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# Mathematical modeling of global covid-19 fatalities

Marín-Machuca Olegario[1*], Humala-Caycho Yuri Esquilo[2], Chinchay-Barragán, Carlos Enrique[3], Yataco-Velásquez, Luis Andrés[4], Rojas Rueda, María del Pilar[5], Bonilla-Ferreyra, Jorge Luis[6], Luis Adolfo Perez-Ton[7], Marín-Sánchez Obert[8]
[1]School of Food Engineering, Faculty of Oceanography, Fisheries, Food Sciences, and Aquaculture. Research Group on Environmental Sustainability (GISA), Graduate School (EUPG). Universidad Nacional Federico Villarreal (UNFV), Lima. Peru. omarin@unfv.edu.pe (M.M.O.).
[2]School of Aquaculture Engineering. Faculty of Oceanography, Fisheries, Food Sciences, and Aquaculture. Universidad Nacional Federico Villarreal. yhumala@unfv.edu.pe (H.C.Y.E.).
[3]Professional School of Food Engineering, Faculty of Fisheries and Food Engineering, Universidad Nacional del Callao. Callao, Peru. cchinchayb@unac.edu.pe (C.B.C.E.).
[4]Public Administration and Management Program, Faculty of Business. Universidad Privada del Norte. Lima, Peru. luis.yataco@upn.pe (Y.V.L.A.).
[5]School of Human Medicine, Norbert Wiener University, Lima, Peru. maria.rojasr@uwiener.edu.pe (R.R.M.D.P.).
[6]Graduate School in Public Management, Universidad Autonoma del Perú. Lima, Peru. jbonillaf@autonoma.edu.pe (B.F.J.L.).
[7]Professional School of Food Engineering, Faculty of Fishery and Food Engineering, National University of the Callao, Callao, Peru. laperezt@unac.edu.pe (L.A.P.T.).
[8]Faculty of Medicine, Universidad Nacional Mayor de San Marcos. Lima, Peru. omarins@unmsm.edu.pe (M.S.O.).

**Abstract:** Objective. Determine was mathematically modeled using the expression $N = M/(1 + Q \times e^{-k \times t})$, which is a predictive equation. Using this model, the number of deaths due to COVID-19 worldwide was estimated.Design. Correlational, prospective, predictive and transversal study. Participans. The data on deceased individuals due to the COVID-19 disease up to November 5, 2022, was considered. Main measurement. This data was used to analyze the pandemic dispersion, which was determined to exhibit logistic sigmoidal behavior. By deriving Equation 3, the rate of deaths due to COVID-19 worldwide was calculated, obtaining the predictive model represented in Figure 3.Results. Using Equation (5), the critical time $t_c = 447\ days$ and the maximum speed $(\frac{d\hat{N}}{dt})_{máx} = 1\ 525\ 028{,}553\ persons/day$ and the date when the global death rate due to COVID-19 reached its maximum was July 6, 2021. The Pearson correlation coefficient between the elapsed time $(t)$ and the number of deceased individuals $(N)$ worldwide, based on 33 cases, was $r = -0{,}9365$. Conclusions. This indicates that the relationship between elapsed time and the number of deceased individuals is **real**, with no significant difference, showing that the predictive model provides a high estimation of the correlated data.There is a "very strong correlation" between elapsed time $(t)$ and the number of deceased individuals $(N)$ with 87,7 % of the variance in $N$ explained by $t$, ue to the COVID-19 disease. These models help us predict the behavior of disease like COVID-19.
***Keywords:*** *COVID-19 disease, Estimation, Global fatalities, Logistic modeling, Validation.*

## 1. Introduction

The 2019 coronavirus is a virus that causes a respiratory disease, spreading from person to person. It was first identified at the end of 2019 during an investigation of an outbreak in Wuhan, China. It is now known as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), responsible for causing COVID-19. In open environments, it remains suspended in the air and can travel greater distances due to atmospheric turbulence[1] remaining viable for less than three hours. Experimental


* Correspondence: omarin@unfv.edu.pe

studies have shown that the virus can remain viable for at least three hours in aerosols, 24 hours on cardboard, and up to 72 hours on plastic or stainless-steel surfaces. The virus has been detected in the gastrointestinal tract, feces, saliva, and urine, representing potential transmission routes that require further evaluation in the near future[2].

