



ISSN: 2230-9926

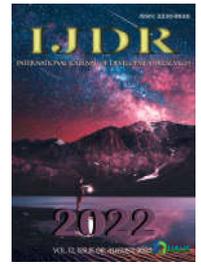
Available online at <http://www.journalijdr.com>

IJDR

International Journal of Development Research

Vol. 12, Issue, 08, pp.58505-58508, August, 2022

<https://doi.org/10.37118/ijdr.25242.08.2022>



RESEARCH ARTICLE

OPEN ACCESS

PANDEMIC AND COVID-19: A MATHEMATICAL ANALYSIS OF THE (UN) PREDICTABILITY OF CASES IN THE STATE OF AMAZON

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ARTICLE INFO

Article History:

Received 25th June, 2022

Received in revised form

26th July, 2022

Accepted 05th July, 2022

Published online 30th August, 2022

Key Words:

COVID-19; Pandemic; Algorithms; Computational Methodologies; Epidemiology.

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ABSTRACT

The pandemic of COVID-19 began in May 2020, as declared worldwide by the World Health Organization (WHO), with approximately 589,680,368 cases and 6,436,519 deaths from the disease being confirmed by the year 2022. In Amazon, up to August 14, 2022, 14,249 Covid-19 deaths have been recorded, 342 this year alone. This is an epidemiological study of a quantitative nature, in the application of mathematical models for event prediction and management in health services. The process of mathematical modeling and data mining was composed of the following steps: library, data preparation, test setup, validation, and results, in the epidemiological weeks comprising the period from 2020 to 2021. The period was composed of 90 epidemiological weeks, total of 22,247 new cases, in the epidemiological week equivalent to 3,178 new cases per day. The 90-week period was maintained, with a total of 14,120 deaths; after applying the moving average, we worked with 1,052 deaths registered at week 56. The mathematical models GBM and KNN, used in this study, showed a significant difference between the predicted and the actual observed number of cases and deaths from Covid-19 in the second wave of the pandemic in Amazon.

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Citation: Daniel Meireles Meira, Adriano Moreira Santos, Danusio Gadelha Guimarães Filho et al. 2022. "Pandemic and Covid-19: A mathematical analysis of the (un) predictability of cases in the state of amazon", *International Journal of Development Research*, 12, (08), 58505-58508.

INTRODUCTION

Covid-19 is an infection caused by the SARS-Cov-2 virus. The first case was reported on December 31, 2019, in Wuhan, China. In Brazil, the first case was confirmed on February 26 of the following year. In Amazon, the first record of infection is from March 13, 2020 (WANG et al, 2020; BRAZIL, 2022). Declared worldwide by the United Nations Organization (UNO) as a pandemic, the most important health problem of the last 100 years begins in May 2020 (MEDEIROS, 2020). According to the WHO, by August 2022, 589,680,368 cases of Covid-19 and 6,436,519 deaths from the disease have been confirmed in the world. Amazon State, situated in the northern region, is the largest Brazilian state in territorial extension, with 62 municipalities. It borders with Bolivia, Peru, Venezuela, and Colombia. Its peculiarity is the significant geographical distance between municipalities with access by land, air, and river, been the capital Manaus, the most populous in Amazon. (IBGE; GUITARRARA, 2022; MELO, 2018). Primary Health Care is the entrance door to the Brazilian health system, called Unified Health System (SUS) and it's the core of the interlocution with the entire care network, for being able to structure the movement of health services. The state of Amazon has a territorial extension of 1,571,000 km², where 4,144,597 people are distributed, and of these, 3,195,752

are covered by primary care, which represents 77.10% of the population (BRASIL, 2021). When it comes to the temporal rise of coronavirus infection in the Amazon territory it was represented by two waves. The first one, in the period from March to May 2020, with an increase in the number of infected people both in the capital and in the interior. The second, in the hiatus from December 2020 to January 2021, due to the spread of the new P1 variant, triggered by year-end celebrations and the seasonality of the respiratory virus dissemination (MOREIRA et al., 2020; BRASIL, 2021). The number of people infected grew exponentially in the second wave, placing Amazon among the states on the Ministry of Health's list of concerns due to the accelerated and disorderly spread of the virus, appearing on the national scene as one of the most affected. According to the Health Surveillance Foundation (2022), in Amazon, up to August 14, 2022, 14,249 deaths from Covid-19 have been recorded, 342 of them this year alone (DINIZ, 2020). The capital city, Manaus, was one of the most affected, having experienced, in the year 2021, the beginning of the crisis, during the second wave. In the first 14 days of January alone, the number of deaths exceeded the number recorded for the entire month in 2019 by 84.75%. The extent of the increase cases in January 2021 alone, exceeded half of that accounted for the entire year of 2020, concerning the management committee against the virus (MARINHO & FERRARI, 2021). Researches have been using rapid and universal screening methods that were essential to save

