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Comprehensive Trends Analysis of Peste Des Petits Ruminants (PPR) Vaccination in Sheep and Goats: A Study in the Northern Region of Ghana

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ABSTRACT

Peste des Petits Ruminants (PPR) is one of the most devastating diseases that affect small ruminants and is capable of causing approximately 90% mortality in affected animals, thus inflicting significant losses on the global livestock industry. The primary solution to mitigate the spread and impact of PPR is to ensure that animals receive PPR vaccine to develop active immunity against the disease. This study, therefore, aimed to analyze the trend of PPR vaccination in sheep and goats by utilizing vaccination data spanning from January 2017 to December 2022. The data was obtained from the Regional Veterinary Services office of the Northern Region of Ghana. The Seasonal Auto-Regressive Integrated Moving Average (SARIMA) model was employed for trend analysis and short-run forecasting of the monthly vaccination values for sheep and goats. The SARIMA model forecasts a fluctuating trend in the number of sheep and goats vaccinated in the region, revealing both upward and downward patterns. This indicates positive and negative impulses, with expectations of a decrease in monthly figures by December 2024. We recommend that the Veterinary Service Directorate of the region have to intensify campaigns and education among farmers in order to encourage them to vaccinate their animals against PPR

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INTRODUCTION

Livestock production has a significant impact on the livelihood of smallholder farmers; it provides the families with income and sustains livelihood resources (Udo et al., 2011; Tembo et al., 2014). For-instance, studies conducted in four regions of Ethiopia showed that livestock accounted for nearly 49.44% of farmers income (Metawi et al., 2013). Among the various livestock species, small ruminants demonstrate significance due to their essential influence on the livelihoods of poor farmers in developing countries, including children, youth, women, and men using them for emergency relief (Kumar and Roy, 2013; Wodajo et al., 2020; Sargison, 2020).

Small ruminants play a critical role in the livelihoods of poor farmers in developing countries, providing a vital source of income and emergency relief for marginalized populations (Kumar and Roy, 2013; Wodajo et al., 2020; Sargison, 2020). Livestock farming holds significant potential to address food security challenges that threaten billions of impoverished people worldwide, particularly in Sub-Saharan Africa (Ehui, 2002; Clover, 2003; Gwaka and Dubihlela, 2020).

Small ruminant farming is the most viable option in agriculture (Suluku et al., 2022). Goat production addresses socio-economic and cultural issues, contributing significantly to smallholder farmers' livelihoods (Kumar and Roy, 2013). Africa hosts approximately 35% of the global goat population (Iñiguez, 2011; Manirakiza et al., 2020).

The Ruminants population constituted 21.2% of the 17,709,547 livestock in Ghana, with sheep and goats making up 29.7% and 49.8% respectively (GSS, 2020). The Northern Region holds about 25% of the national goat population (MoFA, 2020; MoFA, 2021). Since small ruminants' production is a viable venture, it can help to achieve sustainable development Goal 1 and 2 specifically (no poverty and no hunger by 2030 respectively) for the people of northern Ghana (Sargison, 2020; Rota and Urbani, 2021). Notwithstanding the significance of livestock production, diseases pose a serious threat to smallholder livestock farmers in obtaining the full benefits (McDermott et al., 2010). One of the diseases that poses a significant threat is Peste des petits ruminants (PPR) (Diallo, 2007; Njeumi et al., 2015). Again, PPR is a devastating disease affecting small ruminants in approximately 70 countries with an alarming 60% recorded cases originating from Africa (Njeumi et al., 2015). PPR exhibits a 100% morbidity and 90% mortality rates respectively in newly infested areas, although these rates may be lower in endemic areas due to the development of immunity in affected animals. The disease has a deleterious impact on flock productivity, causing economic losses that range from USD 1.2 to 1.7 billion through animal deaths (Njeumi et al., 2015). A study conducted by Jemberu et al. (2022) in Ethiopia confirmed that about 14% of household income is lost due to PPR, with mortality accounting for more than 70% of total losses in both sheep and goat flocks. This implies that the disease poses a threat to food security and negatively affects income.

Vaccination against PPR in Ghana is mandatory for livestock farmers, but the cost of vaccination is the responsibility of the farmers. Due to this, farmers are often reluctant to vaccinate their small ruminants, leading to outbreaks, especially during the rainy season. It is the most effective solution to curb the spread of PPR and its negative effects ensuring that animals are vaccinated to develop active immunity (Kamel and El-Sayed, 2019). It is noted that if approximately 80% of the herd is covered through vaccination, the transmission of the virus could be limited (Kumar et al., 2017). "However, the vaccination trend of small ruminants especially in the Northern part of Ghana remains unknown".

Folitse et al. (2017) examined the pattern, distribution and prevalence of PPR infection in Ghana, as well as the impact of vaccination on PPR burden. The present study focuses on the vaccination trends of PPR in the Northern Region of Ghana. Understanding these trends will provide researchers with valuable insight into the vaccination coverage of small ruminants in the region. The aim of this study is to analyze the trends of PPR vaccination in Northern Region of Ghana by examining the current vaccination pattern in the region as well as forecast short term vaccination trends.

MATERIAL and METHOD

Ethics Statement

This article relied on secondary data from PPR vaccination records sourced from the Veterinary Service Department (VSD) in the Northern Region of Ghana. Consequently, no harm was inflicted upon animal ethics, and no ethical declarations are necessary.

Data Collection and Processing

Data on the number of sheep and goats vaccinated against Peste des Petits Ruminants (PPR) in the Northern Region of Ghana were collected from the records of the Regional Veterinary Service Department (RVSD) to study the trend of vaccination over the years. Longitudinal secondary data from January 2017 to December 2022 were obtained for this study.

The data records were obtained in an Excel spreadsheet and exported into EVIEWS for cleaning, further processing, and analysis. The data collected were first processed to ensure that it was in a suitable format for analysis. The data were then checked for possible missing values and outliers before being converted into time-series format and plotted to visualize the trend, seasonality, and stationarity.

