shown by [15-18], the simple regression line model with the dependent variable m and independent variable/predictor n is expressed as

$$m = a + bn \tag{1}$$

where the values of a, b are the regression constants.

The tabular expression for the malaria infection from 2019 - 2020 is given below:

Table 1.: Table showing the population of persons infected with malaria from 2019 to 2020

YEAR	Years in order (n)	Malaria infection (m) ($\times 10^6$)
2019	1	61
2020	2	65

The values of $a = 57 \times 10^6$ and $b = 4 \times 10^6$.

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The least square regression line for malaria infection is obtained by substituting the values of a and b into Equation (1) to give the statistical prediction model for the population of humans infected with malaria.

$$m = 57 + 4n \tag{2}$$

The expression for the coefficient of determination $d^2 = 1$ and correlation $d = 1$. The values of the sum of squared errors (SSE) and total sum of squares (SST) are equal and obtained as 8×10^6.

MATHEMATICAL MODEL FOR MALERIA INFECTION PREDICTION

[19] established in 1798 the malaria population growth model, which is expressed as

$$\frac{dM}{dt} = xM(t) \tag{3}$$

The linear first order differential equation, which is homogeneous for the malaria population with period (t) and Malthusian growth factor $x,$ is also expressed as

$$M(t) = M_0 e^{xt} \tag{4}$$

The population of the malaria infection grows to $\frac{x}{y}$ when $\frac{x-yM(t)}{x} \to 0$ (Verhulst, 1838).

Logistically, the modified expression for the population of the malaria infection is expressed below [21]:

$$\frac{dM}{dt} = xM[x - yM] \tag{5}$$

The carrying capacity, also known as the ratio of the population coefficient, determines the growth of the population of persons infected with malaria, and is expressed as [22]:

$$M_{max} = M = \frac{x}{y} = \frac{M_1(M_0M_1 - 2M_0M_2 + M_1M_2)}{M_1^2 - M_0M_2} \tag{6}$$

The population growth of persons with malaria infection per year is expressed below [22]:

$$e^{-x} = \left(\frac{\frac{1}{M_2} - \frac{e^{-2x}}{M_0}}{\frac{1}{M_1} - \frac{e^{-x}}{M_0}}\right) - 1 \tag{7}$$

$e^{-x} = 0.8116$ and $\frac{x}{y} = 122{,}000{,}000$. Hence, $x = 0.1$ and $y = 8.2 \times 10^{-10}$

The mathematical model for predicting the population of persons infected with malaria is

$$M = \frac{122000000}{1 + \left(\frac{122000000}{61000000} - 1\right)e^{-0.1t}} \tag{8}$$

This was similar to the result gotten by [5] in prediction of the Nigerian population.

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RESULTS

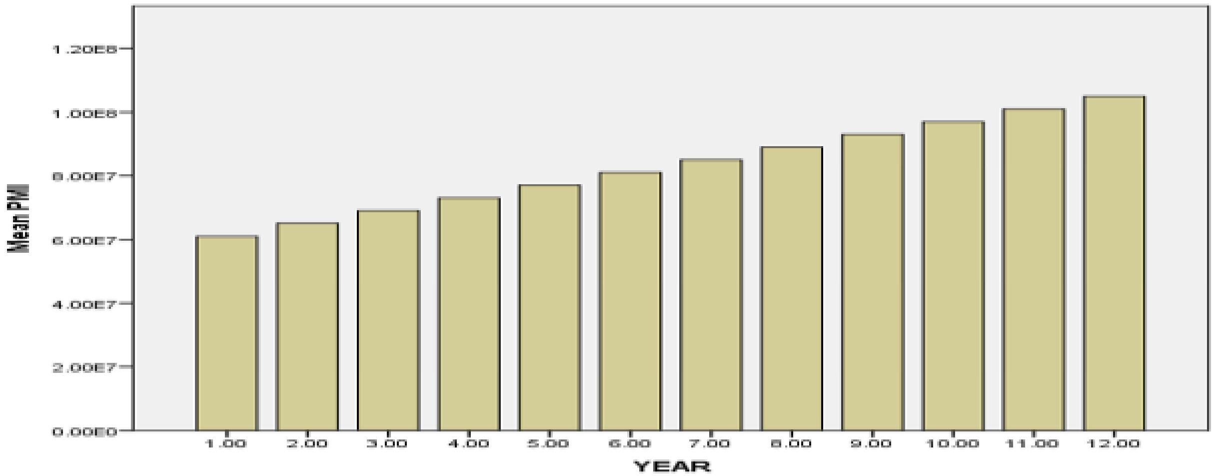
STATISTICAL RESULTS FOR MALERIA INFECTION PREDICTION

The prediction results obtained in the table below were obtained using a MATLAB software to run the code. Below is the prediction for malaria infection for the next 12 years from 2019 to 2030:

Table 2: Table showing the prediction of malaria infection using statistical model

