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Original Article

Forecasting HIV Incidence Trajectories in Cebu City, Philippines: An ARIMA-Based Time-Series Analysis for Epidemic Surveillance and Public Health Planning

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Abstract

Background: *The Philippines is experiencing one of the fastest-growing HIV epidemics in the Western Pacific region, with Cebu City among the most affected urban centers. However, localized forecasting studies remain limited, constraining evidence-based public health planning and resource allocation. This study aims to develop and evaluate an Autoregressive Integrated Moving Average (ARIMA) model for forecasting monthly HIV incidence in Cebu City.*
Methods: *Monthly HIV surveillance data from January 2022 to March 2025 were analyzed using time-series forecasting. Candidate ARIMA models were assessed using the Akaike Information Criterion (AIC), parameter significance, residual diagnostics, and out-of-sample forecasting accuracy.*
Results: *ARIMA (0,1,1) demonstrated the best predictive performance, achieving a Mean Absolute Percentage Error (MAPE) of 25.04% and outperforming Naïve, Simple Moving Average, and Exponential Smoothing models. Forecasts for April to December 2025 project monthly HIV cases to increase from 33 to 36. Although forecasts suggest a persistent rise in HIV incidence, widening confidence intervals indicate greater uncertainty over longer forecasting horizons.*
Conclusion: *The projected increase in HIV incidence signals a continuing public health challenge in Cebu City. ARIMA-based forecasting provides a practical decision-support tool for anticipating disease trends and informing surveillance, targeted prevention, and healthcare resource allocation.*

Keywords
HIV incidence, time-series forecasting, ARIMA, disease surveillance, Philippines, UN SDG 3

INTRODUCTION

The global fight against Human Immunodeficiency Virus (HIV) and Acquired Immunodeficiency Syndrome (AIDS) has witnessed remarkable progress in prevention, treatment, and care over the past decades (Devaux et al., 2008). Despite these advances, HIV remains a major public health concern worldwide, having caused approximately 40.4 million deaths and continuing to impose a significant burden on healthcare systems, particularly in low- and middle-income countries (Gemede & Yazew, 2024). Although global HIV incidence has generally declined, certain regions continue to experience increasing infection rates. Among these, the Western Pacific region, particularly the Philippines, is facing a severe and accelerating HIV epidemic, currently recognized as the fastest-growing HIV outbreak in the region (Cordero, 2025; Gangcuangco & Eustaquio, 2023; Reyes et al., 2024). Since 2007, the Philippines has recorded a dramatic increase in HIV infections, with cases rising by more than 500%, particularly among men who have sex with men (MSM) (Bustamante & Plankey, 2022). This alarming trend necessitates evidence-based approaches to support surveillance, resource allocation, and strategic public health planning (Montegrico et al., 2024).

Cebu City, a major urban center in the Central Visayas region, has emerged as one of the areas most affected by the HIV epidemic in the Philippines (Medland et al., 2020). Recent reports indicate a persistent increase in HIV cases, particularly among young adults and other vulnerable populations (Gangcuangco & Eustaquio, 2023). Historically, the epidemiology of HIV in Cebu City has evolved from predominantly sexual transmission to periods characterized by increased transmission among people who inject drugs (PWID), reflecting the dynamic nature of the local epidemic (Restar et al., 2018). While sexual transmission, particularly among MSM, remains the primary mode of infection nationally (Arellano et al., 2019), HIV transmission in Cebu City continues to be influenced by a complex interplay of behavioral, social, and structural factors. Challenges such as HIV-related stigma, discrimination, barriers to testing, limited awareness of prevention strategies, and socioeconomic disparities continue to hinder effective disease control efforts (Alibudbud, 2022; Eastham et al., 2020). Given the continuing increase in HIV incidence, there is a growing need for quantitative forecasting tools capable of anticipating future case burdens and supporting proactive public health responses.