Existing studies on the influenza virus have shown that its airborne transmission is sensitive to climatic conditions[3]. Its transmission increases in the presence of cold air and low humidity[4]; as observed when saliva droplets expelled by infected individuals while speaking or breathing remain suspended in the air, potentially spreading the disease[5].

It is believed that the virus originated in bats and was transmitted to humans in a seafood and live animal market in Wuhan, China, through an intermediate host sold as an exotic species. Approximately 55% of the initial cases were reported in that location. Subsequent transmission occurred through various human activities, with the incubation period being less than 14 days in 95% of cases, supporting the implementation of a 14-day quarantine period[6,7]. In March 2020, the World Health Organization (WHO) declared the COVID-19 outbreak a pandemic[8].

After nine weeks of sustained transmission, officials from Hubei province reported 64,084 confirmed cases, with 2,346 deaths. The actual number of cases is likely much higher, as only the most severe cases were included in the reports due to a shortage of testing kits. The rapid spread of the virus is significantly higher compared to the 2003 SARS-CoV outbreak, suggesting that SARS-CoV-2 is much more transmissible[9].

Chinese authorities responded on January 23, 2020, by placing millions of people in Hubei province under quarantine. It is estimated that five million people left Wuhan before the lockdown began, leading to a sudden increase in cases in the surrounding Chinese provinces[10].

On January 30, 2020, the WHO Director-General reconvened the Emergency Committee (before the 10-day deadline) and just two days after the first cases of person-to-person transmission of the coronavirus outside China were reported. This time, the Emergency Committee reached a consensus and recommended to the Director-General that the outbreak constitutes a Public Health Emergency of International Concern (PHEIC), marking the sixth time the WHO has declared a PHEIC since the International Health Regulations (IHR) came into effect in 2005[11].

On March 18, 2020, the WHO and its partners launched the "Solidarity" trial, an international clinical trial aimed at generating robust data worldwide to identify the most effective treatments against COVID-19. It was acknowledged that transmission among asymptomatic individuals had been the primary cause of the SARS-CoV-2 pandemic's spread[12].

Wang and Cowled[10] mention that fever is the most common symptom, while Guan[13] indicate that only 43.8% of patients had a fever at the time of admission, although the majority developed it during their hospital stay. Yang[14] refers to the fact that 11% of critically ill patients did not present with fever at the onset of symptoms, with alveolar infiltration being the most common radiological pattern.

In China, 80% of confirmed cases exhibited mild to moderate symptoms, 13.8% had a severe clinical course (dyspnea, tachypnea $\geq$ 30/min, $O_2$ saturation $\leq$ 93%, and pulmonary infiltrates in $\geq$ 50% of radiological fields within 24–48 hours), and 6.1% presented a critical course (respiratory failure, septic shock, and/or multiorgan failure). However, the number of asymptomatic individuals remains unknown[11].

The possible risk factors include age, sex, smoking, chronic obstructive pulmonary disease, coronary disease, diabetes, hypertension, carcinoma, chronic kidney disease, and other comorbidities. In a univariate study, the variables significantly associated with higher mortality were age, coronary disease, diabetes, and hypertension[11].

The global evolution of COVID-19 fatalities up to November 5, 2022, the mathematical statistical modeling, the critical time (in days), the rate at which fatalities occurred, and the validation of the estimated data, along with other global public health indicators, represent a significant prevention challenge. These factors undoubtedly serve as reference data for addressing similar issues of mortality in the future.

A logistic-type mathematical model is a tool that helps analyze and estimate disease cases, aiming to describe, explain, and predict epidemics in defined geographical areas. It is used to understand the dynamics of dispersion and, in this case, mortality caused by the disease across various scenarios. Modeling requires the use of tools from infinitesimal calculus[15].

Marín[16] mentions that modeling for COVID-19 was based on determining the relationship between the variation in the number of reported cases ($dN$) and the variation in elapsed time ($dt$), referred to as the rate of reported cases with respect to elapsed time. To estimate COVID-19 infections, the corresponding predictive logistic model was developed. Manrique[17] highlights that mathematically modeling cases and phenomena involving the exponential function of the form $N = M/(1 + Ae^{k \times t})$ is essential.

