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Time series modeling of poultry mortality rate in Ghana: West Africa

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Abstract
In this study, data on monthly mortality rate and weather variables of average temperature and rainfall were obtained from the Ministry of Agriculture in the Upper West Region and the Meteorological Service Department of Ghana and these were modelled using both Autoregressive integrated moving average (ARIMA) and Autoregressive integrated moving average model with errors (ARIMAX). The results revealed that, regression with ARIMAX (2, 1, 1) model was the best model for the mortality rate. This model had the least AIC, BIC and HQIC values. Furthermore ARIMA (2, 1, 1) model was also identified as the best regression model. Diagnostic checks of both models, using the Ljung-Box test and ARCH-LM test, revealed that both models were free from higher-order serial correlation and conditional heteroscedasticity respectively. All variables under study were best modelled using the log-quadratic trend while rainfall followed a log-linear trend model.

Keywords: time series, modelling, mortality, Ghana

Introduction

Poultry plays an important economic, nutritional and socio-cultural role in the livelihood of poor rural households in many developing countries, including Ghana. Poultry are birds that include fowl, turkey, duck, goose, ostrich, guinea fowl etc. and contribute significantly to human food as a primary supplier of meat, egg and raw materials to industries (Demeke, 2004) [5]. Poultry are efficient converters of feed to egg and meat within a short period of time Agriculturists and nutritionists have generally agreed that, developing the poultry industry of Ghana is the fastest means of bridging the protein deficiency gap presently prevailing in the country. Poultry mortality is a constraint to high production and productivity in the poultry industry and despite considerable efforts throughout the century to eradicate poultry mortality in Ghana, it is still the most prevalent and devastating problem facing the industry, poultry deaths in Ghana generally results from the prevalence of poultry diseases (Amos, 2006) [1]

The most important of these diseases are those caused by viruses, parasites and bacteria. Bacterial infections results in some of the common diseases associated with poultry mortality and these include; coccidiosis, coliforms, new castle, helminthiasis and ecoli. The most common of these diseases is the Newcastle disease. Poultry deaths usually involve the interaction of three determinants; thus disease causing agents, host and the environment (Lancaster, 1981) [8]. High temperature and rainfall have some negative effects on poultry production such as an increase on poultry body temperature; a decrease on feed consumption (Cowan and Michie, 1978).

Poultry flocks are particularly vulnerable to climate change because there is a range of thermal conditions within which they are able to maintain a relatively stable body temperature in their behavioral and physiological activities. Climate change alters global disease distribution which affects poultry feed intake, encourage outbreak of diseases which invariably affects poultry output (egg and meat) and also cost of production (Guis *et al.*, 2011) [6]. This research is aim at investigating the effects of climate change on poultry production which will contribute positively to knowledge of the problem climate change poses to the poultry sector. The study therefore seeks to develop model for the mortality pattern of poultry, to enable stakeholders predict and forecast poultry mortality in Ghana and to possibly take preventive measures. Poultry contribute significantly to the livelihood of the households and also fulfills a range of other functions which are difficult to allocate monetary value. Poultry mortality rate are wide spreading in the rural areas in Ghana, just like the rest of Africa (Ssewanyana and Rees, 2004) [11]. Climatic factors have a relative high impact on poultry mortality rate as it alters global disease distribution. Also temperature change can significantly influence the survivability and performance of the poultry production. This research is to investigate the trend of poultry mortality as well as to determine the monthly effect of poultry mortality and to compare the efficiency of two different models (i.e ARIMA and ARIMAX) on poultry mortality rate.

Methodology

Study area/ Data and Source

This study is carried out in the Upper West Region of Ghana and the Region covers a geographical area of approximately 18,478 square kilometers. This constitutes about 12.7% of the land of Ghana. The region is bordered on the North by the Republic of Burkina Faso, on the East by Upper East Region, on the South by Northern Region, on the West by Coted'Ivoire. Monthly time series data on poultry mortality and meteorological data on temperature and rainfall from January, 2000 to December, 2014 was used in the empirical analysis of poultry mortality rate pattern in Ghana and the prevailing conditions are the in three northern regions.

Method of analysis

The study employed the trend analysis, ARIMA modelling approach and regression with ARIMA errors (ARIMAX), in order to meet the set objectives.

