Performance of Epidemiological Surveillance: Dengue Seasonality and Strategic Insights, Cabo Frio (2015–2024)

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Abstract

This study employs Data Science and epidemiological methods to analyze ten years (2015–2024) of dengue's temporal dynamics in Cabo Frio, a coastal municipality in the State of Rio de Janeiro, Brazil. Using high-information density visualizations (Heatmaps, Time Series, and Annual Comparison Curves), we identified that typical seasonality (peaking in February–May) is not the sole predictive factor for outbreaks. The analysis revealed a critical **temporal heterogeneity** in the major epidemics of **2019** and **2024**, leading to the proposal of actionable insights: (1) The 2024 peak was the **earliest and most explosive**, demanding surveillance interventions as early as December/January, before the height of the summer season. (2) The historical 2019 peak was **late** (May), suggesting that massive population susceptibility and the potential reintroduction of serotypes (e.g., DENV-2) were stronger drivers than immediate climate, necessitating the **extension of vector control until Autumn**, contrary to routine post-Carnival relaxation. The methodology establishes itself as a model for municipal epidemiological surveillance.

Keywords: Dengue, Seasonality, Epidemiological Surveillance, Data Science, Cabo Frio, Time Series Analysis.

“Epidemics are mirrors. They show us
not only the state of our microbes,
but of our societies.”
— *Frank M. Snowden*

1. Introduction

1.1. Contextualization of Dengue in Brazil

Dengue, caused by DENV-1 to DENV-4 viruses and transmitted by the *Aedes aegypti* mosquito, represents a significant burden on Brazilian public health. Its cyclical nature and the occurrence of major epidemics every 3 to 5 years [1], driven by the dynamics of population susceptibility and the introduction of new serotypes, demand increasingly sophisticated surveillance approaches. In the State of Rio de Janeiro (RJ), incidence is chronically high, making the State an epicenter for viral propagation to neighboring municipalities.

1.2. The Importance of Temporal Analysis in Tourist Centers

Cabo Frio, located in the Lakes Region (*Região dos Lagos*), is an important tourist hub. This seasonal flow of people acts as an amplifying vector, facilitating the **introduction and dispersion** of viral strains originating from other regions of the country. Simplified temporal analysis (only annual counts) fails to capture the nuances of transmission that occur under the joint influence of climatic and demographic factors [2].

1.3. Application of Data Science in Epidemiology

The use of Data Science tools (including large-scale data processing and complex visualizations) allows for a detailed decomposition of the case time series. The **Annual Comparison Curve** (overlaying monthly incidences by year) is a superior method to aggregated time series analysis, as it reveals the **speed, onset moment, and peak timing** of the epidemic for each year. This level of granularity is crucial for transforming confirmatory insights ("dengue increases in summer") into **predictive actions** ("in 2024 the epidemic started earlier than the historical standard").

This study proposes to use this methodology to analyze the 2015–2024 decade in Cabo Frio, seeking actionable insights to optimize the time and resource allocation of municipal surveillance.

2. Materials and Methods

2.1. Data Source and Scope

Individual dengue notification data was extracted from the Notifiable Diseases Information System (SINAN), focusing exclusively on cases residing in the municipality of Cabo Frio (IBGE: 330070). The analysis period covers 10 epidemiological years (2015 to 2024).

2.2. Data Cleaning and Consistency

The column **DT_SIN_PRI** (Date of Symptom Onset) was the primary variable used, as it represents the moment closest to infection, minimizing the inherent notification delay.

1. **Conversion and Cleaning:** The DT_SIN_PRI column was converted to datetime format using the pd.to_datetime function (Pandas library), with the parameter errors='coerce' to convert inconsistent or null dates to NaT (Not a Time). This step ensured that only records with valid dates were used.
2. **Temporal Filtering:** The dataset was filtered to ensure that only cases with notification YEAR between 2015 and 2024 were included in the analysis.

2.3. Analytical Methodology and Data Visualization

Data was aggregated by counting cases by Year and Month, resulting in the sazonalidade_df DataFrame. The following visualizations were generated using the Seaborn and Matplotlib libraries:

1. **Heatmap:** A matrix visualization (sazonalidade_pivot) where rows represent Years and columns represent Months (Jan-Dec). The intensity of the red color represents the magnitude of cases, crucial for rapid visual identification of high-incidence periods.
2. **Typical Seasonal Pattern:** Calculated by the average number of cases per month over the entire period (2015–2024). This line graph establishes the **climatological risk pattern**.
3. **Annual Comparison Curve:** The central technique of the analysis. The pivoted data (Index=Month, Columns=Year) was plotted in a line graph where each year is represented by a line. This overlay allows for the **direct comparison** of the curve's slope (transmission speed) and the maximum point (peak timing) for each epidemic year.

3. Results and Discussion

3.1. Seasonality and the Contradiction of the Peak

The results confirm the expected seasonality. The **Typical Seasonal Pattern** (Monthly Average), presented in **Figure 1**, demonstrates that the highest incidence of dengue in Cabo Frio occurs between **February and May**. The **Temporal Evolution of Cases (Figure 3)**, in turn, validates the occurrence of cyclical peaks of large magnitude in 2016, 2019, and 2024. However, the analysis of the **Seasonality Heatmap** (**Figure 2**) reveals the variation in the outbreak magnitude over the years. The lag between the precipitation peak (typically December/January) and the case peak (March/April/May), evident in **Figure 1**, emphasizes that the risk is less linked to the immediate rain event and more to the **maintenance and accumulation of breeding sites** in the subsequent period, potentiated by the high temperatures that persist into early Autumn.

