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Paper

Predictive Analysis and Time Series Modeling of Canine Parvoviral Enteritis: A Case Study from Ibadan, Nigeria

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Abstract

Canine parvoviral enteritis (CPE) is a highly contagious and often fatal disease, particularly affecting young, unvaccinated dogs. Although anecdotal reports suggest seasonal variation in CPE incidence in Nigeria, comprehensive time series analyses remain scarce. This study analyzed clinical records of CPE cases—diagnosed either clinically or via laboratory confirmation—collected from three veterinary clinics in Ibadan, Nigeria, between January 2018 and December 2024. Temporal patterns were decomposed into trend, seasonal, and random components. Stationarity and temporal autocorrelation were assessed using the Augmented Dickey-Fuller and Ljung-Box tests, respectively. An Autoregressive Integrated Moving Average (ARIMA) model was selected using the *auto.arima* function implemented in R (Vienna, Austria), and subsequently used to forecast CPE incidence over a 24-month horizon. The Box-Pierce test on residuals (P = 0.9409) confirmed the model's adequacy. CPE incidence showed distinct seasonal peaks during the dry months, best captured by the ARIMA (1,1,1)(1,0,0) (model non-seasonal autoregressive order =1, differencing order =1, and moving average order =1; seasonal autoregressive order =1, differencing order = 0, and moving average order = 0; monthly seasonality = 12), and exhibited a negative correlation with historical average monthly rainfall (r = −0.55). However, forecasts for 2025–2026 suggest a gradual decline in incidence and a transition toward year-round occurrence with less pronounced seasonal peaks. These findings underscore the need for continuous preventive efforts. Veterinary practitioners should maintain a high index of suspicion for CPE, especially in young dogs with incomplete vaccination status.

Keywords

ARIMA, Diarrhoea, Forecast, Modelling, Parvovirus

Introduction

Canine parvoviral enteritis (CPE) is a highly contagious and often fatal disease affecting dogs and other canids. Characterized by severe gastroenteritis and, in some cases, myocarditis (Zhou et al., 2025), the disease is transmitted through direct or indirect contact with the feces of infected animals. The causative agent, *Carnivore protoparvovirus 1*— previously called Canine parvovirus (CPV) — has circulated globally in canine populations for over four decades and remains a leading cause of morbidity and mortality in young dogs (Cotmore et al., 2019; Voorhees et al., 2019). CPV targets rapidly dividing cells, especially in the bone marrow, lymphoid tissue, and cardiac myocytes, with the gastrointestinal epithelium being particularly vulnerable (Mia & Hasan, 2021). The virus's affinity for the small intestine leads to a cascade of clinical signs, including severe diarrhea, vomiting, and anorexia (Mylonakis et

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al., 2016). A hallmark of CPV infection is profuse, often bloody diarrhea, resulting from damage to the intestinal lining. This, along with persistent vomiting, causes rapid dehydration, electrolyte imbalances, and nutritional deficiencies—factors that contribute significantly to the disease's lethality. Fever may be present in the early stages, but as dehydration and systemic compromise progress, body temperature often falls below normal (Mia & Hasan, 2021). The appearance of feces may vary from watery and yellowish to blood-streaked in severe cases. Several diagnostic methods are available for detecting CPV in clinical samples. While real-time PCR is considered the gold standard, immunochromatographic point-of-care fecal tests have gained popularity in clinical settings due to their high specificity, positive predictive value, and affordability (Walter-Weingärtner et al., 2021). Canine parvovirus (CPV) is believed to have originated as a host-range variant of feline panleukopenia virus (FPV), either through direct mutation or via adaptation through non-domestic carnivores such as mink or foxes (Hoelzer & Parrish, 2010). To differentiate it from Canine Minute Virus (CPV1 or CMV), the virus was designated CPV-2. Interestingly, CPV-2 has also been shown to infect non-canid species, including pigs (Temeeyasen et al., 2022). Historically, two main variants of CPV-2 circulated among dogs: CPV-2a and CPV-2b, first identified in 1979 and 1984, respectively (Hoelzer & Parrish, 2010). In 2000, a novel variant, CPV-2c, was detected in Italy. Sequence analysis of the capsid protein revealed two amino acid substitutions in isolates from dogs with severe hemorrhagic diarrhea, confirming the emergence of CPV-2c (Buonavoglia et al., 2001). Since then, CPV-2c has been reported in several countries and has become the predominant strain in some, including Nigeria (Shima et al., 2020; Umar et al., 2024). According to the current classification of Parvoviruses by the International Committee on Taxonomy of Viruses (ICTV), FPV, CPV, and CMV belong to one species; *Carnivore protoparvovirus 1* (Cotmore et al., 2019)

