Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 1, 381-392
2025
Publisher: Learning Gate
DOI: 10.55214/25768484.v9i1.4135

Prediction of deaths from COVID-19 with the modified logistic model, in Peru

Marín Machuca, Olegario[1,2,3*], Vargas Ayala, Jessica Blanca[4], Pérez Ton, Luis Adolfo[5], Chinchay Barragán, Carlos Enrique[6], Rojas Rueda, María del Pilar[7], Huaranja Montaño, Max Alejandro[8], Sernaqué Auccahuasi, Fernando Antonio[9]

[1]Professional School of Food Engineering, Faculty of Oceanography, Fisheries, Food Sciences and Aquaculture, Federico Villarreal National University, Lima 15074, Peru; omarin@unfv.edu.pe (M.M.O.).
[2]Graduate University School, Federico Villarreal National University, Lima 15001, Peru.
[3]Environmental Sustainability Research Group (GISA), Lima 15001, Peru.
[4]Academic Department of Aquaculture, Faculty of Oceanography, Fisheries, Food Sciences and Aquaculture, Universidad Nacional Federico Villarreal, Lima 15074, Peru; jvargas@unfv.edu.pe (V.A.J.B.).
[5,6]Professional School of Food Engineering, Faculty of Fisheries and Food Engineering, Universidad Nacional del Callao. Callao, Peru; laperezt@unac.edu.pe (P.T.L.A.) cchinchayb@unac.edu.pe (C.B.C.E.).
[7]Professional School of Human Medicine, Norbert Wiener University, Lima, Peru; Maria.Rojasr@wiener.edu.pe (R.R.M.D.P.).
[8]University Graduate School (EUPG), Federico Villareal National University. Lima, Peru; 2022032509@unfv.edu.pe (H.M.M.A.).
[9]Faculty of Geographical, Environmental and Ecotourism Engineering, Federico Villarreal National University, Lima 15082, Peru; fsernaque@unfv.edu.pe (S.A.F.A.).

Abstract: COVID-19 is a public health millions of deaths since the end problem that has had an international impact that has led to of 2019, and the Peruvian population was no stranger to this situation. Therefore, the following investigation was conducted to correlate mortality from COVID-19, estimate the critical time (days) for the maximum rate of estimated deceased people, and validate the reliability of the models. Data on people who died from COVID-19 up to February 27, 2023, were considered, with which the pandemic dispersion was carried out, arriving to determine that they describe a sigmoidal logistic dispersion, an event that was mathematically modeled using the predictive logistic equation N=M⁄((1+A×e^(-k×t))). Using this predictive mathematical model, the number and rate of deaths among people with COVID-19 in Peru were determined. In addition, the critical time (t_c) was estimated, whose value was t_c=396 days for the maximum rate 〖((dN⁄dt)〗_máx=484.7450 people/day, and the date on which the maximum rate of people who died from COVID-19 was April 15, 2021. The Pearson correlation coefficient between the time elapsed (t) and the number of deceased people (N) in Peru, based on 32 cases, turned out to be r=-0.89085; determining that the relationship is real, that there is a non-significant difference, that the predictive model has a high estimate of the correlated data, that there is a " very strong correlation " between the time elapsed (t) and the number of deceased people (N), and that 79.4% of the variance in N is explained by t; for people who died from COVID-19 in Peru.

Keywords: *COVID-19, Deceased in Peru, Estimate, Logistics modeling, Validation.*

1. Introduction

Coronavirus disease 2019 (COVID-19) is a person-to-person respiratory disease virus that was first identified in late 2019 during an outbreak investigation in Wuhan, China. It is currently known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and is responsible for causing COVID-

History: Received: 26 November 2024; Revised: 30 December 2024; Accepted: 6 January 2025; Published: 8 January 2025
* Correspondence: omarin@unfv.edu.pe

19. It remains suspended in the air in open environments and travels over large distances due to atmospheric turbulence. and remains viable for less than 3 hours [1], whereas in closed environments, they are deposited superficially, and their activity continues. Experimental studies have shown that the virus can persist 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, and its potential transmission routes need to be evaluated in the near future [2].

