Modeling of vaccination and its impact on the Covid-19 pandemic studying epidemiological models using Wolfram model

UNIVERSIDAD NACIONAL DE COLOMBIA

Author:Andrés Felipe Bermúdez Mendoza - anfbermudezme@unal.edu.co

Director: Carlos Jose Quimbay Herrera - cjquimbayh@unal.edu.co

Physics Program

Abstract

In this degree work, the model proposed by Christoper Wolfram is used to model the impacts of vaccination in the Covid-19 pandemic. For this, different deterministic models composed of coupled differential equations were presented, showing their behavior, making the corresponding analytical and computational development, focusing as the main approach on the probability of the graph of small worlds known as Watts-Strogatz since these small worlds are taken as the 217 countries connected through Delaunay triangulations. Then, by means of the software known as Mathematica and EasyFit, we had that the behavior of the pandemic in this case distributions are scale invariant, so for reasons of computational performance the small worlds are taken as a representation of a subregion of the region, in this case world, being taken as a sample, representing each country. It was found that for normalized cases of infection, the distribution that meets the Kolmogorov-Smirnov, Anderson-Darling and Chi-Squared goodness of fit is the Pearson type 6 distribution that is rescaled by computational performance to the distribution known as Fisher Snedecor. For the case of normalized deaths, it was found that the pattern can be taken as a distribution known as Burr or Singh-Maddala. Following the Wolfram model, the respective simulations are made, finding that for normalized daily cases the peak of infected does not vary in magnitude. For normalized daily death cases, the expected behavior is that as the probability of the Watts-Strogatz graph decreases, the number of deaths also decreases. The simulations made with the obtained distributions have the same empirical behaviors observed in reality, which is deaths decrease with vaccination.

Introduction

At the end of 2019, a global phenomenon known as the Covid-19 pandemic occurs where a type of virus known as coronavirus mutates, initially affecting the Chinese population. In a few months this virus spread rapidly throughout the world, considerably affecting the world population. Efforts from around the world came together to combat the pandemic, generating new knowledge and revealing the need for strategies to mitigate this type of phenomenon. The models worked analytically are all deterministic, thus limiting the study of different phenomena that can occur in reality. For this degree work, a stochastic and probabilistic model is proposed, where empirical data and results obtained about the behavior of the Covid-19 pandemic are observed. The type of graph used is known as the Watts-Strogatz network introduced in 1998 by Duncan Watts and Steven Strogatz. The objective of this degree work is to observe the effects of vaccination in the Covid-19 pandemic using the Wolfram model.