Forecasting models have become increasingly important in epidemiological research because they provide valuable insights into future disease trends and facilitate evidence-based decision-making. Among the available forecasting approaches, the Autoregressive Integrated Moving Average (ARIMA) model remains one of the most widely used statistical techniques for short-term prediction due to its flexibility, interpretability, and ability to model temporal dependencies using routinely collected surveillance data (Schaffer et al., 2021; Xu et al., 2020). Previous studies have successfully employed ARIMA models to forecast HIV incidence and other infectious diseases in diverse settings, demonstrating their usefulness for public health planning and disease surveillance (Besong et al., 2025; Goh et al., 2024; Yang et al., 2021). In the Philippines, existing HIV-related research has primarily focused on descriptive epidemiology, prevention program evaluation, and transmission dynamics modeling (Velez et al., 2015). However, despite the increasing HIV burden in Cebu City, studies employing quantitative forecasting techniques to project HIV incidence at the city level remain limited. This gap limits the availability of localized evidence to support healthcare planning, resource allocation, and timely intervention strategies.

Therefore, this study aims to develop and evaluate an ARIMA-based forecasting model for monthly HIV incidence in Cebu City using surveillance data from January 2022 to March 2025. Specifically, the study seeks to identify the most appropriate ARIMA model, assess its forecasting performance relative to conventional baseline forecasting approaches, and generate short-term projections of HIV incidence. By providing evidence-based forecasts of future HIV trends, the study contributes a practical decision-support tool that may assist local health authorities in surveillance activities, program planning, and the efficient allocation of public health resources.

METHODS

Study Design and Data Source

This study employed a time-series design to analyze and forecast the monthly HIV incidence in Cebu City, Philippines. The secondary data utilized for this analysis was directly sourced from the official registry of the Cebu City Health Department. The study period spans 39 months from January 2022 to March 2025, capturing historical trends to establish a baseline for statistical forecasting.

The data preparation involved cleaning the raw registry records to ensure consistency and completeness, then converting the HIV cases to a monthly time-series format. To evaluate the predictive accuracy of the models, the dataset was split into training and test sets at 80-20% in accordance with the methodology established by Taslim and Murwantara (2022). The first 80% of the historical data was designated as the training set for model development, while the remaining 20% was reserved as the testing set for out-of-sample validation.

ARIMA Model Development, Validation, and Forecasting

The development of the Autoregressive Integrated Moving Average (ARIMA) model began with stationarity testing using the Augmented Dickey-Fuller (ADF) test on the training data, where a p-value greater than 0.05 indicated non-stationarity. If the series was non-stationary, successive differencing was applied, starting with first-order differencing ($d = 1$) and proceeding to higher orders as needed until stationarity was achieved, thereby determining the final integration parameter (d). Next, the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots of the stationary series were analyzed to identify potential orders for the autoregressive (p) and moving average (q) components. Candidate ARIMA(p, d, q) configurations were evaluated, and the optimal model was selected based on the lowest Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values, followed by diagnostic testing to ensure the residuals exhibited white noise characteristics.

To validate its predictive performance, the optimized ARIMA model was compared against three baseline forecasting models: the Naïve model, the Simple Moving Average, and Exponential Smoothing. The forecasting accuracy of each model was evaluated out-of-sample using the 20% testing data partition. The model selection and validation were guided by evaluating and minimizing standard predictive error metrics, specifically Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE).

Once validated as the most accurate model, the final ARIMA configuration was used to generate forecasts of Cebu City's monthly HIV incidence over a nine-month horizon from April to December 2025. Along with the point forecasts, 95% confidence intervals were calculated to quantify statistical uncertainty and provide an upper and lower boundary for the projections. These forecasts aim to provide actionable, data-driven insights to local health authorities and government agencies to inform public health strategies and optimize resource allocation to reduce new HIV infections.

All statistical operations, including data preparation, ACF/PACF plot analysis, ARIMA parameter estimation, baseline model comparisons, and residual diagnostics, were executed using Gretl software.

Ethical Considerations

This study exclusively analyzed aggregated, de-identified secondary surveillance data provided by the Cebu City Health Department. No individual patient identifiers or private medical charts were accessed or disclosed. The research was exempted from rigid institutional ethics review, ensuring full compliance with ethical data standards and patient confidentiality.

