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COVID-19 Trends in a Northeastern Brazilian State from the Start of the Pandemic: Exploring an Alternative Time Series Method

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Abstract: Pernambuco, a northeastern Brazilian state, suffered significantly during the COVID-19 pandemic. The incidence, mortality, and fatality rates were incredibly high; these outcomes were a direct failure of the public health system to manage the COVID-19 pandemic. We developed an efficient method to analyze the trends in incidence, mortality, and lethality indicators of COVID-19 and the dynamics of their main determinants in the state of Pernambuco from March 2020 to March 2022. This was a time series ecological study. We calculated the lethality, mortality, and incidence rates with official and public data from the Health Department of this state. The effective reproduction number (Rt) was estimated, and then the periods were delimited, thus creating the efficiency model. Differences were considered significant when $p < 0.05$. We found 585,551 cases and 18,233 deaths from COVID-19. January 2022 was the month with the highest number of cases (6312) and, in May 2020, we recorded the highest number of deaths (149). Our method was efficient in analyzing periods of COVID-19, noting a contrast between the early and most recent periods, with the latter showing a stable number of new cases and patient deaths.

Keywords: COVID-19; time series; mortality; case fatality; epidemiology

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1. Introduction

Since the beginning of the COVID-19 pandemic, Brazil has suffered economic, social, and health impacts, with more than 710,000 deaths, ranking second in the world for deaths, only placing behind the United States of America. These high numbers of deaths are evidence of governmental failure along with a lack of rapid and effective public health strategies to face COVID-19 at both the state and national level. As Brazil is a large country divided into 27 states, its lack of political coordination made it divided in applying efficient strategies [1,2].

Among the Brazilian regions, the northeast was deeply impacted during the pandemic. Its lack of resources and historic low human development index (HDI) put this region in a critical and very sensitive situation, culminating in a high mortality rate from COVID-19 [3,4]. Concurrently, the northeast is recognized for its tourism potential, with a natural abundance of fauna and flora, an aspect which was severely affected during the pandemic.

The state of Pernambuco is one of the northeastern region's most important tourism and economic centers, with a great cultural, social, and biodiverse patrimony. The coast of Pernambuco has one of Brazil's largest concentration of paradisiacal and preserved beaches. However, during the pandemic, hotel occupancy in the capital reached 5%, reaching a much lower percentage than most other peripheral regions where beaches are concentrated, severely impacting the region's economy [5,6].

The first case of COVID-19 in Pernambuco was reported on 12 March 2020 in its capital, Recife. Subsequently, several control strategies were promptly executed, being the third state in the northern and northeastern regions to implement a lockdown; however, in a short time, the number of cases and deaths increased dramatically. Pernambuco ranked among the states with the highest incidence of cases in the northeast and a higher mortality rate than the national average during the initial months of the pandemic. Much of this might have been related to its population's difficulty in accessing adequate treatment for early symptoms [1,7]. The initial pandemic results, with high incidence and mortality rates, clearly reflect the social disparity in Pernambuco [8]. Due to the acceleration in vaccinations soon after the first control interventions, there was a sharp drop in incidence and mortality [3,9].

Pernambuco, São Paulo, and the Amazonas are among the states with the highest risk of health system collapse due to the low availability of intensive care unit beds in proportion to the population; this was the case especially in the first year of the pandemic, when the level of occupancy remained almost 100%. In addition to these problems, Pernambuco is the constant epicenter of several viral epidemic outbreaks, such as ZIKA and Chikungunya [10,11], due to the high migratory flow between highways and the port, constantly receiving national and international travelers.

In this scenario, it is essential to observe infectious diseases in the region, including monitoring the COVID-19 situation mainly through time series, so that new collapses in health systems can be avoided. For these reasons, this work aimed to analyze the incidence, mortality, and case fatality during the COVID-19 pandemic in Pernambuco, expanding its methodological analysis to the time series from March 2020 to February 2022.

2. Materials and Methods

This was an ecological study using a time series analysis of official public data available on the website of the Health Department of the state of Pernambuco, Brazil. Cases and deaths related to COVID-19 were reported by the municipalities of the state of Pernambuco [12].

The database was updated on 20 March 2022, considering COVID-19 cases and deaths from March 2020 to February 2022. All notifications of cases and deaths assigned to COVID-19 were considered using *the International Classification of Diseases, 10th edition (ICD-10)*, as "U07.1 COVID-19, virus identified" or "U07.2 COVID-19, virus not-identified", associated with the diagnosis of the disease, according to clinical, laboratory, or epidemiological confirmation.

Information regarding confirmed diagnoses was retrieved from the dataset daily from 1 March 2020 until 28 February 2022, with the following variables: "Numbers of new cases", "Numbers of accumulated cases", "Number of deaths", "Number of accumulated deaths", "Accumulated recovered cases", "In-home treatment accumulated cases", "Accumulated hospitalized cases", "Accumulated cases in ICU", "Ignored accumulated cases", and "Accumulated empty spaces".

