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SARIMA MODEL OF MALARIA IN NIGERIA: A CASE STUDY OF MALARIA CASES OF A TEACHING HOSPITAL IN NIGERIA

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ABSTRACT

The present study aims at examining the trend and pattern of malaria cases with a view of proposing a statistical model based on Box-Jenkins methodology of time series, in order to assess the progress made so far in the fight against malaria by the Nigerian government. Annual records on cases of malaria as extracted from the record of a teaching hospital in Nigeria were employed as a case study. The malaria data was disaggregated into quarterly figures using Boot-Feibes-Lisman first difference (BFL-FD) method so as to achieve data with higher case load that covers relatively long period, to be suitable for time series model. Based on the results of model identification measures, a SARIMA model was proposed for the disaggregated malaria figures. From the analysis, there is a noticeable downward trend in the malaria cases, which may be credited to the aggressive epidemiological surveillance and sensitization of citizenry on malaria by Nigerian government in the recent times. The results of measures of goodness of fit and measures of adequacy show that the model is appropriate for the malaria data. Recommendations were made on proactive measures to take in combating the scourge of malaria in Nigeria. This study has practical utility in serving as an early-detection strategy to aid in monitoring the future trend of the disease, and to assess various government efforts in combating the disease.

KEYWORDS

plasmodium parasites; seasonal autoregressive integrated moving average (SARIMA); disaggregation methods; autocorrelation function (ACF); partial autocorrelation function (pacf).

1. INTRODUCTION

Malaria, a life-threatening vector-borne disease is one of the leading public health challenges in Nigeria, and in tropical countries at large. Malaria though an infectious disease but preventable, is caused by the *Plasmodium* parasites which is transmitted through the bites of infected mosquitoes. Malaria poses a tremendous challenge to public health in terms of mortality and morbidity, not only in Nigeria, but in most of sub-Saharan Africa countries, [27]. The World Health Organisation (WHO) estimated that there were 219 million cases of malaria in 2010, which led to 660,000 deaths, mostly among African, [29]. About 90% of all malaria deaths were attributed to sub-Saharan Africa. According to World Health Organisation (WHO), malaria related-illnesses and mortality cost Africa's economy USD 12 billion per year, [30]. It was also estimated that USD 4.2 billion will be needed every year to fund the fight against the scourge of malaria, [30]. A total number of 2,969,950 of malaria cases were recorded in 2007, while 10,289 malaria death cases were reported in the same year, [29, 31]. It is a disease that thrives in warm, humid climates where pools of water provide breeding grounds for mosquitoes. Malaria transmission could be seasonal since it thrives on some climatic and ecological factors conducive to malaria parasite development such as humidity, rainfall, temperature and elevation, [11]. September through December has been identified as the major malaria transmission season in Nigeria, while April to May of every year is regarded as a period of short transmission [29].

Lagos State can be regarded as the commercial capital city in Nigeria with a population of over 10 million people. Some part of Lagos State is characterized with inappropriate urban planning, densely populated by the less privileged people, who are consequently susceptible to malaria attack. Ditches, gutters, and temporary pools of water which are natural habitats for mosquitoes, are common feature of such settlements without proper urban planning as we have in some part of Lagos State. Data on malaria cases extracted from the record of a teaching hospital will be employed in this study, as a case study.

Time series techniques has a wide application in fields of epidemiological study of various diseases such as short term malaria, [4], tuberculosis [21], forecast of canine rabies [24], prediction of Ross River virus disease in Brisbane, [14], HIV-associated tuberculosis, [19], Viral infections diseases, [12], analysis of Syphilis, [32], analysis of gonorrhea, [23] and so on. Analysis of the trend of a disease aids in identifying the risk factors and target interventions to prevent it, and also identify possible seasonal trends, which may be used to predict the future cases of the disease, [21]. This study is developed with a view of formulating a statistical model for malaria cases in Nigeria based on time series techniques using Lagos State as a case study. The model can aid in monitoring the trend and pattern of malaria, and to make a short term forecasts to determine whether malaria cases are likely to increase or decrease in subsequent months, [18]. If the model indicates an emerging epidemic, this calls for health practitioners and health policy formulators to provide necessary medical interventions.