Methodology

Epidemiological Models

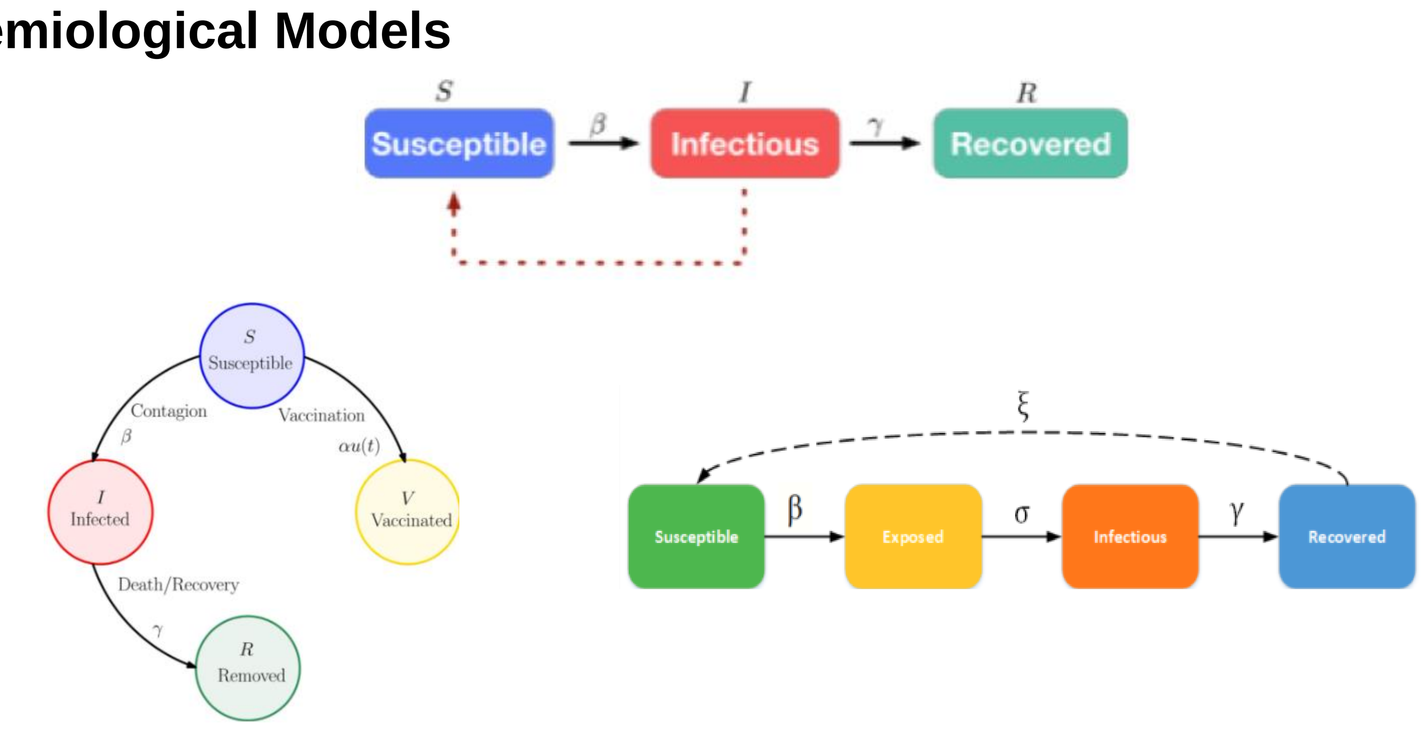

Figure 1: Diagrams of the epidemiological models.