RESULTS

Temporal Characteristics of HIV Incidence in Cebu City

The monthly HIV incidence data from January 2022 to March 2025 are presented in Figure 1(a). Visual inspection of the time-series plot revealed an overall upward trend in reported HIV cases throughout the study period, with a more pronounced increase beginning in late 2023 and peaking around July 2024. To assess seasonality, the autocorrelation function (ACF) of the original series was examined at the 12-month seasonal lag. As shown in Figure 1(b), the lag-12 autocorrelation was weak ($ACF(12) = -0.196$) and remained within the approximate 95% confidence bounds (± 0.314), indicating that the seasonal autocorrelation was not statistically significant. These findings suggest that annual seasonality was not evident in the available monthly HIV incidence data. Given the absence of statistically significant seasonal autocorrelation and the relatively short time series, a non-seasonal ARIMA framework was adopted for the present short-term forecasting analysis.

To facilitate model development and evaluation, the dataset was split into training and test sets using an 80%-20%80% - 20% partition scheme (Taslim & Murwantara, 2022). The training dataset covered the period from January 2022 to July 2024, while the testing dataset comprised observations from August 2024 to March 2025.

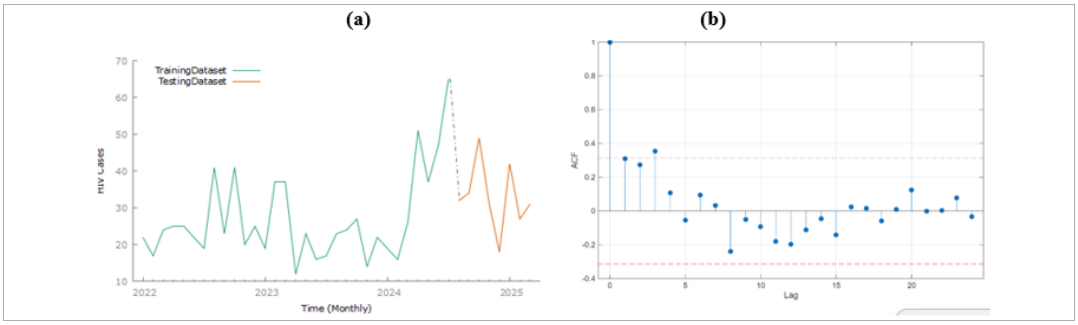

Figure 1. *(a) Monthly HIV incidence in Cebu City from January 2022 to March 2025, showing the temporal evolution of reported HIV cases; (b) Autocorrelation function (ACF) of the monthly HIV incidence series used to assess temporal dependence and potential seasonal patterns.*

Stationarity Assessment

Stationarity of the training data was assessed using the Augmented Dickey-Fuller (ADF) test. Visual inspection of the original data (see Fig. 1) suggested a trend, indicating non-stationarity. Consequently, first-order differencing was applied to remove trend-related effects. The differenced series exhibited a stable mean and variance over time (see Fig. 2), and the ADF test confirmed stationarity ($p < 0.05$). These results indicate that a differencing order of $d = 1$ was sufficient to achieve stationarity and support the application of the ARIMA modeling framework.

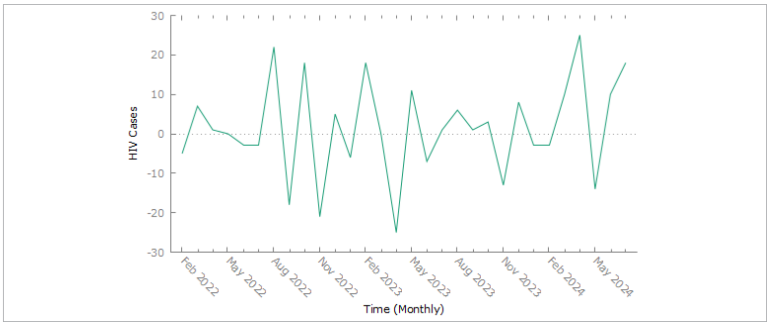

Figure 2. *First-Differenced Time Series Plot of Monthly HIV Cases in Cebu City (Training Data)*

Model Identification and Selection

Upon establishing stationarity, the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots were examined to determine the sequence of the ARIMA model's elements. The ACF measures the correlation between a time series and its lagged values, whereas the PACF separates the impact of intermediate lags. Figure 4 displays the ACF and PACF plots for the differenced series of monthly HIV cases. The ACF shows a sharp decline after lag 1, indicating a moving-average component of order q = 1. At the same time, the PACF exhibits a significant spike at lag 1 followed by a gradual decay, suggesting an autoregressive component of order p = 1. Considering that first-order differencing was applied (d = 1), the underlying process can be represented by an ARIMA (p,d,q) model with small orders.