On March 18, 2020, World Health Organization (WHO) and its partners launch the "Solidarity" trial, an international clinical trial that aims to generate robust data from around the world to find the most effective treatments against COVID-19. Today, it is accepted that contagion among asymptomatic subjects has been the main cause of the extension and propagation of the SARS-CoV-2 pandemic [3], and its spread speed was higher than that of SARS-CoV in 2003 [4].

The possible risk factors included age, sex, smoking status at the time of infection, chronic obstructive pulmonary disease, coronary disease, diabetes, arterial hypertension, carcinoma, chronic kidney disease, and other comorbidities. In a univariate study, the following variables were significantly associated with higher mortality: age, coronary disease, diabetes, and hypertension [5].

On March 6, 2020, the first case of coronavirus was reported in Peru and since then the progress of the pandemic has been evaluated by the Ministerio de Salud del Peru (MINSA) and reported to the public, with 59.2% of cases in adults, that the highest cumulative incidence rates correspond to the group of adults and the elderly; that the analysis of the ratio of incidence rates is 12 times more in adults compared to the rate of children and so far in the pandemic in Peru, cough, fever, general malaise and sore throat are the most frequent symptoms [6].

The evolution of the death of people in Peru by COVID-19 until February 27, 2023, in terms of determining the highest mortality, statistical mathematical modeling, critical time (days), the rate at which the death developed, validation of the estimated data, along with other Peruvian and global public health indicators, constitutes a true problem of prevention, which surely serves as referential data to face similar problems of deaths [4].

As of February 27, 2023, approximately 219,000 deaths from the pandemic have been registered in Peru according to the Chinese CDC series, with a total of 1,023 deaths among confirmed cases (44,672) and a gross lethality of 2.3 %. The age group older than 80 years had the highest lethality among all the age groups (14.8 %). Patients without comorbidities had a case fatality rate of 0.9 % compared to patients with comorbidities who had higher rates: 10.5 % for those with cardiovascular disease, 7.3 % for diabetes, 6.3 % for chronic respiratory disease, 6.0 % for hypertension, and 5.6 % for cancer [7].

A mathematical model of the logistic type is a tool that helps us analyze and estimate the problems caused by diseases. Its objective is to describe, explain, and predict phenomena such as epidemics in specific geographical areas, aiming to understand the dynamics of dispersal and, in this case, mortality due to the disease in various scenarios [8]. These models, including the long short-term memory (LSTM) model for predicting the number of weekly and daily COVID patients [9] the age-stratified mathematical model for describing differences in biological susceptibility to the disease based on age and evaluating the morbidity rate per infection [10, 11] and the exponential model for estimating the growth of new COVID cases [12], have demonstrated good accuracy in forecasting the behavior of the infection.

Marín-Machuca, et al. [7] mention that the modeling for COVID-19 was based on determining the relationship between the variation in the number of reported cases (dN) and the variation in the time elapsed (dt), called velocity of cases reported with respect to the time of what happened in China. To find a relationship that adequately estimated the COVID-19 infections, a corresponding predictive logistic model was obtained. Manrique-Abril, et al. [13] mentioned that mathematically modeling cases and phenomena that contain the exponential function of the form $N = M/(1 + Ae^{k \times t})$…(1); where "$M$" is a maximum possible quantity, "A" is a pre-exponential quantity, "k" is a constant of proportionality, "t" is the elapsed time of contagion (days) and "N" is the number of deaths. It is

DOI: 10.55214/25768484.v9i1.4135

induced to evaluate the values of the constant of proportionality (k) or rate of change of the contagious phenomenon and A it is a pre-exponential factor. The objectives of the present study were to analyze the mortality behavior in Peru due to the SARS-CoV-2 pandemic, which caused COVID-19, compare the representations between deceased and estimated deceased, estimate the critical time (days) for the rate number of estimated deceased people, and statistically validate the reliability of the models.

2. Methodology

2.1. Data Sources

The methodology used was based on the specific growth constant (k), where the conditions of the process will exercise restrictions on deaths from COVID-19 in Peru, bearing in mind that the constant k will decrease as infections increase, and starting from the fact that the k of the deceased only depends on the number of people and not on time-dependent mechanisms, such as non-seasonal phenomena, arriving to determine a logistic equation, in which its solution is a logistic function and whose purpose is to understand the number of deaths and why not make predictions regarding future behavior. The stages covered were: 1) the problem of modeling the number of deaths as a function of time, 2) formulating and choosing, through the dispersion of the data, the logistic model, 3) determining the model, analyzing it, and drawing mathematical conclusions, and 4) making predictions (estimates) about the number of deaths from COVID-19 in Peru and the rate at which deaths have occurred. Considering that the mathematical model is never a completely accurate representation and that it is only an idealization that simplifies the reality of those who died from COVID-19 in Peru, it is accurate enough to promote valuable conclusions and relevant discussions.