Two researchers independently obtained the data to minimize collection bias and guarantee their quality and reliability. The collected data were organized in a spreadsheet using Microsoft® Excel 2016.

The effective reproductive number (R_t) was approximately estimated using Equation (1):

$$R_t \cong \frac{nc_t}{\sum_{i=1}^{t} c_i - \sum_{i=1}^{t}(r_i + o_i + td_i + ili_i + iuti_i)} \quad (1)$$

where nc_t is the number of new cases that occurred on day t, c_i is the number of infective individuals on day i, r_i is the number of individuals recovered on day i, o_i is the number of individuals that died on day i, td_i is the number of individuals undergoing home treatment on day i, ili_i is the number of individuals admitted to an isolation bed on day i, and $iuti_i$ is the number of individuals admitted to the ICU on day i. In Equation (1), cases with an unknown outcome on day i (i_i) and with a known outcome not recorded on day i (nr_i) were disregarded. These missing data are sources of uncertainty that can even significantly mask the Rt value.

Both i_i and nr_i are functions of time, so they varied from day to day during the time interval observed.The efficiency (ef_t) of all equations in instant t was determined, where ef_t expresses the percentage weight of the lack of information due to i_i e nr_i in the study period, given by Equation (2). If values i_i and nr_i were both equal to zero, then ef_t was 100% at instant t.

$$ef_t = \left(1 - \frac{\sum_{i=1}^{t}(i_i + nr_i)}{\sum_{i=1}^{t} c_i}\right) \times 100\% \quad (2)$$

Knowing the temporal region where the efficiency was maximum, the above equation could find the DPC (daily percent change) for each time interval according to the defined regions in the logarithm of reproductive number Rt against the day graphic. The generalized linear regression of Prais–Winsten and Student's t-test were used to compare the DPCs between these regions.

The standard deviation of each DPC and their respective upper and lower value were determined, related to the 95% confidence level. As the mean values of the DPCs obtained by the Prais–Winsten method were approximately central in their respective intervals, it can be inferred that the distribution of each DPC was approximately normal, justifying the calculation of the standard error and the use of the t statistic to compare these magnitudes.

The incidence rate, mortality rate, and lethality were calculated using Equations (3)–(5), respectively [13].

$$Incidence\ rate = \frac{New\ cases\ of\ COVID\text{-}19\ in\ Pernambuco}{Pernambuco\ population} \times 1,000,000 \quad (3)$$

where the rate is given for every one million inhabitants of the state of Pernambuco, which has a population of 9,650,604 inhabitants. The population variation was less than 0.5% throughout the analysis period, so its value was considered constant between 2019 and 2022 [14].

The analysis lasted from 2020 to 2022; for each year's population, the population estimated by the IBGE (Brazilian Institute of Geography and Statistics) for 2021 was used, since the estimate for 2022 was not yet available. After some statistical tests, it was verified that there was no interference in the changes in rates and trends between the annual population estimations from 2020 to 2021 due to the minimal difference between the estimated populations [14].

The mortality rate was given by Equation (4).

$$Mortality\ rate = \frac{New\ deaths\ of\ COVID\text{-}19\ in\ Pernambuco}{Pernambuco\ population} \times 1,000,000 \quad (4)$$

Case fatality was defined according to Equation (5).

$$Case\ fatality = \frac{New\ deaths\ of\ COVID\text{-}19\ in\ Pernambuco}{New\ cases\ of\ COVID\text{-}19\ in\ Pernambuco} \times 100\% \quad (5)$$

Statistical analyses were performed using the software R Studio, version 2022.07.2-576.

3. Results

A total of 585,551 confirmed cases of COVID-19 were recorded from 1 March 2020 to 28 February 2022, with 18,233 cases resulting in mortality. It was noted that 24 January 2022 had the highest peak incidence of cases, amounting to 6312 (1.07%) individuals, whereas the highest recorded fatalities occurred on 11 May 2020, with 149 (0.81%). Figure 1 shows the graphic of R_t versus day.

