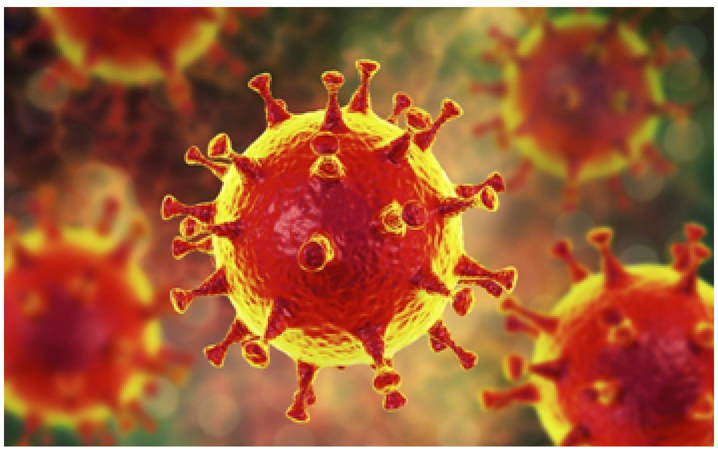
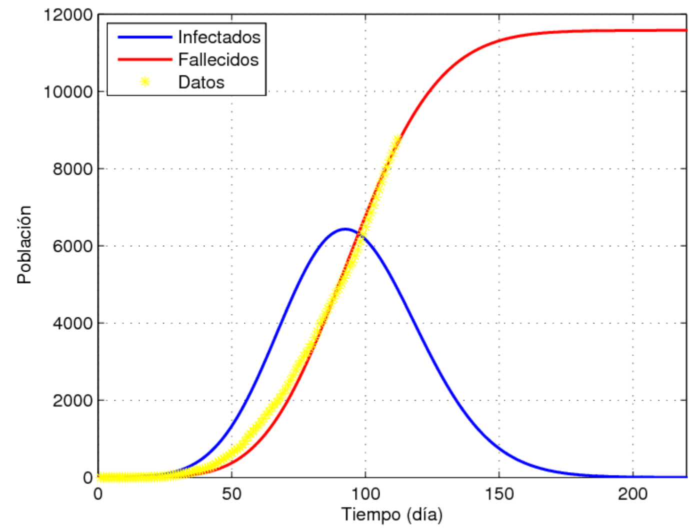
Numerical simulation of Covid19 pandemic in Perú

XIX Meeting of Physics

(25 Sep 2020)





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Is it possible to model the behavior of the population?

*La Policía intervino en Chiclayo a más de 100 personas que se encontraban en una fiesta celebrando los 18 años del anfitrión. La mayoría de ellos eran jóvenes incluso menores de edad, | **Fuente:** RPPNoticias*

Abstract

In this research, the SIR epidemiological numerical model has been revised to obtain a new model (SAIRD), which involves 2 additional variables: the population that died due to the disease (D) and the isolated or quarantined population (A).

The analysis of data on infections and deaths (in Perú) suggests that the evolution of the coronavirus epidemic has reached the plateau and is declining. A sensitivity analysis has been performed to obtain the optimal computational time step (Δt = 0.01 day).

From the data, the average mortality rate has been estimated at 0.05. Through an inversion process, the epidemiological parameters have been obtained, which are variable by section (piecewise).

The effect of quarantine has been simulated, which is an effective measure to reduce the impact of the pandemic. For an isolation rate of 0.0118, the total number of deaths would be 60 thousand; If there were no quarantine, there could be around 1.6 million deaths.

Mathematical model: SIR

The equations that govern the dynamics of an epidemic form a system of non-linear first-order ordinary differentials equations, whose solution is obtained analytically (under certain conditions) or by numerical methods, such as the finite differences method, Euler's method, Runge Kutta's method, etc.

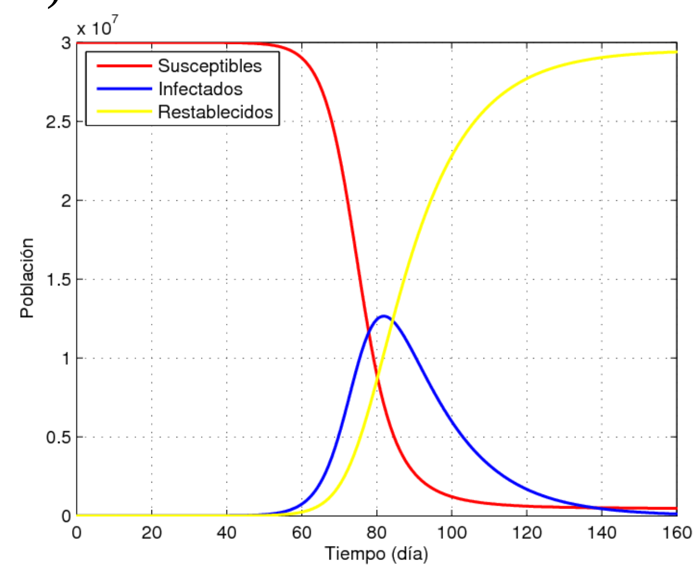
The simplest mathematical model that describes the behavior of an epidemic is the SIR (Susceptible - Infected - Removed), which considers population groups of the different phases of the epidemic process (Kermack & McKendrik, 1927).

$$\frac{dS}{dt} = -\frac{\beta}{N} IS$$

$$\frac{dI}{dt} = \frac{\beta}{N} IS - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$