As of February 27, 2023; 219,431 people have died from the coronavirus (SARS-CoV-2) in Peru, causing the disease COVID-19, which initially originated in the city of Wuhan (China) and has spread to every country in the world [7]. The accumulated cases of deceased people in our country based on the elapsed time (days) are presented in Table 1.

Table 1.
Statistical data on the number of people who died from COVID-19 in Peru based on the time elapsed (days).

Date	Time. t (Days)	N (Accumulated cases)
03/16/2020	0	13
04/07/2020	22	498
05/15/2020	60	12.557
06/22/2020	98	34.757
07/31/2020	137	57.462
08/24/2020	161	71.839
09/07/2020	175	77.609
10/15/2020	213	85.855
11/21/2020	250	90.072
12/29/2020	288	94.448
02/06/2021	327	109.551
03/16/2021	365	135.306
04/23/2021	403	164.069
05/31/2021	441	186.385
07/09/2021	480	195.385
08/14/2021	516	198.605
09/21/2021	554	200.208
10/29/2021	593	201.372
12/07/2021	631	202.653
01/14/2022	668	204.280
02/20/2022	705	210.189
03/30/2022	743	212.290
05/07/2022	781	212.956
06/14/2022	819	213.405

ISSN: 2576-8484
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07/23/2022	858	214.111
08/30/2022	896	215.816
09/07/2022	904	216.069
11/10/2022	938	216.830
11/05/2022	963	217.030
12/25/2022	1.013	218.072
01/11/2023	1.030	218.455
02/27/2023	1.077	219.431

Source: Sistema Informático Nacional De Defunciones [14].