YEAR	Years in order (n)	Malaria infection $(\times 10^6)$ (m)
2019	1	61
2020	2	65
2021	3	69
2022	4	73
2023	5	77
2024	6	81
2025	7	85
2026	8	89
2027	9	93
2028	10	97
2029	11	101
2030	12	105

Figure 1: Graphical representation of population infected with malaria against year:



Matlab code for the statistical prediction

Input:

```
a=[1:1:12]

b=57

x=4

y=b+(x*a)
```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Output: $y(1 \times 10^6)$

61 65 69 73 77 81 85 89 93 97 101 105

DESCRIPTIVE STATISTICAL REPORT FOR RESULT OF STATISTICAL MODEL GOTTEN FOR POPULATION WITH MALARIA INFECTION (PMI)

Table 3: Table showing the descriptive statistics report of population infected with malaria from the results of the statistical model

Year	Size PMI (n)	Degree of Freedom	Mean PMI (Million)	Standard error of mean PMI (Million)	Standard deviation PMI (Million)	Sample Variance PMI	Range PMI (Million)	Minimum PMI (Million)	Maximum PMI (Million)	SUM PMI (Million)
2019-2030	12	11	83.00	4.16	14.42	2.08×10^{14}	44.00	61.00	105.00	966.00

Table 1.4: Table showing the coefficient of determination and correlation for population infected with malaria from the results of the statistical model

COEFFICIENT OF DETERMINATION AND CORRELATION TABLE

Coefficient Of Correlation	Coefficient Of Determination	Std. Error of the Estimate
1.00	1.00	0.00

ANOVA TABLE

Table 5: Table showing ANOVA analysis for population infected with malaria from the results of the statistical model

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	2288000000000000.00	1	2288000000000000.00	-	-
Residual	0.00	10	0.00		
Total	2288000000000000.00	11			

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TABLE SHOWING REGRESSION CONSTANTS, STANDARD ERROR, T-VALUES AND COLLINEARITY

Table 6: Table showing regression, standard error, t-value and collinearity for population infected with malaria from the results of the statistical model

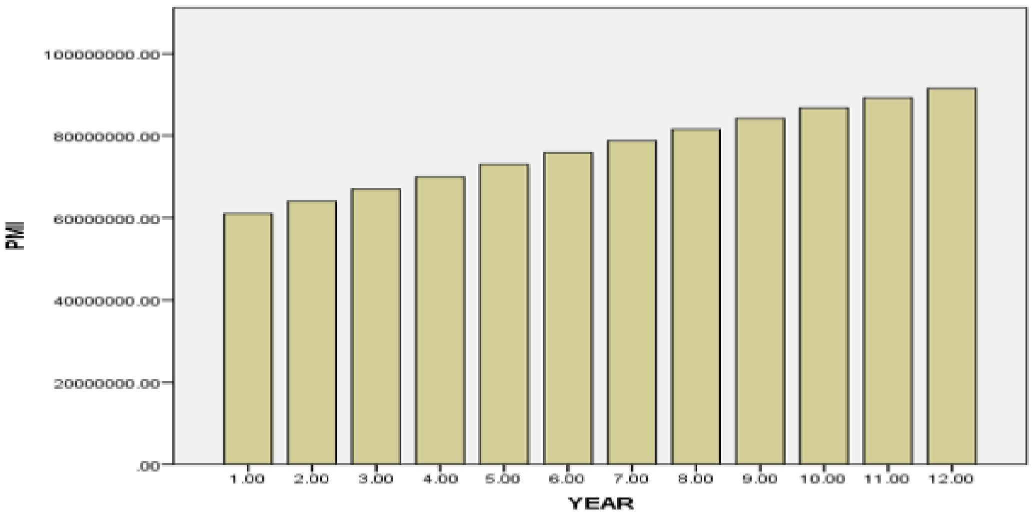
Model	Regression constants	Std. Error	t	Tolerance	VIF
PMI (m)	57000000.00	0.00	-		
YEAR (n)	4000000.00	0.00	-	1.000	1.000

MATHEMATICAL RESULTS FOR MALARIA INFECTION PREDICTION

Table 7: Table showing the prediction of malaria infection using mathematical model

YEAR	Years in order (n)	Malaria infection $(\times 10^6)$ (m)
2019	1	61.00
2020	2	64.05
2021	3	67.01
2022	4	70.01
2023	5	73.04
2024	6	75.94
2025	7	78.77
2026	8	81.52
2027	9	84.18
2028	10	86.74
2029	11	89.19
2030	12	91.53

Figure 2: Graphical representation of population infected with malaria against year from the results of the mathematical model



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Matlab Code for the Mathematical Prediction

Input:

```
a=122000000

b=61000000

c=exp(-0.1*t)

t=[0:1:11]

M=a./(1+((a./b)-1)*c)
```

Output: $M(1 \times 10^7)$

t = 1 2 3 4 5 6 7 8 9 10 11 12

Columns 1 through 12

6.1000 6.4047 6.7080 7.0082 7.3040 7.5940 7.8770 8.1519 8.4177 8.6736 8.9189 9.1532