Univariate SARIMA modeling approach can serve as an indicator of malaria early detection strategy, based on the patterns of historical cases as a baseline to identify anomalies that may indicate the early stages of emerging epidemic, [26, 9]. A SARIMA model may be viewed as describing two effects simultaneously, [15]. If the data is quarterly, the assumption is that the quarter-to-quarter behavior is described by a non-seasonal ARIMA model with parameters (p, d, q), while the residuals from this model are represented by a year-to-year ARIMA model with parameters (P, D, Q). Combination of these two models yield SARIMA(p, d, q)(P, D, Q)$_s$.

2. DATA

Data used in this study are represented by yearly time series of malaria cases obtained from Lagos University Teaching Hospital spanning the period 1991 to 2009. The teaching hospital provides medical treatments to malaria patients with the United Nations standard regimen. A total number of 15,233 blood samples were examined during the period under consideration. A noticeable decrease occurred in 2002, with the malaria cases falling to 887. Malaria cases as observed from the data shows an increase in 2001 with cases increasing to 1221, and a further slight decrease in 2007 to 502. An aggressive epidemiological surveillance in terms of medical campaign, sensitization on media and provision of necessary insecticide-treated materials, provision of highly subsidized and effective malaria drugs by the Nigerian government, and grants in aids as provided by World Health Organisation towards combating malaria, could be responsible for the noticeable decrease in malaria cases since year 2002.

3. METHODOLOGY

3.1 QUARTERLY DISAGGREGATION OF THE ANNUAL MALARIA DATA

In many developing countries, malaria data are recorded on annual basis. However it is when the data are disaggregated that patterns, trends, seasonality and other important information are uncovered. Availability of disaggregated malaria data will satisfy the basic need of analyzing the trend of malaria of such a population. For a demographic series to be suitable for time series forecast, the data must cover a relatively long period and should have a high case load. The higher the caseload, the less the quarterly disaggregated figures are influenced by random fluctuations, [10]. In order to have good estimates for the parameters of a time series model, at least 50 observations of the series must be employed, [3, 7, 5, 22, 10]. Few developing nations with best malaria data have not such long demographic history on yearly recorded cases of malaria. An alternative is to disaggregate those annual observations to quarterly or monthly figures. Some methods of disaggregating annual data to quarterly data have been developed and discussed in the past, [16, 1, 28, 6, 25]. Other researchers have worked extensively

on disaggregation problem, [8, 13, 20]. Boot-Feibes-Lisman first difference (BFL-FD) [1], method is suitable for disaggregating non-stationary or highly positive correlated series, [6]. The BFL-FD procedure is based on minimising the sum of the squared first differences for the quarterly values, i.e

Minimise

$$\sum_{t=2}^{4n}(\Delta X_t)^2 \quad (1)$$

Subject to the constraint

$$\sum_{j=1}^{4} X_{4(T-1)+j} = Y_T$$

where

Y_T : observed annual temporal aggregates of the unobserved quarterly time series X_t.

$\Delta X_t = X_t - X_{t-1}$

and $Y_T = X_{4T-3} + X_{4T-2} + X_{4T-1} + X_{4T}$. i.e The sum of the quarterly total malaria cases should equal the annual total malaria cases.

$T = 1,2,...n$ for $\{Y_T\}$; $t = 1,2,...4n$ for $\{X_T\}$

Boot *et al* [1] derived a simplified solution to (1)

When the sample size n of Y_T is small, i.e $n < 40$, the model based disaggregation method e.g Stram and Wei procedure [25] is not appropriate, but rather BFL-FD becomes suitable in disaggregating annual time series data into quarterly figures. The non-model based method developed by Boot et al, [1] will be employed in this study to disaggregate the Nigeria's annual malaria data to quarterly figures.

3.2 SARIMA MODELLING APPROACH

ARIMA model originated from the autoregressive model (AR), the moving average model (MA), and the combination of the AR and MA which is the ARMA models. Inclusion of seasonal components in this model results into SARIMA model. SARIMA model is therefore an extension of ARMA class of model in order to include realistic dynamics in particular non-stationarity in mean and seasonal behaviours, [15]. When seasonal effect is absent, a SARIMA model reduces to pure ARIMA(p,d,q) and when the series is stationary, a pure ARIMA reduces to ARMA(p,q).