Data Analysis

The data analysis was conducted using EVIEWS (version 10). The study used the Seasonal Autoregressive Integrated Moving Average (SARIMA) model to analyze the trend and forecast the number of sheep and goats vaccinated against Peste des Petits Ruminants (PPR) in the Northern Region. The vaccination data, collected from the Regional Veterinary Service Department, spans from January 2017 to December 2022. The SARIMA model provides valuable insight into the vaccination trends of sheep and goats in the Northern Region, focusing on livestock health, and can therefore assist in resource allocation and planning for future vaccination campaigns (Renald et al., 2023; Abebe, 2018). SARIMA was selected due to the seasonal nature of the vaccination data, where seasons with anticipated PPR outbreaks are expected to have higher vaccination rates compared to other seasons.

Stationarity Test

Stationarity is a critical assumption for SARIMA models (Otu et al., 2014). Due to this, the properties of the data collected were assessed before the models were estimated. This was done to determine whether the series exhibited a random walk (presence of a unit root) or was stationary (Ouliaris et al., 1989; Rahman & Saadi, 2008; Aguayo Torrez, 2021). This study conducted the test by adopting the Augmented Dickey-Fuller (ADF) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. Both tests were used to ensure confirmation and complementation of the results.

SARIMA Model Specification

The Seasonal Auto Regressive Integrated Moving Average (SARIMA) is specified by three main components that include the autoregressive (AR) component, the differencing (I) component, and the moving average (MA) component, represented by p, d, and q, respectively and their seasonal counterparts P, D, Q (Ghosh et al., 2007; Shah et al., 2019).

In this study, two hybrids of the SARIMA model (SARIMA 2,2(0,1) and 4,4,0,1) were adopted to study the trend of the number of sheep and goats vaccinated for PPR in the Northern Region of Ghana. From this, there are two and four autoregressive terms (p=2, 4) which implies that current values of number of animals (sheep and goats) vaccinated against PPR depends on the previous two and four values with corresponding coefficients as: $AR(1){:}\ \varphi_1 Y_{t-1}\ \ AR(2){:}\ \varphi_2\, Y_{t-2}\ AR(3){:}\ \varphi_3 Y_{t-3}\ \ AR(4){:}\ \varphi_4\, Y_{t-4}$ (1)

In the study, both the sheep and goats' data were differenced once to make it stationary, hence d = 1 in the two series; $(Y_t - Y_{t-1})$ to achieve stationarity in both sheep and goat data respectively.

Following the autofit ARIMA function in EVIEWS and the AIC, BIC and HQ values of the SARIMA models estimated, the models with two MA components and four components for sheep and goats respectively, were deemed the best models for this study. This means that current values of the number of sheep and goats vaccinated depends on past two periods for sheep and four periods for goats. Therefore, the corresponding coefficients of the MA components are represented as

$$MA1: \theta_1\ \varepsilon_{t-1};\ MA2: \theta_2\ \varepsilon_{t-2} \quad (2)$$

for sheep and

$$MA1: \theta_1\ \varepsilon_{t-1}, MA2: \theta_2\ \varepsilon_{t-2}, MA3: \theta_3\ \varepsilon_{t-3}, MA4: \theta_4\ \varepsilon_{t-4}, \quad (3)$$

for the goat data.

Therefore, following Benfield et al. (2023), the general SARIMA models for the trend of the number of sheep and goats vaccinated against PPR can be mathematically represented as follows;

Yt=ϕ1Yt−1+ϕ2Yt−2+…+ϕpYt−p+ϵt+θ1ϵt−1+θ2ϵt−2+…+θqϵt−q+ Φ1Yt−s+Φ2Yt−2s +…+ΦPYt−Ps+ ϵt−s+ϵt−2s+…+ϵt−Ps (4)

Whereby;

Yt is the observed value at time t, ϕ and θ are non-seasonal autoregressive and moving average parameters, Φ are seasonal autoregressive parameters and s is the length of the seasonal cycle (Permanasari et al., 2009; Brida and Garrido, 2011; Molapo, 2017).

The SARIMA models were fitted with the autofit function in EVIEWS and the best models, (SARIMA 2,2(0,1) for sheep and (SARIMA 4,4,(0.1)) were selected based on the smaller values of Akaike information criterion (AIC), Bayesian information criterion (BIC), and Hannan-Quinn criterion (HQ). The models were finally checked for models' goodness of fit using appropriate model diagnostics criteria such as the Root Mean Square Errors (RMSE), Mean Absolute Error (MAE), Theil Inequality Coefficient (TIC), and Mean Absolute Percentage Error (MAPE) (Permanasari et al., 2009; Abebe, 2018a; Shadab et al., 2021; Alamrouni et al., 2022). The models' performance was also visually assessed by fitting residual plots of the two models (Archontoulis and Miguez, 2015; Breheny and Burchett, 2015).

In summary, the methodology followed data collection and processing, stationarity test, model specification and data analysis.

RESULTS and DISCUSSION

Descriptive Statistics of Trend of Vaccination of Sheep and Goats

Table 1 provides the descriptive statistics of the data. It offers valuable insights into the distribution, central tendency, spread, and characteristics of the number of vaccinated sheep and goats for Peste des petits ruminants (PPR) in the Northern

Region from 2017 to 2022. These statistics are meant to help us understand the trends and variations in vaccination numbers for these animals within the specified time.

According to the table, the average number of PPR-vaccinated sheep was 1,563.542, and the average number of vaccinated goats was 699.15 over the six years. The median values, which provide a more accurate description of the data when there is skewness, were 1,448 for sheep and 522 for goats respectively. The standard deviations were 1,566.09 for sheep and 691.09 for goats, indicating that the number of vaccinated sheep varies more than the number of vaccinated goats. The descriptive statistics of the number of vaccinated sheep and goats in the Northern Region from 2017 to 2022 are presented in Table 1.