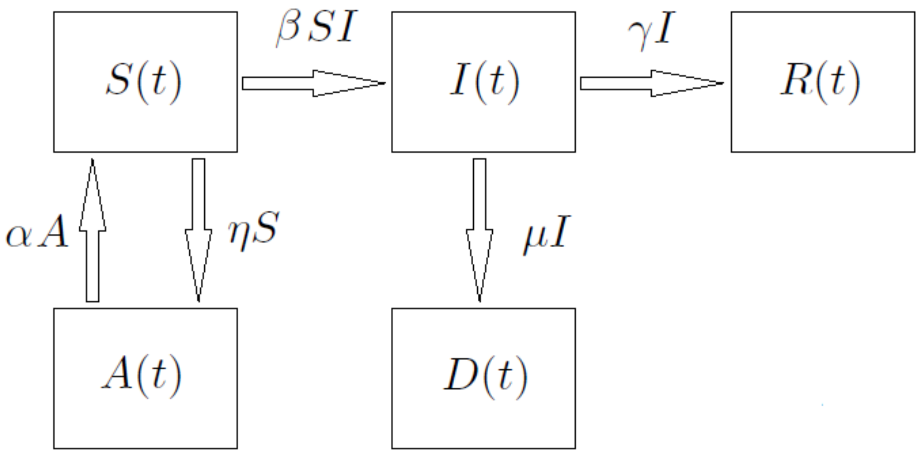
$$\boxed{S(t)} \xrightarrow{\beta SI} \boxed{I(t)} \xrightarrow{\gamma I} \boxed{R(t)}$$



Where *S(t)* is the susceptible population, *I(t)* is the infected population, *R(t)* is the removed population (recovered + deceased), *N* is the total population, β is the infection rate and γ is the recovery rate.

Mathematical model: SAIRD

When the population in quarantine or social isolation is incorporated into the numerical model, then a new numerical model is obtained: SAIRD (Susceptible - Isolated – Infected - Recovered - Deceased). The differential equations that govern this model are:



$$\frac{dS}{dt} = \frac{\alpha}{N}A - \frac{\beta}{N}SI - \eta S$$

$$\frac{dA}{dt} = \eta S - \frac{\alpha}{N}A$$

$$\frac{dI}{dt} = \frac{\beta}{N}SI - (\mu + \gamma)I$$

$$\frac{dR}{dt} = \gamma I$$

$$\frac{dD}{dt} = \mu I$$

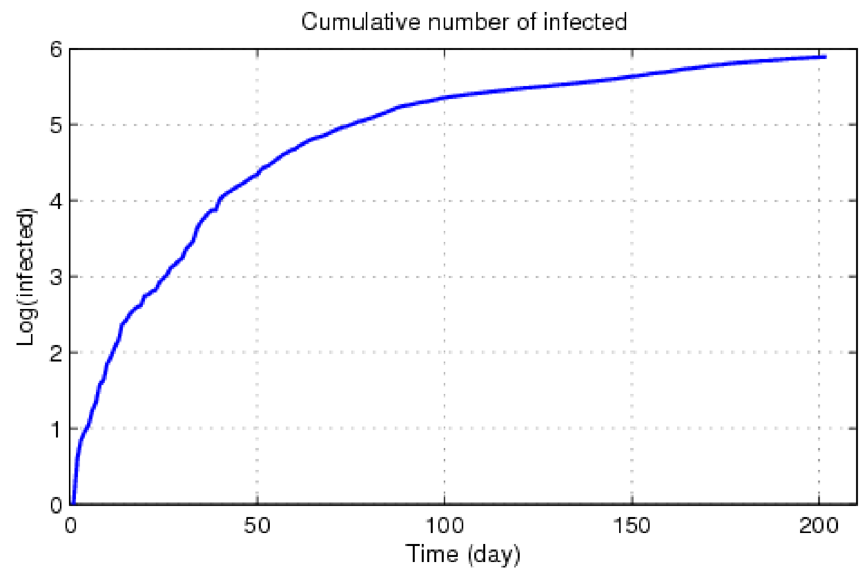
The spread of an epidemic is quantified by the basic reproduction number or ratio R0. This dimensionless quantity is used to represent the average number of infected produced by a member of the infected population.

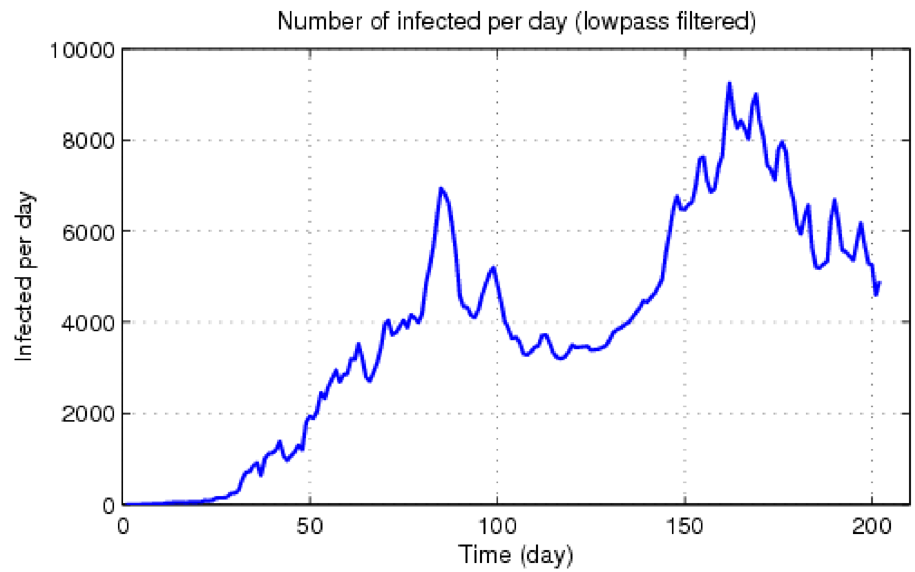
$$R_0 = \frac{\beta}{\mu + \gamma} \qquad R_t(t) = R_0 \frac{S(t)}{N}$$