Univariate *seasonal autoregressive integrated moving average* (SARIMA) developed by Box and Jenkins [3] have been found adequate in modeling epidemiological data, [21]. Univariate SARIMA model is based on temporary patterns of malaria historical cases to make short term forecasts in order to determine the trend of malaria cases, whether it will exhibits an upward or downward trend in upcoming periods which can serve as early warning. SARIMA model, which allow for a parsimonious model building, is based on the strong correlation between data collected periodically when there is seasonality. The seasonal effect implies that observed number of malaria cases in the first quarter of a given year is related to the observations of the first quarter of the previous years. SARIMA is a special case of the ARIMA model, since the AR and MA relationship is modeled for observations of the same seasonal time interval in different years. The procedure of building SARIMA model involves three stages which are model identification, model estimation, and model checking. The three stages are used for determining the best SARIMA model for a particular time series data. The three stages process must be repeated iteratively to ensure that there is no evidence of model inadequacy, [15].

The general multiplicative model for seasonal series, as suggested by Box and Jenkins, [3] is:

$$\varphi_p(B)\Phi_P(B^s)\nabla^d\nabla_s^D x_t = \theta_q(B)\Theta_Q(B^s)\varepsilon_t \quad (2)$$

where

$\varphi_p(B) = 1 - \varphi_1 B - \varphi_2 B^2 - ... - \varphi_p B^p$

$\Phi_P(B^s) = 1 - \Phi_1 B - \Phi_2 B^{2s} - ... - \Phi_p B^{Ps}$

$\theta_q(B) = 1 - \theta_1 B - \theta_2 B^2 - ... - \theta_q B^q$

$\Theta_Q(B^s) = 1 - \Theta_1 B - \Theta_2 B^{2s} - ... - \Theta_Q B^{Qs}$

$\nabla x_t = x_t - x_{t-1}$ and $\nabla^d x_t = \nabla(\nabla^{d-1} x_t) = w_t$

$Bx_t = x_{t-1}$; $B^s x_t = x_{t-s}$

$\nabla = \nabla_1 = 1 - B$

x_t: Quarterly disaggregated malaria figure at time t.

$\{\varepsilon_t\}$: is a sequence of identically and independently distributed random variables, which are normally distributed with mean zero and variance σ_ε^2. It is also referred to as a white noise process.

B: is the backward shift operator.

∇ : is the backward difference operator.

s : Length of the seasonal period.

Parameters p, d, q and P,D,Q are non-negative integers that refer to the order of the autoregressive, integrated and moving average parts for both non-seasonal and seasonal parts of the model respectively.

$\Phi_P(B^S)$ and $\varphi_p(B)$ are autoregressive polynomials in B^S and B of order P and p respectively, while $\Theta_Q(B^S)$ and $\theta_q(B)$ are moving average polynomials in B^S and B of order Q and q respectively; and must satisfy the stationarity and invertibility conditions. Also p, P, q, Q are orders of the various operators so that the resulting multiplicative process is of order $(p,d,q)\times(P,D,Q)_S$. Hence $X_t \sim SARIMA(p,d,q)(P,D,Q)_S$ There is no need for inclusion of the constant term when differencing is necessary. SARIMA $(p,d,q)\times(P,D,Q)_S$ which is used to characterize a multiplicative seasonal ARIMA model, therefore refers to seasonal components of order p, P for AR, q, Q for MA and d, D for differencing. For the quarterly disaggregated malaria figures used in this study, the period length is therefore *s=4.*

3.3 MODEL IDENTIFICATION FOR THE MALARIA DATA

The time series plot of the quarterly disaggregated figures of the malaria data as displayed in figure 1 shows that the data have trend patterns with increasing variation. This is an indication that the disaggregated malaria figures are not stationary both in mean and variance, and possibly in seasonal component. The increasing amplitude of seasonal variations observed in the time plot of the series is suggestive of a multiplicative seasonal pattern. The trend in mean and the variance which varies overtime as exhibited by the disaggregated malaria figures indicates the presence of heteroscedasticity, which is a violation of one of the basic assumptions in time series model. Differencing alone may not be adequate in inducing stationarity in the series. The sample ACF of the disaggregated malaria figures (x_t), declines slowly which is an indication that the series is clearly nonstationary as shown in figure 2. It is therefore necessary to subject the data to variance stabilizing transformation regarded as Box-Cox transformation [2], by taking the natural logarithm of the series and then difference the series to achieve stationarity both in mean and in variance. Logarithmic transformation $z_t = \log(x_t)$ is appropriate since the variance of the disaggregated malaria figures increases quadratically with the mean.

