Forecast predictions for the COVID-19 pandemic in Brazil by statistical modeling using the Weibull distribution for daily new cases and deaths

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Research Article

Keywords: COVID-19, Forecast prediction, Statistical modeling, Weibull

Posted Date: June 9th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-34092/v1>

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Version of Record: A version of this preprint was published at Brazilian Journal of Microbiology on August 27th, 2020. See the published version at <https://doi.org/10.1007/s42770-020-00331-z>.

Brazilian Journal of Microbiology

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Manuscript Number:	BJMI-D-20-00486
Full Title:	Forecast predictions for the COVID-19 pandemic in Brazil by statistical modeling using the Weibull distribution for daily new cases and deaths
Article Type:	Research Paper
Section/Category:	Clinical Microbiology
Funding Information:	
Abstract:	<p>COVID-19 has killed more than 330.000 people worldwide and more than 21,000 Brazilians. Since there are no specific drugs or vaccines, the available tools against COVID-19 are preventive, such as the use of personal protective equipment, social distancing, lockdowns and mass testing. Such measures are hindered in Brazil due to a restrict budget, low educational level of the population and misleading attitudes from the federal authorities. Predictions for COVID-19 are of pivotal importance to subsidize and mobilize health authorities' efforts in applying the necessary preventive strategies. The Weibull distribution was used to model the forecast prediction of COVID-19, in four scenarios, based on the curve of daily new deaths as a function of time. The date in which the number of daily new deaths will fall below the rate of 3 deaths per million, the mean level considered by some countries to relax stay-at-home measures, was estimated. If the daily new deaths curve was bended today (i. e. about 1,250 deaths per day), the predicted date would be on June 18th. Analysis of the lethality rate allowed the estimation of daily new cases and total death toll at the end of the outbreak. Our results suggest that each additional day that lasts to bend the daily new deaths curve can correspond to additional 3,718 deaths at the end of COVID-19 outbreak in Brazil ($R^2 = 0.9938$). Predictions of the outbreak can be used to guide Brazilian health authorities in the decision making to properly fight COVID-19 pandemic.</p>
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Author Comments:	<p>Dear Sirs(Madams)</p> <p>The Original MS attached to this submission brings results based on epidemiological data from COVID-19 outbreak in Brazil. Such results gain special meaning if published as soon as possible. I ask you, if possible, to accelerate the revision process.</p> <p>Thank you and best regards.</p>

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Acknowledgment

To Dr. Ricardo Portela for the critical reading of the manuscript.

To Dr. Gilson Carvalho for valuable discussions of the theme.

Abstract

COVID-19 has killed more than 330.000 people worldwide and more than 21,000 Brazilians. Since there are no specific drugs or vaccines, the available tools against COVID-19 are preventive, such as the use of personal protective equipment, social distancing, lockdowns and mass testing. Such measures are hindered in Brazil due to a restrict budget, low educational level of the population and misleading attitudes from the federal authorities. Predictions for COVID-19 are of pivotal importance to subsidize and mobilize health authorities' efforts in applying the necessary preventive strategies. The Weibull distribution was used to model the forecast prediction of COVID-19, in four scenarios, based on the curve of daily new deaths as a function of time. The date in which the number of daily new deaths will fall below the rate of 3 deaths per million, the mean level considered by some countries to relax stay-at-home measures, was estimated. If the daily new deaths curve was bended today (i. e. about 1,250 deaths per day), the predicted date would be on June 18th. Analysis of the lethality rate allowed the estimation of daily new cases and total death toll at the end of the outbreak. Our results suggest that each additional day that lasts to bend the daily new deaths curve can correspond to additional 3,718 deaths at the end of COVID-19 outbreak in Brazil ($R^2 = 0.9938$). Predictions of the outbreak can be used to guide Brazilian health authorities in the decision making to properly fight COVID-19 pandemic.

Keywords: COVID-19, Forecast predictions, Weibull distribution, Brazil, Death toll

Funding

This work was supported by author's own resources.

Conflicts of interest/Competing interests

The author declares no financial interests or connections, direct or indirect, or other situations that might raise the question of bias in the work reported or the conclusions.

Ethics approval

Not applicable

Consent to participate

Not applicable. VHM is the only author of this MS.

Consent for publication

Not applicable. VHM is the only author of this MS.

Availability of data and material

Not applicable.

Code availability

Not applicable.

Authors' contributions

The Author has gained full consent from the responsible authorities at the institute/organization where the work has been carried out.