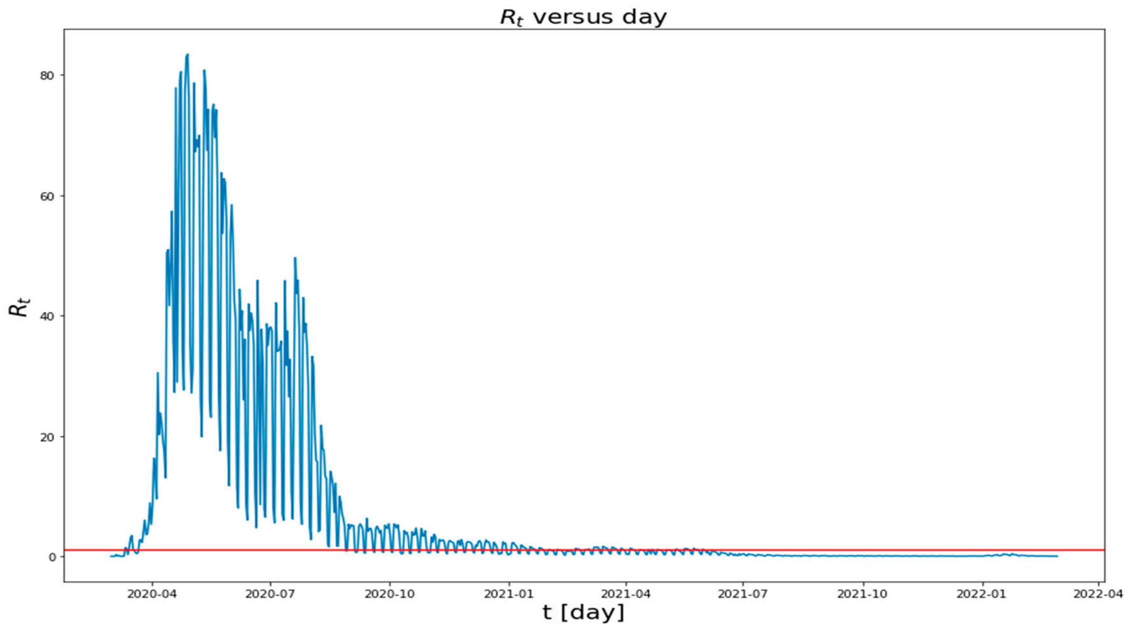


Figure 1. Rt versus day graph for the state of Pernambuco, Brazil. The red line represents the value $R_t = 1$.

Figure 2 shows the graph of ef_t versus t for the entire observation period. In the graph, two black dashed lines delimit the interval between 1 May 2020 and 15 January 2022, where ef_t becomes approximately constant and close to the maximum value of 100%. This suggests that the values i_i nr_i were relatively negligible in this period.

Returning to the graph in Figure 1, this time on a logarithmic scale, it is possible to transport the region of maximum efficiency and study the behavior of Rt with less information lacking. This analysis is shown in Figure 3.

Figure 3 shows the same two black dashed lines that limit the maximum efficiency interval for the analysis of Rt. In the graph, two vertical dashed lines separate regions of well-defined Rt behaviors. In region (A), Rt undergoes a significant reduction from a value close to 80 to a value of 1. In region (B), it can be observed that Rt remains approximately equal to 1. Then, in region (C), Rt begins a marked reduction, similar to the behavior in region (A) but followed by a peak over a short time interval, but always smaller than 1 in this region.

Figure 4 shows the DPC (daily percent change) for each defined time interval in Figure 3. The results are shown in the graph in Figure 4 and in Table 1.

Table 1 was constructed by determining the standard error of each DPC and its respective upper and lower value, related to a 95% confidence level.

The results in Figure 4 suggest that the DPC of period (A) is significantly decreasing, indicating a substantial reduction in Rt in this period. In period (B), the system seems to saturate, and the Rt remains approximately stationary around 1. However, there is a slow reduction in this DPC. Finally, in the period understood as period C, the decrease in Rt is accelerated again, with a decreasing behavior similar to that of period (A).