Failing to apply statistical, mathematical, logistic, and parameter validation knowledge, as well as variation factors, to relate, estimate, predict, or correlate data of a dependent variable such as mortality in terms of one or more independent variables, such as elapsed time or event dates, leads to an imminent scientific preventive gap.

The objectives of this study were to analyze mortality behavior due to COVID-19, compare representations between actual and estimated fatalities, estimate the critical time (in days) to determine the maximum mortality rate, and statistically validate the reliability of the models.

## 2. Methods

### *2.1. Statistical Data*

The methodology used was based on the specific growth constant (*k*), where the conditions of the process impose constraints on the number of deaths caused by COVID-19 worldwide, considering that the constant *k* decreases as the number of deaths increases. This assumes that the *k* of the deceased (growth or decline) depends solely on the number of individuals and not on time-dependent mechanisms, such as non-seasonal phenomena. This led to the determination of a logistic equation whose solution is a logistic function. A mathematical model is a mathematical description, often through a function or equation, of a real-world phenomenon, such as the number of global fatalities caused by COVID-19. Its purpose is to understand deaths and, potentially, make predictions regarding future behavior. The stages covered included: 1) the problem of modeling the number of infections as a function of time; 2) formulating and selecting the logistic model through data dispersion analysis; 3) determining the model, analyzing it, and drawing mathematical conclusions; and 4) making predictions (estimations) about the number of deaths caused by COVID-19 worldwide. It is acknowledged that a mathematical model is never a completely accurate representation; it is an idealization that simplifies the reality of the number of global fatalities caused by COVID-19, yet it is sufficiently precise to support valuable conclusions and foster relevant discussions.

As of February 25, 2023, around 6,832,204 fatalities due to the coronavirus (SARS-CoV-2), caused by COVID-19, have been recorded worldwide. The virus initially originated in the city of Wuhan (China) and has since spread to every country in the world. The accumulated cases of fatalities worldwide as a function of elapsed time (days) are presented in Table 1.

**Table 1**.
Statistical data on the number of fatalities due to COVID-19 worldwide as a function of elapsed time (days).

| Date | Time, t (days) | N (Number of fatalities) |
|---|---|---|
| 03/31/2020 | 0 | 47205 |
| 04/14/2020 | 13 | 144532 |
| 05/26/2020 | 42 | 384344 |
| 06/17/2020 | 63 | 489619 |
| 07/05/2020 | 84 | 576857 |
| 08/16/2020 | 126 | 825733 |
| 09/20/2020 | 161 | 1 021 306 |
| 10/18/2020 | 187 | 1 174 969 |
| 11/29/2020 | 229 | 1 528 933 |
| 12/15/2020 | 243 | 1 707 231 |

| | | |
|---|---|---|
| 01/18/2021 | 278 | 2 124 707 |
| 02/09/2021 | 299 | 2 431 542 |
| 03/24/2021 | 342 | 2 852 496 |
| 04/27/2021 | 376 | 3 260 857 |
| 05/07/2021 | 387 | 3 400 028 |
| 06/18/2021 | 429 | 3 862 475 |
| 07/16/2021 | 457 | 4 087 826 |
| 08/13/2021 | 485 | 4 345 952 |
| 09/25/2021 | 527 | 4 745 551 |
| 10/23/2021 | 561 | 4 948 224 |
| 11/06/2021 | 575 | 5 048 856 |
| 12/30/2021 | 631 | 5 436 623 |
| 01/29/2022 | 659 | 5 665 031 |
| 02/26/2022 | 687 | 5 946 761 |
| 03/25/2022 | 715 | 6 115 681 |
| 04/08/2022 | 728 | 6 168 449 |
| 05/20/2022 | 770 | 6 262 426 |
| 06/17/2022 | 798 | 6 302 937 |
| 07/31/2022 | 842 | 6 382 570 |
| 08/30/2022 | 873 | 6 454 522 |
| 09/16/2022 | 889 | 6 488 025 |
| 10/18/2022 | 921 | 6 534 601 |
| 11/05/2022 | 947 | 6 563 777 |
| 12/15/2022 | 987 | 6 625 253 |
| 01/20/2023 | 1023 | 6 761 565 |
| 02/25/2023 | 1059 | 6 832 250 |