Introduction

Since the World Health Organization declared the COVID-19 outbreak a Public Health Emergency of International Concern, in January 30th 2020, more than 4.5 million cases of the disease and 330.000 deaths related with the infection with SARS-CoV2 virus were registered worldwide. The impacts of COVID-19 in low- and middle- income countries (LMICs) are of great concern [1, 2], since in these countries a large percentage of the population live in overcrowded conditions, with deficient access to clean water and sanitizers, among other factors that limit people living in LMICs to follow the public health advices on how to reduce the spread of the virus [3]. Although Brazil has the ninth larger Gross Domestic Product [4], 42 % of the Brazilian population live with less than 10 USD per day and more than ten million Brazilians live in extreme poverty [5]. As in other countries, poverty and social inequality are being aggravated by the COVID-19 pandemic in Brazil. Brazil occupies now the second place in number of registered COVID-19 cases [6]. Forecast predictions made by the Imperial College (London, UK) present Brazil as the country with the highest rate of transmission and one of the countries from where a large number of deaths are expected in the next weeks [7]. The health crisis is sharpened by a political crisis, depicted by a second change of Health Minister in less than one month, [8], and Federal government authorities constantly denying the severity of COVID-19 pandemic and the scientific consensus on the lockdown and social distancing measures [9].

Forecast predictions configure a pivotal strategy for decision making in the evaluation of measures against COVID-19 [10, 13] and should be closely considered by governments and health authorities. In this work, we have used the Weibull distribution on the number of daily new cases and deaths of COVID-19 data to predict the evolution of pandemic [14]. The Weibull distribution is one of the most commonly used parametric lifetime models [15], mostly for its parsimony, its ability to satisfactorily model data which are commonly encountered in survival analysis and its availability in statistical software packages [15, 16]. A parameter called Diagnostic-Death lag (DDlag), that strongly correlates with lethality rate (LR), was calculated using as a base the Brazil's official data. DDlag can be used to predict COVID-19 evolution and to evaluates the LR, as well as to infer the level of underreported cases [14]. We took in account four distinct scenarios based in the daily number of new deaths, considering the maximum of 1,250, 1,500, 1,750 and 2,000 daily new deaths at the peak top of the curve. Because our predictions are based in the number of daily new deaths, it can be daily reviewed with the objective to evaluate the measures further taken to fight the COVID-19 pandemic in Brazil, such as lockdowns and mass testing, and also when these measures should be reformulated.

Material and Methods

Data on Brazil's daily and total number of confirmed cases and deaths were obtained from the Our World in Data Project [6] as comma-spaced values (CSV) files, processed in MS Excel 2019 and exported to Sigma Plot 14.0 with the objective to build scatter and regression plots. Data fitting was performed through Sigma Plot using the Dynamic Fit Wizard Tool and the Weibull 4-parameter integrated to the software, described as:

$$f(\tau) = \begin{cases} 0 & , \quad \tau \leq \tau_0 - \delta \left(\frac{\gamma-1}{\gamma} \right)^{\frac{1}{\gamma}} \\ a \left(\frac{\gamma-1}{\gamma} \right)^{\frac{1-\gamma}{\gamma}} \left| \frac{\tau-\tau_0}{\delta} + \left(\frac{\gamma-1}{\gamma} \right)^{\frac{1}{\gamma}} \right|^{\gamma-1} e^{-\left| \frac{\tau-\tau_0}{\delta} + \left(\frac{\gamma-1}{\gamma} \right)^{\frac{1}{\gamma}} \right|^{\gamma} + \left(\frac{\gamma-1}{\gamma} \right)}, & otherwise \end{cases} \quad (1)$$

where τ is the time; $f(\tau)$ is the number of new cases or new deaths as a function of τ , τ_0 is the time where the maximum of the projected peak is observed (maximum number of daily cases or deaths, or peak top); a is the value of $f(\tau)$ at τ_0 ; γ and δ are constants. Values of a , τ_0 , γ , and δ were calculated in order to find the best fit to τ and $f(\tau)$ data.

The Diagnostic-Death lag (DDlag) was determined as [14]:

$$\Delta\tau_0 = \tau_0^D - \tau_0^C \quad (2)$$

where $\Delta\tau_0 = \text{DDlag}$, τ_0^C is the value of τ on the inflection of the daily new cases curve and τ_0^D is the value of τ on the inflection of daily new deaths curve. The correlation between DDlag and LR was given by [14]:

$$\text{DDlag} = -10 \ln \frac{LR}{0.1927} \quad (3)$$

The forecast predictions in this work were made taking in account four prospective scenarios, based on the maximum number of daily new deaths for COVID-19 registered at the peak (inflection point): 1,250 death per day, as maximum – this is practically the actual scenario (May, 22) and is being considering the most optimistic possibility, and 1,500, 1,750 and 2,000 deaths per day. Data of daily new deaths for COVID-19 in Brazil were fit within the Weibull distribution (Equation 1). Calculations for each scenario were performed by fixing α in Equation 3.