Table 1. Descriptive statistics of level data of PPR vaccinated sheep and goats of the Northern Region (2017 – 2022)

Statistics	**Sheep**	**Goat**
Mean	1563.542	699.153
Standard Error	184.565	81.445
Median	1448	522
Standard Deviation	1566.0866	691.086
Sample Variance	2452627.125	477599.681
Kurtosis	18.393	2.323
Skewness	3.343	1.407
Range	11085	3179
Minimum	0	0
Maximum	11085	3179
Sum	112575	50339
Count	72	72

The trend of the data is displayed in Figure 1. The graph reveals serpentine movement in the curves, and this indicates variation in the number of animals vaccinated against Peste des petits ruminants (PPR) over time as depicted in the descriptive statistics. The figure demonstrates non-stationarity in the series, with high peaks in the sheep data, especially in the 19th month, compared to the goats' data. This trend implies that the data must be transformed into a stationary series before proceeding with further analysis. The graphical inspection of the data was followed by statistical unit root tests with common test such as Augmented Dickey-Fuller (ADF) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests to confirm the presence of stationarity in the data.

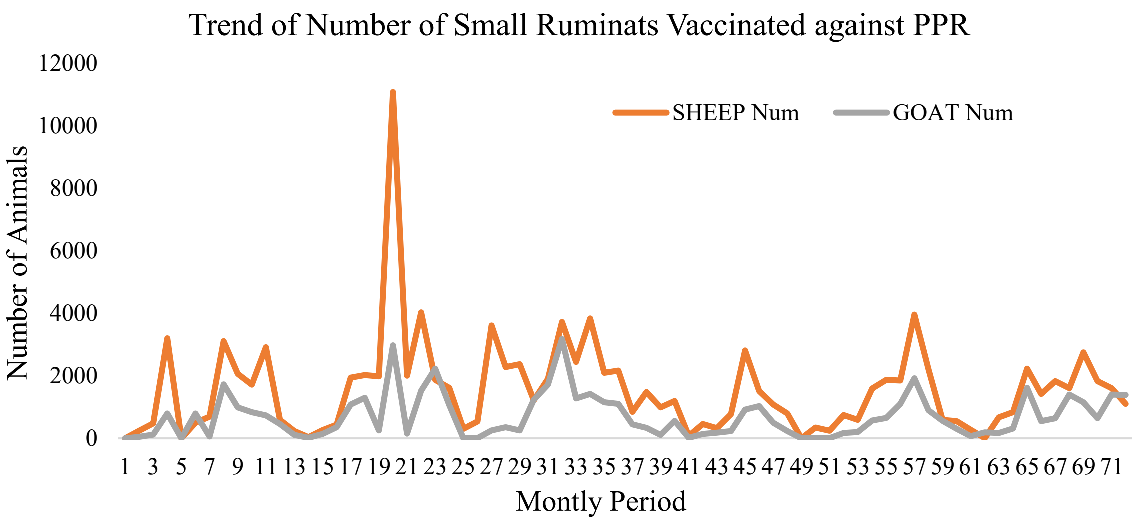
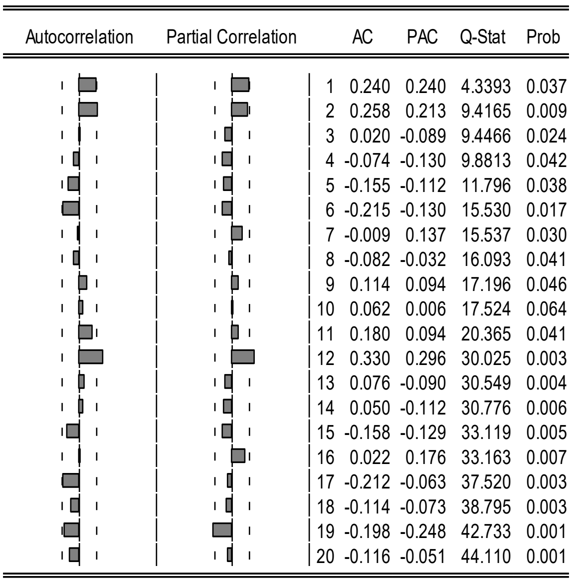


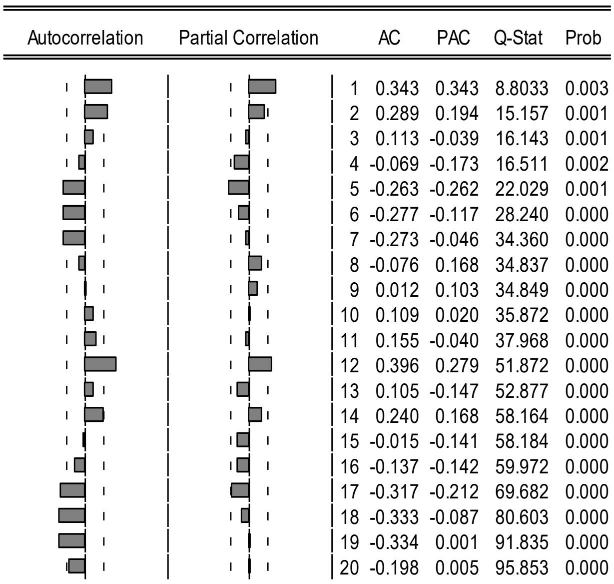
Figure 1. Non-stationarity plots of series data

The ACF and PACF curves displayed in Figures 2 and 3 indicate that the PACF decays gradually towards lag 2 for the sheep data and lag 4 for the goat data. There was no regularity in the movement of the autocorrelation coefficients from which a model could be identified. Therefore, we relied on the autofit function in EVIEWS to fit the appropriate models. The ACF and PACF curves suggest that the suitable models for these data sets are SARIMA(2,2)(0,1) for sheep and SARIMA(4,4)(0,1) for goats.