Trend Analysis

Trend analyses are techniques for extracting an underlying pattern of behaviour in a time series which would otherwise be partly or nearly completely hidden by noise. A trend analysis is an aspect of technical analysis that tries to predict the future movement of the past data. Trend analysis is based on the idea that what has happened will happen in the future (Makridakis *et al.*, 1982) [9]. The simple linear regression model is given by

$$Y = \beta_0 + \beta_1 X + \varepsilon \tag{1}$$

Where *Y* is the response, *X* is the predictor variable, β_0 and β_1 are unknown parameters and ε is an error term. The model parameters, β_0 and β_1 have physical interpretation as the intercept and slope of straight line respectively. When the simple linear regression model is extended to include additional predictor variables say *k* predictors, then we have the multiple linear regression model which is also given as

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon \tag{2}$$

Unit root Test

A weakly stationary time series is one which first and second moments are invariant over time; thus the expected value of the time series does not depend on time and the autocovariance function is given as

$$\mathrm{cov}(y_t, y_{t+k}) \tag{3}$$

For any lag *k* is only a function of *k* and not time, hence

$$\gamma_y(k) = \mathrm{cov}(y_t, y_{t+k}) \tag{4}$$

Augmented Dickey-Fuller (ADF) Test.

Let consider the following time series $\{y_t\}$, which is stationary around the level r_0:

$$y_t = r_0 + \varepsilon_t. \tag{5}$$

Where t=1...*T* and ε_t is independent and identically distributed *i.i.d* with a zero mean and constant variance, denoted $\varepsilon_t \sim iid(0, \sigma_\varepsilon^2)$. the series $\{y_t\}$ can be tested for stationarity by Augmented Dickey-Fuller test. Mathematically, if $\delta = 0$, the series contains a unit root implying non-stationary, whereas if $\delta < 0$, there is no unit root implying stationarity the null hypothesis for ADF test for units root are given by

$H_0^{ADF}: \delta = 0$ Is tested against the alternative hypothesis of no unit root.

$H_1^{ADF}: \delta < 0$ Using the t- test of individual significance

The test is the improved version of Dickey- Fuller (DF) test of the framework

$$t\Delta y_{t-1} = t\delta y_{t-1} + w_t \tag{6}$$

Where w_t is $w_t \sim iid(0, \sigma_\varepsilon^2)$. The null hypothesis of $\delta = 1$ (unit root) is tested against the alternative hypothesis of $\delta < 1$ (no unit root) is given as

$$\Delta y_t = \delta y_{t-1} + \sum_{i=1}^{p} B_i \Delta y_{t-i} + \eta_t \tag{7}$$

Where $y_t \sim iid(0, \sigma_\eta^2)$. *p* is the autoregressive lag length which is large enough to eliminate possible serial correlation in η_t, and δ is the coefficient of interest.

The ADF test proposed by (Dickey and Fuller, 1979) was an improvement of the Dickey-Fuller (DF) test and this test is based on the assumption that the series follows a random walk and it is given by

$$\Delta Y_t = c + \pi Y_{t-1} \sum_{i=1}^{p} \gamma \Delta Y_{t-1} + \varepsilon_t \tag{8}$$

Where *p* is the optimum lag length in the ADF regression which ensures that the residuals are not serially correlated and indicate a white noise process. The sum of the lagged values of the dependent variable is given by

$$DF = \frac{\hat{\pi}}{SE(\hat{\pi})} \tag{9}$$

Where $\hat{\pi}$ denote the Least Squares estimates of π and $SE(\hat{\pi})$ is the standard error. The null hypothesis is rejected if the test statistic is greater than the critical value.

Kwiatkowski-Phillips-Schmidt-Sin (KPSS) Test

The KPSS test is a type of test in which the null hypothesis is the reverse of the ADF test. This test is performed to see if the series can achieve stationarity (Kwiatkowski *et al.*, 1992). The model For Y_t is assume to be written as

$$Y_t = \alpha t + \phi_t + \varepsilon_t. \tag{10}$$

With an auxiliary equation for

$$\phi_t = \phi_{t-1} + \mu_t \tag{11}$$

With $\mu_t \sim iid(0,\sigma_\mu^2)$. A test of $\sigma_\mu^2 = 0$ is a test for stationarity. The hypothesis test of KPSS is given as

H_0: y_t Is stationary.