The estimation of the safe date to relaxing lockdown measures in Brazil were done based on that observed in other countries, such as Spain, Italy, Germany and Canada, which start easing lockdown measures when the number of daily new deaths and cases dropped, in average, below 3 deaths and 20 cases per million habitants, respectively, as presented in data from Our World in Data Project [6]. In Brazil, with actual population of 209.5 million habitants, it corresponds to 628 deaths and 4,190 cases, respectively. We do not have parameters to evaluate if this number can be safely considered as a base for health measures against COVID-19 pandemics, however, purely based on the examples previously described for other countries, we used these numbers to project dates for start easing stay-at-home requirements in Brazil.

Constants' standard errors and the fit root square values were obtained in the same software. Error propagation was done as regular rules [17].

Results

Data analysis can be of outstanding importance during disease outbreaks, mainly if fast decision making is crucial to slow down the spread of the disease. The prediction of the course of COVID-19 pandemic in highly affected countries is considered as a live-saving demand [18, 19]. Data on cases and deaths of COVID-19 in Brazil were extracted from Our World in Data Project on Coronavirus [6]. The lethality rate (LR) for COVID-19 in Brazil was calculated using the number of cumulative deaths divided by the number of cumulative registered cases. First case in Brazil was registered on February, 26th. Since then, the LR for COVID-19 in Brazil has grown until it reaches a constant value and maintain it to the end of the outbreak, as normally observed in other countries (data not show). Figure 1 shows that percentual LR for COVID-19 in Brazil reached $(7.0 \pm 0.2) \%$. As LR tends to be constant to the end of the epidemic, this value was used to estimate the maximum number of daily new cases at the peak of the COVID-19 epidemic curve from the number of daily new deaths chosen for each scenario (see Material and Methods). The number of maximum registered daily new cases for each scenario was then calculated as:

$$\alpha_C = \frac{\alpha_D}{LR} \quad (4)$$

Where α_C is the maximum number of daily new deaths and α_D is the maximum number of daily new cases.

Brazil is still facing an exponential growth of daily new deaths and cases, what does not permit acceptable predictions on when the curve is going to bend. Figure 2 shows the plots of the number of daily new deaths and cases as a function of time, in days. Four scenarios are depicted based on the maximum number of daily new deaths, as described under Material and Methods. The forecast projections were done by using the Weibull distribution with the objective to predict the date of the peak maximum (τ_0), the total number of deaths and at the end of pandemic (area under the curve) and the modeled DDlag values. Each Panel shows predictions made from the number of daily new deaths (solid lines) and from the number of daily new cases (traced lines) select for each scenario.

The analysis of the data fit within the Weibull distribution shown in Figure 2, it was possible to predict the numbers of daily new deaths at the forwarding days. As shown, if the number of the daily new deaths at the inflection of the curve increases the lasting of the peak tail would become longer, what would raise the death toll for COVID-19 in Brazil. Table 1 shows the modeled parameters for each one of the four predicted scenarios: number of daily new registered cases; overall death toll; modeled DDlag value; and estimated dates in which the number of daily new deaths and cases will be less than 626 deaths per day and 4,190 cases per day, respectively. These results supply data for supporting of discussion about the importance of the measures to be taken in order to properly fight COVID-19 outbreak.

Discussion

COVID-19 is a global health emergency that is going to change the way in which people, institutions and governments manage their lives and duties. The fact that there is no known specific drugs or vaccines for COVID-19 until now raises the importance of behavioral strategies, such as social distancing, lockdowns [2–7] and mass testing [8, 19, 20] in the fight against the pandemic. Our results show that the LR of COVID-19 in Brazil raised since the beginning of pandemic and reach a percentual value of $7.0 \pm 0.2 \%$. This value may be maintained constant until the end of the outbreak, as observed in other countries (data not shown). With this value, we were able to estimate the maximum number of daily new cases at the peak of the curve, and to model daily new cases curves for each scenario (Figure 2). For this, we multiplied the maximum number of daily new deaths in each considered scenario by the LR (0.07). Comparison analysis of daily new cases and deaths curves made it possible to estimate the DDlag value for each scenario (Table 1). DDlag has been shown to be an efficient, empiric parameter to evaluate the overall results of several governmental initiatives that affects the spread of COVID-19. DDlag displayed strong correlation with the lethality in some countries and can be used as a tool to evaluate the level of sub notification, as well as the efficacy of measures taken in response to the epidemic [14]. As shown in Table 1, modeled DDlag values were much higher than those observed on the curves displayed in Figure 2 for every scenario herein considered. Figure 2 displays that the observed DDlags – i. e., distances in days, between daily new cases and daily new deaths curves – are close to zero, inconsistently related to the values shown in Table 1. Such inconsistencies, as well as values of DDlag close to zero, suggest a severe underreporting, overwhelming of health center, or even both, in Brazil [14].