Plausible models were identified for Z_t, (the logarithmically transformed malaria figures), from the autocorrelation (ACF), and the partial autocorrelation function (PACF) displayed in figure 3. Series of uncontrolled behaviour of certain process outputs, such as malaria usually possess non-stationary characteristics, [3]. It is therefore expected that the malaria series will possess non-stationary characteristics. As depicted by figure 3, the ACF of z_t has a wavy pattern which reflects the meandering shape of the malaria series, suggesting that the series is non-stationary. Exponential decay of the ACF of Z_t, confirms the need for differencing, to induce stationarity. It appears that the regular or non-seasonal difference is appropriate to induce stationarity in the series, so that (∇Z_t) may be adequate. The purpose of the transformation (∇Z_t) is to take the first differences of the logarithmically transformed malaria disaggregated figures, and thereby obtain a stationary malaria series that can be modeled by fitting appropriate SARIMA model. Differencing will reduce the disaggregated malaria figures to stationarity in the mean, and thereby remove trend in Z_t. Unless the trend is removed, MA or AR components cannot be recognized from the ACF and the PACF.

After taking the first nonseasonal difference a very clear pattern in the sample ACF is produced as shown in figure 4. The ACF shows some alternating pattern of positive and negative values and a spike at lag zero, while the PACF for all lags beyond the first lag are zero. This implies that the PACF cuts off after lag 1, and the rest of the values randomly oscillate about zero, within the 95% non-significance limits. The PACF therefore provides a clearer picture, and clearly suggests SARIMA scheme. Since z_t contained trends, and no noticeable seasonal variation, only non-seasonal differencing is therefore considered adequate (∇Z_t) to induce stationarity in the series. This implies that only one non-seasonal difference, and no seasonal difference is required, so that $d = 1,\ D = 0.$ The disaggregated malaria figures looks like a stationary process after one non-seasonal differencing. Preliminary investigations of the ACF and the PACF suggests SARIMA(1,1,0)(1,0,0)$_4$ a univariate model, as possible provisional model for the logarithmically transformed quarterly disaggregated malaria figures.