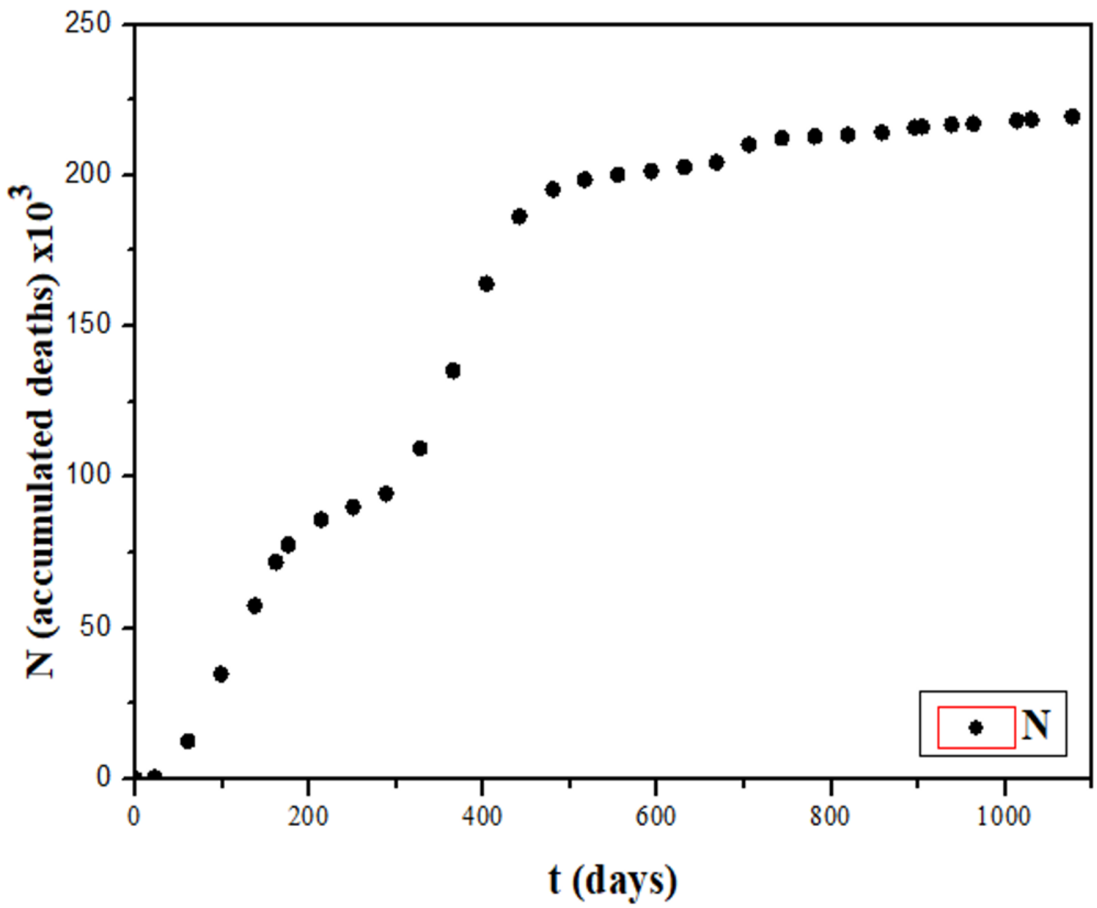

Figure 1.
Representation of the number of people who died from COVID-19 in Peru based on the elapsed time (days).

In Figure 1, the evolution of accumulated cases is plotted as a function of time, showing that the accumulated cases increase with time.

2.2. Statistical Treatment

The model was evaluated according to the following criteria:

1. R-Squared Score. According to Lupón, et al. [15] is a measure that quantifies the relationship between the dependent variable and the mathematical model. The points around the regression are quantized in the closed interval of 0 to 100%.

$$R^2 = \frac{Variance\ explained\ by\ the\ model}{Total\ Variance}$$

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2. Adjusted R-Squared Score. t is a modified model of R^2, it serves as an indicator to quantify how close the points of the curve are. where n is the data size and k is the number of independent variables in the regression equation [15].

$$R^2_{ajusted} = 1 - (1 - R^2)\frac{(n-1)}{n-(k+1)}$$

3. Mean Absolute Error (MAE). The mean absolute error is the average magnitude between the data predicted by the model and the values obtained from the real world, in this measure each pair of data that is compared has the same weight. Where n is the number of data, is the theoretical value and $\hat{y}_j$ is the value obtained from the real data [16].

$$MAE = \frac{1}{n}\sum_{j=1}^{n}\left|N_j - \hat{N}_j\right|$$

4. Mean Square Error (MSE). It is used to measure the efficiency of the model. It is calculated by means of the difference between the theoretical value and the real value, square it, all the values are positive, and it is characterized by the fact that it applies better when the differences between the compared values are greater [16].

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(N_i - \hat{N}_i\right)^2$$

5. Root Mean Square Error (RMSE). Calculates the errors of the predicted values. These values are the residuals between the predicted value and the actual value, it explains how close the actual values are to the model [16].

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(N_i - \hat{N}_i\right)^2}$$

Hernández and Fenández [17] mentioned that in the statistical treatment of correlated data, there is a Pearson correlation coefficient, which has a relative interpretation and indicates the magnitude of the relationship between the dependent and independent variables, and the sign only indicates the direction of the relationship. To validate the models obtained, using the correlation and determination coefficients, a significance test was performed r, to determine if this value represents a real relationship between the two variables. The standard error of r was calculated using the expression:

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

Comparing those t of Student, calculated (t_{cal}) and table (t_{tab}), the relationship between the elapsed time t (days) and the number of deceased people (N), the degree of difference and the estimate of the predictive model was determinate.

2.3. Correction of the Estimated Logistic Model

Marín-Machuca, et al. [18] mention that the models that present an effect called "loop", similar to a hysteresis phenomenon, as can be seen in Figure 2, a factor of correction ("period") for the independent variable *t*. For this purpose, parameter T was evaluated, which acts as the period given by the expression (3):

$T = \frac{\sum_{t_1}^{t_n}(N - f(t))}{n(\Delta t)}$… (3)