Data processing

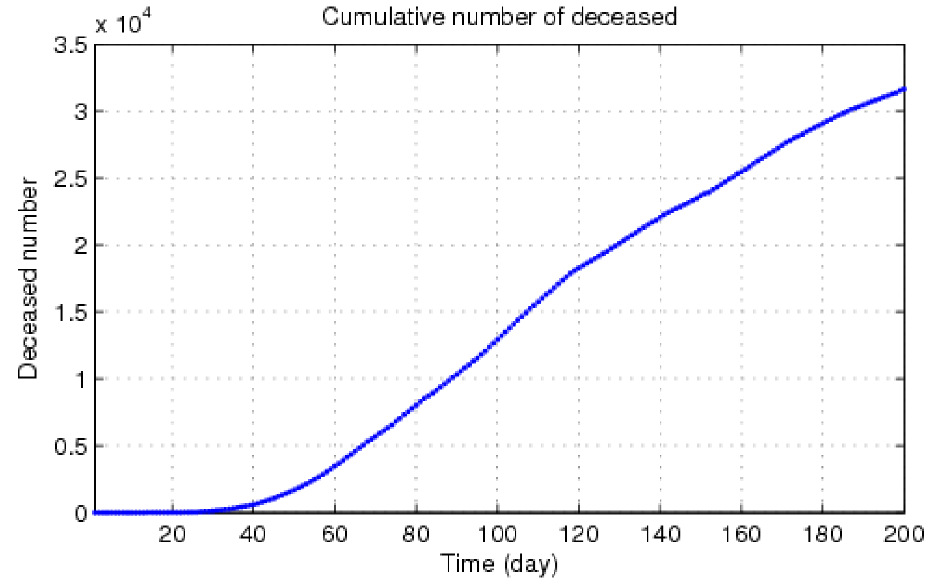
The digital data processing of the time series of the number of infected and the number of deaths has been conducted, through an interpolation process, with a sampling interval of 1 day, to obtain the missing data from the first days.

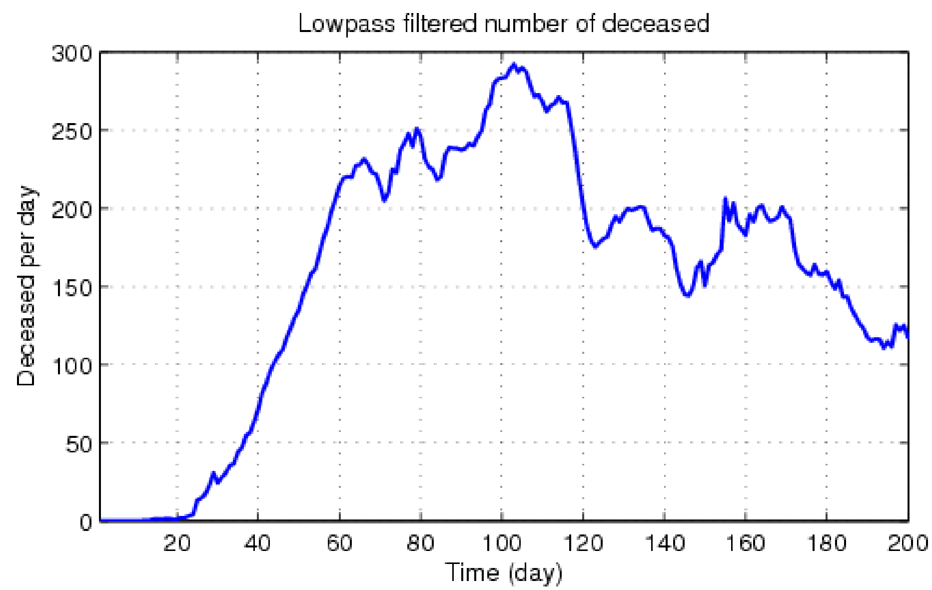
Then, a filtering process has been carried out to reduce the data dispersion, by applying a low pass filter, which consists on the average of a moving window of 5 consecutive data.





