Covid-19 Modelization in Morocco.

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1 Abstract

What you are about to read is a study about the propagation of covid-19 virus in Morocco, the interest of the study lies in the fact that the modelling of Covid-19 evolution in Morocco allows you to predict various outcomes in the future given various assumptions and constants.Therefore, granting you enough time to make wise decisions about managing this epidemic and also to visualize the various effects of other factors such as temperature, the season,the state's management efforts.All in the goal of managing the epidemic in the most optimal way possible.

2 Introduction

Coronavirus disease 2019 (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).It was first identified in December 2019 in Wuhan, China, and has since spread globally, resulting in an ongoing pandemic.As of 25 May 2020, more than 5.41 million cases have been reported across 188 countries and territories, resulting in more than 345,000 deaths. More than 2.16 million people have recovered. Common symptoms include fever, cough, fatigue, shortness of breath, and loss of smell and taste.While the majority of cases result in mild symptoms, some progress to acute respiratory distress syndrome (ARDS) likely precipitated by a cytokine storm,multi-organ failure, septic shock, and blood clots. The time from exposure to onset of symptoms is typically around five days but may range from two to fourteen days. Many studies have been published regarding the analysis of the propagation of the disease including the spread of Covid-19 in Mexico, These studies will be referenced down below.

The COVID-19 pandemic was confirmed to have spread to Morocco on 2 March 2020, when the first case COVID-19 case was confirmed in Casablanca.As of 10 May 2020, there have been 6,063 confirmed cases, of which 2,554 have recovered and 188 have died.The following plots will describe the situation better than any words.

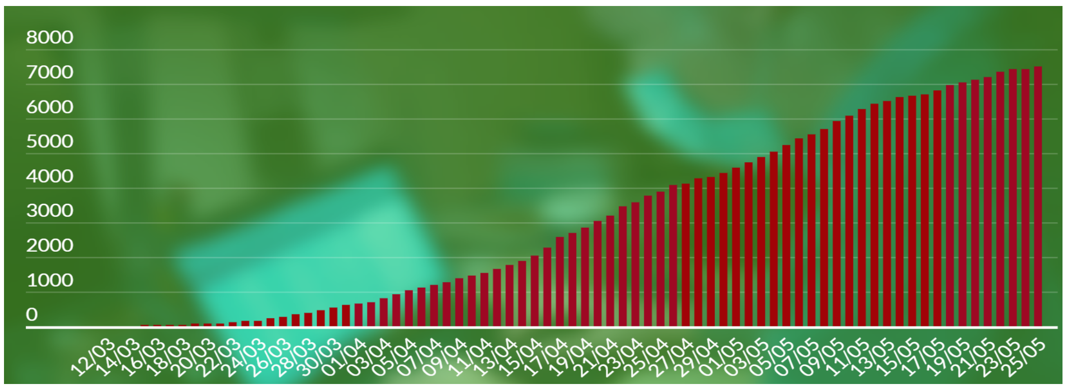

Figure 1: Evolution of total number of cases in Morocco

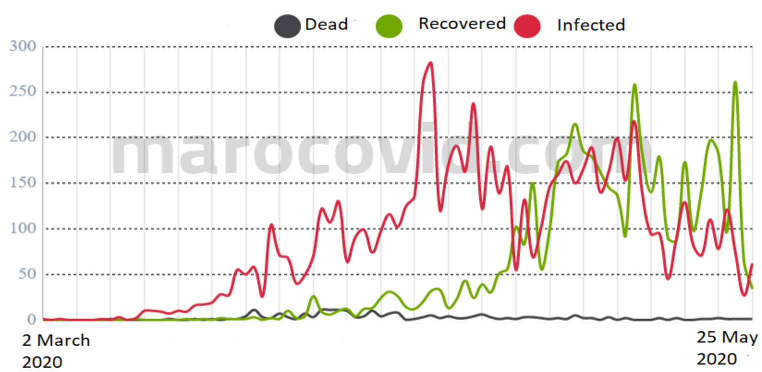

Figure 2: Evolution of number of Infected,Recovered and Dead in Morocco

In this study we have followed the same approach done by the study of covid-19 spread in Mexico by which we modelize the spread using two models,the first one based on a Markov chain in which each region is a state and each geographical border represents a probabilty of transition from one state to another, the second model is based on the SIR model(Suspected,Infected,Recovered) in which every state is a differential equation and by solving these we predict the states in time.