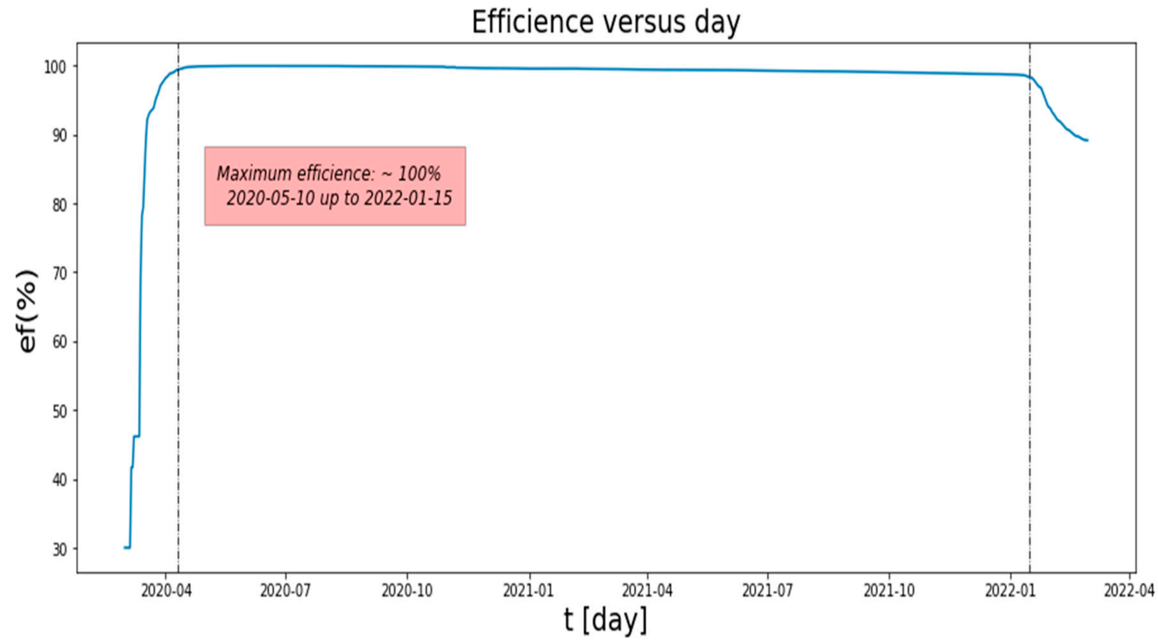


Figure 2. Graph of efficiency ef_t at instant t, as a function of time t. The black dashed lines delimit the time interval between 1 May 2020 and 15 January 2022, during which efficiency was at its maximum.

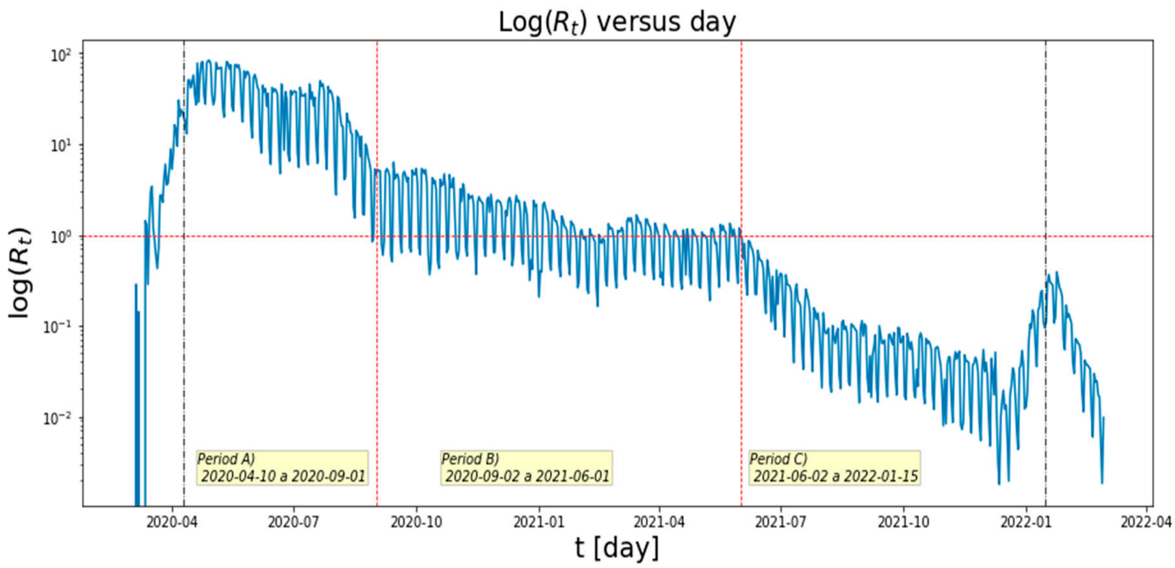


Figure 3. Logarithm of reproductive number Rt versus day. Three temporal regions are delimited on the graph—(A), (B), and (C)—separated by dashed lines. The black dashed lines delimit the region where the efficiency of information about R_t is maximum.

Table 1. *t*-test to compare the DPCs between the three temporal regions (A), (B), and (C).

DPC (%)	df	t Statistic	*p*-Value
$DPC_A = -1.52$ and $DPC_B = -0.54$	181	−3.942	<0.001
$DPC_B = -0.54$ and $DPC_C = -1.20$	499	3569	<0.001
$DPC_A = -1.52$ and $DPC_C = -1.20$	371	−1103	0.217

Table 1 reinforces these results because it shows a significant difference between the DCPs in periods "(A) and (B)" and "(B) and (C)". Furthermore, the table shows that the DCPs between periods (A) and (C) are not different. In all comparisons, significance $\alpha = 0.05$ was used.

