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SCIENTIFIC ARTICLE - ORIGINAL

PREDICTING THE 2026–2027 WHOOPING COUGH TREND IN BRAZIL BASED ON ARIMA AND SARIMA MODELS

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ABSTRACT

Introduction: Although the introduction of vaccination against whooping cough significantly reduced its incidence, recent years have shown a resurgence, emphasizing the importance of temporal and regional analyses to understand disease dynamics and support epidemiological surveillance. **Objective:** To develop a time series model to forecast whooping cough cases in Brazil for the years 2026 and 2027. **Material and Methods:** This ecological time series study analyzed whooping cough notifications in Brazil from 2007 to 2024 using publicly available data from SINAN/Tabnet/DataSUS. Data were organized into monthly and annual series following GATHER guidelines. Series characteristics were evaluated using Dickey-Fuller, Mann-Kendall, Kruskal-Wallis, and Box-Pierce tests. ARIMA and SARIMA models were applied to forecast cases for 2026 and 2027 with 95% confidence intervals. Analyses were performed using R (v4.3.2) and Excel, according to established protocols previously. **Results:** Between 2007 and 2024, 42354 cases were recorded of whooping cough. It was observed that the South and Southeast were the regions most affected by whooping cough during this period. The results indicated that, although the ARIMA and SARIMA models identified for each region exhibited relatively stable profiles of stationarity, trend, and seasonality, the analysis based on the model adjusted with the complete dataset up to 2024 allowed for more robust and reliable forecasts. The forecast indicates an increase in whooping cough cases in the Southeast region from May to October 2026 and from July to December 2027. In the South region, a smaller but prolonged increase is observed from January and March 2026 and from August 2026 to December 2027, suggesting significant seasonal variations. Conclusion: Whooping cough is reemerging in Brazil with cyclical trends and unequal geographic distribution. Forecasts suggest increasing cases in the coming years, especially in the Southeast and South, reinforcing the need for continuous surveillance, targeted vaccination campaigns, and proactive public health interventions.

Keywords: ARIMA, Brazil, SARIMA, TSM, Whooping cough.

INTRODUCTION

Whooping Whooping cough, also known as *pertussis*, is an acute respiratory infection caused by the Gram-Negative bacterium *Bordetella pertussis*. This is disease is highly contagious beging transmitted through direct contact with respiratory droplets expelled by infected individuals when they cough, sneeze, or speak. The disease is clinically characterized by intense paroxysmal coughing followed by a high-pitched inspiratory "whoop" or post-tussive vomiting. In severe cases, symptoms may progress for apnea, hypoxia, seizures, pneumonia, encephalopathy, and until death.[1-3] The diagnostic is realized for through microbiological identification (culture), PCR and/or serology, but delayed diagnosis is common due to the overlap of symptoms with other respiratory conditions.[1, 2]

Vaccination remains the cornerstone of prevention and it consists of primary immunization (infancy) with DTaP, followed by booster doses in adolescence. Some studies, they also propose the vaccination during the phase adulthood.[4] Immunization during pregnancy is particularly recommended to protect newborns through passive antibody transfer.[4-6]

Despite the availability of the vaccine, short-lived immunity combined with low adherence to immunization programs complete in some countries, contribute to the occurrence of periodic outbreaks.[7,8] These factors enhance the cyclic nature of whooping cough incidence, which recur every 3 to 5 years, regardless of the type of immunization or vaccination coverage.[9]

Other factors may also play a role important in these outbreaks, such as the introduction, in various countries, of the acellular vaccine replacing the attenuated vaccine, the phenotypic variability of B. pertussis, and the increasing resistance bacterial to commonly used antibiotics, especially macrolides.[10] These outbreaks primarily affect unvaccinated individuals, particularly infants, posing significant health risks during early childhood.[4]