3. Results

To model the behavior of the number of people who died from COVID-19 in Peru, we based ourselves on the Empirical Modeling theory [19] on the number of people who died (N), as a function of the elapsed time, t (days). Determining the behavior (figure 1) of the statistical data (Table 1) of the number of people who died from COVID-19, it has been considered that the model is logistic, of the type of equation (1). The method of calculating M is by considering three independent values and their corresponding dependent values from Table 1. Bronshtein and Semendiaev [19] mentioned that to obtain the maximum values (M) and for this type of logistic model, the first value (P) must be precisely at the moment in which the behavior presents an inflection point, the second value (Q) is the last data and the third value (I) is an intermediate value between the values P and Q. This intermediate value is the average of the first and last values. The following formula was then applied:

$M = \frac{P \times Q - I^2}{P + Q - 2I}$...(4)

First value: $t_1 = 365\ days$, corresponds to: $P = 135{,}306$ deaths

Second value: $t_2 = 1{,}077\ days$, corresponds to: $Q = 219{,}431$ deaths

Third value: $t_3 = \frac{365+1\ 077}{2} = 721\ days$, corresponds to: $I = 211{,}416$ deaths

Now, we substitute into equation (4). $M = \frac{135{,}306 \times 219{,}431 - 211{,}416^2}{135{,}306 + 219{,}431 - 2(211{,}416)} = 220{,}374$ deaths

The model $N = \frac{M}{1 + A \times e^{K \times t}}$ can be written $\widehat{N} = \frac{220{,}374}{1 + A \times e^{k \times t}}$

Applying the method of least squares to the expression $\ln\left(\frac{220{,}374}{N} - 1\right) = A + k \times t,$ we obtain the prediction or estimation model.

$\widehat{N} = \frac{220{,}374}{1 + 32.5421 \times e^{-0.0088 \times t}}$...(5)

With a correlation coefficient $r = -0.89085$. Deriving equation (5), the equation for the rate of infected people is obtained and expressed by equation (6).

$\frac{dN}{dt} = \frac{63{,}098.55672 \times e^{-0.0083 \times t}}{(1 + 32.5421 \times e^{-0.0083 \times t})^2}$...(6)

Deriving equation (6) and equaling it to zero, it is possible to determine the critical time (t_c) for which the rate of the infected people is maximum.

$t_c = -\frac{1}{k} \times \ln\left({}^{1}/_{A}\right)$... (7)

Then: $t_c = 396\ days$ and the maximum velocity is $\left(\frac{dN}{dt}\right)_{máx} = 484.7450\ deaths/day$

Scheduling the process of people who died from COVID-19 in Peru; April 15, 2023, was the date on which there was the maximum rate of deaths.

The number of estimated deaths in Peru due to COVID-19 is determined by equation (3) and is represented in figure 2. The rate of estimated deaths due to COVID-19 is determined by equation (6) and is represented in Figure 3. In addition, Table 2 presents the data on time, accumulated deaths, estimated accumulated deaths, and the rate of estimated deaths due to COVID-19 in Peru.

Table 2.
Time data, accumulated cases of deaths, estimated deaths, and rate of deaths estimated by COVID-19 in Peru.

Time. t (Days)	N (Accumulated deaths)	$\widehat{N}$	dN/dt $(people/day)$	$\widehat{N}_m$
0	13	6.570	56.0840	11.521
22	498	7.923	67.2054	13.841
60	12.557	10.913	91.2682	18.900
98	34.757	14.953	122.6400	25.578
137	57.462	20.506	163.6321	34.473
161	71.839	24.786	193.5533	41.109
175	77.609	27.628	212.6135	45.413
213	85.855	36.769	269.5371	58.730
250	90.072	47.847	329.5851	73.857
288	94.448	61.542	390.2665	91.168
327	109.551	77.840	442.9689	109.991
365	135.306	95.373	475.9832	128.352
403	164.069	113.704	484.2516	145.731
441	186.385	131.843	466.0206	161.338
480	195.385	149.263	423.7820	175.023
516	198.605	163.597	370.8539	186.208
554	200.208	176.523	309.0515	194.229
593	201.372	187.353	247.0015	201.197
631	202.653	195.688	192.8745	206.324
668	204.280	201.976	148.3674	210.064
705	210.189	206.773	112.2853	212.845
743	212.290	210.465	83.2659	214.942
781	212.956	213.190	61.1521	216.466
819	213.405	215.184	44.5933	217.568
858	214.111	216.666	32.0762	218.379
896	215.816	217.707	23.1803	218.945
904	216.069	217.886	21.6401	219.042
938	216.830	218.524	16.1383	219.389
963	217.030	218.887	12.9943	219.582
1.013	218.072	219.414	8.4092	219.865
1.030	218.455	219.547	7.2495	219.936
1.077	219.431	219.826	7.8061	220.085