In brief, First of all in this study we are going to fully describe the SIR model(second Model) and some of its variants and how it is applied to Morocco,Secondly we are showing how we wrote the transtion Matrix of states in Morocco(First Model) using geographic borders,Finally we are going to display the results of both models and discuss the various outcomes and scenarios.

3 SIR model and Application to Morocco

The Susceptible-Infectious-Removed-Model consists of three compartments: S for the number of susceptible, I for the number of infectious, and R for the number of removed (recovered, deceased or immune) individuals.These variables (S, I, and R) represent the number of people in each compartment at a particular time.we make the precise numbers a function of t (time): S(t), I(t) and R(t). For a specific disease in a specific population. There are other models derived from this model which add more compartements for further realism such as the SEIR model the 'E' stands for exposed or SEIRD where the 'D' stands for Dead people. Now back to our SIR model The functions S(t),I(t) and R(t) obey the following differential equations [4]:

$$\frac{dS}{dt} = -\beta \cdot I \cdot \frac{S}{N}$$
$$\frac{dI}{dt} = \beta \cdot I \cdot \frac{S}{N} - \gamma \cdot I$$
$$\frac{dR}{dt} = \gamma \cdot I$$

Where

- **β:** expected amount of people an infected person infects per day
- **D:** number of days an infected person has and can spread the disease
- **γ:** the proportion of infected recovering per day ($\gamma = 1/D$)
- **R_0:** the total number of people an infected person infects ($R_0 = \beta / \gamma$)

These equations are valid given certain assumptions:

- The population is constant
- The rate of spread is proportional to the contact between the Infected and the Susceptible.
- Removal rate is constant

Transitions from one compartement to another are caracterized by a rate , a probability and a population.

The rate describes how long the transition takes, population is the group of individuals that this transition applies to, and probability is the probability of the transition taking place for an individual.

Now generally for the whole model the transitions frm one compartement to another are represented as follows.

$$\boxed{S} \xrightarrow{1 \cdot \frac{S}{N} \cdot \beta I} \boxed{I} \xrightarrow{\gamma \cdot 1 \cdot I} \boxed{R}$$

Now given our equations and compartements transitions we shall ask some important questions:

Will the disease spread ?

We know that the susceptible population will always decrease over time since people will get infected and removed and that removes them from the susceptible list, so S $\leq S0$

meaning that $\frac{dI}{dt} \leq I(rS0 - a)$

so it all comes down to the value of R0 [5]

if R0=$\frac{rS0}{a} \geq 1thediseasewillspread$

if R0=$\frac{rS0}{a} \leq 1thediseasewillnotspread$

We have everything set now to simulate the moroccan case using this model with python (The full code will available to check out in references below) .

We solved the system of differential equations and plotted the evolution of Infected, susceptible and removed people over time using the initial parameters of Morocco(S0=30000000,R0=) and we got the following results.

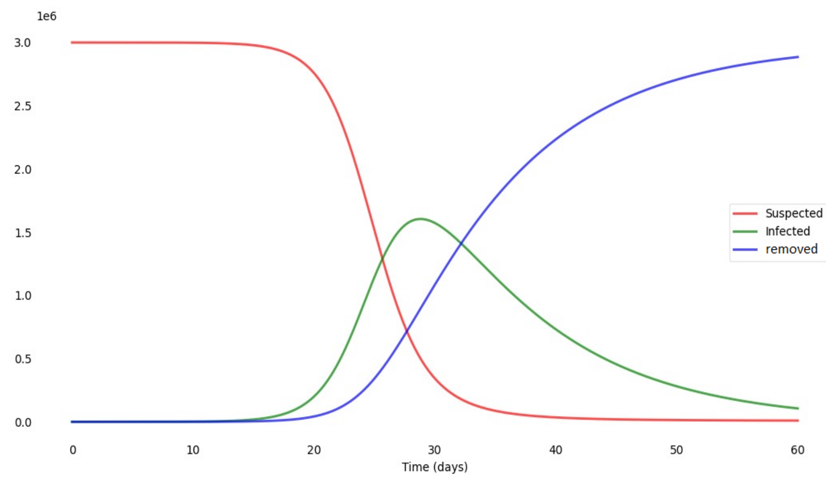

Figure 3: Evolution of Susceptible,Infected and Removed people from covid-19 in Morocco over time

4 The Markov chain based model

The following model will be based on a Markov chain which consists of 12 states each state representing one of the 12 regions of Morocco.