The resurgence of whooping cough cases in recent years underscores its ongoing importance as a public health concern globally (11). Among the countries of South America, Brazil stands out for the resurgence of whooping cough, with a marked peak starting in 2024. This scenario can indicate the beginning of a new epidemic cycle, particularly in the Southeast and South regions, and highlights regional disparities.[12] Thus, the epidemiological vigilance, especially during epidemic peaks, is fundamental to improving outcomes and to assist in the health decision-making process.[1,2]

The application of time series modeling (TSM) has become increasingly relevant in epidemiological surveillance of various diseases.[13-16] The ARIMA/SARIMA models allow for the identification of temporal patterns, seasonality, and regional disparities.[13-16] These approaches enhance the ability to project future trends with statistical reliability.[17,18] Predictive modeling based on historical data helps identify high-risk periods and regions and strengthens decision-making processes in public health for optimizing resource allocation, vaccination campaigns. Moreover, outbreak prediction supports faster responses to emerging outbreaks.[14]

This study had with aims, using time series modeling, to forecast case of whooping cough counts for 2026, and 2027. These projections aim to support proactive planning in surveillance, prevention efforts and more effective epidemic management strategies.

MATERIAL AND METHODS

Ethical Aspects

The data analyzed of whooping cough in this study were obtained from the Information System for Notifiable Diseases (SINAN), a publicly accessible and unrestricted database provided by SINAN via Tabnet/ DataSUS.[19] According to Resolution No. 510/2016 of the National Health Council, studies using exclusively public data do not require approval by a Research Ethics Committee.[20] Furthermore, no individualized or sensitive information was accessed or disclosed.

Study design and context

This is an ecological study with a time series approach, conducted in accordance with the GATHER guidelines.[21] Whooping cough notifications in Brazil from 2007 to 2024 were analyzed. The data were obtained from SINAN through the platform Tabnet / DataSUS which consolidates the mandatory notifications of whooping cough made within 24 hours after suspicion, as established by Consolidation Ordinance No. 4, dated September 28, 2017 can be accessed at: http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sinannet/cnv/coquebr.def.[22]

Brazil was selected as the study area due to the availability of data and the epidemiological significance of whooping cough at the national level. The data, sourced from SINAN, were initially organized in annual spreadsheets and subsequently consolidated into a single database. A rigorous data quality control procedure was conducted to identify inconsistencies, missing values, and ensure overall data integrity. The consolidated dataset was used for model development. The methodology is summarized in the flowchart presented in Figure 1.

Statistical analysis and predictions of Whooping Cough for 2026 and 2027

The data were organized into monthly and annual time series for statistical analysis. Preliminary assessments were conducted to examine the characteristics of the time series using the following hypothesis tests: Dickey-Fuller test (stationarity), Mann-Kendall test (trend), Kruskal-Wallis test (seasonality), and Box-Pierce test (residual autocorrelation).

Based on the results of these tests, the data were modeled using ARIMA and SARIMA approaches. The best model was used to forecast whooping cough cases for the years 2025, as well as 2026 and 2027. Although 2025 is the current year, predictive modeling was necessary due to the unavailability of confirmed data at the time of analysis. This preliminary forecast enabled the extension of projections to 2026 and 2027. Estimates were generated using point and interval statistical inference, with a 95% confidence interval to enhance the robustness of the predictions. All analyses were conducted using Microsoft Excel 2020 and R software (version 4.3.2) for statistical processing and model development.[23] The methodology applied follows the time series simulation protocol previously outlined.[14, 24]