Lag	AC	PAC	Q-Stat	Prob
1	0.240	0.240	4.3393	0.037
2	0.258	0.213	9.4165	0.009
3	0.020	-0.089	9.4466	0.024
4	-0.074	-0.130	9.8813	0.042
5	-0.155	-0.112	11.796	0.038
6	-0.215	-0.130	15.530	0.017
7	-0.009	0.137	15.537	0.030
8	-0.082	-0.032	16.093	0.041
9	0.114	0.094	17.196	0.046
10	0.062	0.006	17.524	0.064
11	0.180	0.094	20.365	0.041
12	0.330	0.296	30.025	0.003
13	0.076	-0.090	30.549	0.004
14	0.050	-0.112	30.776	0.006
15	-0.158	-0.129	33.119	0.005
16	0.022	0.176	33.163	0.007
17	-0.212	-0.063	37.520	0.003
18	-0.114	-0.073	38.795	0.003
19	-0.198	-0.248	42.733	0.001
20	-0.116	-0.051	44.110	0.001

Figure 2. ACF and PACF curves for the Goat Data



Lag	AC	PAC	Q-Stat	Prob
1	0.343	0.343	8.8033	0.003
2	0.289	0.194	15.157	0.001
3	0.113	-0.039	16.143	0.001
4	-0.069	-0.173	16.511	0.002
5	-0.263	-0.262	22.029	0.001
6	-0.277	-0.117	28.240	0.000
7	-0.273	-0.046	34.360	0.000
8	-0.076	0.168	34.837	0.000
9	0.012	0.103	34.849	0.000
10	0.109	0.020	35.872	0.000
11	0.155	-0.040	37.968	0.000
12	0.396	0.279	51.872	0.000
13	0.105	-0.147	52.877	0.000
14	0.240	0.168	58.164	0.000
15	-0.015	-0.141	58.184	0.000
16	-0.137	-0.142	59.972	0.000
17	-0.317	-0.212	69.682	0.000
18	-0.333	-0.087	80.603	0.000
19	-0.334	0.001	91.835	0.000
20	-0.198	0.005	95.853	0.000

Figure 3. ACF and PACF curves for the Sheep Data

The auto ARIMA forecasting function in EVIEWS was used to estimate 225 different SARIMA models, and the models with the lowest model selection criteria were selected as the appropriate models for the study (Aidoo, 2010; Brida & Garrido, 2011; Permanasari et al., 2009).

Statistical Test for Stationarity of Time Series Data

The Augmented Dickey-Fuller (ADF) unit root test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test were used to assess the stationarity of time series data. Stationarity is a crucial concept in time series analysis, as it impacts the modeling and forecasting of the data (Ouliaris et al., 1989; Rahman & Saadi, 2008; Abebe, 2018a).

The null hypothesis of the ADF test is that the data contains a unit root, indicating non-stationarity. The test statistic is compared to critical values to determine whether to reject the null hypothesis. In contrast, the KPSS test has a null hypothesis that assumes stationarity or the absence of a unit root.

From Table 2, the ADF statistic for the sheep data at the level is less than the critical value of -4.059 for the trend specification but greater than -2.6 for the constant specification. Similarly, the test statistic for the ADF test at the level of the goat data (-4.0575) suggests evidence of non-stationarity or the presence of unit roots in the data. Therefore, the null hypotheses in both cases could not be rejected, indicating that the data required differencing to achieve stationarity.

Table 2. Results of stationarity test of sheep and goat data on PPR vaccination in the Northern Region of Ghana

Test Statistics	Sheep	Goat
ADF (Level)	-3.159	-4.057
ADF (Difference)	-9.158***	-8.165***
Lag order	4	4
Critical Values at 1% and 5% are -3.474 and -4.092 for constant and trend specification respectively)		
KPSS (Level)	0.176***	0.257***
KPSS (Difference)	0.058	0.060
Lags	3	3
Critical Values 10pct 5pct 1pct		
0.1190, 0.1460, and 0.2160 for constant and trend specification respectively)		

Reference to the table reveals that the KPSS statistics for both the sheep and goat data (0.1761 and 0.2574, respectively) imply that the data were not stationary at levels, and the null hypothesis of stationarity could be rejected with 99% confidence in both cases. Therefore, the data were different to achieve stationarity.

From Table 2, there is evidence of stationarity in both the Sheep and Goat data after differencing. The ADF test at lag order 4, with statistics of -9.1583 and -8.1653, respectively, indicates a rejection of the null hypothesis of non-stationarity. This suggests that differing the data (i.e., creating a first difference with a lag order of 4) resulted in stationary time series data. The statistical test results of the ADF and KPSS are presented in Table 2, while the graphs are shown in Figure 4.

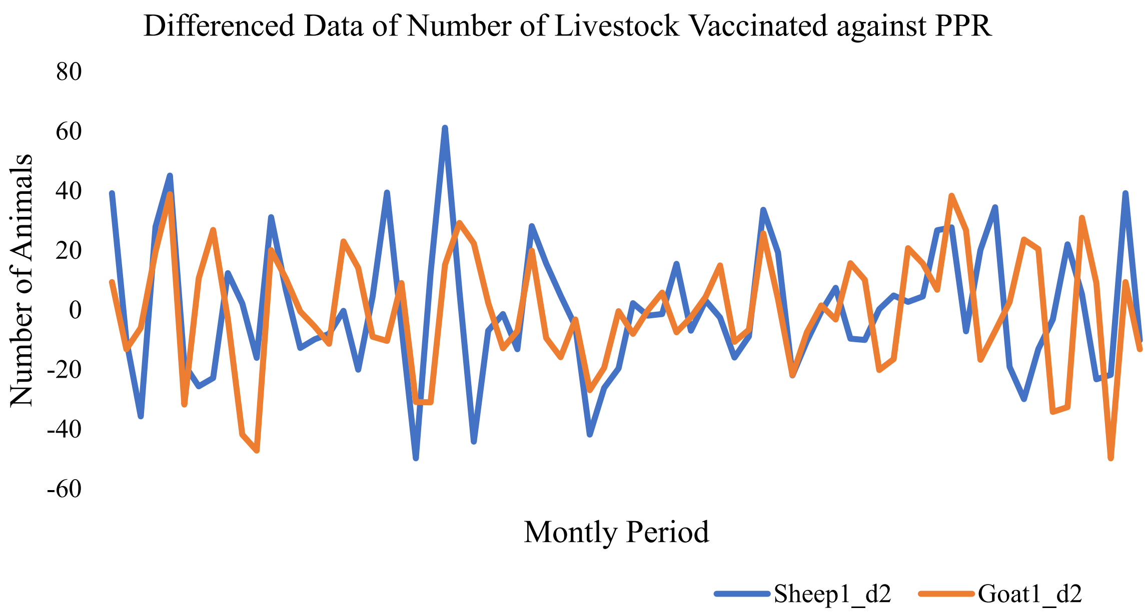


Figure 4. Stationary series (First Difference)

Regression Results of ARIMA Models and Fitness Test Results

Table 3 provides estimates of the SARIMA models for the trend of the number of sheep and goats vaccinated against Peste des Petits Ruminants (PPR) in the Northern Region from 2017 to 2022. The results in Table 3 indicate that, in terms of model fitness, the SARIMA (2,2)(0,1) model for sheep was the best fit among the 225 SARIMA models estimated using the ARIMA auto forecasting function in EVIEWS. The estimates for the AIC (17.39075), Schwarz criterion (17.61209), and HQ (17.47887) were the smallest among the SARIMA models fitted for this data. The lower values of these criteria indicate that the ARIMA (2,2) (0,1) model was the best fit for the data and was therefore selected over the other SARIMA models.