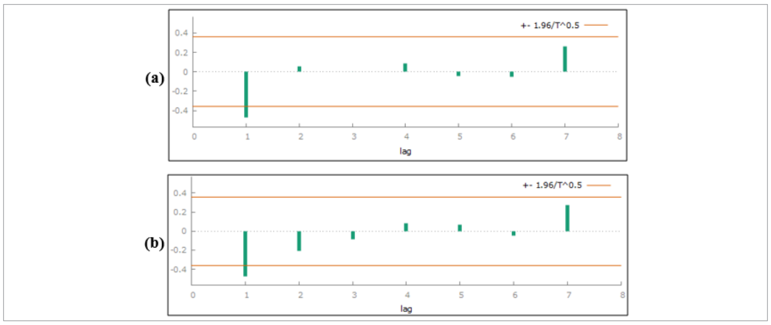

Figure 3. *Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plots of the First-Differenced Monthly HIV Cases in Cebu City (Training Data)*

To identify the most suitable ARIMA specification, four candidate models were estimated: ARIMA(1,1,1), ARIMA(1,1,0), ARIMA(0,1,1), and ARIMA(0,1,0). Model selection was based on parameter significance and goodness-of-fit indicators, specifically the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The comparative results summarized in Table 1 reveal that the ARIMA (0,1,1) model yields the lowest AIC (232.93) and BIC (237.14) values and yielded a statistically significant MA(1) parameter (p = 0.0009). Based on these criteria, ARIMA (0,1,1) was selected as the final model for subsequent diagnostic evaluation and forecasting.

Table 1. *ARIMA model identification based on the training data with a confidence level of 95%*

Model	Parameter	p-value	AIC	BIC
ARIMA (1,1,1)	AR = −0.254624 MA = −0.329108	0.4197 0.2912	234.3555	239.9603
ARIMA (1,1,0)	AR = −0.484761	0.0027	233.2484	237.4520
ARIMA (0,1,1)	**MA = −0.516678**	**0.0009**	**232.9335**	**237.1371**
ARIMA (0,1,0)	Constant = 1.43333	0.5252	238.9672	241.7696

Diagnostic Evaluation of the Selected Model

Residual diagnostics were performed to confirm the adequacy of the selected ARIMA (0,1,1) model. As presented in Table 2, the Ljung-Box Q-test (p = 0.76) indicated no significant autocorrelation among residuals, suggesting that they are independent and behave as white noise. Similarly, the Chi-square normality test (p = 0.29) indicated no deviation from normality, as shown in Figure 4. These findings confirm that the ARIMA (0,1,1) model satisfies the assumptions for reliable time-series forecasting.

Table 2. *ARIMA model diagnostic check*

Test Statistics	p-value	Decision
Ljung-Box	0.7585	Residual White Noise
Chi-square	0.2911	Normal