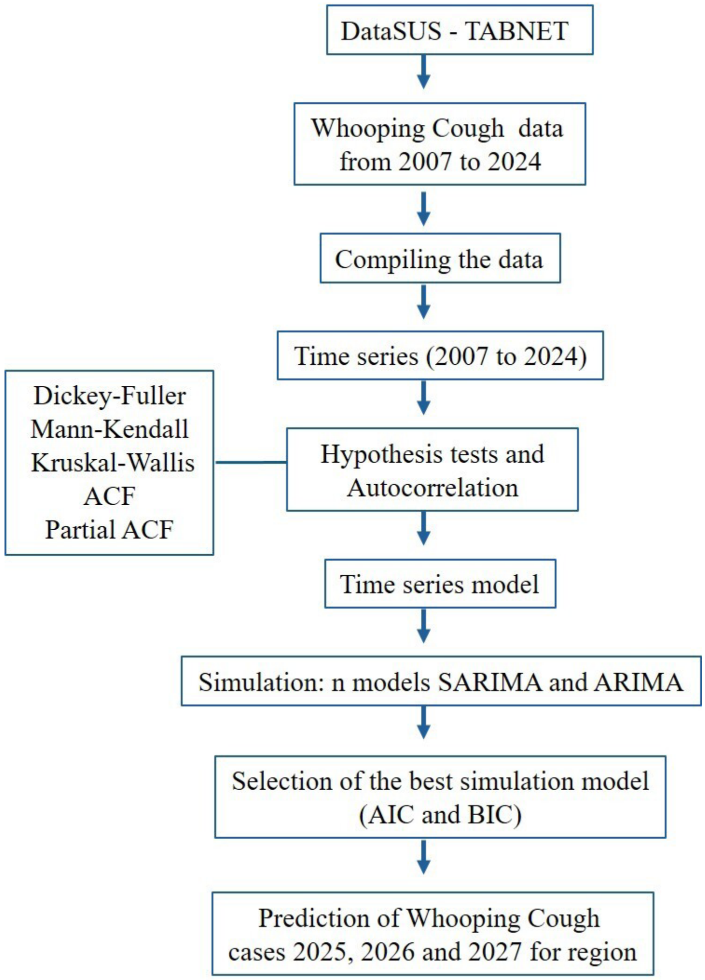

Figure 1 : Flowchart representing the methodology used in this study. SARIMA: Seasonal Auto-Regressive Integrated Moving Average Model; ARIMA: Auto-Regressive Integrated Moving Average Model; ACF: Autocorrelation Function; AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion.

RESULTS

In the SINAN/ Tabnet/ DataSUS database, 18 dataframes were identified containing a total of 42354 whooping cough notifications in Brazil, from 2007 to 2024. All these notifications of whooping cough of DataSUS were included in the study. The total number of whooping cough cases recorded in the SINAN/Tabnet/DataSUS database between 2007 and 2024 are described in the Table 1.

Table 1 : Total number of whooping cough cases in the SINAN/Tabnet/DataSUS (2007 for 2024).

Year	Case
2007	781
2008	1309
2009	1131
2010	548
2011	2034
2012	5137
2013	6451
2014	8603
2015	3321
2016	1318
2017	1759
2018	2237
2019	1615
2020	302
2021	154
2022	246
2023	207
2024	5201
Total	42354

The total number and relative frequency of whooping cough cases by region are presented in Table 2. The total number of cases of whooping cough by year and region is detailed in the supplementary Table 1.

Table 2 : Total number and relative frequency of whooping cough cases by región (2007 for 2024).

Region	Case	Frequence relative (%)
Central-West	2901	6,85
North	2569	6,07
North East	9203	21,73
South	10308	24,34
Southeast	17373	41,02
Total	42354	100

Between 2020 and 2023, the world faced the COVID-19 pandemic, a period marked by a substantial reduction in whooping cough cases, followed by a significant increase in 2024. In this context, a preliminary analysis was conducted using the AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) information criteria, as well as hypothesis tests, to compare the models built with data up to 2019 and those that included data up to 2024. In total, 233 models were generated using data up to 2019 and 232 models using data up to 2024. The AIC and BIC values for each model are detailed in Supplementary Table 2.

The AIC and BIC parameters indicate that the best model generated for 2019 showed higher quality than the best model generated for the dataset up to 2024. All AIC and BIC parameters of the best models generated for 2019 and 2024 are presented in Table 3.

Table 3 : Parameters of the hypothesis tests and models applied to the datasets up to 2019 and 2024.