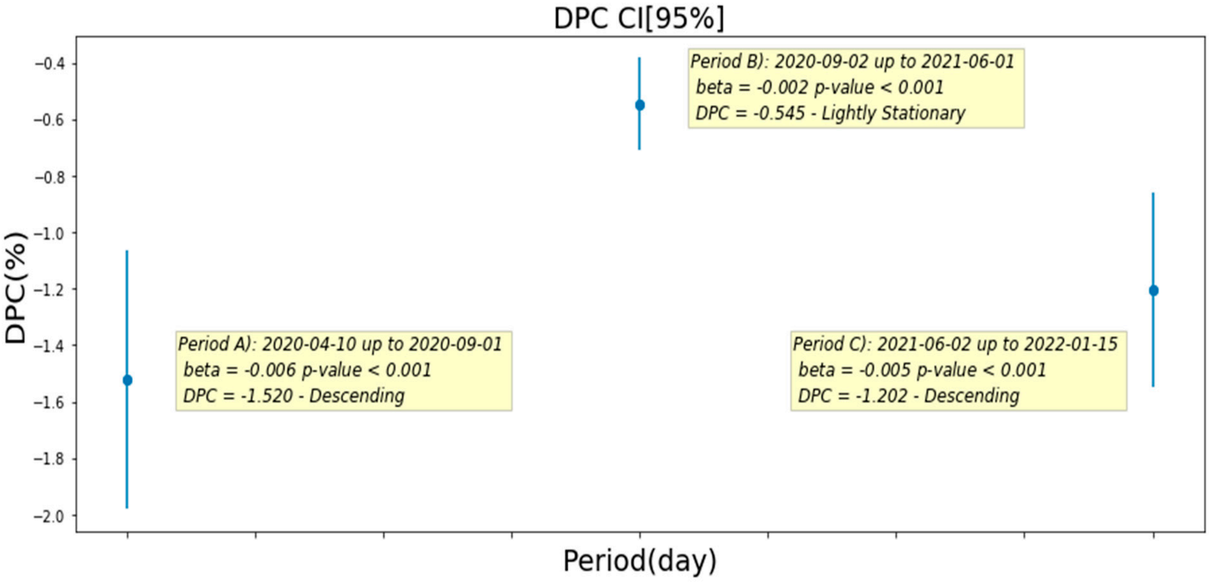
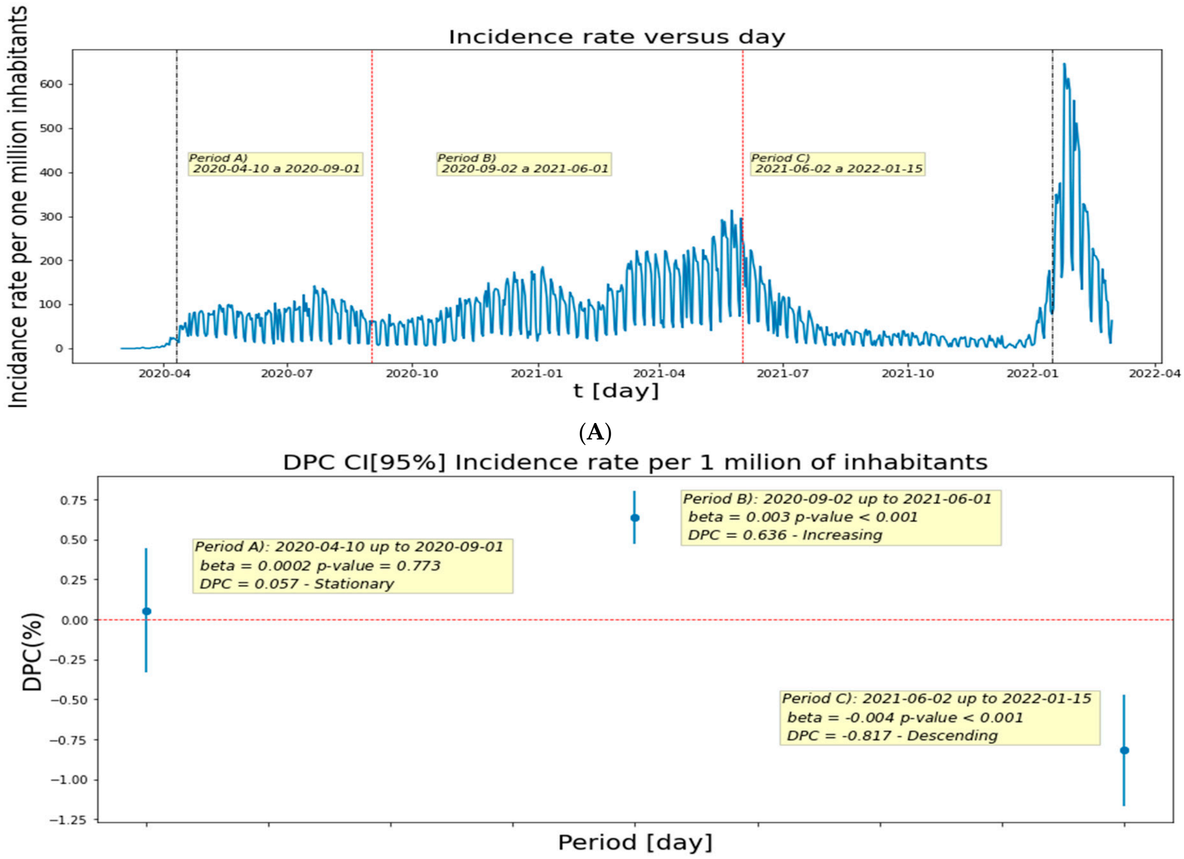


Figure 4. Graph showing the 95% confidence intervals for the respective DPCs of the three study periods, according to the temporal regions defined in Figure 2.