FIG. 1: TIME SERIES PLOT OF X_T, THE QUARTERLY DISAGGREGATED MALARIA CASES

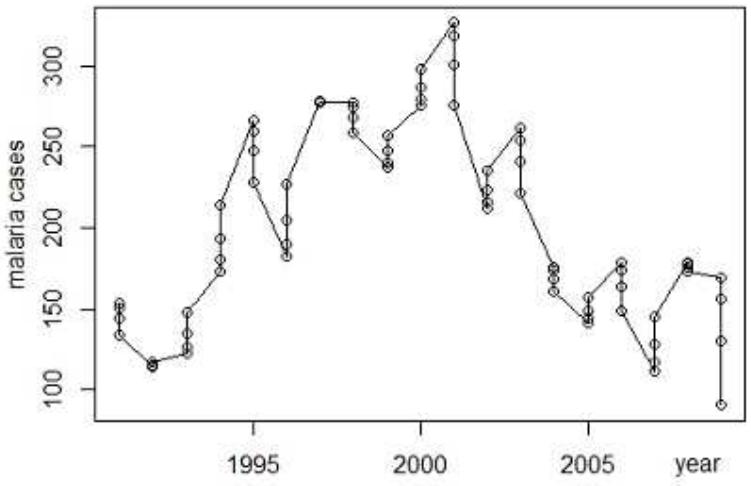


FIG. 2: ACF AND PACF OF x_t, THE DISAGGREGATED MALARIA FIGURES

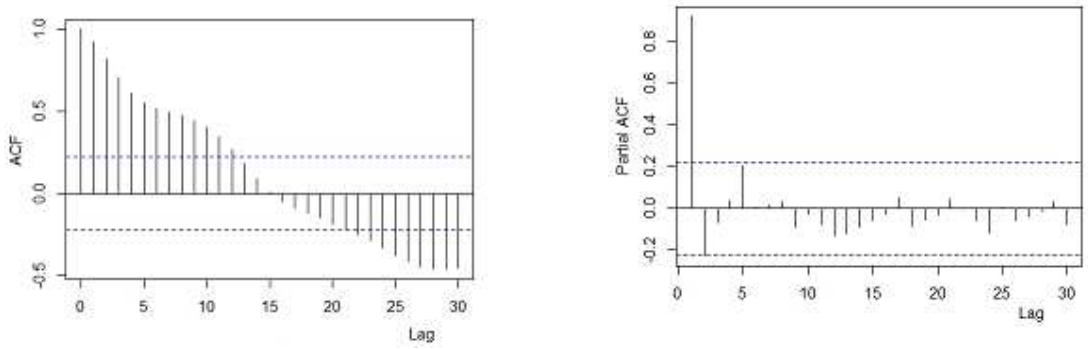


FIG. 3: ACF AND PACF OF z_t, WITHOUT DIFFERENCING

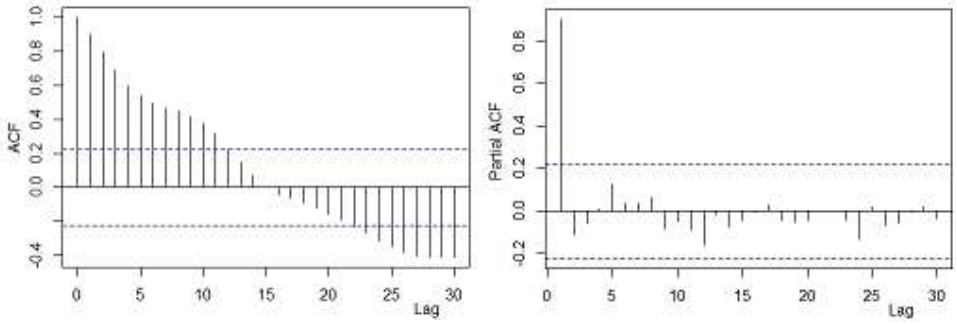
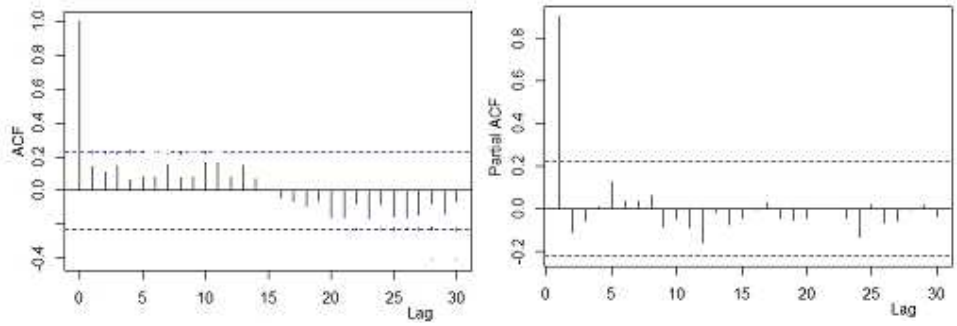


FIG. 4: ACF AND PACF OF THE NON-SEASONAL DIFFERENCE OF z_t, DIFFERENCED ONCE



$$(1-\varphi B)\nabla z_t = \left(1-\Phi B^4\right)\varepsilon_t \tag{3}$$

This is ARIMA(1,1,0)(1,0,0)$_4$

The expanded form of SARIMA(1,1,0)(1,0,0)$_4$ is given as follows:

$$z_t - z_{t-1} - \varphi z_{t-1} + \varphi z_{t-2} = \varepsilon_t - \Phi\varepsilon_{t-4} \tag{4}$$

$$z_t - z_{t-1} - \varphi\left(z_{t-1} + z_{t-2}\right) = \varepsilon_t - \Phi\varepsilon_{t-4} \tag{5}$$

3.4 CHECKING FOR MODEL ADEQUACY

Diagnostic checks to evaluate model adequacy and appropriateness of the fit should be conducted on the model residuals to check for homoskedasticity and normality; and to uncover possible lack of fit and diagnose the cause. There are various checks that should be performed before it can be accepted that a SARIMA model is adequate. Some of the checks that will be considered in this study are: plot of the residual ACF, Ljung-Box Q-statistics (portmanteau test), R^2 statistic and the stationary R^2 statistic.