Data: number of deceased

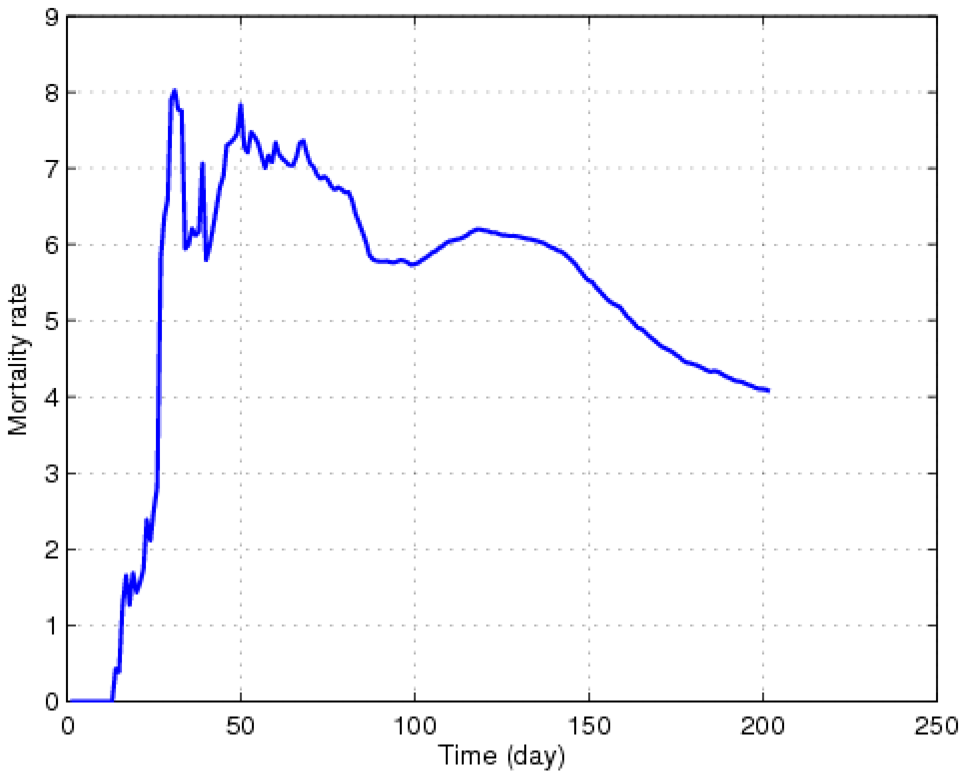


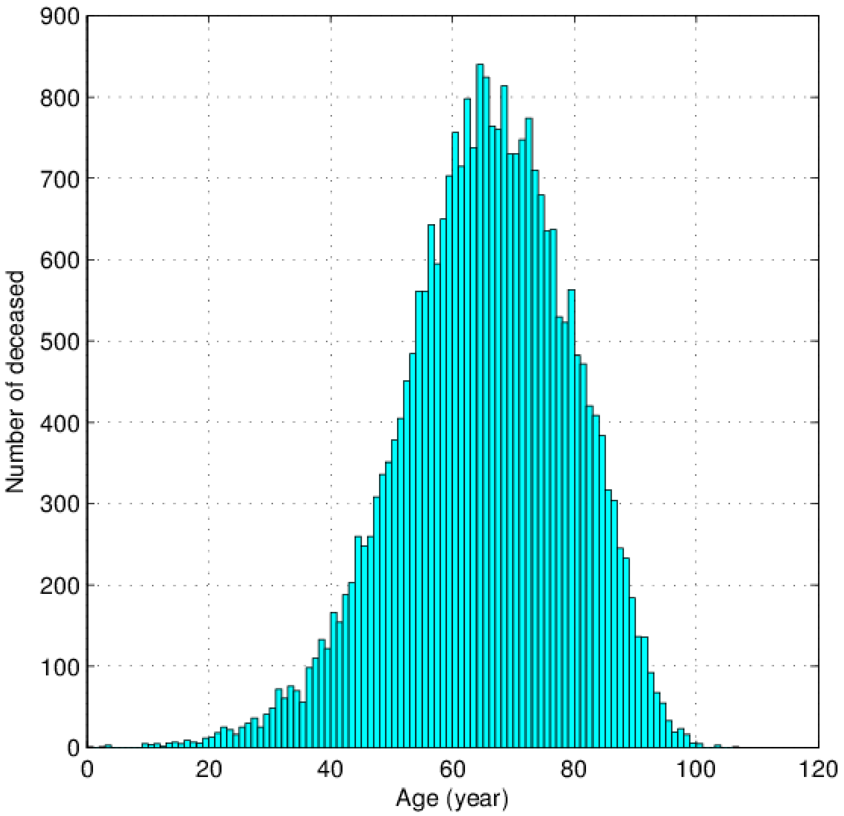


Data: mortality rate (μ)

The mortality ratio or rate is obtained by dividing the cumulative number of infected by the cumulative number of deaths. The secular average is 6%; however, this parameter is decreasing to 4%.

The histogram shows the distribution of deaths by age. The peak corresponds to the age of 64 years.





Methodology: discretization of ODE

Under certain conditions, it is possible to find an analytical solution of the SIR model. However, the use of numerical modeling is more computationally efficient. The finite difference method is used to discretize ordinary differential equations, to form a system of recursive equations:

$$S(k+1) = S(k) + \Delta t \left[\frac{\alpha}{N} A(k) - \frac{\beta}{N} S(k) I(k) - \eta S(k) \right]$$

$$A(k+1) = A(k) + \Delta t \left[\eta S(k) - \frac{\alpha}{N} A(k) \right]$$

$$I(k+1) = I(k) \left[1 + \Delta t \left[\frac{\beta}{N} S(k) - (\mu + \gamma) \right] \right]$$

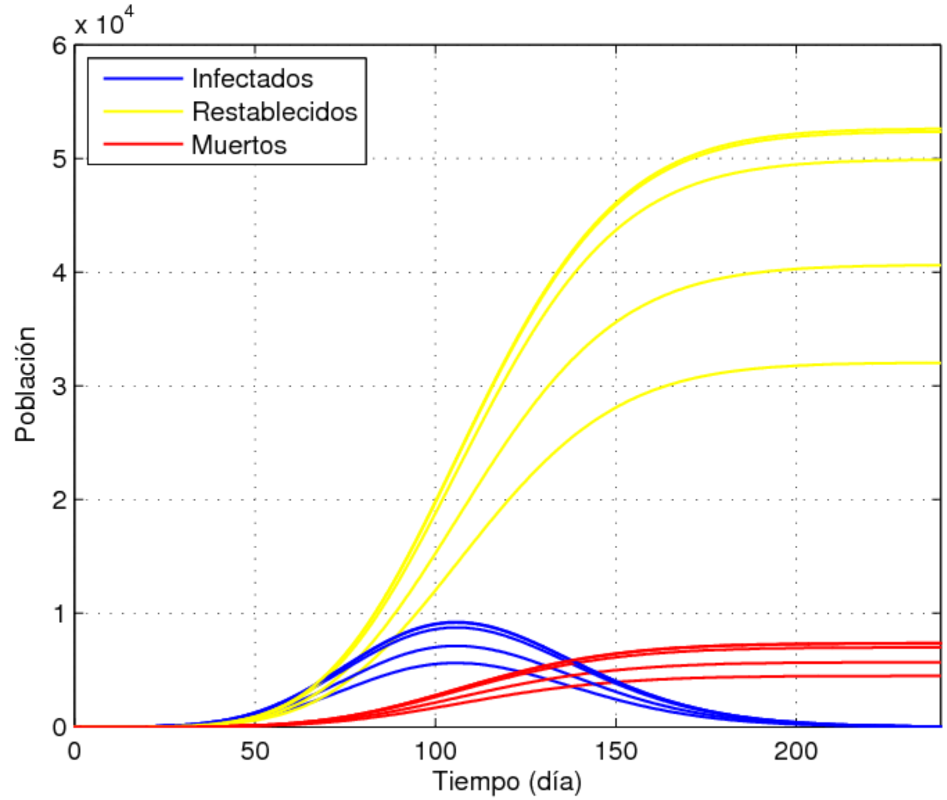
$$R(k+1) = R(k) + \Delta t \gamma I(k)$$

$$D(k+1) = D(k) + \Delta t \mu I(k)$$

The initial conditions have been chosen based on the reality of Peru. The total population is N = 32 million, at the beginning of the epidemic there was only one infected $I(1) = 1$, the initial susceptible population $S(1) = N\text{-}I(1)$ = 31'999,999. The initial population in quarantine, restored and deceased is null: $A(1) = 0$, $R(1) = 0$ and $D(1) = 0$.