Region	Year	Models	AIC	BIC	Dickey-Fuller	Mann-Kendall	Kruskal-Walis
North	2024	ARIMA(3,1,2)	1533,65	1553,88	0,01	0,00	0,58
	2019	SARIMA(3,2,3)(3,2,3)	1072,23	1109,51	0,02	0,02	0,02
North East	2024	ARIMA(3,1,2)	1926,60	1946,82	0,28	0,01	0,99
	2019	ARIMA(3,1,2)	1435,47	1453,73	0,35	0,00	0,99
Southeast	2024	ARIMA(3,1,2)	2209,87	2230,09	0,18	0,00	0,98
	2019	ARIMA(3,2,3)	1597,48	1618,74	0,56	0,01	0,49
Central-West	2024	ARIMA(3,1,2)	1538,22	1558,44	0,29	0,00	0,99
	2019	ARIMA(3,1,2)	1117,19	1135,45	0,60	0,00	0,99
South	2024	ARIMA(2,0,3)	2182,81	2206,44	0,46	0,00	0,91
	2019	ARIMA(1,1,1)	1407,58	1416,71	0,55	0,05	0,25

Additionally, the application of hypothesis tests indicated that the ARIMA (3,1,2) models for the Northeast and Central-West regions showed similar parameters for both the dataset up to 2019 and the dataset up to 2024, maintaining the same stationarity (Dickey-Fuller), trend (Mann-Kendall), and seasonality (Kruskal-Wallis) profiles (Table 3).

For the South region, the model identified for the dataset up to 2019 and since 2024 was ARIMA (1,1,1) and ARIMA (2,0,3), respectively. The parameters obtained from the hypothesis tests indicate that the profiles of stationarity (Dickey-Fuller: 2019 = 0.55; 2024 = 0.46), trend (Mann-Kendall: 2019 = 0.05; 2024 = 0.00), and seasonality (Kruskal-Wallis: 2019 = 0.25; 2024 = 0.91) remain similar (Table 3).

For the Southeast region, the model identified for the dataset up to 2019 was ARIMA (3,1,2), and for the dataset up to 2024, it was ARIMA (3,2,3). The parameters obtained from the hypothesis tests indicate that the profiles of stationarity (Dickey-Fuller: 2019 = 0.56; 2024 = 0.18), trend (Mann-Kendall: 2019 = 0.01; 2024 = 0.00), and seasonality (Kruskal-Wallis: 2019 = 0.49; 2024 = 0.98) remain similar (Table 3).

For the North region, the model identified for the dataset up to 2019 was SARIMA (3,2,3)(3,2,3), and for the dataset up to 2024, it was ARIMA (3,1,2). The hypothesis tests indicate that the profiles of stationarity (Dickey-Fuller: 2019 = 0.02; 2024 = 0.01) and trend (Mann-Kendall: 2019 = 0.02; 2024 = 0.00) are similar. However, the ARIMA (3,1,2) model for 2024 did not show evidence of seasonality (Kruskal-Wallis: 2024 = 0.58), whereas the SARIMA (3,2,3)(3,2,3) model for 2019 did show evidence of seasonality (Kruskal-Wallis: 2019 = 0.02) (Table 3).

Despite these findings, using the models based on the dataset up to 2019 could result in biased predictions for 2025, 2026, and 2027, due to the absence of five years of whooping cough notifications recorded in SINAN/Tabnet/DataSUS. Conversely, using the model estimated with higher AIC and BIC parameters would yield higher-quality predictions, owing to the larger amount of data. Therefore, the present study proceeded with the preliminary analysis considering the model generated from the dataset that included whooping cough data up to 2024.

Figure 2A presents the number of whooping cough cases in Brazil from 2007 to 2024, shown both on a monthly and annual basis, highlighting a marked decrease in cases between 2020 and 2023, followed by a substantial increase in 2024. Figure 2B provides the same data, also on a monthly and annual basis, disaggregated by region (North, Northeast, Southeast, South, and Central-West), allowing for a regional analysis of the disease's epidemiological dynamics. Between 2012 and 2014, a whooping cough outbreak was observed in the country, with the Southeast region standing out for having the highest number of reported cases. Furthermore, the pronounced increase in cases recorded in 2023 was primarily driven by a rise in notifications in the Northeast and Southeast regions. Figure 2C presents a heat map illustrating the distribution of whooping cough cases across the Brazilian regions from 2007 to 2024.