The residual autocorrelation function which consists of the plot of the residual autocorrelation functions and the lag will be plotted to check for unusual values. For an adequate SARIMA model, theoretically, autocorrelation function of a series of random residual should be zero for all lags, [15]. Practically, the ACF of the residuals will show fluctuations due to the finite length of the time series data. Under the assumption that the series is random, a check for model inadequacy is that the residual autocorrelations are large compared with their standard errors, which will necessitate a transformation of the series as a remedy. The R^2 value and the stationary R^2 value are good measures in checking the overall fit of a model. The R^2 value is the total variation explained by the model, while stationary R^2 value gives the value of the remaining variation explained by the model after differencing. The portmanteau test of model adequacy also called Ljung-Box Q statistic [17], based on the residual correlogram is of the form:

$$Q_{LB} = n(n+2)\sum_{j=1}^{k}\frac{\tau_j^2}{n-j} \tag{6}$$

where

n denotes the length of z_t after differencing.

τ_j is the sample autocorrelation in lag j.

k is the number of lags to be tested.

Q_{LB} the Q-statistic in lag k is the test statistic for the null hypothesis about zero autocorrelation up to lag *k*. Q_{LB} has the asymptotic chi-square distribution with degrees of freedom equal to k reduced by the number of MA and AR terms employed in the model.

3.5 RESULTS

The results of fitting the SARIMA model of the logarithmically transformed malaria figures are shown in tables 1 and 2. Table 1 shows the result of the maximum likelihood estimates of the parameters of the model with their standard errors, the t-values and their corresponding p-values. The values of the corresponding standard errors of the model parameters are low, which implies that the specified SARIMA model is adequate for the malaria series. The corresponding p-values of the t-tests show that both the non-seasonal AR (φ) and the seasonal AR (Φ) coefficients are significant, an indication that the parameters of the model have significant contributions to the adequacy of the model. The values of R^2 and the *stationary* R^2, which are measures of the goodness of fit of the model, are approximately 93% and 35% respectively. The R^2 value shows that about 93% of the total variation in the malaria series is accounted for by the SARIMA model, while the *stationary* R^2 value indicates that after differencing, about 35% of the remaining variation is explained by the model, which implies a strong relationship. The portmanteau test of model adequacy, also referred to as Box-Ljung Q-statistic yield a value of Q = 12.99 with an associated p-value of 0.674, which is not significant. The value of the Q-statistic therefore does not provide any evidence of model inadequacy. Based on the assumption that the residuals series is a sequence of independent, identically distributed random variables with mean zero and constant variance, the ACF of the residuals of the SARIMA model of malaria as shown in figure 5 is not significantly different from zero, so that the residual serial correlations are all within $\pm 2E$. The value of the normalized Bayesian information criterion (Normalized BIC) is -6.473, which is low and consequently show that the model is appropriate for the malaria series. The diagnostic results of the SARIMA model of malaria cases are therefore satisfactory, since there is no evidence of lack of fit.

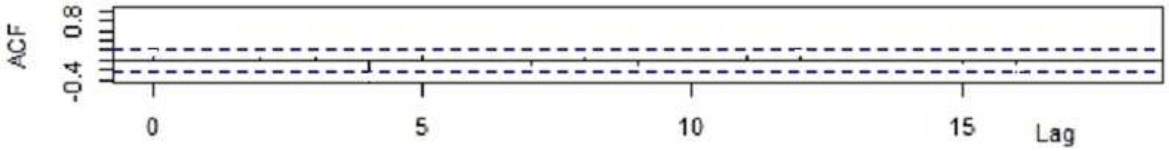
TABLE 1: MAXIMUM LIKELIHOOD ESTIMATES OF THE PARAMETERS OF THE SARIMA MODEL

Model	*Parameter*	*MLE*	*SE*	*t-value*	*p-value*
$SARIMA(1,1,0)(1,0,0)_4$	φ	0.546	0.114	4.810	0.000
	Φ	-0.453	0.114	-4.001	0.000

TABLE 2: SUMMARY OF THE FITTED SARIMA MODEL

Fitted model	*R squared*	*Stationary* R squared	*MSE*	*MAPE*	*Normalized BIC*
$(1-0.546B)\nabla z_t = (1+0.453B^4)\varepsilon_t$	92.8%	34.9%	0.037	1.226	-6.473

FIG. 5: ACF OF RESIDUALS



4. DISCUSSION AND RECOMMENDATIONS

The SARIMA model proposed in this study is based on the malaria data extracted from the record of a Nigeria teaching hospital, as a case study to understand the trend of malaria cases in Nigeria. The model was developed based on the trend of recorded malaria cases over the years and the presuming stability pattern as exhibited by the ACF and the PACF, after subjecting the disaggregated malaria figures to Box-Cox transformation and differencing. The model was validated and appeared to fit the malaria data well.