While modified-live vaccines containing CPV-2a or CPV-2b are widely available, vaccines specifically formulated against CPV-2c remain scarce. Moreover, there is no consensus on whether vaccines based on CPV-2a/2b provide sufficient protection against CPV-2c-induced disease (Hernández-Blanco & Catala-López, 2015). The questionable efficacy of existing vaccines, combined with low vaccination coverage and substandard husbandry practices—particularly in developing countries—have contributed to the persistence of CPE in Nigeria, often with seasonal surges during the dry months (Ukwueze et al., 2020; Ukwueze et al., 2018). Several studies in Nigeria have reported a seasonal pattern in CPE incidence, with increased cases during the dry season. This has been linked to the negative correlation between incidence and precipitation (Ukwueze et al., 2020; Agada et al., 2022). However, despite these observations, time-series analyses aimed at forecasting CPE trends remain lacking. Such analyses are essential for developing proactive control strategies and contingency plans. Ibadan, a major city in southwestern Nigeria, is home to numerous commercial breeders and private dog owners, many of whom suffer significant economic losses due to CPE-related puppy deaths (Ishola et al., 2016; Tion et al., 2021). Given the disease's impact and seasonal recurrence, the present study aims to analyze the temporal pattern of CPE in Ibadan and generate short-term forecasts to support improved disease prevention and control strategies.

Materials and methods

Study location and data sources

The study was conducted in Ibadan, the capital city of Oyo State, located in southwestern Nigeria. Geographically, Ibadan lies at coordinates 7.3767° N and 3.9398° E, and covers a land area of approximately 3,080 square kilometers. As of 2017, the city had an estimated human population of 3,678,000 (Olaleye & Ajuwon, 2018). Ibadan is served by three government-owned veterinary clinics, while the exact number of private veterinary clinics and the dog population remains undocumented. However, an unpublished directory from the Association of Private Veterinary Medical Practitioners of Oyo State lists 130 registered veterinary practitioners.

Clinical records of canine parvoviral enteritis (CPE) cases from January 2018 to December 2024 were obtained from the three government-owned veterinary hospitals, selected due to their robust record-keeping systems and willingness to participate in the study. The specific facilities involved were: Veterinary Teaching Hospital, University of Ibadan, Ibadan; State Veterinary Hospital, Mokola, Ibadan; College of Animal Health and Production Technology Veterinary Clinic, Apata, Ibadan

Formal authorization was obtained from the heads of each clinic prior to data access. Information retrieved from clinical case files included the dog's signalment, date of presentation, and method of diagnosis. These data were systematically recorded in a digital spreadsheet for further analysis.

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Data sorting and cleaning

Entries in the spreadsheet were reviewed for accuracy and completeness. Incidence records were sorted according to the veterinary facility, and further disaggregated by month and year of case presentation as well as by method of diagnosis.

Cases that tested positive using fecal point-of-care kits based on immunochromatography—commonly referred to as rapid diagnostic tests (RDTs)—were classified as “Confirmed” CPE cases. There were no records indicating the use of PCR, ELISA, or other advanced diagnostic techniques for clinical diagnosis of CPV in the reviewed facilities.

Cases classified as “Presumptive” were identified based on the following clinical and epidemiological criteria:

Acute onset of emesis and diarrhea lasting 1–3 days;

Incomplete or absent vaccination history for CPV;

Onset of gastroenteritis within two weeks following CPV vaccination;

Gastroenteritis in dogs with known exposure to a confirmed case;

Gastroenteritis not attributable to gastrointestinal parasitism, dietary causes (e.g., food poisoning), or bacterial enteritis.