As also shown in Table 1, the higher the number of daily new deaths, the longer it will last for Brazil to safely relax the stay-at-home measures. Our results suggest that, if the daily new deaths curve bends these days and starts to decrease (i. e. around 1,250 deaths per day), the number of daily new deaths in Brazil would fall under 629 at June, 18th 2020 (Table 1). As the maximum number of daily deaths impacts both the inflection of the curve and the lasting of the curve tail, our projections suggest that each additional day that Brazil takes to bend the daily new deaths curve adds more 3,718 deaths to the overall COVID-19 death counts in Brazil ($R^2 = 0.9938$). Because the forecast predictions on the number of daily new deaths were calculated based on each selected scenario (Figure 2, solid lines), while that one based on the number of daily new cases were estimated from LR (Figure 2, traced lines), we considered the first one more trustable than the last one. Predictions based on daily new cases and deaths are especially efficient because they can be daily revised, offering to governments and health authorities the opportunity of reconducting their measures as new data become available. We believe

that such predictions can be used by decision makers in order to define strategies to fight COVID-19 both in the present days and in the future. These results depict the primal importance of reinforce the strict surveillance measures in Brazil, such as hardening lock-down measures, increasing the number of performed tests, improving the quality of health services and the work conditions of health professionals. These measures might be taken in order to flat the infections curve, i. e. the curves for daily new deaths and cases in view to mitigate the social and economic impact of COVID-19 outbreak in Brazil.

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Figures Captions

Fig 1 Evolution of the lethality rate (LR) during the COVID-19 pandemic in Brazil

LR is given by the number of cumulative deaths divided by the number of cumulative cases. Points were fit within the Weibull equation for cumulative data. Dotted lines represent the 99 % confidential intervals.

Fig 2 Weibull distribution on daily new cases and deaths as a function of time

Data on daily new cases (closed circles) and daily new deaths (open circles) were fit within the Weibull distribution (solid lines for deaths, traced line for cases). Four scenarios with distinct maximum rates at the peak top are shown (a) 1,250 deaths per day; (b) 1,500 deaths per day; (c) 1,750 deaths per day; and (d) 2,000 deaths per day.

Table 1: Forecast projection parameters from modeled curves shown in Figure 2.

Scenario (deaths/day)	Max. registered cases / day	Overall Death toll	Model DDlag (days)	Less than 626 deaths/day ^b	Less than 4,190 cases/day ^b
1,250	17,934 ± 3	78,347 ± 3,691	13.7 ± 0.7	July, 11 th ± 6.4	June, 18 th ± 4.7
1,500	21,521 ± 3	108,871 ± 5,129	19.0 ± 1.2	July, 29 th ± 7.3	June, 24 th ± 4.8
1,750	25,108 ± 4	141,731 ± 6,684	24.0 ± 1.8	August, 14 th ± 8.0	June, 29 th ± 4.9
2,000	28,694 ± 4	176,757 ± 8,336	28.8 ± 2.6	August, 29 th ± 8,7	July, 19 th ± 5.7

^a Errors propagated from standard errors and R^2 and given by fit software.

^b Errors are presented in days.

Figure 1

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Figure 2

Figures

Figure 1

Evolution of the lethality rate (LR) during the COVID-19 pandemic in Brazil. LR is given by the number of cumulative deaths divided by the number of cumulative cases. Points were fit within the Weibull equation for cumulative data. Dotted lines represent the 99 % confidential intervals.

Figure 2

Weibull distribution on daily new cases and deaths as a function of time. Data on daily new cases (closed circles) and daily new deaths (open circles) were fit within the Weibull distribution (solid lines for deaths, traced line for cases). Four scenarios with distinct maximum rates at the peak top are shown (a) 1,250 deaths per day; (b) 1,500 deaths per day; (c) 1,750 deaths per day; and (d) 2,000 deaths per day.