The SARIMA model has its usefulness in planning and managing malaria prevention and controlling the disease in Nigeria, and consequently enhances the fight against the scourge of malaria by the public health policy makers and health practitioners. The model for the malaria data is useful in understanding the trend and pattern of malaria in Nigeria overtime, and in estimating the number of malaria cases which is a useful guidance for timely prevention and control measures to be effectively planned by the health policy makers in the country, by giving adequate medical attention to areas and periods most at risk in allocating the scarce health facilities. Early diagnosis and treatment of malaria will not only reduce the disease and prevent malaria deaths, but will also contribute to reducing malaria transmission.

A critical examination of the data shows that the results should be interpreted with some cautions. Limitations to the clinically diagnosed malaria data could result from inconsistent registration of malaria cases, incomplete recording, and lack of platform for centralized data sharing. Incompleteness in reporting systems of the malaria cases could be as a result of self-medication, and patients lost to follow up or not seeking treatment at all. These uncertainties largely translated to the levels of error that resulted in the current model predictions. Nevertheless the SARIMA model attempts to quantify the trend of malaria disease by using data on malaria cases in an effort to develop a statistical model for the disease in Nigeria.

The main limitation of using time series models in epidemiological study is the unavailability of long term data. Time series models are data-driven requiring large volume of historical data for model parameterization. At least 50 observations of the data are required in order to have good estimates of the parameters of the time series model [22, 3], and most developing countries do not have such long data on malaria cases. With the development of disaggregating annual data into either quarterly or monthly figures, this limitation can be overcome.

Intensified effort on National Malaria Control Program is necessary in order to reduce the devastating effects of the disease on both the Nigerian economy and human lives. Vector control remains the main method to reducing malaria transmission from very high levels to zero. With the increasing levels of drug resistance in the treatment of malaria, use of insecticide-treated nets which is a form an effective vector control should be provided to households that are previously without nets, to prevent the acquisition of malaria immunity. Provision and proper use of insecticide treated materials will aid in achieving reductions in malaria transmission, deaths and in mosquito population. Currently there are no licensed vaccines to inoculate people against malaria; there is a challenge therefore, to develop an effective vaccine to immunize people against the disease. It is advisable that Nigeria government should fund researches on malaria to encourage researchers in this field to come up with a viable vaccine to inoculate people, and thereby produce immunity to the disease. Increased community awareness and public sensitization using the media, are necessary for effective malaria treatment and prevention. People should be educated on the benefits of maintaining a high social and personal hygiene attitude. Ditches, gutters, pools of water, some of which results from broken pipes and blocked drainage systems which are natural habitat for breeding mosquito larvae should be discouraged.

There should be an improved capacity for policy development, planning and co-ordination in all levels of government geared towards prevention of malaria. Quality of healthcare should be improved upon in terms of state-of-earth health facilities, and constant training of the health practitioners. Affordable and preventive malaria drugs should be made available to pregnant women, people living with HIV/ AIDS, international travelers from non-endemic areas, (because they lack immunity), immigrants from endemic areas and children under-five years who are regarded to as malaria population risk groups, to prevent malaria transmission.

APPENDIX

The appendix is written with a view of giving a short introduction about the time series technique employed in this study to help the understanding of the reader.

A time series is a set of observations $y_t, y_{t-1}, y_{t-2}\cdots\cdots$ made sequentially in time at regular interval of time $t, t-1, t-2\ldots\ldots$

Stationary Time series models

Stationary stochastic process is based on the assumption that the process is in a particular state of statistical equilibrium, [3]. A time series $\{y_t\}$ is said to be strictly stationary if the random vectors $\left(y_{t_1},\ldots\ldots y_{t_n}\right)^T$ and $\left(y_{t_1+\tau},\ldots\ldots y_{t_n+\tau}\right)^T$ have the same joint distribution for all sets of indices $\{t_1\ldots\ldots t_n\}$ and for all integers τ and $n>0$. i.e

$$\left(y_{t_1},\ldots\ldots y_{t_n}\right)^T \overset{d}{=} \left(y_{t_1+\tau},\ldots\ldots y_{t_n+\tau}\right)^T$$

where *d* means 'equal in means'

This implies that shifting the time origin by an amount τ has no effect on the joint distribution of the series. The joint distribution depends on $t_1, t_2, \ldots t_n$.