These classification criteria allowed for inclusion of both clinically and epidemiologically relevant cases in the time series analysis.

Correlation analysis

Average monthly rainfall data for Ibadan were obtained from an open-access online repository (https://www.worldweatheronline.com/ibadan-weather-averages/oyo/ng.aspx, accessed January 4, 2025) and used to compare the city’s historical weather patterns with CPE case incidence. The relationship was evaluated using Spearman’s rank correlation analysis.

Time Series Analysis on the R Programming Platform

Time series analysis was performed using the R programming environment (The R Foundation for Statistical Computing, Vienna, Austria). The following R packages were utilized: readxl (for importing digital spreadsheets), xts and zoo (for time series data manipulation), tseries (for testing stationarity and autocorrelation), forecast (for ARIMA modeling and forecasting), and writexl (for exporting results to Microsoft Excel, Washington, USA). Monthly incidence of CPE was plotted over time and decomposed into trend, seasonal, and random components using the classical additive moving average technique (Mills, 2019). This decomposition enables clearer understanding of temporal dynamics by separating recurring seasonal patterns, long-term trends, and irregular fluctuations not explained by either. A key assumption of the ARIMA model is stationarity, where the mean and variance of the time series remain constant over time. To evaluate this, the Augmented Dickey-Fuller (ADF) test was applied. Since the dataset did not initially meet the stationarity requirement, a log transformation was performed to stabilize variance. Another critical assumption is temporal autocorrelation, which indicates that each observation is influenced by prior values at fixed time intervals. The Ljung-Box test was used to assess the presence of autocorrelation in the CPE time series. The best-fitting ARIMA model was selected using the auto.arima function from the forecast package, which automatically identifies the optimal model based on the lowest Akaike Information Criterion (AIC) value, thereby eliminating the need for manual inspection of autocorrelation (ACF) and partial autocorrelation (PACF) plots. A lower AIC value denotes a better-fitting model. Model validation was performed by examining the residuals for white noise characteristics using the Box-Pierce test. To further assess the predictive performance of the ARIMA model, data from 2018 to 2023 were used to forecast CPE incidence for 2024. The predicted values were then visually compared with actual incidence data from 2024. Finally, the model was used to forecast CPE incidence for a 24-month period (2025–2026), and the results were exported to Microsoft Excel for visualization and interpretation.

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Results

Description of CPE incidence in Ibadan (2018-2024)

A total of 726 canine parvoviral enteritis (CPE) cases were included in this study, comprising 202 confirmed cases and 524 presumptive cases. The overall incidence of CPE (both confirmed and presumptive) across the three selected veterinary clinics in Ibadan showed a marked increase from 2018 to 2020, followed by a continuous decline thereafter (Figure 1).

Monthly trends revealed a sharp decrease in total CPE cases from January to April, followed by a gradual increase peaking in July. This was succeeded by a moderate decline until October and another gradual rise into December (Figure 2). In contrast, average monthly rainfall increased from its lowest point in February to a relatively high and uneven plateau between June and September, then declined sharply in October and November. December and January were notably dry months. A negative correlation was observed between average monthly rainfall and CPE incidence ($r = -0.55$), indicating an inverse relationship between precipitation and disease occurrence.

A line plot of historical monthly CPE incidence revealed clear seasonal fluctuations over the years (Figure 3). A pronounced peak occurred in the first quarter of 2021, indicating a sudden surge in cases, after which incidence decreased significantly but continued to exhibit periodic patterns. The seasonal component showed consistent spikes in January each year and a secondary, less prominent peak in June, with recurring troughs in September.