Note: $\widehat{N}$: Estimated deaths
$\widehat{N}_m$: Modified estimate of deaths.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 1: 381-392, 2025
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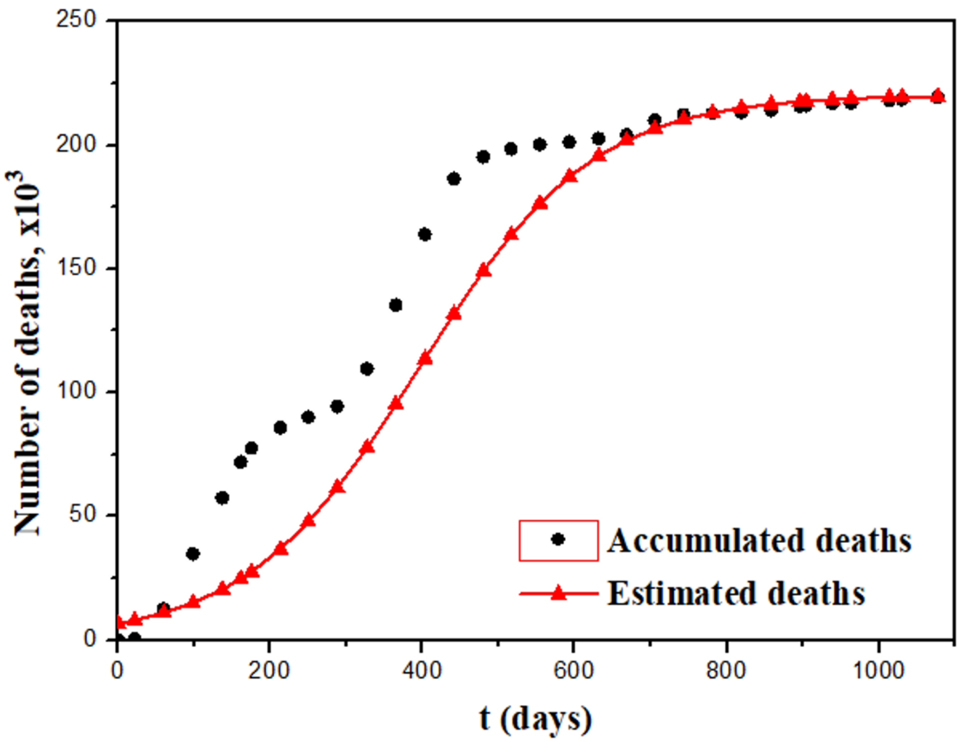

Figure 2.
Representation of the number of deaths and the estimated number of deaths from COVID-19 in Peru based on the time elapsed (days).

In Figure 2 The number of deaths and the number of estimated deaths from COVID-19 in Peru are represented based on the time elapsed, the accumulated cases and the mathematical model used.