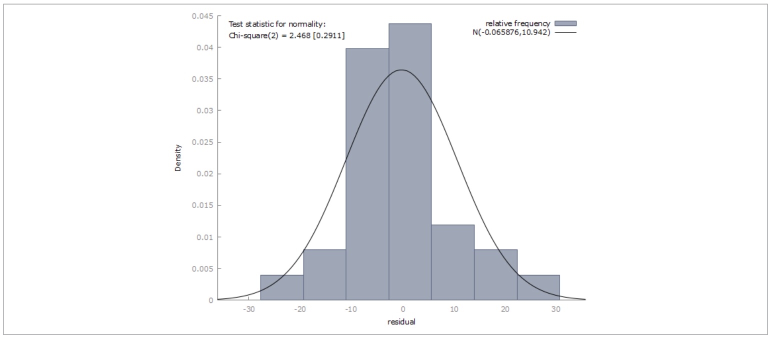

Figure 4. *Normality Testing of Residuals*

Forecast Validation and Model Performance

To evaluate predictive performance, the selected ARIMA (0,1,1) model was compared with three baseline forecasting models: the Naïve model, the 2-period Simple Moving Average (SMA), and the Exponential Smoothing (α = 0.2) technique. Model evaluation was conducted using three performance metrics, namely the Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE), computed from the testing data. As shown in Table 3, the ARIMA (0,1,1) model achieved the lowest MAD (7.36), MSE (81.93), and MAPE (25.04), outperforming all baseline models. The improvement in forecast accuracy indicates that the ARIMA model effectively accounts for temporal dependencies in HIV cases. In contrast, exponential smoothing or a simple moving average forecasting model fails to capture them. The model's predictive performance and satisfaction of the residual diagnostics support its use as the optimal forecasting model for short-term prediction of HIV cases in Cebu City. The comparative visualization in Figure 6 shows alignment between actual and forecast data, with minimal deviations over time. This graphical representation, which serves as a validation of the model's performance, strengthens confidence in its utility for predicting future HIV trends in Cebu City and provides insights for control interventions.

Table 3. *Comparative Forecast Accuracy of the ARIMA (0,1,1) Model and Baseline Models Based on the Testing Data*

Model	MAD	MSE	MAPE	Rank
Naïve	13	219.86	41.77	4
2-period Simple Moving Average	10.64	168.82	36.96	3
Exponential Smoothing (α=0.2)	8.35	105.63	28.79	2
ARIMA (0, 1, 1)	7.36	81.93	25.04	1

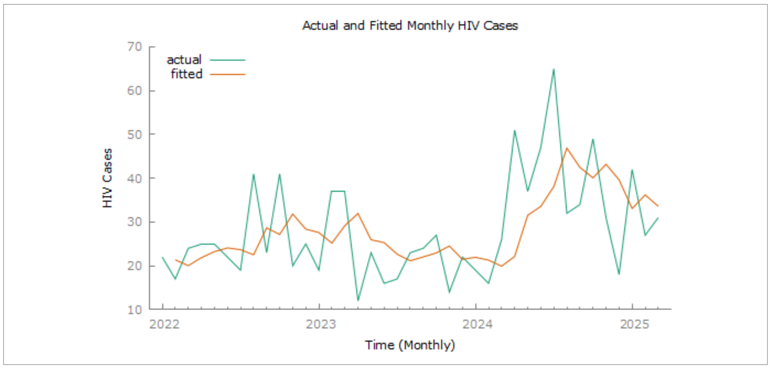

Figure 5. *Comparison of Actual Data with Forecasted Data Based on the ARIMA Model (0,1,1)*

Forecasted HIV Incidence and Forecast Uncertainty

Employing this validated ARIMA (0,1,1) model, forecasts for the period April to December 2025 were obtained. The forecasted values, together with their 95% confidence intervals, are presented in Table 4 and graphically depicted in Figure 6. The forecasts indicate a gradual and consistent increase in the number of HIV cases over the nine-month periods. The model predicts approximately 34 to 36 cases per month, suggesting the rising trend observed in late 2024 may persist into 2025. Specifically, the number of forecasted cases rises from 33 in April to 36 in December, reflecting a sustained upward trajectory. The 95% confidence intervals indicate the uncertainty surrounding the forecasts. The upper bounds of the predicted values range from 56 in April to 66 in December, while the lower bounds vary between 10 and 5 over the same period. The widening interval over time reflects the expected increase in forecast uncertainty as the forecasted period extends. Despite this, the relatively stable mean forecast suggests that epidemic growth is not accelerating rapidly but is continuing at a steady pace.