Methodology: sensitivity test

Sensitivity test of the SAIRD model, for different time steps Δt. For the same variable (a single color), the curves correspond from bottom to top to: Δt = 1.0, 0.5, 0.1, 0.01 and 0.001 day. For the last 2 values, the curves practically overlap.

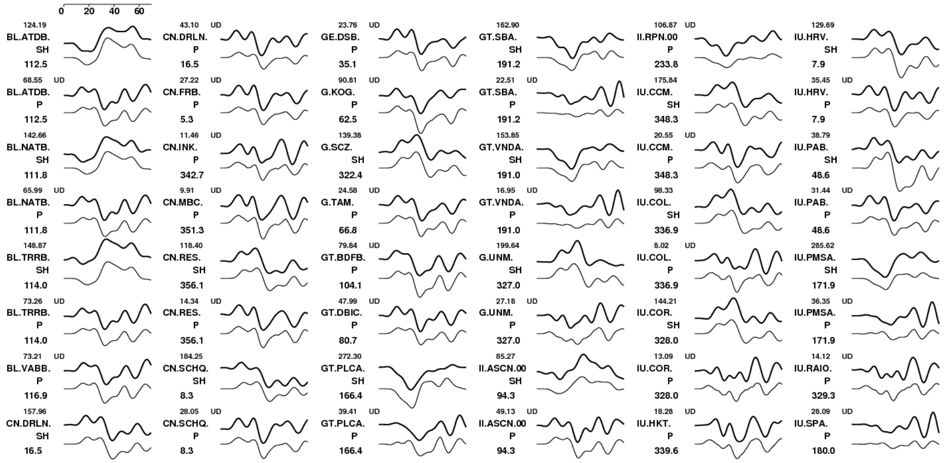


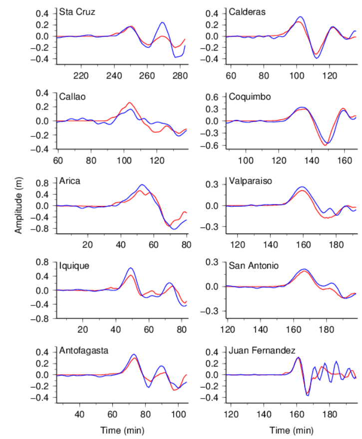
Below is the Matlab code for the iteration subroutine:

```
for k=1:Nk
    t(k+1) = dt*k;
    S(k+1)=S(k)+dt*(alfa/N0*A(k)-beta/N0*S(k)*I(k)-eta*S(k));
    A(k+1)=A(k)+dt*(eta*S(k)-alfa/N0*A(k));
    I(k+1)=I(k)*(1+dt*(beta/N0*S(k)-(mu+gama)));
    R(k+1)=R(k)+dt*gama*I(k);
    D(k+1)=D(k)+dt*mu*I(k);
end
```

Methodology: Data Inversion

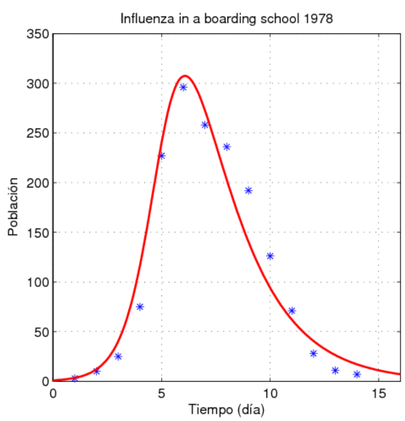
In seismology, to obtain the parameters of the seismic source, the waveform inversion (earthquake of Chimbote 1996) or tsunami inversion method (tsunami of Camaná 2001) is used:

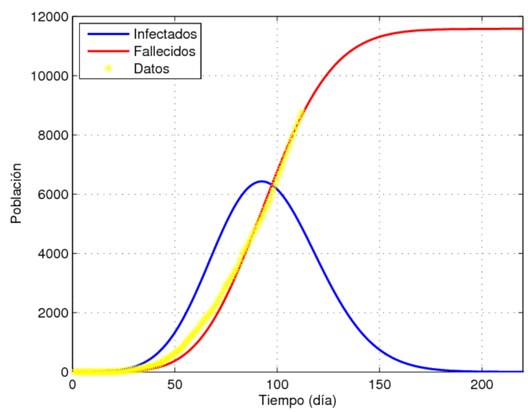


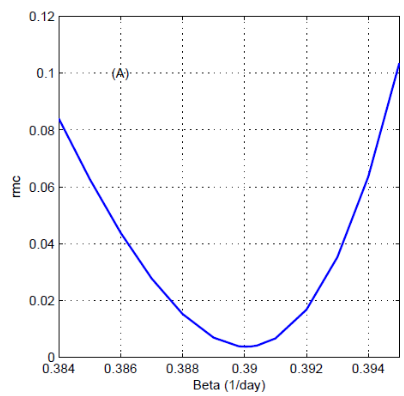


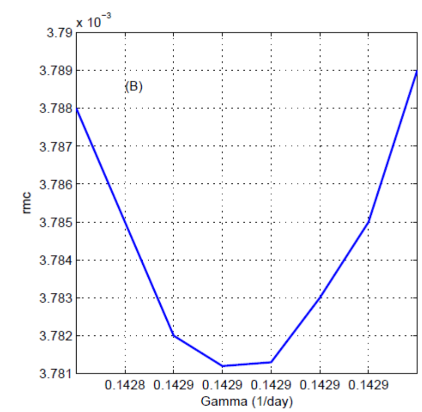
In this research, to fit the curves to data, the method of iterative approximations was used through a sensitivity test, to choose the parameters that minimize the normalized variance:

$$Var = \frac{\sum_{k=1}^{Nk}[obs(k) - sim(k)]^2}{\sum_{k=1}^{Nk}[obs(k)]^2}$$

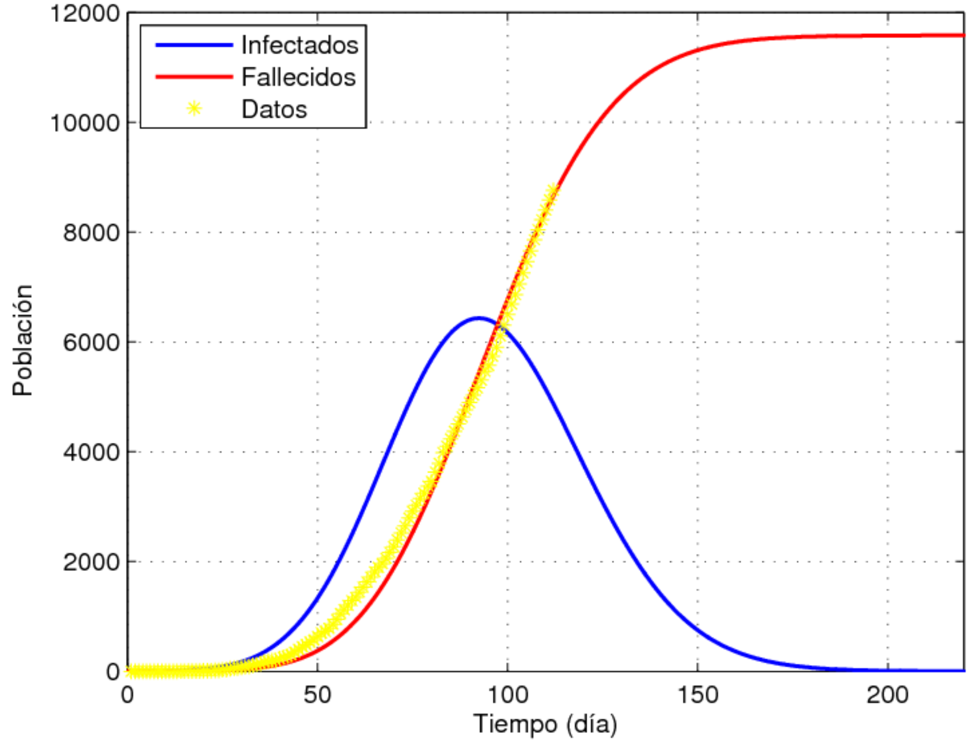






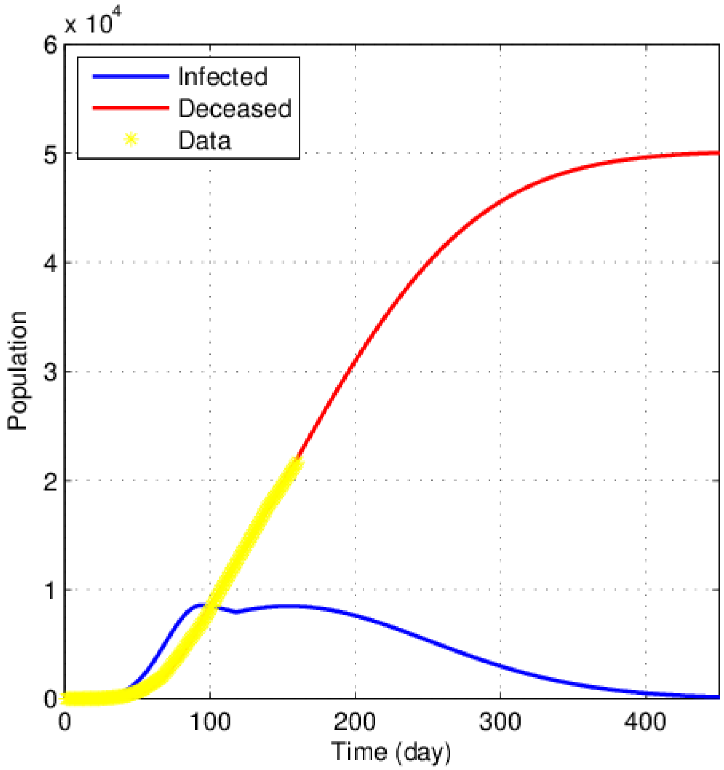


Results: before the 1st update of deceased



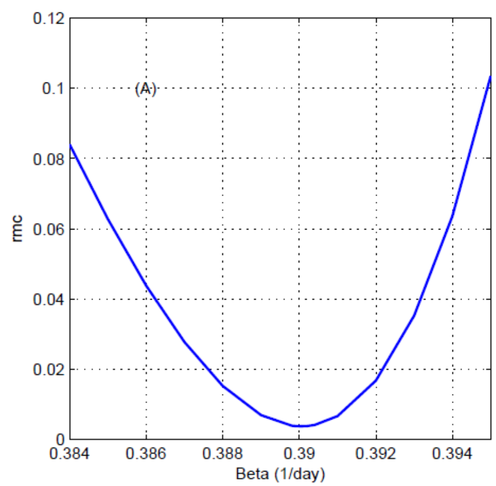
Parámetro	Valor promedio	Definición
α	0.018	Tasa de deserción
β	0.39	Tasa de contagio
γ	1/7	Tasa de recuperación
η	0.0089	Tasa de reclutamiento
μ	0.028	Tasa de mortalidad
R_0	2.3	Número de reproducción