Table 3 also shows that the constant term, representing the intercept of the model, has a significant coefficient (1491.578). This coefficient is statistically significant at the 1% level, indicating that the mean number of sheep vaccinated is significantly different from zero. Additionally, the coefficient of AR1 is statistically significant at the 1% level (0.685610) and this suggests that the first lag of the sheep vaccination data has a significant positive impact on the current sheep PPR vaccination value. Specifically, an increase in the number of vaccinated sheep in the previous period leads to an increase in the number of PPR vaccinations in the current period, ceteris paribus. Conversely, the coefficient of AR2 (-0.588412) is statistically significant at the 1% level and therefore imply that the second lag of the sheep PPR vaccination data has a significant negative influence on the current number of sheep vaccinated, all else being equal.

The MA terms in this SARIMA model show that the coefficients of MA1 (-0.565270) and MA2 (-0.565270) are highly significant at the 1% and 5% levels, respectively.

Table 3. Regression results of SARIMA models and fitness test results for sheep vaccination in the Northern Region of Ghana

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	1491.578***	448.2999	3.327188	0.0014
AR(1)	0.685610***	0.193078	3.550941	0.0007
AR(2)	-0.588412**	0.238029	-2.472020	0.0161
MA(1)	-0.565270***	0.118090	-4.786780	0.0000
MA(2)	0.913352***	0.178835	5.107228	0.0000
SMA(12)	0.405232*	0.201359	2.012487	0.0483
SIGMASQ	1606487***.	282692.9	5.682801	0.0000
R-squared	0.335768	Mean dependent var		1563.542
Adjusted R-squared	0.274454	S.D. dependent var		1566.087
S.E. of regression	1333.977	Akaike info criterion		17.39075
Sum squared resid	1.16E+08	Schwarz criterion		17.61209
Log likelihood	-619.0669	Hannan-Quinn criter.		17.47887
F-statistic	5.476225	Durbin-Watson stat		1.990676
Prob(F-statistic)	0.000123			
SARIMA (4,4(0,1)) model of number of goats vaccinated against PPR in northern region of Ghana				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Constant	695.6870***	152.6035	4.558788	0.0000
AR(1)	-0.499269***	0.155512	-3.210477	0.0021
AR(2)	0.417745**	0.186477	2.240191	0.0287
AR(3)	-0.567722***	0.177024	-3.207026	0.0021
AR(4)	-0.538710***	0.161036	-3.345284	0.0014
MA(1)	0.903563	407.7434	0.002216	0.9982
MA(2)	-0.102939	58.94927	-0.001746	0.9986
MA(3)	0.903572	631.2192	0.001431	0.9989
MA(4)	0.999992	1145.655	0.000873	0.9993
SMA(12)	0.405160**	0.154624	2.620291	0.0111
SIGMASQ	239538.2	22861886	0.010478	0.9917
R-squared	0.491390	Mean dependent var		699.1528
Adjusted R-squared	0.408011	S.D. dependent var		691.0859
S.E. of regression	531.7270	Akaike info criterion		15.68047
Sum squared resid	17246748	Schwarz criterion		16.02830
Log-likelihood	-553.4970	Hannan-Quinn criterion.		15.81894
F-statistic	5.893474	Durbin-Watson stat		1.916006
Prob(F-statistic)	0.000004			

This indicates that the first and second lags of the moving average component are strong predictors of the current PPR vaccination values when other factors are held constant. In the SARIMA (2,2) (0,1) model, the seasonal moving average (SMA(12)) has a coefficient of 0.405232. The positive coefficient indicates a seasonal moving average effect at lag 12, suggesting that the error term from the same season in the previous year positively impacts the current number of sheep vaccinated, all else being equal. The SARIMA (2,2) (0,1) model appears to fit the sheep data well, with the AR and MA terms significantly explaining the variations in the number of sheep vaccinations for

PPR during the period. The SIGMASQ term indicates that the model adequately accounts for the variability in the data and has perfectly modeled the data very well.

For goats, the SARIMA (4,4) (0,1) model was selected as the best fit for the data after recording the lowest values for the AIC (15.68047), Schwarz criterion (16.02830), and HQ (15.81894) during the fitting of multiple ARIMA models (225) using the auto ARIMA fitting function in EVIEWS.

Evidence from Table 3 shows that the coefficients of the AR terms in the SARIMA (4,4) (0,1) model for goats, AR1 (-0.499269), AR2 (0.417745), AR3 (-0.567722), and AR4 (-0.538710) are all statistically significant at conventional levels, indicating a strong influence of past values on the current value of vaccinated goats.

The results also reveal that the MA1, MA2, MA3, and MA4 moving average terms in the SARIMA (4,4)(0,1) model are all statistically insignificant at conventional levels and do not influence the PPR vaccination dynamics of goats. The SMA(12) term (0.405160) is however statistically significant at the 5% level and suggests a seasonal pattern in the data with a yearly cycle.

The results of the SARIMA (2,2) (0,1) model and the SARIMA (4,4) (0,1) model are presented in Table 3.