H_1: y_t Has unit root.

Autoregressive integrated moving average (ARIMA)

An ARIMA model is a concatenation of Autoregressive (AR) model which shows that there is a relationship between present and past values, a random value and a Moving Average (MA) model which shows that the present value has something to do with the past shocks. The ARIMA (*p, d, q)* model is used when a series is non-stationary and stationary after a given order of differencing.

The complete ARIMA model is a linear combination of AR and MA processes or ARMA that their parameters derived from a time-series that becomes stationary through differencing with the form:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_p Y_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots - \theta_p \varepsilon_{t-p}. \quad (12)$$

Regression with ARIMA errors (ARIMAX)

The regression model with ARIMA errors also known as ARIMAX model is an ARIMA model with input variables and this model is an integration of a regression model with an ARIMA model. The regression method describes the explanatory relationship while the ARIMA method takes care of the autocorrelation in the residuals of the regression model (Andrews, 2013).

The ARIMAX model has a form as follows:

$$Y_t = \beta X_t + \phi Y_{t-1} + \ldots + \phi_p Y_{t-p} - \ldots - \theta_q Z_{t-q} + Z_t \quad (13)$$

Where X_t is a covariate at time t and β is the coefficient. The presences of lagged values of the response variable on the right hand side of the equation means that β can only be interpreted conditional on the values of previous response variable, which is hardly intuitive. Using the back shift operators, the ARIMAX model is given by:

$$\phi(\mathrm{B}) Y_t = \mathrm{B} X_t + \theta(\mathrm{B}) Z_t \quad (14)$$

The above shows how the AR coefficients get mixed up with both the covariates and the error term (Shumway and Stoffe, 2000) [10].

Analysis and Discussion of Results

Introduction

Basically this chapter is based on the analysis and discussion of results obtained from the study of poultry mortality in the Upper West Region.

Preliminary Analysis

The minimum and maximum values of all the variables as showed in Table 4.1 are 727.60 for rainfall, 31.80 for average temperature and 27.00 for poultry mortality rate. The data for both mortality rate and rainfall are positively skewed and average temperature is negatively skewed and the various means are mortality 6.606, rainfall 89.912 and average temperature 26.941 respectively. All the variables are leptokurtic in nature since they have positive excess kurtosis.

Trend Analysis

From Table 1 to 2 showed the various trend models for the various series. In considering the model type from Table 1 to 2, we compared the models and select the one with the least value of AIC, BIC and HQIC. It was seen from the results that, the best trend model for the poultry mortality is the log-quadratic, since the log-quadratic model has the least values of the information criteria.

Table 1: Trend Analysis of Mortality Rate

Variable	AIC	BIC	HQIC
Log-quadratic	342.979***	349.365***	345.568***

The estimated parameters of the log-quadratic trend model for poultry mortality rate is given as

$$\ln(mortality) = 0.889 + 0.0264 Time - 0.00014 Time^2 \quad (15)$$

Rainfall was observed to have a log-linear trend model as seen in Table 2. Since log-linear trend had the least values AIC, BIC and HQIC.

Table 2: Trend Analysis of Rainfall

Variable	AIC	BIC	HQIC
Log-linear	662.731***	669.116***	665.320***

The parameters of the log-linear trend model were estimated and fitted as

$$In(Rainfall) = 3.4839 + 0.0015 Time. \quad (16)$$

The trend in the average temperature was observed to be a log-quadratic trend model as seen in Table 3. Since log-quadratic had the least AIC, BIC and HQIC values it is chosen as the best model.

Table 3: Trend Analysis of Average Temperature

Variable	AIC	BIC	HQIC
Log-quadratic	-379.961***	-373.575***	-377.372***

The estimated parameters of the log-quadratic trend model were estimated as shown in Table 3. Only the intercept was highly significant at the 5% level of significance. The estimated model is:

$$In(Temperature) = 3.3966 - 0.00047 Time + 0.000003 Time^2 \quad (17)$$

Further Analysis

To confirm non-stationarity in the levels of the poultry mortality the Augmented Dickey-Fuller (ADF) test is used to test for stationarity of the series with the null hypothesis that, there is unit root in data against the alternative that the data is stationary.

Table 4 revealed that the series are not stationary and hence we fail to reject the null hypothesis at 5% level of significance.