DESCRIPTIVE STATISTICAL REPORT FOR RESULT OF MATHEMATICAL MODEL GOTTEN FOR POPULATION WITH MALARIA INFECTION (PMI)

Table 8: Table showing the descriptive statistics report of population infected with malaria from the results of the mathematical model

Year	Size PMI (n)	Degree of Freedom	Mean PMI (Million)	Standard error of mean PMI (Million)	Standard deviation PMI (Million)	Sample Variance PMI	Range PMI (Million)	Minimum PMI (Million)	Maximum PMI (Million)	SUM PMI (Million)
2019 - 2030	12	11	76.915	2.91	10.09	1.02×10^{14}	30.53	61	91.53	922.98

COEFFICIENT OF DETERMINATION AND CORRELATION TABLE

Table 1.9: Table showing coefficient of determination and correlation for population infected with malaria from the results of the mathematical model

Coefficient Of Correlation	Coefficient Of Determination	Std. Error of the Estimate
.999	.998	424460.90861

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ANOVA TABLE

Table 10: Table showing ANOVA analysis for population infected with malaria from the results of the mathematical model

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1116979829370629.600	1	1116979829370629.600	6199.689	0.00
Residual	1801670629370.527	10	180167062937.053		
Total	1118781500000000.100	11			

TABLE SHOWING REGRESSION CONSTANTS, STANDARD ERROR, T-VALUES AND COLLINEARITY

Table 11: Table showing regression, standard error, t-value and collinearity for population infected with malaria from the results of the mathematical model

Model	Regression constants	Std. Error	t	Tolerance	VIF
PMI (m)	58748636.364	261237.631	224.886		
YEAR (n)	2794825.175	35495.204	78.738	1.000	1.000

DIFFERENCE BETWEEN MATHEMATICAL AND STATISTICAL MODEL FOR MALARIA INFECTION PREDICTION

Table 12: Difference between mathematical and statistical model for malaria infection prediction

YEAR	Malaria infection $(\times 10^6)$ (ms)	Malaria infection $(\times 10^6)$ (mm)	Difference $(\times 10^6)$ (md)
2019	61	61.00	0
2020	65	64.05	0.95
2021	69	67.01	1.99
2022	73	70.01	2.99
2023	77	73.04	3.96
2024	81	75.94	5.06
2025	85	78.77	6.23
2026	89	81.52	7.48
2027	93	84.18	8.82
2028	97	86.74	10.26
2029	101	89.19	11.81
2030	105	91.53	13.47

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DISCUSSION

The results obtained from both the statistical and mathematical models show that as the year increases, the infection of malaria on the population of humans in the country increases. This was observed in Figure 1 and Figure 2.

The statistical measurement shows how the change in the year affects the output of the population of persons infected with malaria. Using the linear regression model, the coefficient of determination was gotten as one (1). This shows that the model was reliable to forecast the outcome of the population of persons that will be infected with malaria over the next 12 years. Using the Malthusian growth model, the coefficient of determination was obtained as 0.998. This shows that the model was also reliable to forecast the outcome of the population of persons that will be infected with malaria over the next 12 years.

From the results gotten in Table 5, there was no value for the residual sum of squares, causing the F- and t-values to be zero, which was less than the table values for F and t. The null hypothesis was accepted, making it insignificant statistically. Contrary to this, the results from Table 10 had a residual sum of squares as 1801670629370.527, which made the F-value to be 6199.689 and the t-value to be 224.886 for PMI (m) and 78.738 for the order of year (n). These values were found to be greater than the F- and t-tabular values; hence, the null hypothesis was rejected, making it significant statistically.

Under the critical region of 5% significance level for the mathematics model, the F-value, which was greater than that of the F-tabular value, and the t-value, which was greater than the t-tabular value, showed that the null hypothesis is rejected, implying that it is statistically significant. This was not the case for the simple regression model because the result was the opposite, hence not significant. This shows that the results from the Malthusian model gave significance statistically, compared to the simple linear regression model.

This forecast, when used by health practitioners, government organizations and non-government organizations, will help in the planning and implementation of policies which will reduce malaria infection to the population within the country.

The results from the Malthusian mathematical model also show a similar result to that of the statistical regression model for a forecast of the human population that will be infected with malaria for a period of 10 years, from 2021 to 2030. There was only a slight variation in the results due to differences in the mathematical formulation applied.

As a result of the increase in infection of malaria on the human population in the country from 2019 to 2030, proactive measures should be taken to curb the increase of the malaria infection on humans in the country.

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CONCLUSION

This study shows a comparative analysis between results gotten from the Malthusian growth model and the simple linear regression model, with predictions of the population of persons that might be infected with malaria within the country for a period of 12 years (2019–2030), using the simple linear regression statistical model and the Malthusian growth mathematical model. The result from the Malthusian growth model was statistically significant when compared to the results from the simple linear regression model. Predicted results from both models will be useful in managing the increase of malaria infection on the population within the country. The results and mathematical approach will also be helpful for researchers in the mathematics and statistical field. Further research will be done using the bio-mathematical model to manage the spread of malaria within the country.

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