healthcare resources, improve diagnostic efficiency, and avoid cross-contamination. Using emerging machine learning techniques that enable the analysis of existing multidimensional data, applying appropriate algorithms to express and classify features, we have the potential to improve diagnostic accuracy (MENG et al., 2020). Given the pandemic scenario presented, this study aims to answer the following question: Would it be possible to mathematically predict the number of new cases of Covid-19 in the second wave of the virus through mathematical models of high accuracy and recognized worldwide?

In this context, the objective of the study focused on performing a mathematical analysis of the predictability of the increase in cases in the second wave of the virus, based on the numbers recorded in the first wave.

METHODOLOGY

This is a quantitative epidemiological study in the application of mathematical models for event prediction and management in health services. Epidemiological studies tend to analyze a phenomenon in a given population and, more recently, with the use of algorithms and mathematical models, helped managers by bringing to light the applicability of predictive technology. The mathematical modeling and data mining process was composed of the following steps: library, data preparation, test setup, validation, and results (DOS SANTOS et al., 2019; SILVA FILHO & CAMPOS, 2021). The data analyzed were from the epidemiological weeks, in the period from 2020 to 2021, by the Covid-19 Amazon Panel - Source: Covid-19 Amazon Panel: Link: <http://www.saude.am.gov.br/painel/corona/>; by the Corona virus Brazil - Source: <https://covid.saude.gov.br/>; and by the Press Consortium - Source: <https://covid19br.wcota.me/>. New cases and deaths confirmed by Covid-19 in 2021 in the 90-week period, called epidemiological weeks in the State of Amazon, were eligible. Considering that this information is in the public domain, it justifies the release of the Ethics and Research Committee appreciation.

Initially, it was decided to standardize the information from the three documentary sources, using the moving average. After this step, the data was submitted to mathematical models of metaheuristics, which are computational procedures, usually of local search, exploring the space of solutions, beyond the local optimum (SILVA FILHOS & CAMPOS, 2021). Linear regression, *Weighted KNN* and Gradient Boosting Machine (GBM) were applied to predict the number of new cases and deaths. *Weighted KNN* (The K Nearest Neighbors - KNN) classifier is a classic supervised method in the field of machine learning, based on statistical data. Cover and Hart proved that the K nearest neighbor classification deviation approaches the optimal Bayesian classifier (Cover and Hart, 1967). The k nearest neighbor classifier is widely used in areas such as text classification, pattern recognition, image processing, and spatio-temporal classification (MELO, 2018). The *Gradient Boosting Machine (GBM)* is a supervised learning meta-algorithm that is commonly used in classification and regression problems. The algorithmic principle behind GBM is the production of predictions/classifications derived from weak predictive models (*Weak Learners*), in particular decision trees. In turn are combined via *ensemble learning* to reduce the biases of the algorithms². For the statistical analysis we used the statistical software R studio, version 4.0.3 and the data presented in comparative graphs.

RESULTS

The data presentation is divided into two samples: new cases and the absolute number of deaths related to Covid-19 infection.

¹ The information was extracted from <https://scialert.net/fulltext/?doi=jse.2016.109.118> Accessed on 20 Feb. 2022.

² The information was extracted from <https://mineracaodados.wordpress.com/tag/gbm/> Accessed on 20 Feb. 2022.

New Cases: The period was composed of 90 epidemiological weeks, total of 22,247 new cases, in the epidemiological week equivalent to 3,178 new cases per day. During the predictions, in epidemiological week 55, it was verified that the WBG projected a quantity of 8,088 new cases, that is, there was a difference of 14,159 new cases between the observed and the predicted. This numerical difference represented 65% between the actual cases and the projection. By KNN analysis the algorithm projected 7,672 new cases. In other words, there was a numerical difference of 14,575 new cases between the observed and the predicted. This numerical difference represented 65% between the actual cases and the projection. When analyzing the graph of KNN and GBM it is noted that they performed well throughout the period, however, there was a large discrepancy between the predicted and observed in week 55, a fact that is attributed, as studied in previous lines, to the arrival of the new variant *Gamma* (Figure 1).