The probability of transition from one state to another is calculated as follows, for every existence of a geographical border between one state and another there is a probability of transition between then in other words let's say the i'th state has n borders the probablity of transition $P_{ik} = \frac{1}{n}$ where k is the index of one of those n states.[1]

We can now calculate the Transition Matrix for morocco using this rule with the help of a map

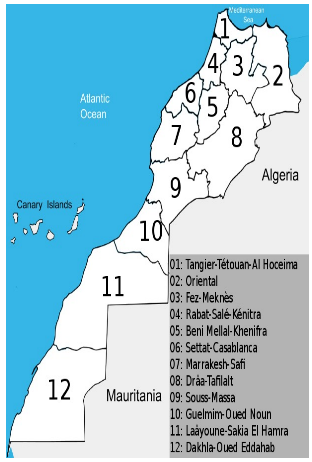

Figure 4: The map which numbering was used to calculate the matrix

```
In [15]: matrix=pd.DataFrame(P,columns=c,index=c)

In [16]: matrix
Out[16]:
```

	Tange	Souss	Rabat	L'Ori	Marra	Laâyo	Guelm	Fès-M	Dakhl	Drâa-	Casab	Béni
Tange	0.000000	0.333333	0.333333	0.333333	0.000000	0.00	0.000000	0.000000	0.00	0.000000	0.0	0.0
Souss	0.333333	0.000000	0.333333	0.000000	0.000000	0.00	0.000000	0.333333	0.00	0.000000	0.0	0.0
Rabat	0.200000	0.200000	0.000000	0.200000	0.200000	0.00	0.000000	0.200000	0.00	0.000000	0.0	0.0
L'Ori	0.250000	0.000000	0.250000	0.000000	0.250000	0.25	0.000000	0.000000	0.00	0.000000	0.0	0.0
Marra	0.000000	0.000000	0.200000	0.200000	0.000000	0.20	0.200000	0.200000	0.00	0.000000	0.0	0.0
Laâyo	0.000000	0.000000	0.000000	0.333333	0.333333	0.00	0.333333	0.000000	0.00	0.000000	0.0	0.0
Guelm	0.000000	0.000000	0.000000	0.000000	0.250000	0.25	0.000000	0.250000	0.25	0.000000	0.0	0.0
Fès-M	0.000000	0.200000	0.200000	0.000000	0.200000	0.00	0.000000	0.200000	0.00	0.200000	0.0	0.0
Dakhl	0.000000	0.000000	0.000000	0.000000	0.000000	0.00	0.333333	0.333333	0.00	0.333333	0.0	0.0
Drâa-	0.000000	0.000000	0.000000	0.000000	0.000000	0.00	0.000000	0.000000	0.50	0.000000	0.5	0.0
Casab	0.000000	0.000000	0.000000	0.000000	0.000000	0.00	0.000000	0.000000	0.00	0.500000	0.0	0.5
Béni	0.000000	0.000000	0.000000	0.000000	0.000000	0.00	0.000000	0.000000	0.00	0.000000	1.0	0.0

Now that we have our transition matrix ready we can use python to predict the probability distribution at any given time in the future(again the python code used will be listed in references below[3]) knowing the initial probability vector at the start of the pandemic. we ran our code and got the following results.

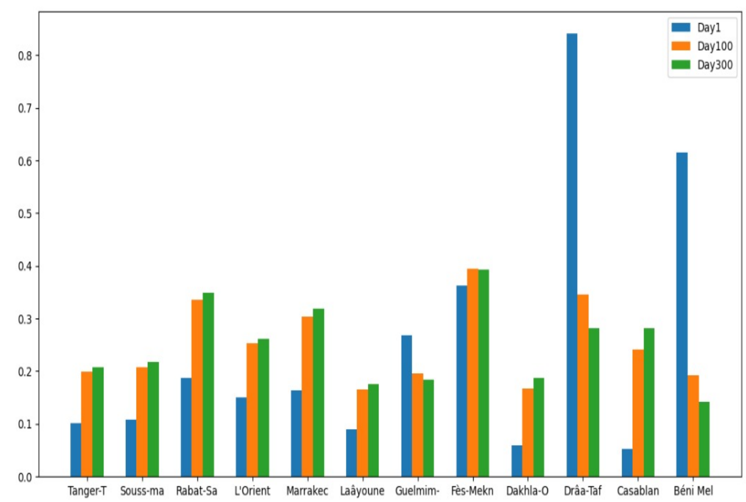

Figure 5: Probability distribution in each region at days 1,100 and 300

5 Comparison between our models and the reality

now that we have modeled the covid-19 epidemic in Morocco using two models (SIR and Markov chain) its time to test the accuracy of our models by comparing with real data that we gathered from the Moroccan Ministry of health. for the SIR model we got the following results when compared with reality