Table 4. *Forecasted monthly HIV cases (April-December 2025)*

Month (2025)	Predicted	95% Confidence Interval	
		Upper Predicted Limit	Lower Predicted Limit
April	33	56	10
May	34	58	9
June	34	59	9
July	34	60	8
August	35	62	8
September	35	63	7
October	35	64	6
November	35	65	6
December	36	66	5

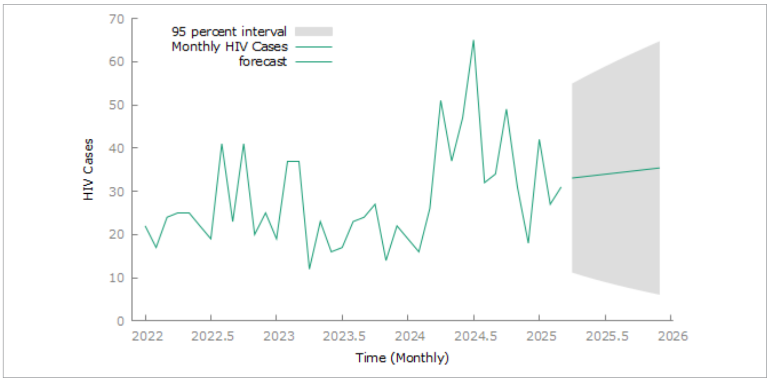

Figure 6. *Nine-month forecast of monthly HIV cases in Cebu City using ARIMA (0,1,1)*

DISCUSSION

The projected increase in HIV incidence in Cebu City is consistent with findings from previous ARIMA-based forecasting studies conducted in diverse epidemiological settings. Kurniasari et al. (2020) reported a similar upward trajectory of HIV cases in Indonesia, while Yang et al. (2021) and Besong et al. (2025) documented increasing HIV incidence trends in China and Cameroon, respectively. Collectively, these studies highlight the robustness of ARIMA models in capturing temporal dynamics and generating reliable short-term forecasts of HIV epidemics, particularly in settings where routinely collected surveillance data are available.

Although the present study was designed primarily for forecasting purposes and does not explicitly investigate the determinants of HIV transmission, the observed upward trend should be interpreted within the broader epidemiological context. Previous studies have identified several factors associated with HIV transmission, including high-risk sexual behaviors (Afriyie & Essilfie, 2019; Hirbo & Addisu, 2017; Iqbal et al., 2024; Kasahun et al., 2017; Teklemariam et al., 2018; Yang et al., 2021; Yang et al., 2022), injection drug use (Amadora-Nolasco et al., 2002; Restar et al., 2022), HIV-related stigma and discrimination (Harris et al., 1992; Karuna & Corey, 2020; Kennedy et al., 2017; Mavragani & Ochoa, 2018; Melgar et al., 2022; Nyamayaro et al., 2019; Palmer & Poon, 2019), limited uptake of HIV testing services (Jordão et al., 2022), and inadequate awareness of HIV prevention and transmission (Kwan et al., 2022; Zarwell et al., 2023). Similar behavioral, social, and structural challenges have been reported in the Philippine context, particularly in Cebu City, where barriers to prevention, testing, and treatment continue to contribute to HIV vulnerability among at-risk populations (Alibudbud, 2022; Gangcuangco & Eustaquio, 2023). Nevertheless, it is important to emphasize that the ARIMA framework is a univariate time-series approach that relies exclusively on historical incidence data; therefore, the present analysis does not permit causal inference regarding the contribution of these factors to the projected trends.

The ARIMA (0,1,1) model forecasts that reported HIV cases in Cebu City will remain elevated throughout the forecast horizon, with projected monthly incidences ranging from 33 to 36 cases between April and December 2025. While the point forecasts indicate a continuing upward trajectory, the accompanying 95% confidence intervals widen progressively over time, reflecting increasing forecast uncertainty as the prediction horizon extends. Such behavior is inherent to time-series forecasting models and arises from the accumulation of uncertainty about future observations. Consequently, the forecasted values should not be interpreted as precise estimates of future HIV incidence, but rather as the most probable trajectory under the assumption that recent epidemiological patterns and transmission dynamics remain relatively unchanged.

From a public health perspective, these projections provide valuable evidence for strategic planning and resource allocation. The forecasted increase in HIV incidence underscores the need for sustained surveillance, expanded testing initiatives, timely linkage to care, and strengthened prevention programs. Moreover, the projected ranges help health authorities anticipate future service demand and optimize the allocation of healthcare resources. However, policymakers should interpret these forecasts with caution, recognizing that future HIV incidence may deviate from the projected trajectory due to changes in intervention coverage, healthcare accessibility, behavioral patterns, testing practices, or other epidemiological factors not explicitly incorporated into the model.