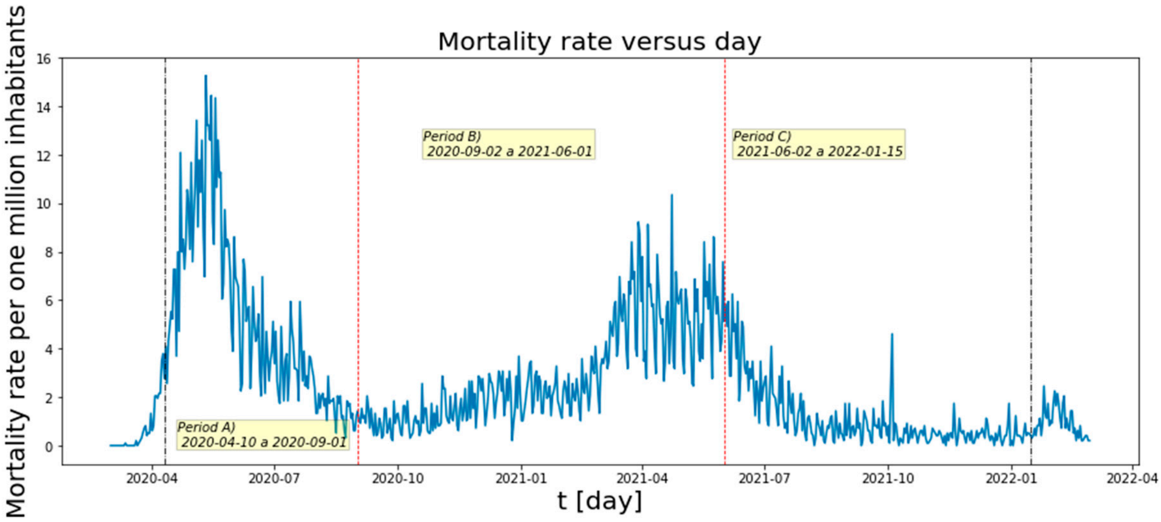
Figures 5A,B, 6A,B and 7A,B show the graphs of the two rates and one mathematical reason defined by Equations (3)–(5), as well as the respective DPCs.



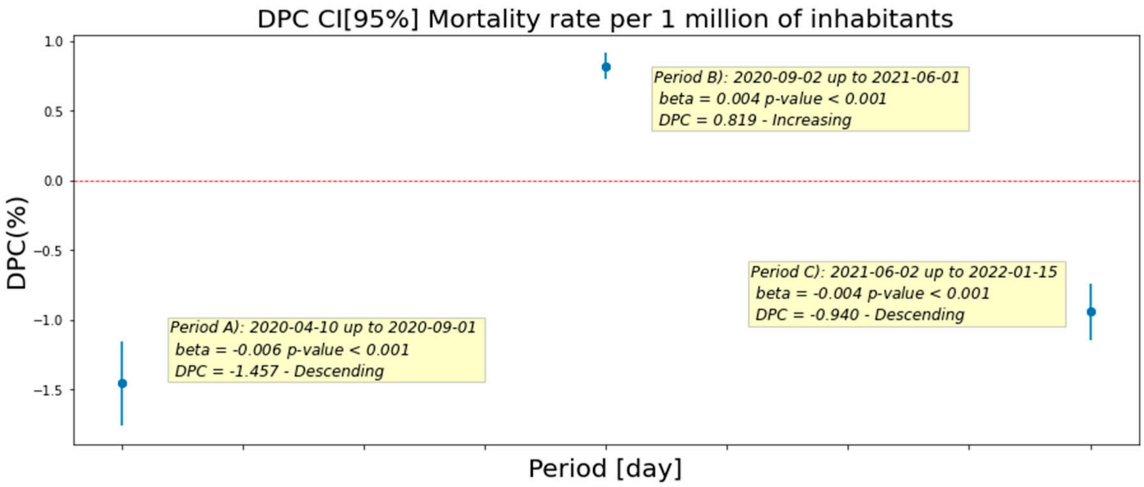
(A)

(B)

Figure 5. (**A**,**B**) show the incidence rate of COVID-19 cases per one million inhabitants for the state of Pernambuco and the respective DPCs. The graph shows the three regions—(A), (B) and (C)—and the vertical black dashed lines represent the approximate efficiency range of 100%.



(**A**)