**Note:** Pan american health organization[18].

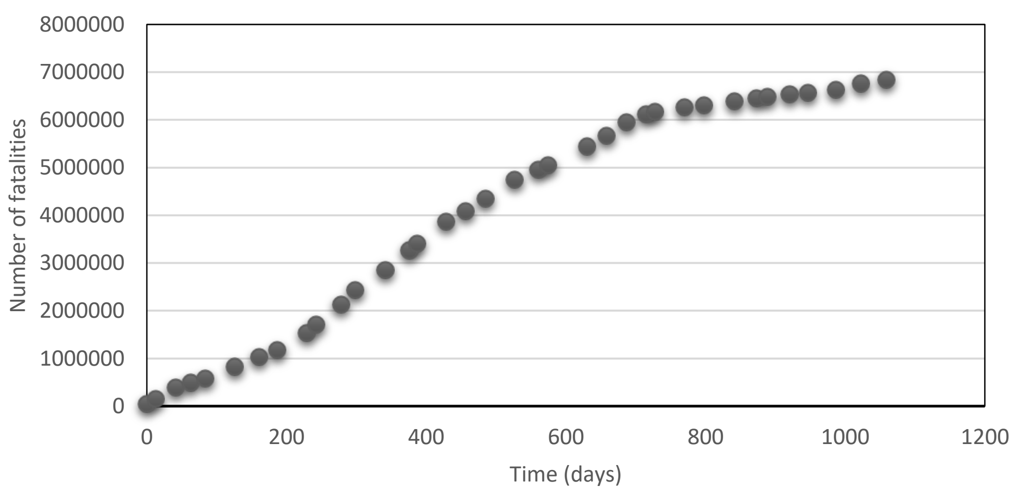


**Figure 1**.
Representation of the number of fatalities due to COVID-19 worldwide as a function of elapsed time (days).

In Figure 1, the evolution of accumulated cases over time is plotted, showing that the number of accumulated cases increases as time progresses.

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Statistical Treatment. Hernández[19] mentions that in the statistical treatment of correlated data, the Pearson correlation coefficient is used, which provides a relative interpretation and indicates the magnitude of the relationship between the dependent and independent variables, with the sign only indicating the direction of the relationship. To validate the obtained models, the significance test of $r$, was performed using the correlation and determination coefficients, aiming to determine whether this value represents a real relationship between the two variables. The standard error of $r$ was calculated using the following expression:

$t_{cal} = \frac{|r|}{\sqrt{1-r^2}} \times \sqrt{N-2}$… (1)

By comparing the student's $t$ values, calculated ($t_{cal}$) and tabulated ( $t_{tab}$) the relationship between elapsed time, $t$(days) and the number of fatalities ($N$), was determined, along with the degree of difference and the estimation of the predictive model.

## 3. Results

For modeling the number of fatalities worldwide ($N$), due to COVID-19 as a function of elapsed time, $t$, (days), we relied on the Empirical Modeling Theory[16].

Analyzing the dispersion of statistical data (Figure 1 and Table 1), it was determined that the model is logistic, of the form $N = \frac{M}{1+A\times e^{k\times t}}$; where "$M$" is the maximum quantity, "$A$" is a pre-exponential quantity, "$k$" is the proportionality constant, "$t$" is the elapsed time of fatalities (days), and "$N$" s the number of fatalities. The value of "$M$" is calculated by considering three independent values and their corresponding dependent values from Table 1. Bronshtein and Semendiaev[20] mention that, to evaluate the maximum value ($M$), preference should be given to the first value ($A$), which corresponds to the moment when the behavior exhibits an inflection point. The second value ($B$) is the last data point, and the third value ($I$) is an intermediate value between $A$ y $B$, specifically the mean of the first and last values. The formula is then applied as follows: $M = \frac{A\times B - I^2}{A+B-2I}$ …(2)

First value: $t_1 = 387\ days$, corresponding to: $A = 3\ 400\ 028\ fatalities$

Second value: $t_2 = 1\ 059\ days$, corresponding to: $B = 6\ 832\ 250\ fatalities$

Third value: $t_3 = \frac{387+1059}{2} = 723\ days$, corresponding to: $I = 6\ 149\ 819\ fatalities$

Now, replacing into Equation (1): $M = \frac{3400028\times 6832250 - 6149819^2}{3400028+6832250-2(6149819)} = 7057519\ fatalities$

The model $N = \frac{M}{1+A\times e^{k\times t}}$ can then be written as: $N = \frac{7057519}{1+Q\times e^{k\times t}}$

Applying the method of least squares to the expression $\ln\left(\frac{7057519}{N} - 1\right) = Q + k\times t$; the estimation model is obtained.