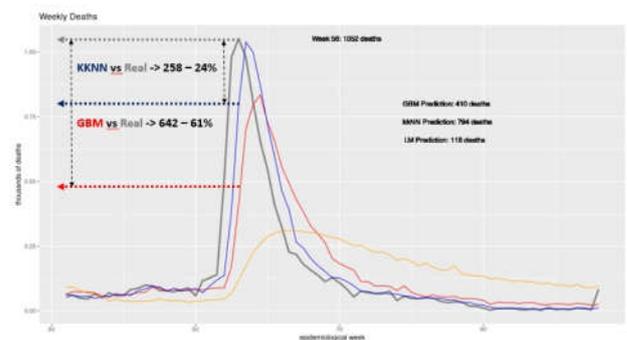


Figure 1. Mathematical Modeling Results for New Cases. Manaus, Amazon, Brazil – 2021

Deaths: The 90-week period was maintained, with a total of 14,120 deaths; after applying the moving average, we worked with 1,052 deaths registered at week 56. The projection by the GBM was a total of 410 deaths, that is, there was a difference of 642, between the observed and the predicted. This numerical difference represented 61% between the actual cases and the projection. The KNN analysis shows a prediction of 794 deaths, with a numerical difference of 258 between the observed and the predicted. In percentage, it represented 24% between the actual cases and the projection (Figure 2).

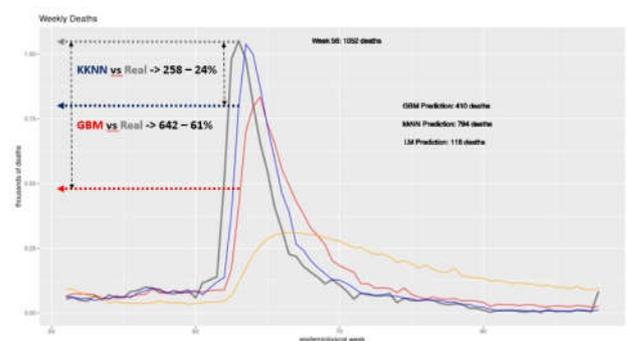


Figure 2. Result of the Mathematical Modeling for the deaths. Manaus, Amazon, Brazil – 2021

DISCUSSION

The data between the simulations projected by the mathematical models applied in this study and the actual numbers registered by the regulatory agencies investigated, evidence a fragile chance of prediction about the investigated phenomena for the following weeks, as exemplified in Figure 3. Technology applied to healthcare has been gaining space with impact on clinical and management services in the sector. With the development of algorithms and/or mathematical models it is possible to predict from risks related to genetically transmitted diseases on an individual basis to vaccine performance in the collective environment (DOS SANTOS et al., 2019; SALDANHA et al., 2021).

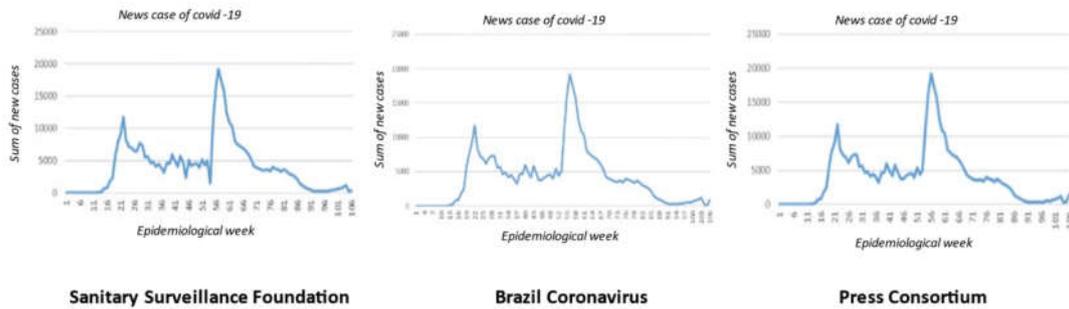


Figure 3. Comparison between Sanitary Surveillance Foundation, CoronaVirus Brazil and Press Consortium databases for new cases. Manaus, Amazon, Brazil, 2021

