Covid-19 in North Africa: Comparative analysis by macroscopic growth laws

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A comparative analysis of the Covid-19 diffusion in North African countries, Algeria, Egypt, Morocco, and Tunisia has been carried out, with the aim to study the effects of the containment efforts in different nations and the reliability of the predictions based on the data fits by macroscopic growth laws, with a small number of free parameters. The comparison with data shows that the Coronavirus spreading has often different phases: an initial exponential behavior, followed by a Gompertz one and/or by a logistic phase, due to containment effort. The study of the growth phases permits to verify the restarting of the disease spreading after a stationarity period, due to new outbreaks or to the weakness of the social control measures. The response of the National Health Systems to the emergency is discussed and some short term predictions on the cumulative number of confirmed infected, on the hospitalizations and on the total number of deaths is done. The possible correlation with immigration in other Mediterranean Countries has been analyzed. Stable (or unstable) condition of the spreading can quickly change due to a stronger or weaker application of the lockdown measures and short term predictions turn out to be reliable.

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INTRODUCTION

The pandemic spreading of the new Coronavirus disease 2019 (COVID-19) [1–3] is producing the strongest containment attempt in recent history: billion of people are forced to live in isolation and in difficult conditions. The socio-economic impact of COVID-19 is enormous. Various sectors of industry, logistics and services have been enforced to shutdown.

In all Countries the political decisions aim at the spreading reduction and at reaching an almost stable configuration of coexistence with the disease, where a small number of new infected individuals per day is sustainable by the National Health Systems.

In China, where the Covid-19 spreading started earlier, the strong containment effects have been able to slowdown the diffusion. However in USA, South America, India and Africa and, more recently, in many European Countries there are large specific growth rates of the number of infected people.

In particular, the national health systems of African Countries are, in general, not ready to face a fast evolution of the virus spread. Indeed, the number of infected people is large and the effects of containment are essentially evaluated on empirical basis. In this respect, a more quantitative analysis of the epidemic spreading would be very useful.

Microscopic models which take into account the details of the social and economical conditions require a coupled dynamics of the stakeholders [4–8]. Many simulations are based on stochastic epidemic models, including the age dependence, the demographic structure, the heterogeneity of social contacts in different meeting places (home, school, work, public transportation, cultural activity, shop, bank, post office) and many work sub-sectors (public health, manufacturing, building, trade, ...) [9]. On the other hand, complementary and less detailed approaches, which outline the Covid-19 evolution on the basis of macroscopic growth laws and of the collected data, are a useful tool for monitoring the spreading [10–20] and for short term predictions (see also [21] and references therein).

Macroscopic deterministic growth models have the advantage with respect to microscopic and stochastic ones of the strong reduction of the free parameters driving the time evolution of the spread. This is a crucial aspect in predicting the behavior of the disease diffusion since when there are many free parameters the possible band of predictions, which comes from their mean values, standard deviations and correlation matrix, is, in general, so large that the predictive power of the models turns out to be weak.

On the other hand, a "coarse grain" model misses the microscopic dynamics and therefore is not able to understand why a set of data follows a specific macroscopic law, which has to be, therefore, considered as a emerging behavior at a large level of magnification. The main effects contained in the macroscopic description are the "resource" limitation (carrying capacity parameter) and the feedback non-linearity (modification of the exponential growth), but the effective dynamics, well understood in the microscopic models, is not described.

In this paper we carry out an analysis of the Covid-19 diffusion in the North African countries Algeria, Egypt, Morocco, and Tunisia with the aim to study the phases of the spreading and to compare the containment efforts in different, but similar, nations. We also analyze the response of the National Health Systems to the emergency. Some short term predictions on the cumulative number of confirmed infected, on the hospitalizations, and on the total number of deaths will be discussed, including the study of a possible correlation with immigration in other Mediterranean Countries.

The paper is organized as follows. the macroscopic growth laws are recalled in Sec. 1. Sec. 2 is devoted to the analysis of the single Countries. The comparative study is in Sec. 3. The short term predictions are detailed in Sec. 4 The correlation with Mediterranean sea immigration is discussed in Sec. 5. Sec. 6 is devoted to comments and the final conclusions.

I. MACROSCOPIC GROWTH LAWS

A general classification of macroscopic growth laws is reported in Refs. [22, 23]. In the present study we focus on well-known laws, namely the Gompertz law (GL) [24] and the logistic law (LL) [25], compared with the exponential spreading, which implies that the containment efforts have no effect.