$\hat{N} = \frac{7057519}{1+18{,}9727\times e^{-0{,}0063\times t}}$…(3)

With a correlation coefficient of $r = -0{,}9728$. By deriving Equation (3) the velocity equation for fatalities is obtained, expressed as Equation (4).

$\frac{d\hat{N}}{dt} = \frac{848304{,}4693\times e^{-0{,}0063\times t}}{(1+18{,}9727\times e^{-0{,}0063\times t})^2}$…(4)

By deriving Equation (4) and setting it equal to zero, the critical time ($t_c$) is determined, at which the velocity of fatalities is maximum.

$t_c = -\frac{1}{k}\times \ln\left({}^{1}/_{Q}\right)$… (5)

Therefore $t_c = 465\ days$ and the maximum velocity is $(\frac{d\hat{N}}{dt})_{máx} = 11\ 177{,}4525\ persons/day$

According to the calendar, the maximum velocity of fatalities due to COVID-19 worldwide occurred on July 24, 2021.

**Table 2**.
Number of fatalities, estimated fatalities, and estimated velocity of fatalities due to COVID-19 worldwide as a function of elapsed time (days).

| **Time, t (days)** | **N (Number of fatalities)** | $\widehat{N}$ | $dN/dt\,(Persons/day)$ |
|---|---|---|---|
| 0 | 47205 | 353358 | 21265627 |
| 13 | 144532 | 381885 | 22804592 |
| 42 | 384344 | 455316 | 26885507 |
| 63 | 489619 | 513003 | 30138103 |
| 84 | 576857 | 579608 | 33704504 |
| 126 | 825733 | 736847 | 41807951 |
| 161 | 1 021 306 | 895560 | 49537251 |
| 187 | 1 174 969 | 1031651 | 55804718 |
| 229 | 1 528 933 | 1287155 | 66673381 |
| 243 | 1 707 231 | 1382588 | 70432309 |
| 278 | 2 124 707 | 1644209 | 79898472 |
| 299 | 2 431 542 | 1816909 | 85473904 |
| 342 | 2 852 496 | 2205560 | 96062636 |
| 376 | 3 260 857 | 2542599 | 103049617 |
| 387 | 3 400 028 | 2656377 | 104947857 |
| 429 | 3 862 475 | 3106807 | 110181355 |
| 457 | 4 087 826 | 3416052 | 111665588 |
| 485 | 4 345 952 | 3727041 | 111426693 |
| 527 | 4 745 551 | 4186331 | 107898074 |
| 561 | 4 948 224 | 4542667 | 102551500 |
| 575 | 5 048 856 | 4683559 | 99808583 |
| 631 | 5 436 623 | 5203942 | 86588782 |
| 659 | 5 665 031 | 5434774 | 79168104 |
| 687 | 5 946 761 | 5644665 | 71590271 |
| 715 | 6 115 681 | 5833522 | 64095831 |
| 728 | 6 168 449 | 5914179 | 60699954 |
| 770 | 6 262 426 | 6145646 | 50306053 |
| 798 | 6 302 937 | 6276799 | 43989803 |
| 842 | 6 382 570 | 6449526 | 35200170 |
| 873 | 6 454 522 | 6549629 | 29861033 |
| 889 | 6 488 025 | 6595138 | 27374256 |
| 921 | 6 534 601 | 6674983 | 22921397 |
| 947 | 6 563 777 | 6730098 | 19780904 |
| 987 | 6 625 253 | 6800376 | 15697371 |
| 1023 | 6 761 565 | 6851028 | 12699150 |
| 1059 | 6 832 250 | 6891946 | 10243513 |

The estimated number of fatalities due to COVID-19 worldwide is determined by Equation (3) and represented in Figure 2.

The estimated velocity of fatalities due to COVID-19 worldwide is determined by Equation (4) and represented in Figure 3.