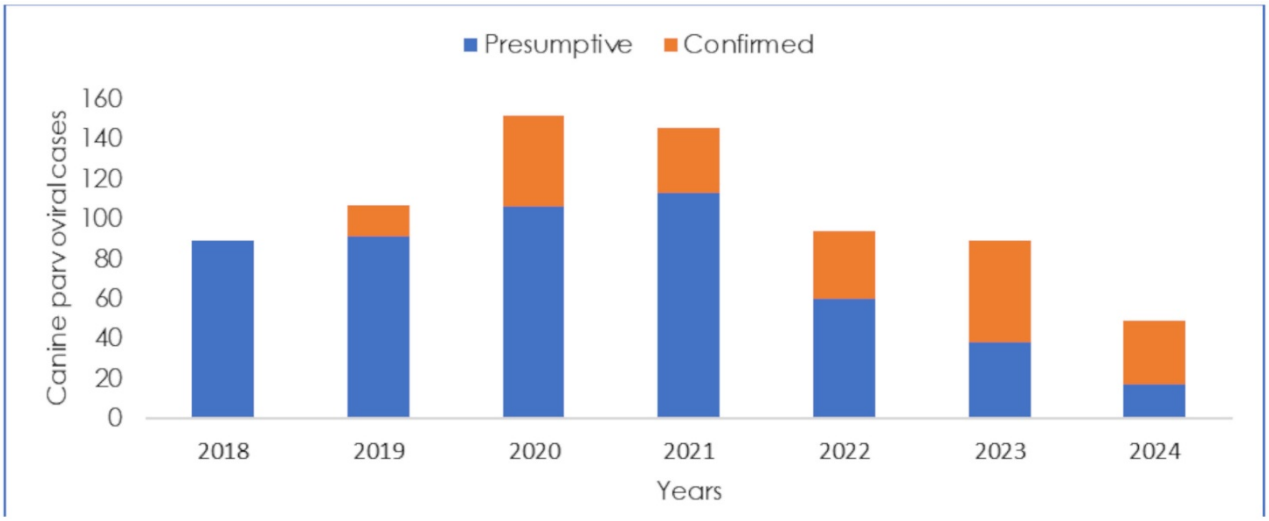

Figure 1. Incidence of canine parvoviral enteritis among selected veterinary clinics in Ibadan, Nigeria.

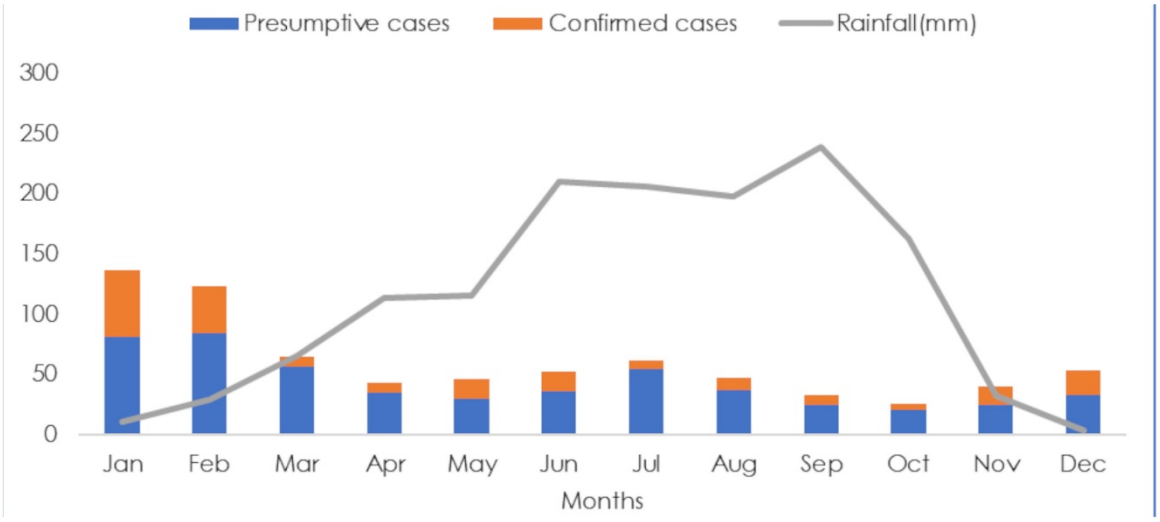

Figure 2. Canine parvoviral incidence and rain fall pattern in Ibadan, Nigeria (2018 – 2024).