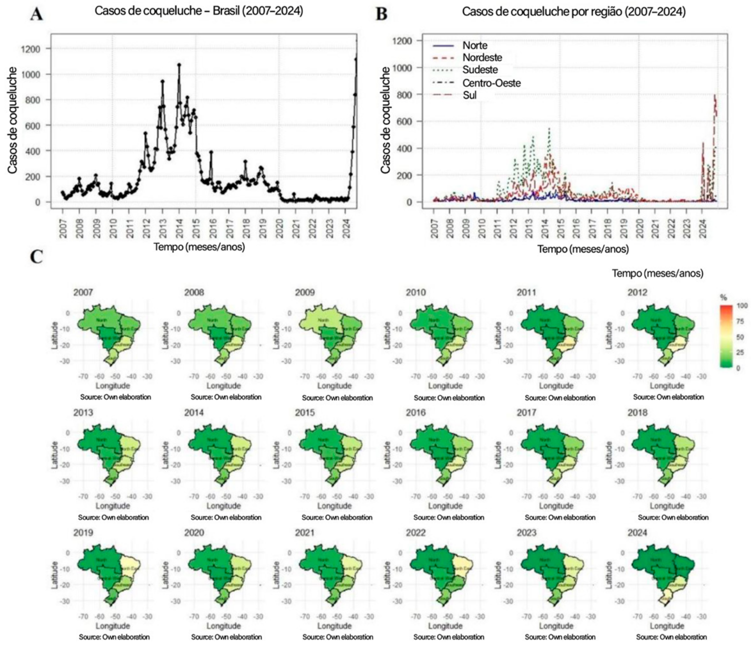

Figure 2 : A) Whooping Cough Cases in Brazil, 2007 for 2024; B) Whooping Cough Cases by Brazilian Region, 2007 for 2024; C) Heat map illustrating the distribution of whooping cough cases across the Brazilian regions from 2007 to 2024. In the map, the colors range from green to red, corresponding to the intensity of case numbers: darker green tones indicate a lower number of whooping cough cases, while lighter tones represent regions with a higher number of reported cases.

Figures 3A, 3B, and 3C present heat maps showing the predicted number of whooping cough cases by region for the years 2025, 2026, and 2027, respectively. The prediction for 2025 was included because, at the time of the analysis, data for that year were not yet available. Figure 3D illustrates the monthly predicted cases by region, highlighting an expected increase between May and October 2026 in the Southeast region. A similar pattern is projected for 2027, with a rise in cases anticipated between July and December in the same region. Additionally, an increase in reported cases is expected in the South region between December 2025 and February 2026, indicating significant seasonal variations, with a more gradual but prolonged increase projected from August 2026 to December 2027.

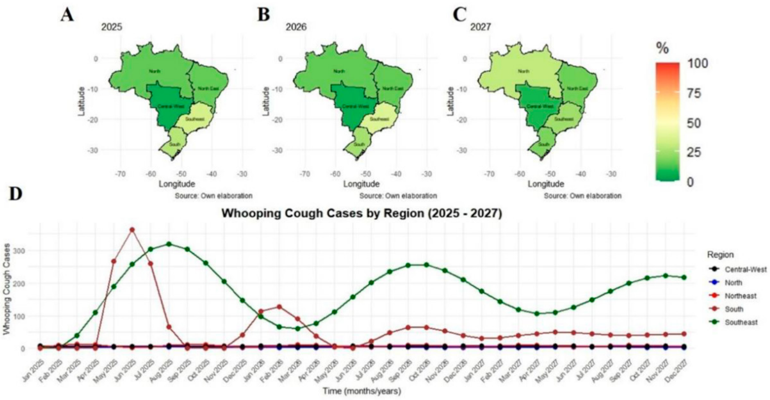

Figure 3 : A - C) Heat maps showing the predicted number of whooping cough cases by region for the years 2025, 2026, and 2027, respectively. In the map, the colors range from green to red, corresponding to the intensity of case numbers: darker green tones indicate a lower number of whooping cough cases, while lighter tones represent regions with a higher number of reported cases. D) Prediction of monthly whooping cough cases from 2025 to 2027, stratified by region.