Table 4: ADF Test for Stationarity in poultry Mortality in a Level Form

Variable	Test	Constant		Constant + Trend	
		Test statistic	*p*-value	Test statistic	*p*-value
Mortality	ADF	-1.666	0.4487	-1.9901	0.6062

To use the KPSS test, we test the null hypothesis of the original series whether it is stationary at the seasonal level. From Table 5 showed that the calculated value fall outside the acceptance region at 0.05 level of significance and we therefore say that we fail to reject the null hypothesis and hence the series is not stationary as shown in Table 5

Table 5: KPSS Test for Stationarity in poultry Mortality in a Level Form

Variable	Test	Test statistic	Critical value
Mortality	KPSS	0.5697	0.464

From Table 4 and 5 indicates clearly that the series are non-stationary and we need to transform the series by differencing and test for stationarity. ADF test in Table 6 revealed that the differencing series is stationary for 0.05, level of significance

Table 6: ADF Test for Stationarity in the first Differenced Mortality rate

Variable	Test	Constant		Constant + Trend	
		Test statistic	*p*-value	Test statistic	*p*-value
Mortality	ADF	-5.9042	0.0000	-8.8468	0.0000

The KPSS test for stationarity in first differenced mortality rate indicated that the series is now stationary at the 5% level of significance as shown in Table 7

Table 7: KPSS Test for Stationarity in the first Differenced Mortality rate

Variable	Test	Test statistic	Critical value
Mortality	KPSS	0.3017	0.464

Graphical illustration of stationarity can be seen from the time series plot of the differenced series for the poultry mortality series as shown in Figure 1, which indicates that the series fluctuates about the zero line and have a zero mean and constant variance and this is an indication of stationarity.

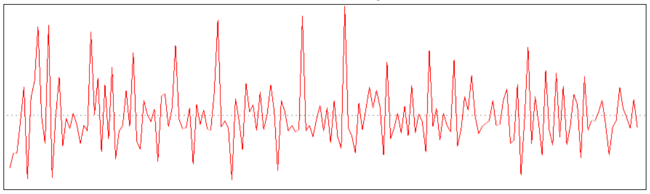

Fig 1: Time series plot of differenced mortality rate

In fitting the ARIMA (p, d, q) model, the order of the ARIMA model is obtained from the ACF and PACF plots based on the Box-Jenkins (1976) approach from Figures 2

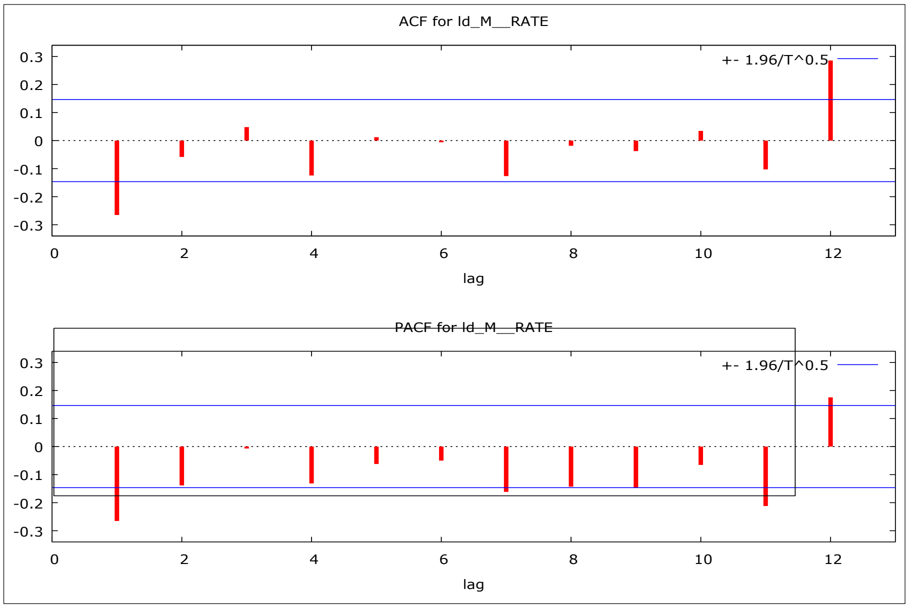

Fig 2: ACF and PACF plot of differenced mortality rate

Observing the various tentative models identified in Table 8. Among these possible models presented, ARIMA (2, 1, 1) was chosen as the appropriate model that fit the data since it has the minimum values of AIC, HQIC and BIC compared to other models.