The GL [24], initially applied to human mortality tables (i.e. aging) and tumor growth [26, 27], also describes kinetics of enzymatic reactions, oxygenation of hemoglobin, intensity of photosynthesis as a function of CO2 concentration, drug dose-response curve, dynamics of growth, (e.g., bacteria, normal eukaryotic organisms). The LL [25] has been applied in population dynamics, in economics, in material science and in many other sectors.

The previous laws differ in the description of the virus containment effects, which in the LL is stronger (power law behavior) than in the GL, which has a logarithmic decrease of the specific growth rate. More precisely, the macroscopic growth laws for a population $N(t)$ are solutions of a general differential equation that can be written as

$$\frac{1}{N(t)}\frac{dN(t)}{dt} = f[N(t)], \tag{1}$$

where $f(N)$ is the specific growth rate and its N dependence describes the feedback effects during the time evolution. If $f(N)$ becomes constant, the growth follows an exponential pattern.

In particular, the Gompertz and the logistic equations are:

$$\frac{1}{N(t)}\frac{dN(t)}{dt} = -k_g \ln\frac{N(t)}{N^g_\infty} \quad \text{Gompertz}, \tag{2}$$

$$\frac{1}{N(t)}\frac{dN(t)}{dt} = k_l\left(1-\frac{N(t)}{N^l_\infty}\right) \quad \text{logistic}, \tag{3}$$

where $k_g \ln(N^g_\infty)$ and k_l are respectively the initial exponential rates and the other terms determine the slowdown. In both cases the steady

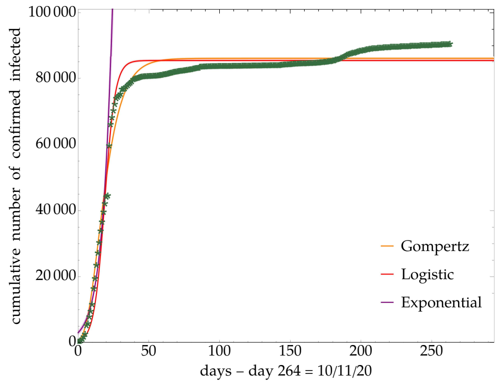

FIG. 1: Comparison of the growth laws with the data of the cumulative number of infected individuals in China. Final day - October 11.

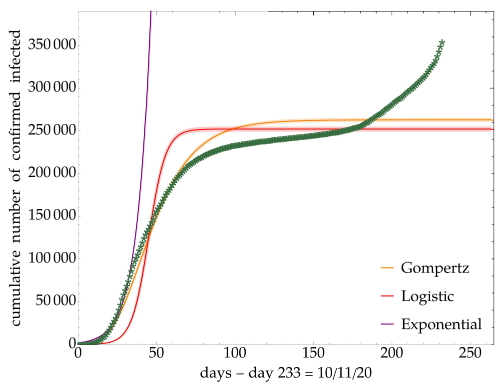

FIG. 2: Comparison of the growth laws with the data of the cumulative number of infected individuals in Italy. Final day - October 11.

state condition, $dN/dt = 0$, is reached when N is equal to the carrying capacity N_∞.

The contrast effect, mathematically represented by the second term in Eqs. (2) and (3), depends on many possible mechanisms of clinical and political origin (medical cure, biological conditions, isolation, information, *et cetera*).

The comparison of the growth laws, solutions of the previous differential equations, with the data on the cumulative number of infected individuals is reported in Fig. 1 for China, showing that the Coronavirus spreading has three phases: an initial exponential behavior, followed by a Gompertz one and by a final logistic phase. After the two or three phases, the spreading can restart, as shown in Fig. 2 for Italy.

In general, the previous growth laws signal different phases and the restarting of the disease spreading after a stationarity period, due to new

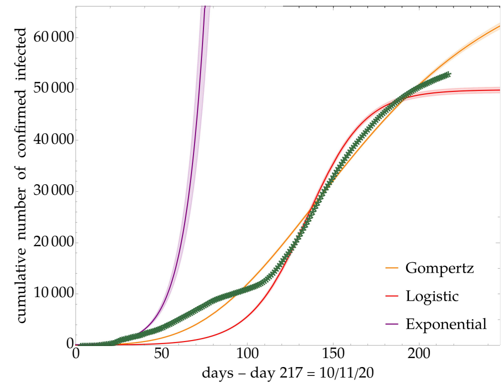

FIG. 3: Comparison of the growth laws with the data of the cumulative number of infected individuals in Algeria. Final day - October 11.

outbreaks or to the weakness of the control effort.

II. NORTH AFRICA

In this section we apply the GL and the LL to fit the most important indices of the Covid-19 spread in North African Countries on the basis of the available data [1–3] (data from Libya are actually not reliable to be included in this study).