Therefore, the final SARIMA models for predicting the trend in the vaccination of sheep and goats are depicted in the following formulas.

$$\Delta Sheep_t = 1491.578 + 0.685610\Delta Sheep_{t-1} - 0.588412\Delta Sheep_{t-2} - -0.565270\Delta Sheep_{t-3} + 0.913352\Delta Sheep_{t-5} + 0.405232\Delta Sheep_{t-5} \quad (2)$$

$$\Delta Goat_t = 695.6870 - 0.499269\Delta Goat_{t-1} + 0.417745\Delta Goat_{t-2} - 0.567722\Delta Goat_{t-3} - 0.538710\Delta Goat_{t-4} + 0.405160\Delta Goat_{t-5} \quad (3)$$

From a policy perspective, the significance of the coefficients implies that past values of vaccination figures influence current vaccination figures. Specifically, higher previous vaccination figures positively affect the current values of vaccinated livestock. This is particularly true if mortality related to PPR also declines drastically, as reported by Folitse et al. (2017). This finding is important for veterinary services directorate, animal production department and other policymakers, who should intensify campaigns and other interventions to promote vaccination and reduce infestation and mortality.

Postestimation Diagnosis

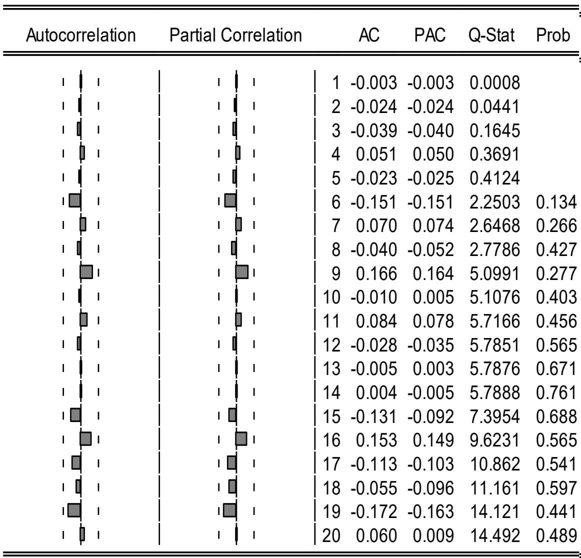
The effectiveness of the selected SARIMA models was evaluated using standard metrics for assessing goodness of fit, including the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Theil Inequality Coefficient (TIC), and Mean Absolute Percentage Error (MAPE). These metrics are widely recognized for evaluating the performance of SARIMA models. Table 4 displays the results of the postestimation tests applied to analyze the vaccination counts of sheep and goats against Peste des Petits Ruminants (PPR) in the Northern Region. Out of the 225 models generated in EVIEWS using the autofit function, SARIMA (2,2(0,1)) and SARIMA (4,4(0,1)) consistently show smaller values for RMSE, MAE, TIC, and MAPE, indicating a superior fit compared to the other SARIMA models. The summary values for these two models are presented in Table 4, with residual plots shown in Figures 5 and 6.

Table 4. Post-estimation Test Results of SARIMA Models

	Models	
Test	**Sheep SARIMA (2,2(0,1))**	**Goats SARIMA (4,4(0,1))**
RMSE	1557.788	690.814
MAE	996.534	550.054
TIC	0.420	0.407
MAPE	69.539	86.960

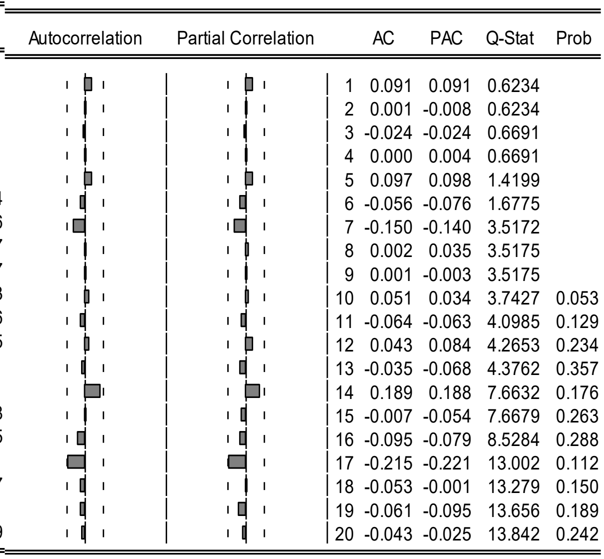
(Source: Analyzed from Laboratory Data, 2023)

In summary, the two SARIMA models appeared well-suited for capturing trends in the count of Peste des Petits Ruminants (PPR) vaccinated sheep and goats in the Northern Region. This conclusion is supported by the reasonable goodness-of-fit indicated by the AIC, SC, and HQ values. Additionally, the non-significant p-values from the Box-Ljung test for autocorrelation in the ACF and PACF of the residual plots (Figures 4 and 5) suggest that the models adequately capture temporal patterns without significant autocorrelation in the residuals. Again, the insignificant values of these Q-statistics for the residuals imply that all autocorrelations are within acceptable limits, indicating that the residuals exhibit behavior similar to white noise.



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.003	-0.003	0.0008	
		2	-0.024	-0.024	0.0441	
		3	-0.039	-0.040	0.1645	
		4	0.051	0.050	0.3691	
		5	-0.023	-0.025	0.4124	
		6	-0.151	-0.151	2.2503	0.134
		7	0.070	0.074	2.6468	0.266
		8	-0.040	-0.052	2.7786	0.427
		9	0.166	0.164	5.0991	0.277
		10	-0.010	0.005	5.1076	0.403
		11	0.084	0.078	5.7166	0.456
		12	-0.028	-0.035	5.7851	0.565
		13	-0.005	0.003	5.7876	0.671
		14	0.004	-0.005	5.7888	0.761
		15	-0.131	-0.092	7.3954	0.688
		16	0.153	0.149	9.6231	0.565
		17	-0.113	-0.103	10.862	0.541
		18	-0.055	-0.096	11.161	0.597
		19	-0.172	-0.163	14.121	0.441
		20	0.060	0.009	14.492	0.489