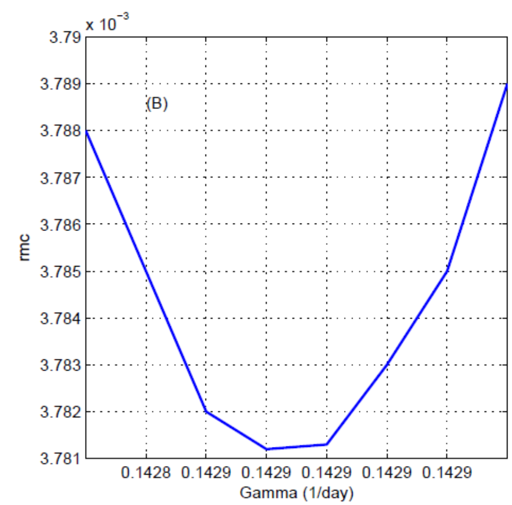
Results: after the 1st update of the deceased



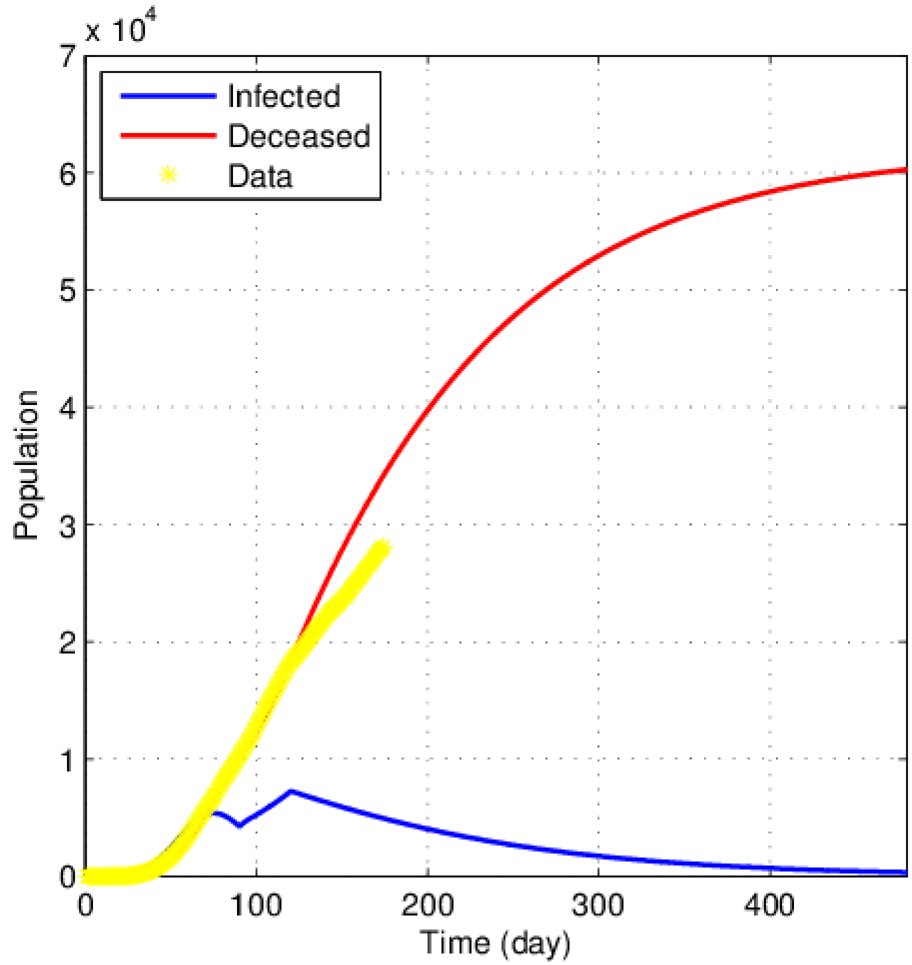
Parameter	Definition	Mean value (day^{-1})
α	Dropout rate	0.018
β	Infection rate	0.39005 (day$\leq$117)
		0.41000 (day>117)
γ	Recovery rate	0.14286 ($\approx$1/7)
η	Isolation rate	0.0089 (dia$\leq$96)
		0.0005 (dia>96)
μ	Mortality rate	0.028
R_0	Reproduction number	2.41 (dimensionless)

$$Var = \frac{\sum_{k=1}^{Nk}[obs(k) - sim(k)]^2}{\sum_{k=1}^{Nk}[obs(k)]^2}$$





After the 2nd update of the deceased …



The model predicts a higher number of deaths than the MINSA report

Waiting for a 3rd update in the number of deceased?

Results: quarantine (“hammer” effect)

No quarantine:

Infected ≈ 32 million

Deaths ≈ 1.6 million

Duration ≈ 4 months

In this case, the government does not implement any control measures.

With quarantine (η = 0.0089):

Contaminated = 420 thousand

Deceased = 12 thousand

Duration ≈ 6 months

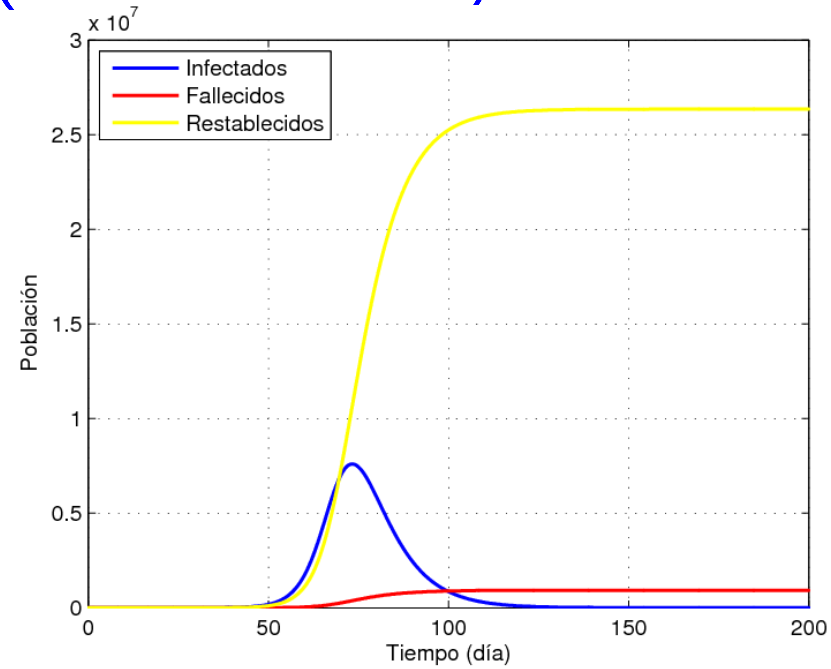
In this case, the government decrees a quarantine, social distancing, etc.