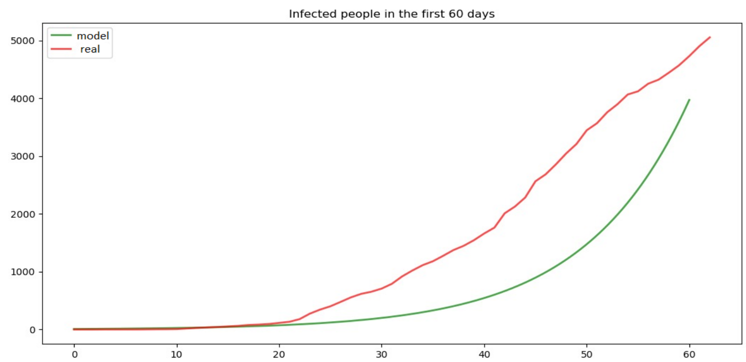

Figure 6: The predicted Infected people using SIR model and infected people in reality for the first 60 days

We notice that in the first days the reality is pretty much going according to the model but as we go further in time the model diverges from reality.

For the Markov chain model we compared the probability distributions between our model and the reality and got the following results

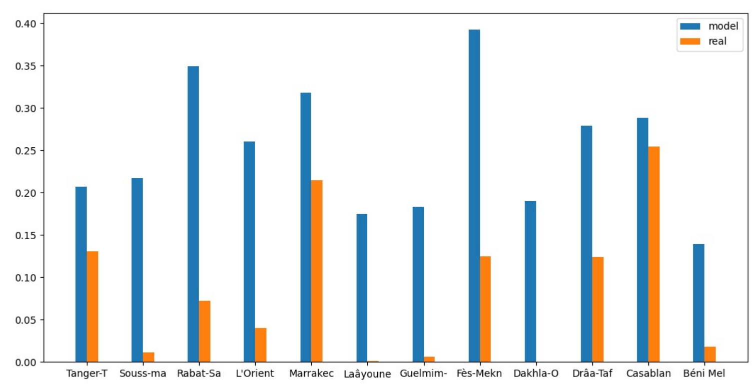

Figure 7: Probability distributions comparison between the model and reality in day 50 (bar plot)

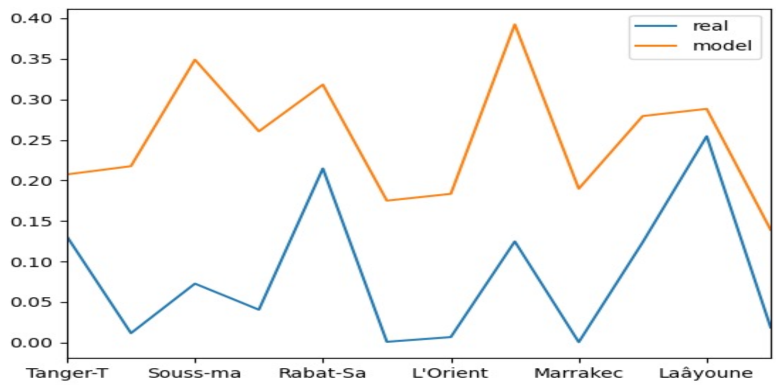

Figure 8: Probability distributions comparison between the model and reality in day 50

We notice that the model mainly follows reality except for some irregularities for some regions such as "Draa Tafilalet" in which the probability of infection and transmission is quite high in contrary to reality, this is explainable by the fact that this region has 5 geographical borders suggesting higher probability of transmission from multiple other regions where in reality its rarely visited and economically marginalized.

6 conclusion

working on this project has given us the chance to have a better grasp of the disease that's currently wreaking havoc worldwide, and has also introduced us to interesting field of pandemics mathematics which can be very useful in times like these. we were also able to put the grey matter to action referring to all the mathematical equations and python programming that we have learned in the past few years. The model albeit not necessarily accurate it still provided us with some very interesting insights and showed us how much of a dire need we are in for such studies that in this case would account for efficient resource distribution that is much needed in our country in elsewhere.This work has been a great addition to our academical acquisitions for which we are thankful of each member of our group who worked on it and our professor who guided through it

References

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