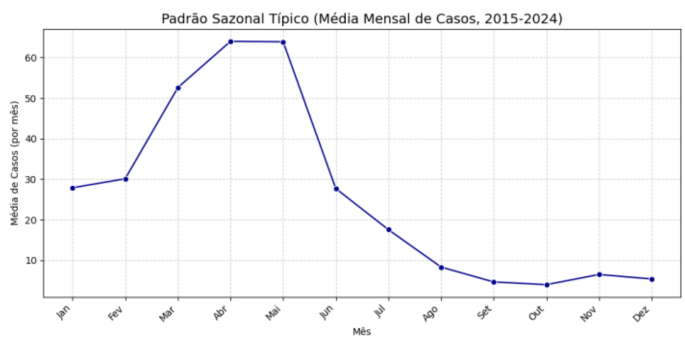

Figure 1. Typical Seasonal Pattern of Dengue in Cabo Frio (2015–2024). The line graph (monthly average) demonstrates the average risk pattern. The peak risk concentrates and prolongs from March to May.

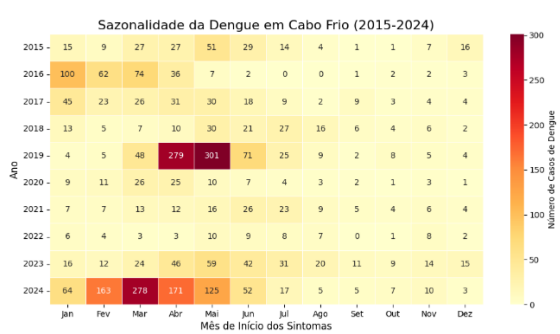

Figure 2. Seasonality Heatmap of Dengue in Cabo Frio (2015–2024). Color intensity (scale from 0 to >300 cases) illustrates the high concentration of outbreaks in the months of February to May (horizontal axis), and the immediate visual identification of the epidemic years with the greatest magnitude (2019 and 2024, on the vertical axis).

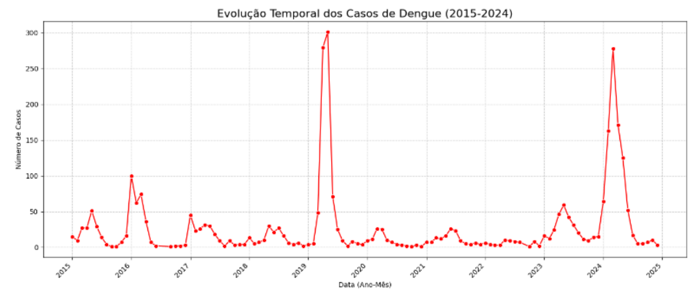

Figure 3. Temporal Evolution of Dengue Cases (2015–2024). Time series demonstrating the total cases month by month over the decade, highlighting the cyclical nature of the disease and the magnitude of the 2016, 2019, and notably, 2024 peaks.

3.2. Temporal Heterogeneity of Epidemic Outbreaks (2019 vs. 2024)

The **Annual Comparison Curve (Figure 4)**, which overlays the monthly incidence of each year, is the centerpiece of this analysis, as it disaggregates epidemic years from the endemic baseline. It allows for a direct assessment of the **speed** and **timing** of each outbreak, revealing crucial nuances for surveillance.

3.2.1. The "Maximum Susceptibility" Profile (2019)

The **2019** outbreak (purple line in Figure 4) presented the highest magnitude in terms of absolute peak, reaching approximately **300 cases** with a late peak in **May**. This late timing suggests that external factors, such as population susceptibility and serotype introduction, played a dominant role over the immediate climatic season.

3.2.2. The "Explosive Speed" Profile (2024)

The **2024** curve (cyan line in Figure 4) reveals the outbreak that was **earliest and had the highest initial growth rate** of the period. Incidence was already high in **January**, reaching its peak in **March** (~280 cases). This explosive acceleration demands a more anticipatory surveillance model.

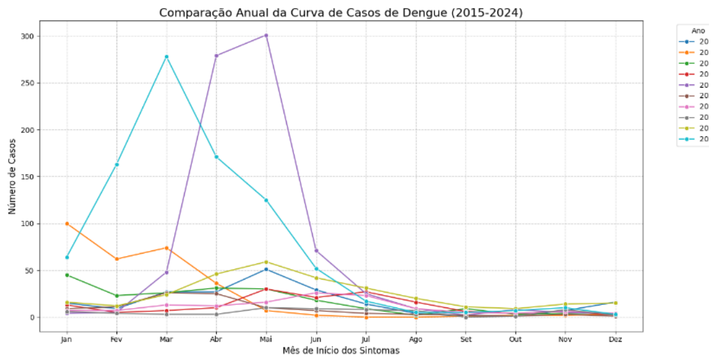

Figure 4. Annual Comparison Curve of Dengue Incidence in Cabo Frio (2015–2024). The overlaid line graph illustrates the heterogeneity of transmission. The 2024 line (cyan) demonstrates the earliest outbreak with the highest initial growth speed, peaking in March. The 2019 line (purple) demonstrates the outbreak of greatest magnitude, with a late peak in May.

4. Conclusions and Implications for Surveillance

The detailed analysis of the time series has transformed the understanding of dengue in Cabo Frio:

1. **Dual Critical Intervention Window:** The risk is not monolithic. Surveillance must operate in two critical windows:

- **Early Warning (December/January):** Focused on preventing the 2024 scenario, mitigating the initial acceleration of transmission.
- **Sustained Control (April/May):** Focused on preventing the 2019 scenario, combating prolonged transmission into the Autumn, essential for containing propagation among susceptible populations.

2. **Serological Factor:** The discrepancy between the 2019 and 2024 peaks suggests that municipal surveillance should integrate temporal analysis with **serological circulation data** from the State, using the growth profile of the curves as an alert indicator for the potential reintroduction of aggressive serotypes (DENV-2 or DENV-3).

References

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