DOI: 10.55214/25768484.v9i1.4135

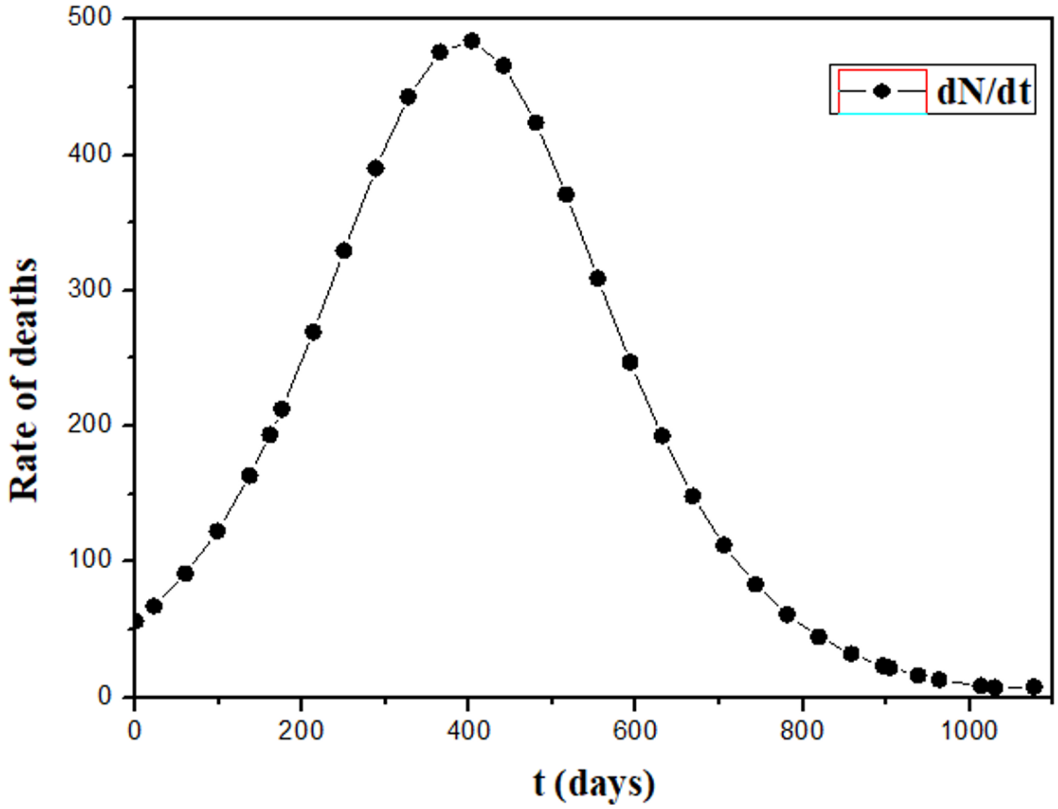

Figure 3.
Rate of the number of people estimated to have died (people/day) due to COVID-19 in Peru based on the time elapsed (Days).

In Figure 3, the rate of the number of estimated deaths (people/day) by COVID-19 in Peru is graphed as a function of the time elapsed, and the maximum point in time of 396 days was observed.

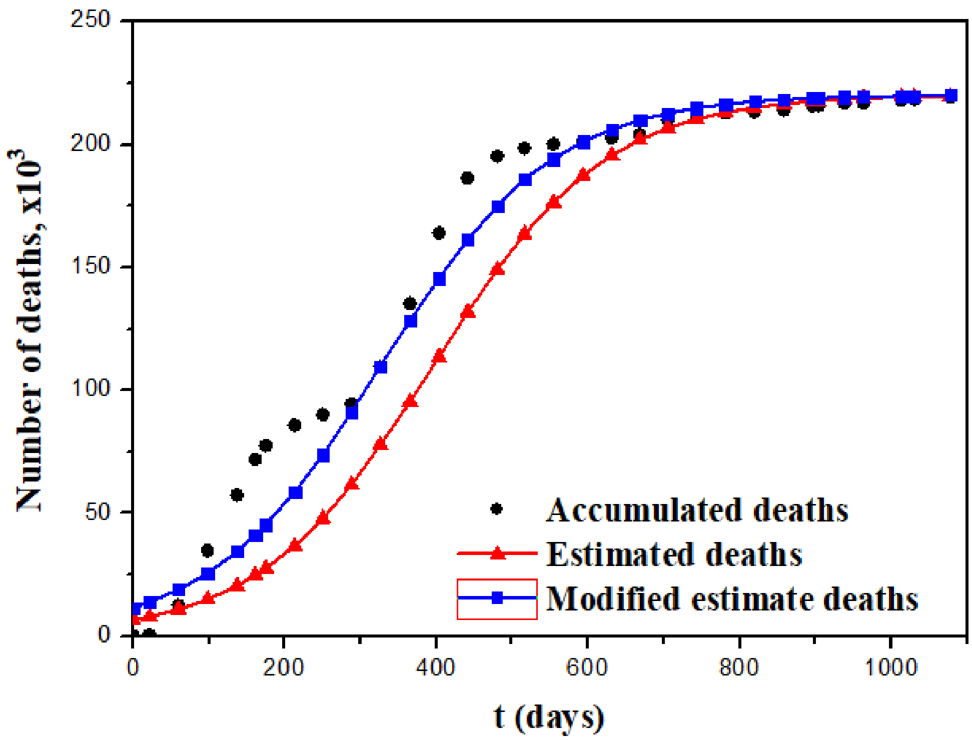

Figure 4.
Representation of accumulated (N), estimated ($\widehat{N}$), and modified estimate ($\widehat{N}_m$) deaths.