Pandemic Modeling using Wolfram Model

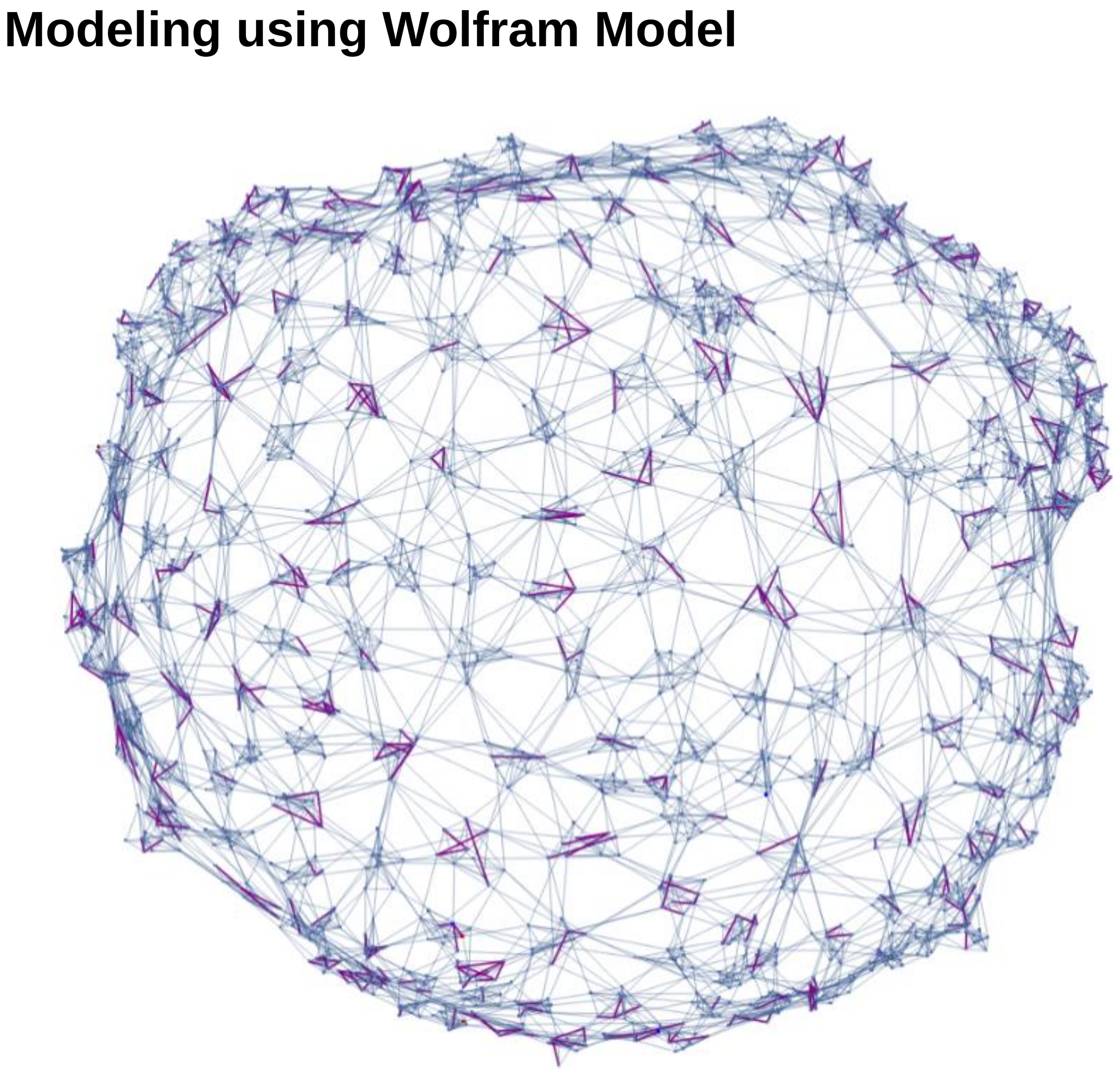

Figure 3: Watts-Strogatz small worlds networks connecting using Delaunay Triangulatio.

$$C = \frac{3(k-1)}{2(2k-1)+4kp(p+2)}$$

$$P_j = \begin{cases} 0, & if \quad j < 2k \\ \binom{n}{j-2k}\frac{2kp}{n}^{j-2k}\left[1-\frac{2kp}{n}\right]^{n-j+2k}, & if \quad j \geq 2k. \end{cases}$$