Non-stationary time series models

A SARIMA model is the generalization of a non-seasonal ARIMA model, (Jenkins, 1979). A SARIMA may be viewed as a model which describes two effects simultaneously. For a quarterly data, the quarter-to-quarter behavior is assumed to be described by a saeonal ARIMA model with parameters (p,d,q). The residuals from this model are assumed to be represented by a year-to-year ARIMA model with parameters (P,D,Q). Combination of these two models yield a seasonal ARIMA (p,d,q)(P,D,Q)$_s$ model. In real life many series encountered exhibit non-stationary behaviour. This is the case of the malaria data employed in this study. A non-stationary series can be transformed to induce stationarity by taking differences in level. A stationary $\mathrm{ARMA}(p,q)$ could be written explicitly as

$$\varphi_p(B)\hat{y}_t = \theta_q(B)\varepsilon_t$$

which is called autoregressive moving average scheme of orders (p,q).

If differencing is necessary to produce a stationary series, then the model corresponding to the original series, after being differenced is referred to as S ARIMA (p,d,q) S $\mathrm{ARIMA}\ (p,d,q)(P,D,Q)_s$ model which is a mixed seasonal model of period *s* with regular and seasonal components of order p, P for AR, q, Q for MA and d, D for differencing. (Integrated ARMA model).

The general form of the S ARIMA (p,d,q) (P,D,Q)$_s$ model is:

$$\varphi_p(B)\Phi_P\left(B^s\right)\nabla^d\nabla_s^D\hat{y}_t = \theta_q(B)\Theta_Q\left(B^s\right)\varepsilon_t$$

where

$y_t = y_t - \mu$ and μ is the mean of the series.

$By_{t-1} = y_{t-1}$ and $B^s y_t = y_{t-s}$

$\Phi_P\left(B^s\right)$ and $\varphi_p(B)$ are autoregressive polynomials in B^s and B of order P and p respectively, while $\Theta_Q\left(B^s\right)$ and $\theta_q(B)$ are moving average polynomials in B^s and B of order Q and q respectively. The backward difference operators are $\nabla = (1-B)$ and $\nabla_s = \left(1-B^s\right)$

ε_t is a series of independently, identically distributed random variables with mean zero and constant variance σ_ε^2, i.e $\{\varepsilon_t\} \sim \mathrm{WN}\left(0,\sigma^2\right)$. It is the estimated white noise variance. *S* is the order of seasonality in the series.

Identification of the appropriate ARMA model for a particular time series is achieved by examining both the sample autocorrelation function (ACF) and the partial autoregressive function, (PACF). The ACF is calculated by computing the correlation between variable and successive lags of the same variable, while the partial autocorrelation at lag k is the correlation between y_k and y_{t-k} after removing the effect of the intervening variables $y_{t-1}, y_{t-2}, \ldots\ldots y_{t-k+1}$.

Selection criteria

Two of the criteria for selecting the best parsimonious models are Akaike information criterion and Bayesian information criterion. An approach to the comparison of two models is to compare their likelihood function (LF). Akaike (1974) proposed an information criterion (AIC) which is a method of comparison between log-likelihoods, and is of the form

$$\mathrm{AIC} = -2\mathrm{In}(L) + 2k$$

where

k: number of parameters in the model

L: Likelihood function

The model with the smallest AIC is considered best in the sense of minimising the forecast mean square error, (FMSE). Schwartz (1978) pointed out that AIC is an inconsistent criterion in that it does not select the true model with probability approaching 1 as $n \to \infty$. Schwartz [18] therefore proposed the Bayesian information criterion (BIC) to overcome the problem.

$$\mathrm{BIC} = -2\mathrm{In}(L) + k\mathrm{In}(n)$$

The preferred model will be the one with minimum AIC.

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