The algorithms are able to bring up metrics based on registered data, which weakens when strain modification occurs. Comparing the first and second waves of the virus in Amazon, a significant rise in the Covid-19 mortality rate is observed due to the *Gamma* variant, with Manaus as the epicenter of the disease in the north of the country (BRASIL, 2021). The study analyzed the mortality and lethality profile in patients hospitalized for Covid-19 before and after the intensification of the *Gamma* variant circulation in Amazon (ORELLANA *et al.*, 2022; ORELLANA, 2021). The change in gender and age range of hospitalization is reported. In the first wave, the elderly predominated, and in the second wave, the 20 to 39 age group. Another important movement was the increase in severe cases in individuals without comorbidities, evidenced by up to 43% in the first wave and 56% in the second wave (BUTANTAN, 2021). Focusing on lethality, the study revealed the aggressive behavior regarding mortality and lethality of the *Gamma* variant in Brazil, as well as its occurrence in different age groups, punctuating it as a tormentor in the exhaustion of health service resources. However, another study in the same region does not emphasize the worsened viral behavior between the 1st and 2nd waves (ORELLANA *et al.*, 2021; VALENZUELA *et al.*, 2021). It is emphasized that predictive technology uses data, and this data can suffer from feed-back weaknesses in the different systems. In possession of this knowledge, authors punctuate the theory of unpredictability and public management by bringing into discussion exceptionality and measures of extreme urgency (KNOERR & KNOERR, 2020).

The measures suggested for pandemic control permeated notification, testing, physical distancing, and lastly, vaccination. Consisting of a potentially serious, highly transmissible, and globally distributed acute respiratory infection caused by the SARS-CoV-2 virus, Covid-19 is primarily transmitted in three ways: contact, droplets, or aerosols. The epidemiology of SARS-CoV-2 suggests that most infections are spread by close contact (less than 1 meter), primarily through respiratory droplets (Brazil, 2021). To control the transmission of the strain, measures were adopted to minimize the movement of individuals in public and private areas, as well as the physical isolation of the infected and symptomatic (HOUVÉSSOU *et al.*, 2021). Given its importance, it has become a notifiable disease in order to obtain epidemiological data to help map the infections. It is pointed out that record fragilities of multifactorial magnitude, making public management difficult (DO PRADO *et al.*, 2020; SALLAS *et al.*, 2022). Currently, with the advance in the immunization of the population against Covid-19, it is evident the reduction of transmission, especially hospitalizations and deaths, in Amazon, allowing the return of activities considered non-essential, and even the release of masks by the population. However, individuals with comorbidities are advised to maintain hygiene measures and disinfection of surfaces and to use masks in closed environments if there is a risk of worsening the infection (BRASIL, 2022).

CONCLUSION

COVID-19 infection is a young disease, their natural history is happening amidst studies and their population impact variables investigated.

Amazon has characteristics that make it peculiar, and they are: the high population concentration in the capital, the logical-spatial system of transporting people and materials, especially through the predominant use of waterways, besides the transnational borders and the great flow of foreigners and Brazilians that pass through the region daily. These specificities contributed significantly to the state of Amazon, more specifically the capital Manaus, becoming the epicenter of the virus in the country. The city has been heavily impacted since the first wave, not only by the sheer number of cases, but also by the significant geographical distances from the other Brazilian regions, factors that were felt even more sensitively by the advent of the second wave of Covid-19. The month of January 2021 was marked with one of the worst memories of the pandemic. The alarming number of cases has made clear the powerlessness in the face of Covid-19's voracity and lethality. But would the large number of cases be a predictable event? Therefore, back to the main question of this paper: would it be possible to mathematically predict the number of new cases of Covid-19 in the second wave of the virus through mathematical models of high accuracy and recognized worldwide?

The mathematical models GBM and KNN, used in this study, showed a significant difference between the predicted and the actual observed number of cases and deaths from Covid-19 in the second wave of the pandemic in Amazon. Despite the history of these models being of high accuracy in other works, it can be concluded that this difference can significantly impact management decision making, as well as the provision of healthcare services in adequate quantity and quality. However, further studies with different time slices and other predictive modeling are suggested.

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