Pearson N correlation coefficient " r" for the elapsed time t (days) and the number of people who died (N) in Peru from COVID-19 based on 32 cases was $r = -0.89085$. The standard error of r was calculated using the equation (1):

$$t_{cal} = \frac{|-0.89085|}{\sqrt{1-(-0.89085)^2}} \times \sqrt{32-2} = 23.64201$$

and $t_{t(30;0.95)} = 1.7033$

Because $t_{cal} = 23.64201$ is greater than $t_{tab} = 1.7033$; it is concluded that the relationship between time, t(days) and the number of deceased people (N) is real; therefore, there is a non-significant difference and that the predictive model (equation 2) has a high estimate of the correlated data and that there is a "very strong correlation" between the time elapsed (t) and the number of deceased people (N) and that the 79.4 % of the variance in N is explained by t; for the number of people who died from COVID-19 in Peru.

In addition, the parameter T, which acts as the period, was calculated, resulting in,

$$T = \frac{\sum_{t=98}^{t=593}(N - f(t))}{15(593-98)} = \frac{\sum_{t=98}^{t=593}(N - \widehat{N})}{15(593-98)} = \frac{490{,}833}{7{,}425} = 66.1055$$

$\widehat{N} = \frac{220{,}374}{1+47.38779\times e^{-0.00855\times(t+66.1055)}} \cdots (6)$

To compare the logistic model and the modified logistic model, three equations were used to quantify the errors, namely MAE (Mean Absolute Error), MSE (Mean Squared Error), and RMSE (Root Mean Squared Error). In all cases, it was found that the modified logistic model has lower error compared to the logistic model, indicating a better fit of the data to the proposed model.

Table 3.
Parameter values.

No	Parameter	Logistic model	Modified logistic model
1	R-squared score	79.40%	97.59 %
2	Adjusted R-squared score	84.25%	84.25%
3	Mean absolute error (MAE)	19.318	9.514
4	Mean square error (MSE)	755'092,668	178'640,321
5	Root mean square error (RMSE)	27.479	13.366

4. Results and Discussion

The mathematical model (equation 3) to estimate the number of people who died from COVID-19 in Peru turned out to be acceptable, reaching a Pearson correlation coefficient of , $r = -0.89085$ coinciding with what was reported by Florencio [8]. From the mathematical model of rate (equation 4), it is estimated that the critical time (t_c) is 396 días, which corresponds to the maximum rate of people estimated to have died from COVID-19 in Peru of $484.7450\, people/day$, whose scheduled date was April 15, 2021, coinciding with what was reported by Marín-Machuca, et al. [7] and Marín-Machuca, et al. [7]. The value of the correction factor for the independent variable is 66.1055 days, whose predictive mathematical model (equation 6), the constant of proportionality ($k = -0.0088$) and the coefficients of correlation ($r = -0.9879$) and determination ($r^2 \times 100 = 97{,}59\%$) are of great importance for analyze and estimate data on epidemiological and pandemic phenomena, observable in figure 3; coinciding with what was mentioned by Hernández and Fenández [17]. The theory of Bronshtein and Semendiaev [19] can be applied without difficulty, if it is considered that the processes show behavior that will not always ascend or will not always descend. The logistic model provides excellent prediction, with an error of less than 7% on a weekly basis and less than 12% monthly. This aligns with the findings of Arora, et al. [9] who reported an error of less than 8% on a weekly basis and less than 14% monthly. The number of deaths due to COVID-19 follows a behavior consistent with a logistic model, which helps adjust the trend limit of the epidemic. This corresponds to the findings reported by Wang, et al. [20].

5. Conclusion

Logistic (factual) model can generally be applied as rigorously as possible to pandemic and epidemiological phenomena with high resolution and a high degree of estimation of real data. Statistically, it has been determined that the correlation coefficient of equation 3 has a "very strong negative correlation" between the number of infections by COVID-19 and the time elapsed, 79.40% of the variance in N is explained by t for the number of deaths in Peru from COVID-19. To obtain a better estimate of the predictive model, it is recommended that the statistical data, in terms of the dependent variable (consisting of the number of people infected by COVID-19).

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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