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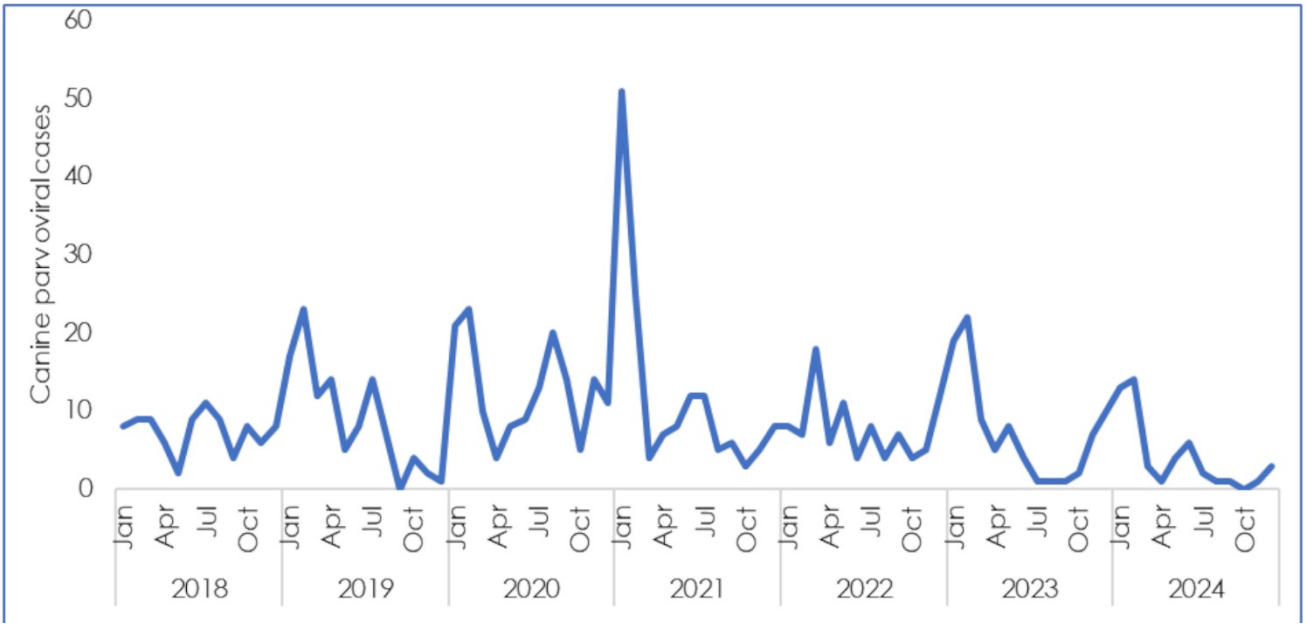

Figure 3. Time series of canine parvoviral enteritis among selected veterinary clinics in Ibadan, Nigeria.

Decomposition of the time series (Figure 4) showed:

A trend component marked by a gradual increase in incidence up to late 2020, peaking in the fourth quarter, followed by a sustained decline;

A seasonal component with recurring annual patterns;

A random component characterized by a notable spike in December 2020, suggesting the occurrence of an anomalous event or data outlier that significantly impacted the series.