Determination of Probability Distributions

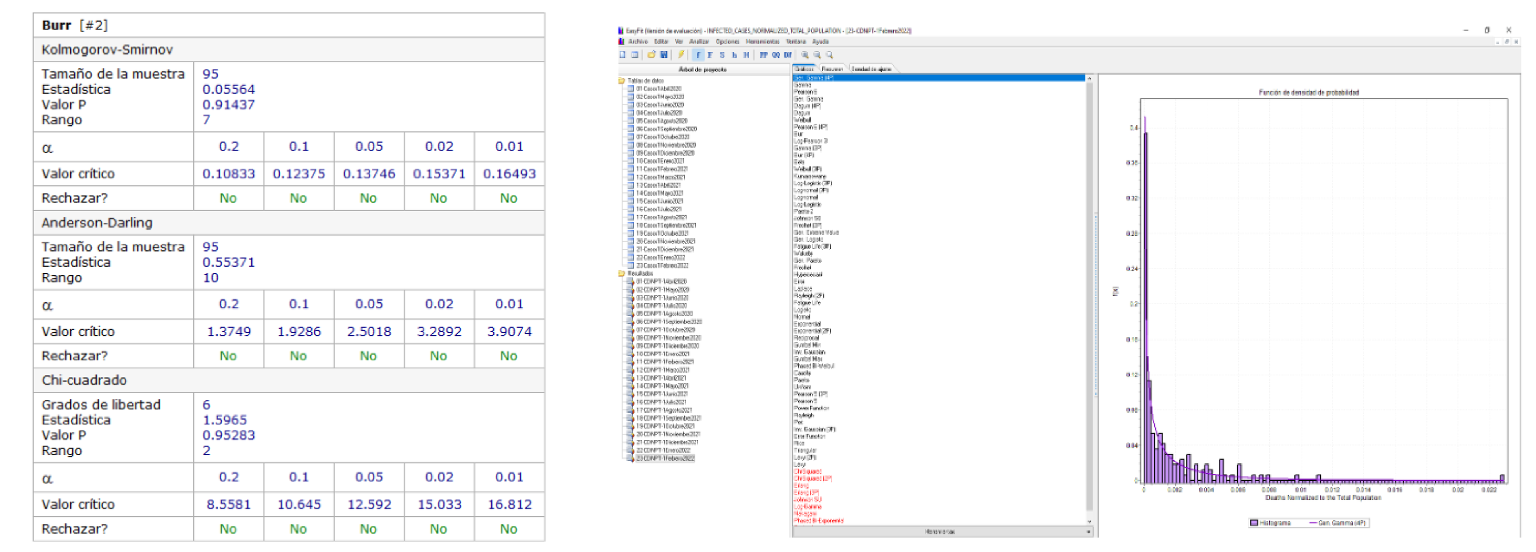

Figure 4: EasyFit example to determine the respective distribution of probability

Country/Date	Total Population	2021-05-08	$\cdots$	2022-02-18	2022-02-19
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$	$\vdots$
India	1393409033	0.0002895	$\cdots$	1.598×10^{-5}	1.433×10^{-5}
Ireland	4982904	8.007×10^{-5}	$\cdots$	0.0009623	0
Iran	85028760	0.0001597	$\cdots$	0.0002272	0.0001418
Iraq	36792	0.0001119	$\cdots$	5.648×10^{-5}	2.997×10^{-5}
Iceland	9291000	0	$\cdots$	0	0
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$	$\vdots$
Pakistan	225199929	1.681×10^{-5}	$\cdots$	8.806×10^{-6}	7.3×10^{-6}
Panama	4381583	0.0001159	$\cdots$	0.0002782	0
Peru	33359415	0.0006175	$\cdots$	0.0002035	0.0002769
Philippines	111046910	6.271×10^{-5}	$\cdots$	1.92×10^{-5}	1.642×10^{-5}
Palau	18174	0	$\cdots$	0.0020909	0
$\vdots$	$\vdots$	$\vdots$	$\cdots$	$\vdots$	$\vdots$
Romania	19127772	6.823×10^{-5}	$\cdots$	0.0007593	0.000644
Russia	145912022	5.618×10^{-5}	$\cdots$	0.00122	0.0012125
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

Table 1: Databases Example Construction

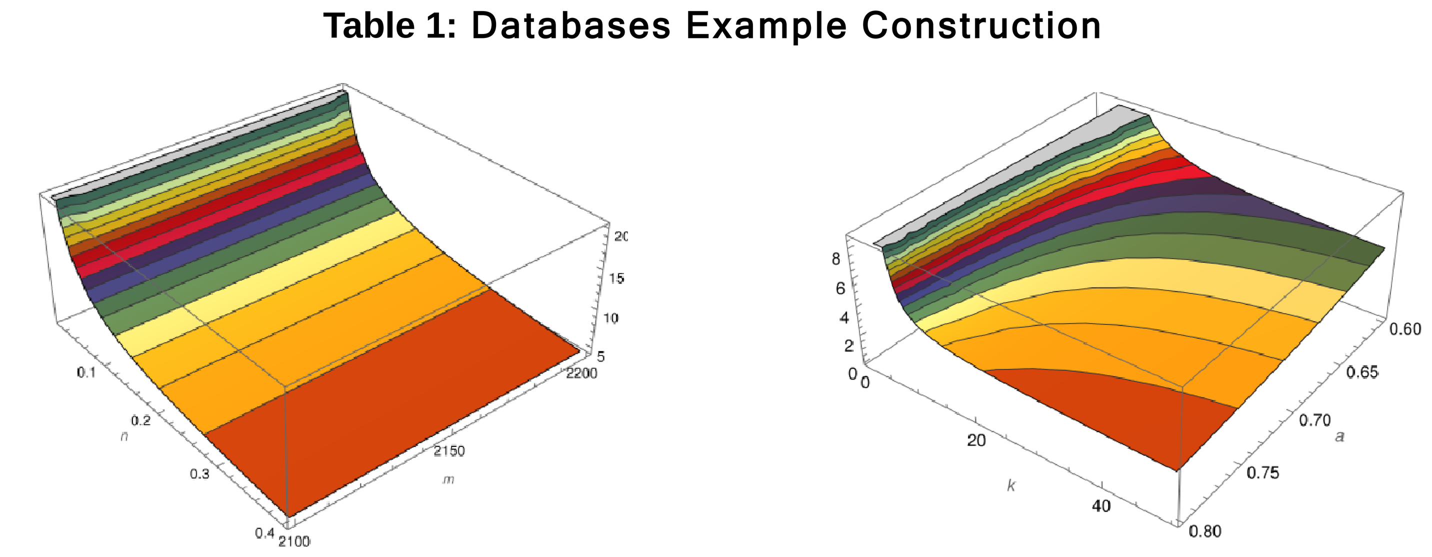

Figure 2: Parameter n varied to the daily cases normalized to the total population for the Fisher-Snedecor distribution and Parameter k varied to the daily death cases normalized to the total population for the Burr or Singh-Maddala distribution