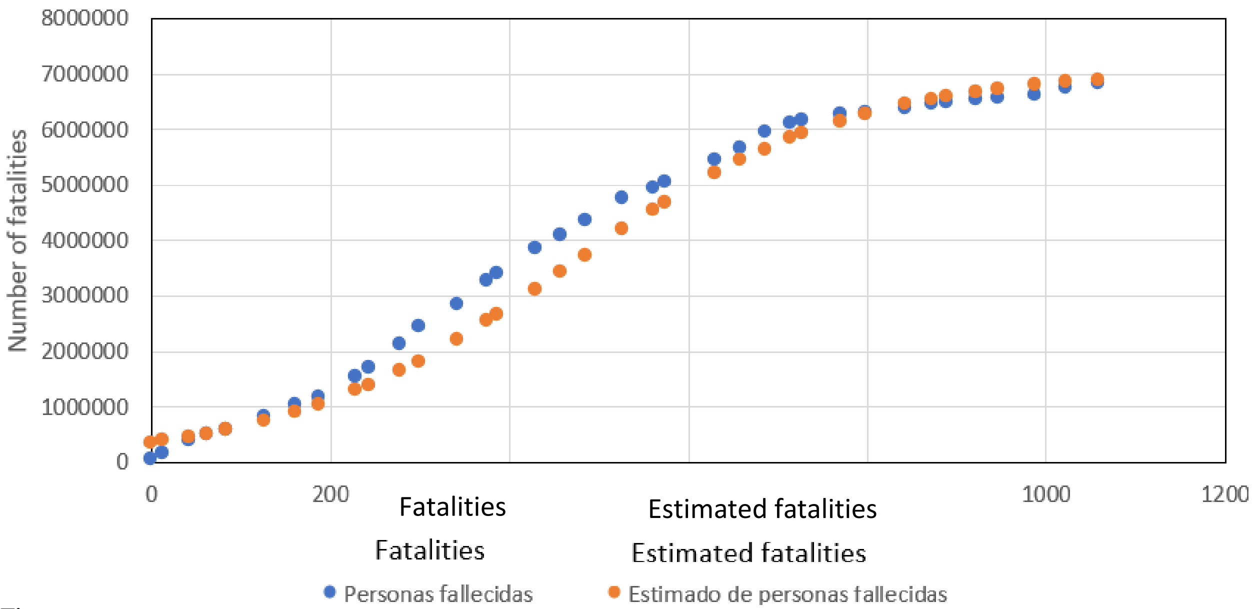


**Figure 2**.
Representation of the number of fatalities and the estimated number of fatalities as a function of elapsed time (days).

Figure 2 represents the accumulated number of fatalities and the estimated number of fatalities due to COVID-19 worldwide as a function of elapsed time.