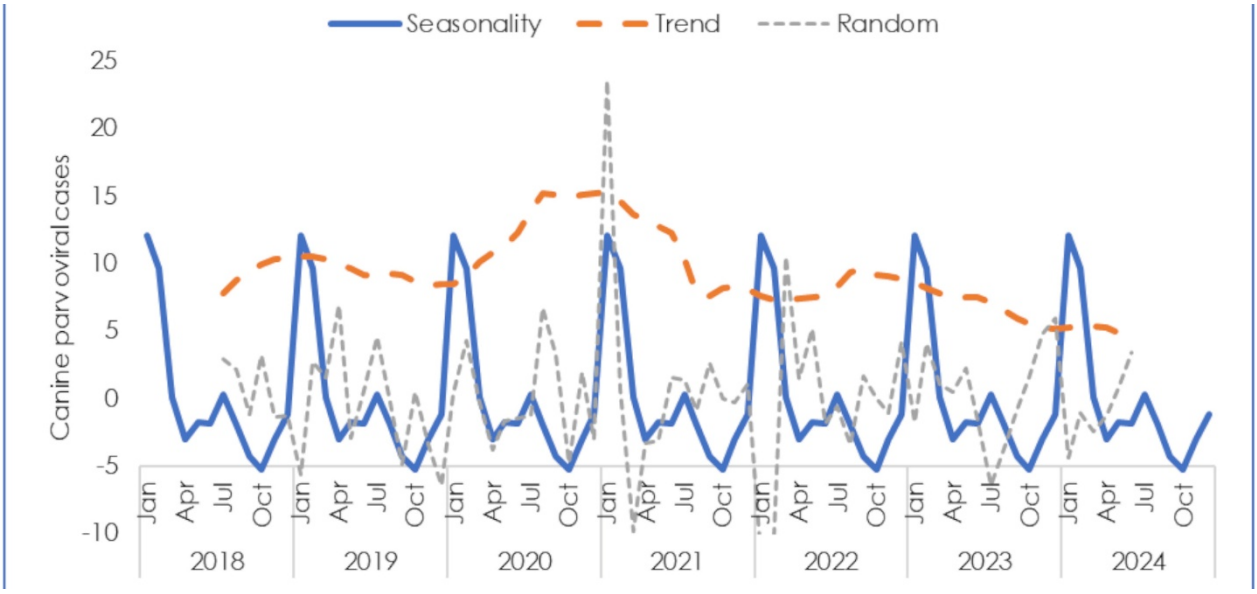

Figure 4. Additive time series decomposition of canine parvoviral enteritis among selected veterinary clinics in Ibadan, Nigeria.

Pre-model data validation

The Augmented Dickey-Fuller test conducted on the log-transformed CPE incidence data indicated that the time series was adequately stationary (Dickey-Fuller = –3.6779, lag order = 4, p-value = 0.03162). Similarly, the Ljung-Box test revealed significant temporal autocorrelation within the series (χ^2 = 25.214, df = 1, p-value = 5.13×10^{-7}).

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Summary of the ARIMA model

The best-fitting model, selected based on the lowest Akaike Information Criterion (AIC = 164), was ARIMA (1,1,1)(1,0,0)[12] without drift. In this model, the non-seasonal components (1,1,1) represent:

AR (1): the autoregressive term, capturing the influence of past values

I (1): first-order differencing, applied to remove trends and achieve stationarity

MA (1): the moving average term, accounting for the impact of past forecast errors

The seasonal component (1,0,0)[12] denotes:

SAR (1): seasonal autoregressive term

SD (0): no seasonal differencing applied

SMA (0): no seasonal moving average term

[12]: a seasonal period of 12 months, indicating annual seasonality in the data

The estimated parameters of the fitted model are presented in Table I**.**

Parameter	Estimate	Std. Error	Interpretation
AR (1)	0.48	0.12	Positive autocorrelation with lag-1.
MA (1)	-0.95	0.05	Strongly negative moving average effect.
SAR (1)	0.32	0.11	Seasonal Dependence at lag 12.
$Sigma^2$	0.07	-	Estimated variance of residuals.
Log likelihood	-77.72	-	Measure of goodness of fit

Table I. ARIMA model coefficients and parameters.

Model validation

The Box-Pierce test, used to assess autocorrelation in the model residuals, supported the null hypothesis (H_0) that the residuals are independently distributed (i.e., white noise), with $\chi^2 = 0.0055$, df = 1, and p-value = 0.9409. This result indicates that the ARIMA (1,1,1)(1,0,0)[12] model provides an adequate fit for the CPE incidence time series.

Table II presents the rounded ARIMA-predicted monthly CPE incidence for the year 2024, based on training data from 2018 to 2023, alongside the actual recorded values. The model closely matched the observed incidence between March and December, although it underestimated the number of cases in January and February. Nevertheless, the model accurately reproduced the seasonal pattern observed in the real-life data, confirming its reliability in capturing the underlying temporal structure of CPE incidence.

Short-term ARIMA forecast of CPE case for selected Veterinary clinics in Ibadan

The forecast generated by the ARIMA (1,1,1)(1,0,0)[12] model indicates a stable trajectory following the last observed value, suggesting that future CPE incidence is expected to fluctuate within a relatively controlled range, with less pronounced seasonal peaks (Figure 5). As typical of time series forecasting, the widening confidence intervals reflect increasing uncertainty as the prediction horizon extends further into the future.