DISCUSSION

The recent resurgence of whooping cough in countries such as China, the United States, Brazil, and Mexico has once again become a global public health concern, despite the availability of effective immunization.[12,25,26] In parallel, the prediction of epidemiological scenarios has become established as a strategic tool for the surveillance of various diseases, including whooping cough.[27,28] These predictions aim to provide more accurate information to support the optimization of financial resources, the appropriate allocation of human resources, and the public health decision-making process for addressing various diseases.[27]

In the present study, data were obtained from SINAN/Tabnet/DataSUS, a public database managed by the Brazilian Ministry of Health, which compiles notifications of whooping cough cases reported since 2007 (29, 30). The analysis of 42354 notifications recorded between 2007 and 2024 enabled the assessment of the epidemiological dynamics of whooping cough in Brazil. This analysis reinforced the cyclical nature of the disease, with 3 to 5 years intervals, as previously reported by the Brazilian Ministry of Health and also observed in other populations worldwide.[11, 29, 31]

Interestingly, in the present study, a marked increase in whooping cough notifications was observed in 2014, possibly resulting from the updated definitions of suspected and confirmed cases issued by the Brazilian Ministry of Health, which began to incorporate age-specific criteria and cough duration.[32] This change made the Brazilian surveillance system more sensitive to case detection, particularly among infants, who represent the group most affected by the disease. Additionally, this increase coincides with the final phase of the epidemic peak that began in Epidemiological Week (EW) 30 of 2011 and extended until EW 33 of 2014.[32,33]

In the present study, the initial analyses indicated a marked reduction in whooping cough cases between 2020 and 2023, followed by a substantial increase in 2024. This pattern is similar to that observed in a study conducted in China, which reported a peak in whooping cough cases shortly after the COVID-19 pandemic.[25] In our study, we believe that the reduction in cases between 2020 and 2023, followed by the sharp increase in 2024, reflects the impacts of the COVID-19 pandemic on epidemiological surveillance, the decrease in whooping cough vaccination coverage, and the resumption of mobility and social interaction patterns.[34] Previous studies have reported that social distancing measures and the prioritization of COVID-19 vaccination contributed to a temporary reduction in the circulation of other respiratory pathogens, including B. pertussis.[25,34] On the other hand, the increase observed in 2024 may reflect a rebound effect associated with the resumption of epidemiological surveillance, the reopening of schools and borders, and the low population immunity (herd immunity) following a prolonged period of reduced exposure to the infectious agent.[25]

This is recent study conducted by (2024) also reported a notable increase in whooping cough cases following the COVID-19 pandemic, with shifts in the affected age groups, a higher incidence among older children, increased vaccine hesitancy, and a greater prevalence of macrolide-resistant B. pertussis strains.[35] In our study, vaccine hesitancy and macrolide resistance were not assessed due to the absence of these variables in the SINAN/Tabnet/DataSUS databases.

In our study, the distribution of whooping cough cases by region from 2007 to 2024 showed a higher number of notifications in the Southeast, South, and Northeast regions, respectively. This pattern may be explained by several factors, including the higher population density and urban concentration in the Southeast and South regions, which can facilitate the transmission of highly contagious respiratory diseases such as whooping cough.36 Furthermore, these regions have more structured surveillance systems with greater diagnostic capacity, which may result in higher case notification rates. The heterogeneity in whooping cough vaccination coverage, both among children and pregnant women, may also contribute to the presence of susceptible populations, particularly in areas of the Northeast where access to healthcare services is more limited.[37,38] Other factors, such as population mobility and socioeconomic inequalities, may have further amplified transmission, contributing to the case peaks observed in these regions.