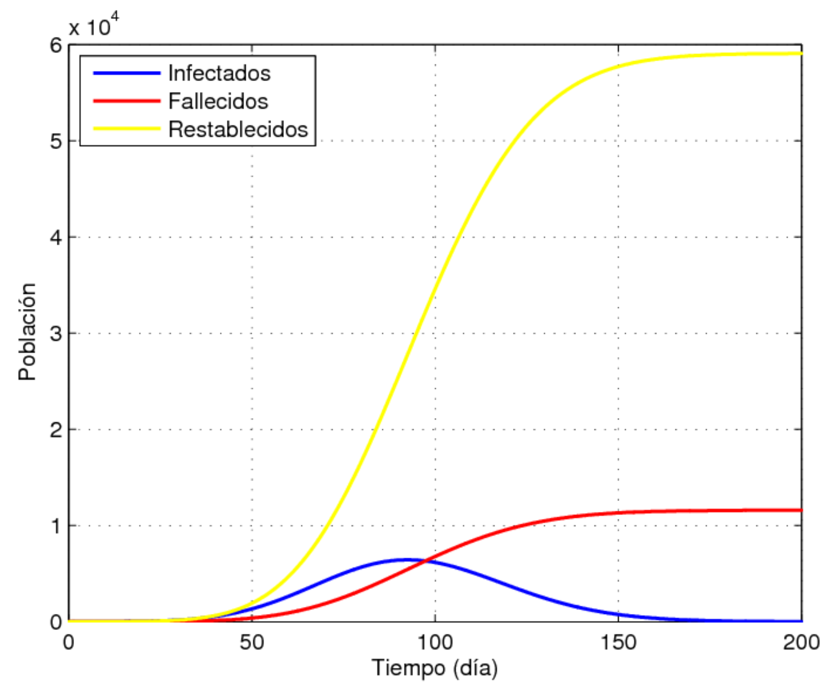
Total quarantine (η > 1.0):

Contaminated = 6

Deceased = 4

In this case, the government decrees a total quarantine. Example: New Zealand





Conclusions

The dynamic evolution of an epidemic depends on the behavior of the population in the face of health measures dictated by the government. However, numerical models are useful to simulate probable scenarios, which allows more efficient decision making.

Official data up to day 200 (September 21) show a downward trend in the number of infections per day and in the number of deaths per day. Therefore, we have already reached the plateau of the pandemic and the trend is to decrease.

The most challenging point in all epidemiological simulation research is the estimation of the epidemiological parameters from the numerical model. The available data allow estimation through an inversion process ($\gamma \approx 1 / 7$). For the estimation of the mortality rate, an average value of 5% ($\mu = 0.05$) has been obtained. The epidemiological parameters are variable by section.

The SAIRD model (whose numerical solution has been obtained with the finite difference method) is very sensitive to the choice of the computational time step. Through a sensitivity analysis, an optimal value of $\Delta t = 0.01$ day was obtained.

The effect of quarantine has been simulated by varying the isolation rate η. If there were no quarantine, the number of deaths would be 1.6 million; if $\eta = 0.0118$, the number of deaths would be 60 thousand. For a total quarantine, there would only be 4 deaths.

Research paper to be published …

Numerical modeling of coronavirus pandemic in Peru

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Abstract

In this research, the SIR epidemiological numerical model has been revised to obtain a new model (SAIRD), which involves 2 additional variables: the population that died due to the disease (D) and the isolated or quarantined population (A). A sensitivity analysis has been conducted to obtain the optimal computational time step (Δt=0.01 day). From data, the average mortality rate has been estimated at 0.028. Analysis of the data of infected and deceased suggest that the evolution of coronavirus epidemic in Peru has reached the plateau. We have simulated the effect of the quarantine, which is an effective measure to reduce the impact of the pandemic. For a variable isolation rate, due to the end of the quarantine (0.0089 for day$\leq$96 and 0.0005 for day>96) the death toll would be 35 thousand; if there were no quarantine, there could be around 960 thousand deaths.
Keywords: numerical simulation, coronavirus, epidemic.

1 Introduction

The coronavirus pandemic, due to the fatality of Covid-19, has negatively impacted health and the global economy. In the case of Peru, a reduction of more than 10% of the gross domestic product has been estimated for the year 2020, it is estimated that millions of workers have lost their jobs; to date, more than 15,000 people have already died and more than 350,000 people have been infected with coronavirus in Peru.

Covid-19 disease (caused by coronavirus) was first reported in the city of Wuhan in China, towards the end of 2019. In Europe, the first cases were reported in early 2020. In Peru, the first case (patient zero) was reported on March 7, 2020, so the evolution of the epidemic in Peru is out of date by about 2 months compared to the countries of Europe.

There are three possible strategies to face this pandemic: 1) not intervene and wait for the disease curve to stop when all susceptible people get sick; 2) mitigate the effects of the epidemic; 3) seek the suppression of the epidemic [Acc20].

On March 15, 2020, the Government of Peru issued several legal regulations in the health, economic and social fields to mitigate and suppress the effects and impact of the coronavirus pandemic, such as: the closure of frontiers, the quarantine or social isolation, economic support for vulnerable families, etc.

FIN

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