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Month	95% CI low bound	Point forecast	95% CI high bound	Real life data
January	1	2	13	19
February	1	2	15	22
March	1	2	12	9
April	1	2	11	5
May	1	2	12	8
June	1	2	10	4
July	1	2	8	1
August	1	2	8	1
September	1	2	8	1
October	1	2	9	2
November	1	2	11	7
December	1	2	12	10

Table II. Comparison of ARIMA predicted CPE incidence and real-life data.

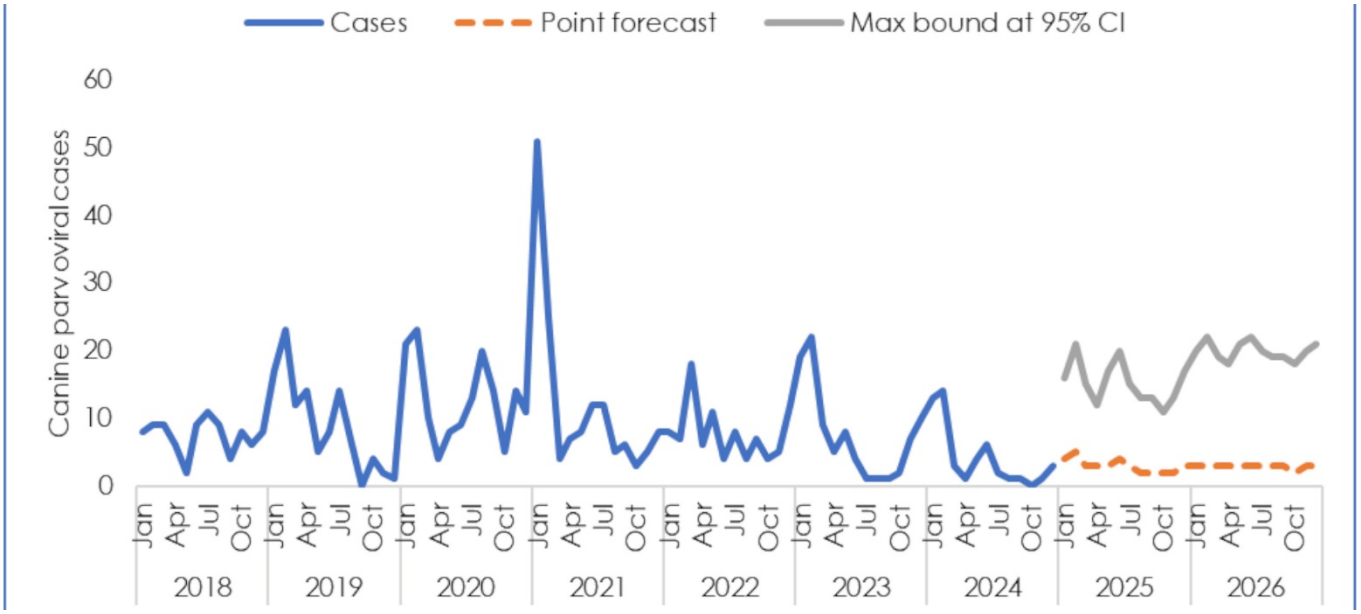

Figure 5. Time series and short-term forecast of canine parvoviral enteritis among selected veterinary clinics in Ibadan, Nigeria.

Discussion

This study provides an in-depth analysis of the temporal patterns of canine parvoviral enteritis (CPE) in Ibadan, Nigeria, from 2018 to 2024, employing classical moving average decomposition and an Autoregressive Integrated Moving Average (ARIMA) model for forecasting future incidence. It builds upon earlier works conducted in Nigeria (Ukwueze et al., 2020; Agada et al., 2022). For instance, Ukwueze et al. (2018) reported a prevalence of confirmed CPE ranging from 31% to 43% among diarrheic dogs in southeastern Nigeria, though their study did not address seasonality. Conversely, Agada et al. (2022) explored seasonal trends in CPE cases in Abuja, north-central Nigeria, from 2011 to 2021, noting peak incidence during the dry season—an observation consistent with our findings.