Results and Conclusions

When the distributions are found, the different simulations are run obtaining the expected effects of vaccination, which are that as the number of vaccinated increases, the probability of death decreases and therefore the number of deaths decreases. It is allowed to show through this degree work, that it is possible to reproduce the effects of vaccination in the Covid-19 pandemic without the need to use deterministic models. It is also allowed to show that the empirical behaviors of the pandemic can be reproduced by means of an entirely stochastic model

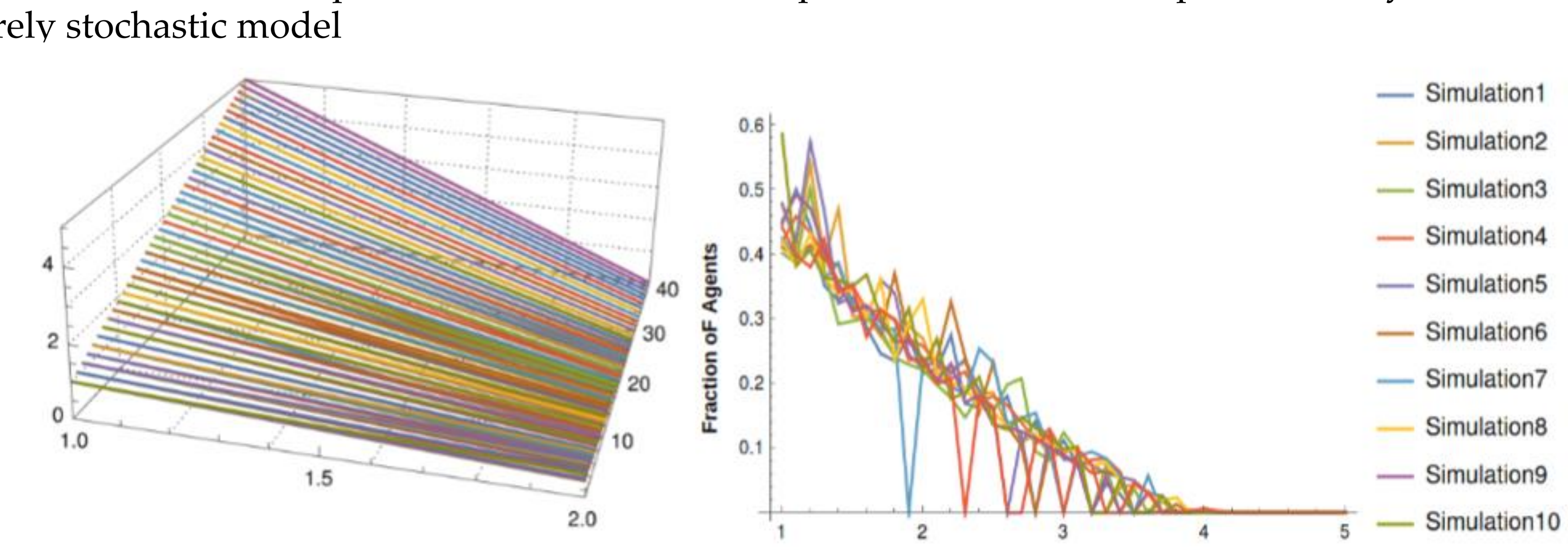

Figure 5: Figure corresponding to the results obtained for the simulation of daily death cases normalized to the total population of each country..

References

1 https://github.com/anfbermudezme/Physics_analysis_Covid-19, 2022, .

2 Christopher Wolfram. An agent-based model of covid-19s. Complex Systems, 2020. https://doi.org/10.25088/ComplexSystems.29.1.87