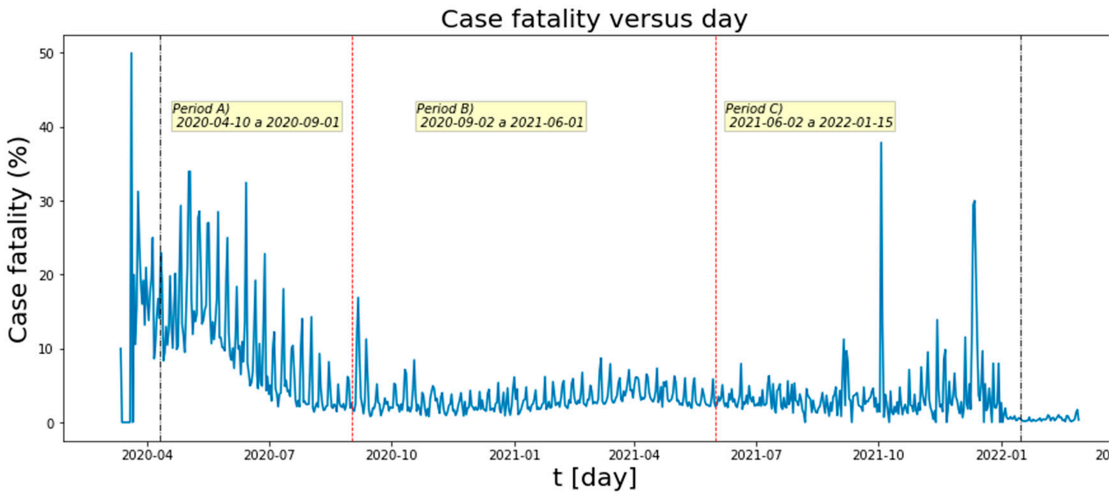
(**B**)

Figure 6. (**A**,**B**) shows the mortality rate of COVID-19 cases per one million inhabitants for the state of Pernambuco and the respective DPCs. The graph shows the three regions—(A), (B), and (C)—and the vertical black dashed lines represent the approximate efficiency range of 100%.

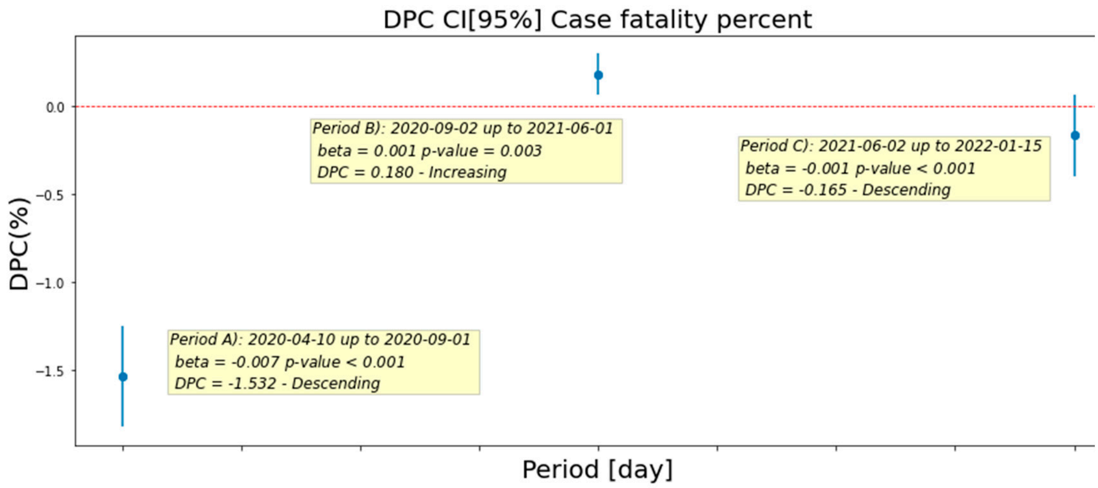
As can be seen in Figure 5A,B, period (B) had the highest incidence levels, followed by period (A), and the lower incidence was recorded in period (C). When analyzing the trends in the DPCs, all periods had different trends, with period (A) showing a stationary trend, period (B) an increasing trend, and (C) a descending trend.

Figure 6A,B show that period (A) has the highest mortality levels, followed by period (B) and, with the lowest levels, period (C). The trend descends in periods (A) and (C), while period (B) shows an increasing trend.

The case fatality of COVID-19 was highest in period (A), followed by period (B), while the lowest case fatality was observed in period (C). On the other hand, the DPC had a descending trend in periods (A) and (C), while period (B) showed an increasing trend, as seen in Figure 7A,B.



(**A**)



(**B**)

Figure 7. (**A**,**B**) show the case fatality of COVID-19 in percentage for the state of Pernambuco. The graphs show the three periods—(A), (B), and (C)—and the vertical black dashed lines represent the approximate efficiency range of 100% and the respective DPCs, in Figure (**B**).

4. Discussion

From temporal series analyses, one can evaluate and understand the behavior of COVID-19; however, using more robust and specific statistical methods is essential to improve these analyses. Within this scope, we analyzed the pandemic from the beginning, and with newfound resolution and a combination of statistical methods, we could accurately discover trends and conduct analyses on aspects of public health and health surveillance.

Upon analyzing the results, we could verify that, with a population of 9,650,604 inhabitants, the state of Pernambuco faced its most critical periods at the start of the pandemic, recording higher levels of mortality and case fatality in period (A), from April 2020 until early September 2020, and higher incidence in period (B), from September 2020 until June 2021. This shows that the initial year of the pandemic was the most problematic, with the collapse of the healthcare network. The lowest data values within the efficiency measure were seen in the Rt and trends of period (C), following on from the beginning of period (B), in the middle of October 2020, as corroborated by existing studies [15,16].