Table 8: Tentative ARIMA models

Model	AIC	BIC	HQIC
ARIMA (2, 1, 1)	265.835***	281.744***	272.286

Table 9: Estimates of Parameters for ARIMA (2, 1, 1)

Variable	Coefficient	Std. error	z-statistic	*p*-value
Constant	-0.00014	0.00049	-0.2932	0.7694
ϕ_1	-0.3055	0.07510	-4.0660	0.0000
ϕ_2	-0.1426	0.07530	-1.8940	0.0582
θ_1	-1.0000	0.01440	-69.4000	0.0000

Model Diagnostic of ARIMA (2, 1, 1)

The estimated model must be check to verify if it adequately represents the series. Diagnostic checking are performed on the residuals to see if they are randomly and normally distributed. Here, the residual plot of ARIMA (2, 1, 1) was used to check if the residuals are randomly distributed. An overall check of the model adequacy was made using the Ljung-Box *Q*-statistics which showed that there is no significant deviation from random walk for the residuals as the *p*-value of the test statistic is greater than 0.05 significant levels for the lag orders. The standardized residuals plot of the series showed that, the residuals of the model have zero mean and constant variance, while the ACF plot of the residuals indicates that the autocorrelation of the residuals are all zeroes and are uncorrelated.

Table 10: Ljung-Box Test of ARIMA (2, 1, 1)

Variable	Lag	Test statistic	*p*- value
Mortality	12	41.642	1.000

Fitting the ARIMAX Model

The ARIMAX model is an extension of the ARIMA model and this model includes predictor or exogenous variables. It is used in this study to evaluate the relationship between the monthly weather variables and the monthly poultry mortality rate.

Table 11: ADF Test of Rainfall and Average Temperature in a Level Form

Variable	Test	Constant		Constant	+ Trend
		Test statistic	*p*-value	Test statistic	*p*-value
Rainfall	ADF	-2.565	0.100	-2.722	0.228
Average Temp.	ADF	-2.468	0.125	-2.582	0.289

Table 12 further indicated that, both rainfall and average temperature are not stationary at 5% significance level. The test results as shown in Table 12 indicated that, the calculated value is outside the critical region at the 5% level of significance.

Table 12: KPSS Test of Rainfall and Average Temp. In a Level Form

Variable	Test	Test statistic	Critical value
Rainfall	KPSS	0.506	0.464
Average Temp.	KPSS	0.611	0.464

From Tables 14 and 15, both transformed and first differenced variables were stationary when ADF and KPSS test were performed on them. This was an evident in the significant *p*-values and test statistics realized from both tests respectively.

Table 14: ADF Test for first Differenced Rainfall and Temperature

Variable	Test	Constant		Constant	+ Trend
		Test statistic	p-value	Test statistic	p-value
Average Temp.	ADF	-5.1990	0.0000	-5.1800	0.0000
Rainfall	ADF	-3.5830	0.0000	-3.4370	0.0000

The KPSS test of the first differenced series for rainfall and average temperature showed that, the series is stationary at the 5% level of significance as seen in Table 14

Table 15: KPSS Test for first Differenced Rainfall and Average Temp.

Variable	Test	Test statistic	Critical value
Average Temp.	KPSS	0.020	0.464
Rainfall	KPSS	0.023	0464

Table 16: Tentative ARIMAX models

Model	AIC	BIC	HQIC
ARIMAX (2, 1, 1)***	267.7015***	289.9740***	276.7336***

Table 17: Estimates of Parameters for ARIMAX (2, 1, 1)

Variable	Coefficient	Std. error	z-statistic	p-value
Constant	-0.0001	0.0005	-0.2830	0.0777
ϕ_1	-0.3218	0.0755	-4.2630	0.0000
ϕ_2	-0.1653	0.0764	-2.1630	0.0305
θ_1	-1.0000	0.0144	-69.4300	0.0000
Rainfall	-0.1053	0.4569	-0.2304	0.8178
Average Temp.	-0.0426	0.0288	-1.4770	0.1395