Figure 5. Residual plots of Sheep Data



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.091	0.091	0.6234	
		2	0.001	-0.008	0.6234	
		3	-0.024	-0.024	0.6691	
		4	0.000	0.004	0.6691	
		5	0.097	0.098	1.4199	
		6	-0.056	-0.076	1.6775	
		7	-0.150	-0.140	3.5172	
		8	0.002	0.035	3.5175	
		9	0.001	-0.003	3.5175	
		10	0.051	0.034	3.7427	0.053
		11	-0.064	-0.063	4.0985	0.129
		12	0.043	0.084	4.2653	0.234
		13	-0.035	-0.068	4.3762	0.357
		14	0.189	0.188	7.6632	0.176
		15	-0.007	-0.054	7.6679	0.263
		16	-0.095	-0.079	8.5284	0.288
		17	-0.215	-0.221	13.002	0.112
		18	-0.053	-0.001	13.279	0.150
		19	-0.061	-0.095	13.656	0.189
		20	-0.043	-0.025	13.842	0.242

Figure 6. Residual plots of Goat Data

Forecast Results and Evaluation of SARIMA Models (Goats and Sheep)

This section presents the forecast outcomes of SARIMA models applied to vaccination data for sheep and goats in the Northern Region of Ghana. Out of the 225 models estimated, the two SARIMA models discussed in this paper show fitted values that closely align with the actual data for both time series. Table 5 provides the forecasted figures, which indicate fluctuations similar to those observed in the original data. Additionally, Figure 7 presents comparison curves alongside the forecasted values for each animal species. This figure is presented below Table 5.

Table 5. Forecast Results of SARIMA Models of Sheep and Goats

Months	Goat	Sheep
2022M06	546	1418
2022M07	640	1827
2022M08	1402	1606
2022M09	1151	2752
2022M10	640	1827
2022M11	1402	1606
2022M12	1391	1103
2023M01	1178	1263
2023M02	933	907
2023M03	564	1114
2023M04	212	1296
2023M05	802	1924
2023M06	417	1453
2023M07	811	1470
2023M08	1065	1422
2023M09	922	1641
2023M10	614	1484
2023M11	885	1661
2023M12	779	1435
2024M01	900	1501
2024M02	845	1406
2024M03	857	1428
2024M04	603	1498
2024M05	615	1534
2024M06	525	1517
2024M07	713	1484
2024M08	712	1472
2024M09	835	1482
2024M10	715	1497
2024M11	725	1501
2024M12	600	1495

(Source: Laboratory Data, 2023)

For instance, the SARIMA (2,2)(0,1) model for sheep vaccination indicates that approximately 1,418 sheep were vaccinated in June 2022, increasing to 1,453 by June 2023 reflecting a marginal rise of 2.47%. Projections for June 2024 anticipate that 1,517 sheep will be vaccinated, representing a 4.40% increase from the 2023 figure.

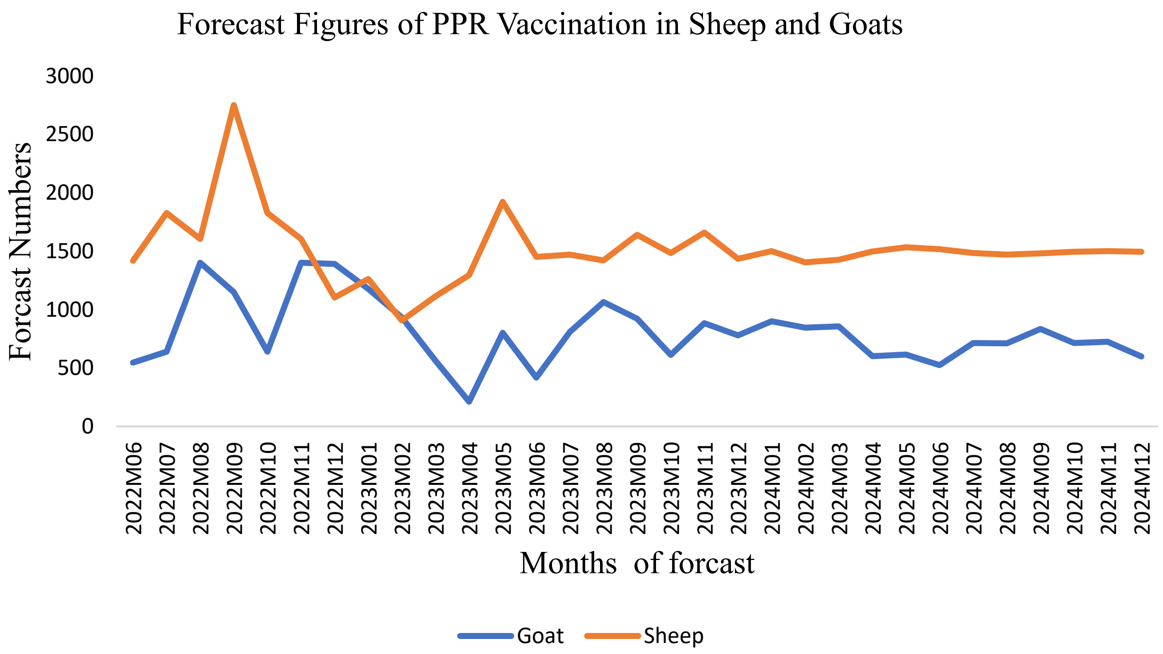


Figure 7. Forecast figures of PPR vaccination in sheep and goats

Regarding the SARIMA (4,4) (0,1) model for goat vaccination, the forecasted figures show a decline from 546 goats vaccinated in June 2022 to 417 in June 2023, representing a significant decrease of 23.63%. However, the projections suggest that by June 2024, approximately 525 goats will be vaccinated, marking an increase of nearly 26%. These results indicate a fluctuating yet declining trend in goat vaccination compared to the steady rise in sheep vaccination observed in this study.

In summary, the SARIMA (2,2) (0,1) model suggests an upward trend in sheep vaccination, whereas the SARIMA (4,4) (0,1) model indicates a downward trend for goats. Both models provide forecasts over a 24-month period, from December 2022 to December 2024, with the results presented in tables and graphs as presented and discussed above in this paper.

DISCUSSION

This section presents the forecast outcomes of SARIMA models applied to the vaccination data of sheep and goats in the Northern Region of Ghana. Among the 225 models estimated, the two SARIMA models discussed herein exhibit closely aligned fitted values with the actual data for both time series. Table 5 in the appendix outlines the forecasted figures, indicating fluctuations similar to the original data. Additionally, Figures 7 plot a comparison curve with the forecast figures for each of the animal species.