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Although this study did not investigate the specific CPV-2 variants responsible for the observed cases, previous molecular studies in Nigeria have identified CPV-2a and CPV-2c as the predominant strains, with CPV-2c being more prevalent (Shima et al., 2020; Ukwueze et al., 2020). Further studies are warranted to explore the seasonal dynamics of CPV-2a and CPV-2c circulation across different ecological zones in the country.

Time series analyses using ARIMA modeling remain relatively uncommon in veterinary epidemiology. Ward et al. (2020) attributed this gap to the limited availability of long-term datasets, lack of familiarity with time series methods and software, and difficulty translating statistical output into practical veterinary insights. Similarly, this study encountered data limitations, as many private veterinary clinics in Ibadan lacked structured or accessible clinical records. Consequently, only records from three government-owned veterinary clinics were included in the analysis. Decomposition of the CPE time series revealed a consistent seasonal pattern, with higher incidence during the dry season, particularly in January and February. These findings are supported by prior studies and anecdotal observations suggesting that seasonality significantly influences CPV transmission in Nigeria (Ukwueze et al., 2020; Agada et al., 2022). Similar incidence trends have been documented in studies from Abuja and Yola, where CPE peaks were also observed in the dry months (Francis et al., 2019). In line with these findings, a moderate negative correlation ($r = -0.55$) was observed between average monthly rainfall and CPE incidence in the present study. The dry season spike may be linked to increased environmental stability of the virus, which enhances its persistence on surfaces (Decaro & Buonavoglia, 2012).

The ARIMA model developed in this study proved effective in capturing trends and generating a 24-month forecast of CPE incidence in Ibadan, illustrating its utility as a decision-support tool. Such forecasting can enable veterinary clinics, public health authorities, and dog breeders to anticipate outbreaks and allocate resources for preventive measures such as vaccination, early treatment, and public awareness campaigns. In contexts like Nigeria, where economic constraints affect veterinary service delivery, predictive tools such as ARIMA offer a cost-effective approach to disease control planning. Similar methods have been applied successfully in human infectious disease surveillance and response (Singh et al., 2021). However, several limitations should be acknowledged. As shown in the comparison between predicted and actual CPE incidence for 2024 (Table I), the ARIMA model more accurately captured the trend than the absolute values, particularly underestimating incidence in the early months. This suggests that actual peak values may exceed forecasted levels. Furthermore, the dataset was derived solely from government veterinary hospitals, which may not fully represent the broader canine population in Ibadan. Consequently, the forecasted incidence should be interpreted as applicable to a subset of the city's dog population. Nevertheless, the model remains valuable for identifying seasonal patterns, which are particularly relevant for decisions such as the timing of puppy acquisition and vaccination by breeders.

Another limitation lies in diagnostic methodology. Most CPE cases included in this study were classified based on clinical signs alone, which increases the risk of false positives and could affect model accuracy. To enhance future research, it is recommended that participating clinics be equipped with CPV rapid diagnostic test kits to ensure consistent confirmation of cases and improve the reliability of incidence data used for modeling.

Conclusion

This study contributes to the growing body of knowledge on the epidemiology of canine parvoviral enteritis (CPE) in Nigeria by providing essential data for disease trend analysis and short-term forecasting. By integrating statistical modeling with veterinary epidemiology, the findings support the development of more proactive and cost-effective strategies for CPE control, ultimately promoting improved canine health and welfare in Ibadan and potentially in other regions. Veterinary clinics are encouraged to prioritize contingency planning, with a focus on increasing vaccine stockpiles rather than emphasizing the procurement of treatment drugs. A high index of suspicion for CPE should be maintained not only during historically recognized peak periods, but also throughout presumed off-peak months, as the forecast suggests a shift toward year-round incidence in the coming years. To improve diagnostic accuracy and surveillance quality, greater investment is needed to ensure the availability of rapid diagnostic test (RDT) kits, especially in resource-limited settings. Furthermore, veterinary clinics should adopt standardized and detailed record-keeping practices, as historical data are crucial for guiding evidence-based disease preparedness and response efforts.

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Conflict of interest statement

The authors have no conflict of interest to declare.

Ethical approval

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Author Contributions

xxx

All authors reviewed and approved the final version of the manuscript and agree to be accountable for its contents.

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Data Availability Statement

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