Using the method of maximum likelihood, the estimated parameters of our derived model are shown in Table 17 is ARIMAX (2, 1, 1) model which can be expressed in terms of the lag operator as;

$$X_t = -0.0001 - 0.3218X_{t-1} - 0.1653X_{t-2} + 1.0000Z_{t-1}. \quad (18)$$

Diagnostic of ARIMAX (2, 1, 1)

In checking the adequacy of the model, the regression model with ARIMAX (2, 1, 1,) was diagnosed and the residuals of the model was observed to have zero mean and constant variance. Furthermore, the ACF plot of the residuals showed that, the residuals are uncorrelated. The Ljung Box test in Table 18, further showed that, the test of residuals for predictors' variables of the mortality rate had a *p*-value of all the variables greater than 0.05 and we therefore say that we fail to reject the null hypothesis of no serial correlation and hence the residuals of the ARIMAX (2, 1, 1) model are uncorrelated.

Table 18: Ljung-Box Test of Rainfall and Average Temperature

Variable	Test	Test statistic	*p*- value
Rainfall	12	33.838	1.000
Average Temperature	12	23.030	1.000

Comparative Analysis of the Developed Models

To select the best model for forecasting the mortality rate of poultry, there is the need for us to check for forecasting accuracy by comparing the two developed models, that is the ARIMA (2, 1, 1) model and regression with ARIMAX (2, 1, 1). From Table

19, it is seen that the ARIMAX (2, 1, 1) model is more accurate since it has the best information criteria.

Table 19: Comparative analysis of ARIMA (2, 1, 1) and ARIMAX (2, 1, 1)

Model	ME	MSE	RMSE	MAE	MPE	MAPE
ARIMAX (2, 1, 1)	0.0316*	0.2476*	0.4972*	0.3642*	89.611*	-11.83*
ARIMA (2, 1, 1)	0.0398	0.2499	0.4999	0.3651	94.362	-7.06

Discussion of results

It is observed from the results that poultry mortality rate and rainfall are positively skewed and average temperature is negatively skewed and the various means are mortality 6.606, rainfall 89.912 and average temperature 26.941 respectively. All the variables are leptokurtic in nature since they have positive excess kurtosis. From the monthly descriptive analysis of the mortality rate values, the month of August and January recorded the maximum poultry deaths; this can be attributed to the series of maximum rains and the excessive harmattan often recorded in those months. The findings of this work contradicts that of Baylis and Caminade (2011) [4], who identified sssignificant effects of rainfall and temperature effects on poultry production in Ghana. The presence of the unit roots in the mortality rate and climate data were assessed through Augmented Dickey- Fuller (ADF) test, Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test and the diagnostic checks performed on the residuals of ARIMA (2, 1, 1) revealed that the model were adequately describes by the data since the Ljung-Box *Q*-statistics showed that there is no significant deviation from random walk for the residuals as the *p*-value of the test statistic is greater than 0.05 significant levels for the lag orders. The standardized residuals plot of the series also showed that, the residuals of the model have zero mean and constant variance, while the ACF plot of the residuals indicated that, no autocorrelation in the residuals. The finding of this research is in line with Armstrong (2005), he modeled the relationship between temperature and poultry mortality in Ghana using autoregressive integrated moving average with errors (ARIMAX) models.

Conclusion

In this research, the monthly descriptive statistics of poultry mortality revealed that, the month of January, July and October had the highest maximum poultry mortality. The trend analysis performed on each study variable showed that mortality and average temperature were best modeled using the log-quadratic trend and rainfall follows the log-linear trend model. From the ACF and PACF plots of the stationary dependent variable (poultry mortality) and independent weather variables (rainfall and average temperature) in the case of the (ARIMA) and (ARIMAX) several tentative models were fitted as ARIMA (2, 1, 1) and ARIMAX (2, 1, 1). From the comparative model analysis, the ARIMAX (2, 1, 1) model appeared to be the best based on the model selection criteria.

Recommendations

In this research work, the following recommendations were made:

From the log-quadratic trend model of the poultry mortality, it is indicative that, poultry mortality levels are increasing quadratically with time. It is therefore recommended that Governments and other stake holders should support research into poultry production to identify various challenges and prospects in the industry and further aid poultry farmers by way of capital and enhance breeds to produce more and stop importation of poultry meat.

It is also recommended that farmers should make sure that they select species that are suitable and can resist the prevailing climatic condition in the area.

Conflict of interest declaration

There is no conflict of interest in this work.

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