In 2018, the number of vaccinated sheep increased from April to August, then fluctuated gradually before finally dropping in December. It shows that in April to august there was a large number of sheep vaccinated against PPR than Goats and also it indicated farmers' biasness toward sheep and Goat's vaccination against PPR infection though they most often keep the two species of small ruminants together. A similar pattern occurred in the subsequent years. For goats, vaccination figures increased each August from 2017 to 2019, dropped in 2020, and then rose again in August 2021, continuing through to 2022. The ADF test is generally considered to have low statistical power for determining the stationarity of a time series variable, so the KPSS test was used to complement the ADF test results (Bennett et al., 2013; Aguayo Torrez, 2021; Adeboye et al., 2023).

The mean number of sheep vaccinated is significantly different from zero, indicating that the first lag of the sheep vaccination data has a significant positive impact on the current PPR vaccination value. Specifically, an increase in the number of vaccinated sheep in the previous period leads to an increase in the number of PPR vaccinations in the current period, ceteris paribus. However, the second lag of the sheep PPR vaccination data has a significant negative influence on the current number of sheep vaccinated, all else being equal. This suggests that the first and second lags of the moving average component are strong predictors of the current PPR vaccination values when other factors are held constant. Additionally, the positive coefficient at lag 12 indicates a seasonal moving average effect, suggesting that the error term from the same season in the previous year positively impacts the current number of sheep vaccinated, all else being equal.

From a policy perspective, the significance of the coefficients implies that past values of vaccination figures influence current vaccination figures. Specifically, higher previous vaccination figures positively affect the current values of vaccinated livestock. This is particularly true if mortality related to PPR also declines drastically, as reported by Folitse et al. (2017). This finding is important for the veterinary services directorate and animal production department who should intensify campaigns and other interventions to promote vaccination and reduce infections and mortality.

This study is limited to secondary data collected from the Northern Region, Tamale. The data comprises the figures obtained from the various PPR vaccination reports from the Veterinary Services Department of the region. Furthermore, we wish to draw attention to the fact that the proposed models used in this study may not directly address the issue of increasing vaccination figures for sheep and goats but serve as tools for exploring potential solutions. While the results are crucial for informing well-coordinated policies, they may not fully address the underlying factors influencing these trends. However, they can provide a robust foundation for developing methods and policies to enhance vaccination coverage and numbers in the region.

In summary, the two SARIMA models appeared well-suited for capturing trends in the count of PPR vaccinated sheep and goats in the Northern Region. This conclusion is supported by reasonable goodness-of-fit indicated by the AIC, SC, and HQ values. Additionally, the non-significant p-values from the Box-Ljung test for autocorrelation in the ACF and PACF of the residual plot (Figure 4 and 5) suggest that the models adequately capture temporal patterns without significant autocorrelation in the residuals. Again, the insignificant values of these Q-statistics for the residuals imply that all autocorrelations are within acceptable limits, indicating that the residuals exhibit behavior similar to white noise. A similar pattern occurred in the subsequent years. For goats, vaccination figures increased each August from 2017 to 2019, dropped in 2020, and then rose again in August 2021, continuing through to 2022. As portrayed in the SARIMA (2,2) (0,1) model, sheep vaccination shows a marginal 2.47% increase from 1,418 sheep in June 2022 to 1,453 in June 2023, with projections indicating a 4.40% rise to 1,517 by June 2024. In contrast, the SARIMA (4,4) (0,1) model for goat vaccination reveals a decline from 546 goats in June 2022 to 417 in June 2023 (-23.63%), though an increase to 525 goats (26%) is expected by June 2024. The fluctuating trends, possibly influenced by rising vaccination costs and farmer reluctance, highlight the need for intensified vaccination efforts to prevent future PPR outbreaks

In summary, the SARIMA (2,2) (0,1) model implies an upward trend in sheep vaccination, while the SARIMA (4,4) (0,1) model for goats suggests a downward trend. Both models were forecasted over 24 months, from December 2022 to December 2024, and the results, presented in tables and graphs in the paper.

CONCLUSION and RECOMMENDATIONS

The analysis of PPR vaccination trends in sheep and goats in the Northern Region of Ghana revealed valuable insights into vaccination patterns over the six-year period. it precisely depicts the dynamics of PPR vaccination, it also exposed farmers' preferences toward vaccinating Sheep than Goats in the northern region of Ghana as portrayed in the rising and fall of the forecasted figures between sheep and goats vaccinated figures. The application of the SARIMA model provided a reliable tool for understanding past trends and generating short-term forecasts to aid in planning and disease control efforts. These findings underscore the importance of sustained vaccination programs to mitigate losses in the small ruminant industry and enhance livestock health in the region.

Over the six-year period, the highest vaccination figures were recorded in May, June, July, and August, with August having the highest numbers, while December recorded the lowest. The findings reveal significant fluctuations in monthly vaccination numbers, highlighting periods of both high and low coverage. Forecast results indicate a fluctuating trend, with an anticipated decline in vaccination numbers by the end of December 2024. Although the SARIMA model provides useful insights by identifying trends and informing policy decisions, it does not directly address the challenge of increasing vaccination rates. These results underscore the need for comprehensive strategies to enhance vaccination coverage. Although the SARIMA models offer valid estimates, their accuracy may be limited, particularly in the presence of structural breaks in the data. Future research should consider expanding the study to a national level and employing more advanced forecasting techniques, such as hybrid models, artificial neural networks, conditional volatility models, Holt–Winter models, vector autoregressive models, and Gaussian mixture models, to improve predictive accuracy. To support the eradication of PPR, it is recommended that the Veterinary Service Directorate intensify awareness campaigns, farmer education, and other targeted interventions to encourage widespread vaccination uptake in the northern region of Ghana.

Availability of Data and Materials

Data for this study was obtained from the Northern Regional Veterinary Service Department and is available upon request.

Conflict of Interest Statement

The authors of this study declare no competing interest or conflict of interest

Authors Contributions

YN and EZ conceptualized the idea, analyzed the data and co-wrote the manuscript. AJ took the data. EAN and EAC supervised the study.

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