On the other hand, time series modeling based on SARIMA and ARIMA frameworks has been widely used to reflect incidence rates of various infectious diseases, including dengue, malaria, hepatitis E, among others (39-43). In our study, the model analysis showed that despite the alterations in case dynamics during the pandemic, the patterns of stationarity, trend, and seasonality remained similar for most regions when comparing the models constructed with data up to 2019 and those incorporating data up to 2024.

In the Northeast and Central-West regions, the ARIMA (3,1,2) models exhibited consistent parameters, indicating stability in the historical patterns of the disease even in the face of disruptions caused by the COVID-19 pandemic. In the South and Southeast regions, changes were observed in the model parameters, with the ARIMA (1,1,1) model shifting to ARIMA (2,0,3) in the South, and the ARIMA (3,1,2) model shifting to ARIMA (3,2,3) in the Southeast, respectively. These modifications suggest slight changes in trend and seasonality patterns; however, hypothesis testing indicated that these variations were not statistically significant. In the Northern region, the replacement of the SARIMA model with an ARIMA model suggests a possible loss of seasonality, which may be associated with underreporting and reduced sensitivity of the surveillance system during the pandemic period.

In our study, the model generated from the dataset that included whooping cough information up to 2024 was used to perform the predictions. At the time of the analysis, data for 2025 were not yet available in DataSUS; therefore, a prediction was generated for that year, estimating 3338 whooping cough cases in 2025. In the latest update (14 November 2025), DataSUS reported 2403 confirmed cases.[29] Although this number is lower than our prediction, it remains consistent with the global upward trend, considering that several weeks still remain before the end of the year. Our projections for 2026 indicate an expected increase in cases between May and October in the Southeast region, with similar seasonal patterns predicted from July to December in 2027. Additionally, in the South region, a trend toward higher whooping cough incidence is observed between January and March 2026, extending from August 2026 to December 2027, suggesting significant seasonal variations.

A potential limitation of this study is the occurrence of underreporting, particularly during exceptional events such as the COVID-19 pandemic. However, the results highlight the usefulness of time series models for forecasting infectious diseases. Furthermore, the projected whooping cough scenario for 2026 and 2027 reinforces its relevance as one of the most challenging infectious diseases for public health in Brazil, providing essential information for resource planning, strengthening immunization campaigns, and enhancing epidemiological surveillance during periods of increased risk.[11]

CONCLUSION

This study demonstrates that, despite the advances achieved through vaccination, whooping cough continues to exhibit a complex epidemiological dynamic in Brazil, characterized by seasonal fluctuations and regional disparities. The reduction in cases between 2020 and 2023, followed by the increase in 2024, reflects the impacts of the COVID-19 pandemic on surveillance, vaccination coverage, and social mobility. Time series models (ARIMA and SARIMA) proved effective in identifying trends and regional patterns, and the projections for 2026 and 2027 indicate a sustained increase in cases. These findings reinforce the importance of continuous surveillance, targeted vaccination strategies, and strategic public health planning, highlighting whooping cough as a persistent challenge in the country.

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AVAILABILITY OF DATA AND MATERIALS

All raw data are available on SINAN / Tabnet / DataSUS. The methodology applied in this study was previously detailed in the protocol "Algorithm with time series simulation versus auto-adjustment in R for predicting tuberculosis cases in Goiás."

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHORS CONTRIBUTION

The authors LRBA and LPA contributed equally to the preparation of this article. LRBA and LPA contributed to the conceptualization, methodology, investigation, and creation of the figures. BRSN, IMMO, ALEM, LORM and LRBA: drafting the original manuscript; LRBA and LPA: editing the figures. LPA: statistical analysis and review and editing of the manuscript. All authors agreed on the final version of the manuscript prior to submission.

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EDITORIAL AND REVIEW

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