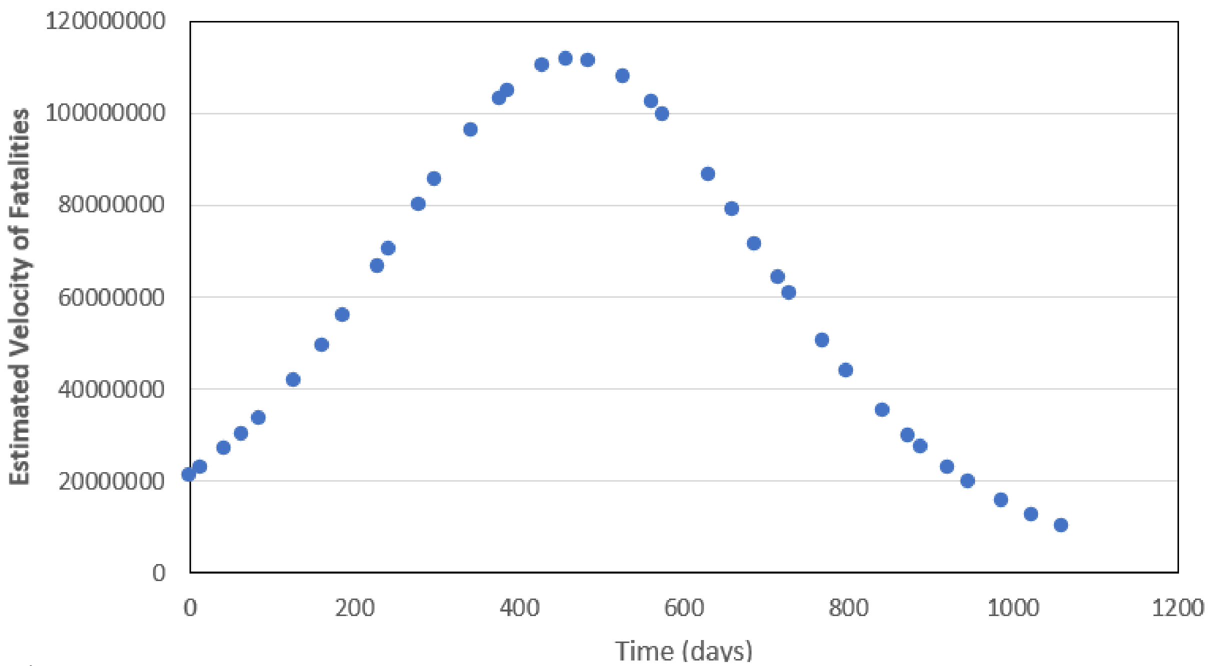


**Figure 3**.
Estimated velocity of fatalities (persons/day) due to COVID-19 worldwide as a function of elapsed time (days).

In Figure 3, the estimated velocity of fatalities (persons/day) due to COVID-19 worldwide is plotted as a function of elapsed time.

Significance test of $r$. The Pearson correlation coefficient "$r$" between elapsed time t, (days) and the number of fatalities ($N$), worldwide due to COVID-19, based on 36 cases, was $r = -0{,}9728$; The standard error of $r$ was calculated using the following expression:

$$t_c = \frac{|r|}{\sqrt{1-r^2}} \times \sqrt{N-2} \ldots (1)$$

$$t_c = \frac{|-0{,}9728|}{\sqrt{1-(-0{,}9728)^2}} \times \sqrt{36-2} = 24{,}4871 \quad \text{and} \quad t_{t(34;0{,}95)} = 1{,}6955$$

Interpretation: Since $t_{cal} = 24{,}4871$ is greater tan $t_{tab} = 1{,}6955$; it is concluded that the relationship between time, $t$(days) and the number of fatalities ($N$) is real; Therefore, there is no significant difference, and the predictive model provides a high estimation of the correlated data. There is a "very strong correlation" between elapsed time ($t$) and the number of fatalities ($N$) with 94,67 % of the variance in $N$ explained by $t$; for the global number of fatalities due to COVID-19.

## 4. Discussion

The mathematical model (Equation 3) to estimate the number of fatalities due to COVID-19 worldwide proved to be quite reliable, achieving a Pearson correlation coefficient of $\boldsymbol{r = -0,9728}$, consistent with what was reported by Florencio[15]. Using Equation 5, the critical time ($t_c$) was estimated to be 465 days, corresponding to the maximum estimated velocity of infections worldwide due to COVID-19, which was $11\,177{,}4525\ persons/day$. According to the calendar, this occurred on July 24, 2021, aligning with the findings of Manrique et al[17] and Marín et al[16]. The predictive mathematical model (Equation 3), the proportionality constant ($k = -0{,}0063$) and the correlation ($r = -0{,}9728$) and determination ($r^2 \times 100 = 94{,}67\%$) coefficients are of great importance for analyzing and estimating data related to epidemiological and pandemic phenomena, which coincides with the observations of Hernández et al[19].

It is concluded from the study that the theory of Bronshtein and Semendiaev[20] can be applied without difficulty, provided that the timing (time) of processes or phenomena is carefully considered, particularly when they exhibit behavior that does not always ascend or descend continuously. Logistic (factual) models can generally be applied, with the utmost rigor, to pandemic and epidemiological phenomena, offering high resolution and a strong degree of estimation compared to real data. Statistical analysis determined that the correlation coefficient of Equation 3 indicates a "very strong negative correlation" between the number of fatalities and elapsed time, with 94.67% of the variance in $N$ explained by $t$; for the global number of fatalities due to COVID-19.

It is recommended that the statistical data for the dependent variable (number of people infected with COVID-19) be analyzed as a function of more than one independent variable. Additionally, the data for the independent variable should be evenly spaced to enable the application and improvement of other calculation, analysis, and interpretation techniques.

## Copyright:



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