Mathematical and statistical forecasting models have become essential tools in public health decision-making by providing quantitative insights into disease dynamics and supporting evidence-based planning (Azuaba et al., 2022; Dayap et al., 2025; Dayap & Rabajante, 2025; Delva et al., 2012; Oluwafemi et al., 2024). Using surveillance data from January 2022 to March 2025, the ARIMA (0,1,1) model developed in this study provides a practical, data-driven framework for monitoring HIV trends in Cebu City and generating short-term forecasts. Although the model is not intended to explain the underlying drivers of HIV transmission, its forecasts can serve as an early-warning mechanism for public health authorities, enabling proactive planning and more responsive intervention strategies.

Several limitations should be considered when interpreting the findings of this study. The analysis was based on 39 monthly observations from January 2022 to March 2025, representing approximately three annual cycles. While this observation period was adequate for developing and validating a short-term forecasting model, a longer time series would enhance the ability to detect long-term trends, structural changes, and subtle cyclical and seasonal patterns in HIV incidence. Although visual inspection and lag-12 autocorrelation analysis did not indicate statistically significant annual seasonality, the relatively short duration of the series limits the ability to exclude weak seasonal effects definitively. Consequently, the forecasts should be interpreted as short-term projections, with increasing uncertainty at longer horizons, as reflected in the widening confidence intervals.

Second, the study employed a univariate ARIMA model that relies exclusively on historical HIV incidence data. While this approach is well established for short-term time-series forecasting, it does not explicitly incorporate behavioral, demographic, socioeconomic, healthcare, or policy-related factors that may influence HIV transmission dynamics. Therefore, the model is intended to characterize temporal patterns and generate forecasts rather than explain the underlying determinants of HIV incidence.

Finally, the present study evaluates the performance of a non-seasonal ARIMA model using recent surveillance data. It did not include comparisons with alternative forecasting approaches, such as seasonal ARIMA (SARIMA), ARIMAX, or machine-learning models. The selected ARIMA model demonstrated satisfactory diagnostic properties and superior forecasting accuracy relative to the baseline methods evaluated in this study; however, these findings should not be interpreted as evidence of superiority over forecasting approaches that were beyond the scope of the present investigation. Future studies should use longer surveillance records, incorporate relevant exogenous variables, and compare statistical and machine-learning forecasting techniques to improve predictive performance further and strengthen evidence-based HIV surveillance.

CONCLUSION

This study demonstrates the value of ARIMA-based time-series forecasting as an evidence-based approach to strengthen HIV surveillance and support public health planning at the local level. By leveraging routinely collected surveillance data, the proposed forecasting framework provides a practical, reproducible methodology for anticipating short-term epidemiological trends, thereby supporting timely resource allocation, healthcare preparedness, and targeted HIV prevention initiatives. Integrating quantitative forecasting into surveillance and policy frameworks may further enhance the timeliness and effectiveness of public health responses to the evolving HIV epidemic. Although the model does not explicitly account for the complex behavioral, socioeconomic, and healthcare determinants underlying HIV transmission, it provides a robust quantitative complement to existing surveillance systems and supports proactive, data-driven decision-making. Future research should extend this work by utilizing longer surveillance records, incorporating relevant exogenous variables, and systematically comparing statistical and machine-learning forecasting approaches to improve predictive performance and strengthen evidence-based HIV epidemic monitoring and control.

Author Contribution Statement

J. Dayap: Conceptualization, Writing of the Discussion, Methodology, Formal Analysis, and Supervision; **J. M. B. Genterolizo:** Data Curation, Writing of the Discussion, Validation, Reviewing, and Editing; **M. A. Ruelan:** Data Curation, Writing – Original Draft, and Writing – Reviewing and Editing; **J. S. Estorosos:** Methodology, Visualization, Reviewing and Editing, and Investigation; **A. C. Albina:** Writing – Original Draft, Writing – Review and Editing.

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Ethical Approval

Not applicable.

Competing interest

The authors declare no conflicts of interest.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

Declaration of Artificial Intelligence Use

In this work, the authors' utilized ChatGPT to assist with improving language clarity and structuring the initial literature review. After using this tool/service, the authors evaluated and revised the content as necessary and takes full responsibility for the published content.

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