These results regarding periods (A) and (B) align with the period of high disease transmission observed in other studies. These numbers were linked to low adherence to COVID-19 mitigation policies, delays in vaccination, new variants, and the use of ineffective clinical protocols, leading to a greater spread of the disease and increasing its incidence and, consequently, mortality, as seen in other studies conducted in the same period, from April 2020 to June 2021 [8,17].

When we analyzed period (C), running from June 2021 to January 2022, we could that it had the lowest Rt and DPCs, with a decreasing trend for all parameters analyzed since the beginning of the COVID-19 pandemic. These results are aligned with those from Silva et al. [3] from 2022, related to the efforts of health authorities, industry, governments, and global researchers which improved public health resilience, open search methods, allowing for more studies like this one to be performed, and the industry's engagement to rapidly approve efficient diagnostics and vaccines.

4.1. Temporal Series and COVID-19

Since the beginning of the COVID-19 pandemic, there has been a global race featuring scientific publications in the field of epidemiology and, more specifically, on the development of temporal series of the pandemic situation using secondary data. In this context, various models have been used to fit the data more efficiently, constructed and analyzed to conform to pre-existing models.

Several authors from various global regions [18–22] obtained and analyzed COVID-19 data adopting different methods of research. It became clear that this was a solid and robust approach to measure the level of COVID-19 spread at a specific moment in time, determining whether it was under control or not and evaluating whether a given state or country was implementing effective strategies to mitigate the pandemic.

In the context of scientific publications specifically from Brazil, several authors analyzed trends in different regions and states within the country [23–30]. With the constant advancement and analysis of time series, it was possible to gain a more meaningful picture of the development of COVID-19 in the country, showing that more studies in this area are needed to facilitate comparative analyses in future research endeavors.

Our methods and results are useful for researchers wishing to conduct time series research, mainly around COVID-19. Through this method, we can advance the field of time series analyses of pandemics, leaving room for different correlations and aspects of said events. By combining the efficiency method and time series analyses, we can provide more robust data. Based on the above findings, our results align with this objective.

4.2. Limitation

As with all studies, this one has some limitations worth mentioning. This study only analyzed cases, deaths, and their related trends; the aim of any discussions concerning public health policy was only to relate the results to parallel studies carried out on this or other themes.

Another limitation is that this study was based on secondary data and had errors in their feed and origin; such errors are inherent to any general database that compiles data from different locations. Despite the database in this study being a state-owned and high-quality one, we could not verify with certainty that all the information in the database was fully cohesive in terms of the most significant details.

5. Conclusions

Through our analysis, we could see a contrast between the high rates of incidence, mortality, and lethality recorded during the two initial periods of the pandemic and the most recent period, during which we could see a stable increase in new cases and patient survival, exemplified by the low mortality and fatality rate observed from June 2021 to early 2022.

This study underscores that, despite the relatively stabilized rates of incidence, mortality, and case fatality observed in recent periods, the emergence of new outbreaks may be on the horizon, particularly in the northeastern Brazilian region, potentially resulting in additional consequences for both hospitalized patients and the overall structure of the healthcare system.

Researchers and health workers share a responsibility to mitigate the harms of the COVID-19 pandemic. This can be achieved by providing timely scientific updates, particularly through time series studies which align with and support the health system. By addressing gaps in existing research, we can gain a comprehensive understanding of the public health factors that influence this disease.

Author Contributions: Conceptualization, M.P.E.C. and J.d.O.E.; methodology, M.P.E.C. and J.d.O.E.; software, J.d.O.E.; validation, M.P.E.C., J.d.O.E. and B.E.G.D.; formal analysis, M.P.E.C., J.d.O.E., B.E.G.D., T.C.M., F.A.M.d.S.F. and C.M.T.; investigation, M.P.E.C.; resources, J.d.O.E. and L.C.d.A.; data curation, M.P.E.C.; writing—original draft preparation, M.P.E.C. and J.d.O.E.; writing—review and editing, M.P.E.C., J.d.O.E. and B.E.G.D.; visualization, M.P.E.C. and J.d.O.E.; supervision, J.d.O.E. and L.C.d.A.; project administration, L.C.d.A.; and funding acquisition, L.C.d.A. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: This study utilized secondary data obtained from publicly available databases. The research focused on the description and analysis of this information, without the collection or use of any data which could have led to the identification of individual subjects. Thus, this study fully adheres to the ethical precepts and guidelines established in Resolution 466/2012 and its derivations of resolution 510 of 7 April 2016, of the National Health Council, as well as its interinstitutional prerogatives, ensuring the privacy and protection of individuals whose data were originally collected.

Data Availability Statement: All data were retrieved from the Brazilian Ministry of Health's database. For details regarding the data analysis, please contact the author at mpaivaemi@usp.br.

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Conflicts of Interest: The authors declare no conflicts of interest.

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