We focus on the cumulative and daily numbers of confirmed infected people, of deaths and of hospitalizations and on the ratio, H, between the total number of infected people and the total number of hospitalization.

The available data for the cumulative quantities (infected people, number of deaths and hospitalizations) determines the corresponding values of the parameters, according to the specific growth law. By those fixed parameters (i.e. the carrying capacity and the exponential initial rate) one can predict the short term evolution.

A. Algeria

The time series of the cumulative number of confirmed infected people is depicted in Fig. 3 (green stars) and compared with the exponential rate (purple line), the GL (orange line) an the LL (red line).

After an initial exponential growth rate, the GL shows a better agreement with data, with a further reduction towards a LL.

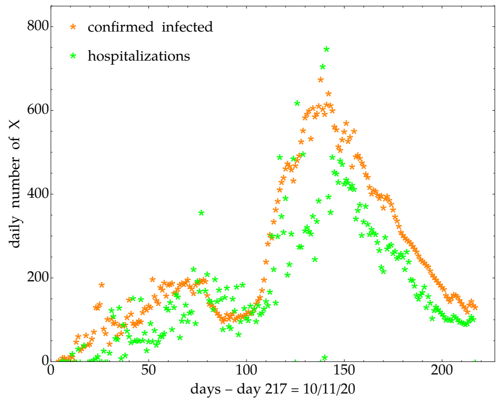

FIG. 4: Daily number of infected individuals and of hospitalizations in Algeria. Final day - October 11.

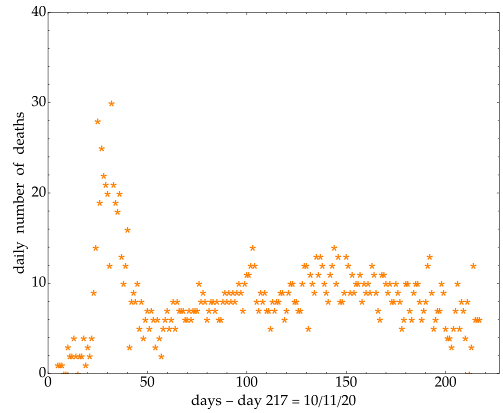

FIG. 6: Daily number of deaths in Algeria. Final day - October 11.

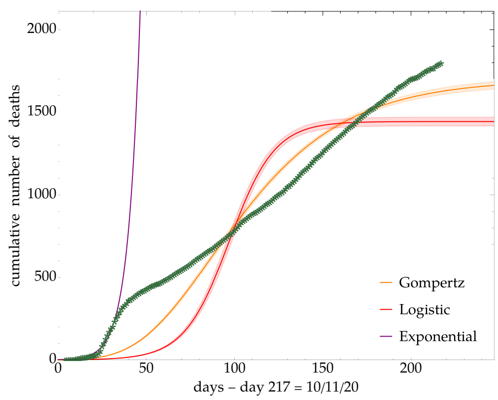

FIG. 5: Comparison of the growth laws with the data of the cumulative number of deaths in Algeria. Final day - October 11.

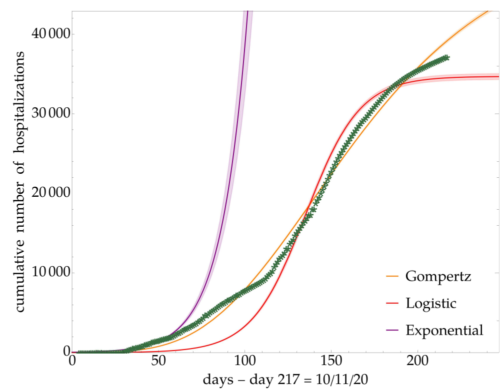

FIG. 7: Comparison of the growth laws with the data of the cumulative number of hospitalizations in Algeria. Final day - October 11.

The daily number of infected individuals is in Fig. 4 (orange stars) together with the daily number of hospitalizations (light-green stars): after a fast growth, there is a peak on (about) July the 26th and a decreasing trend, which suggests a strong containment effort although the mortality rate data in Fig. 5 (cumulative) indicates no saturation, with a steep linear increase, and the day by day ones, in Fig. 6, follows an almost stable trends in the last weeks.

The total number of hospitalizations follows a GL and the daily data shows a clear recent decreasing behavior (Figs. 7 and 4).

The ratio between the total number of hospitalization and the total number of infected people, H, in Fig. 8, could signal a saturation in the effort of the National Health System in response to the diffusion of the disease in the last weeks.

In conclusion, in Algeria there is an increasing trend in the daily confirmed infected people, but a new peak on July 26 is now observed and the containment effort is recently able to reduce the spread. The number of daily hospitalizations shows a possible peak on the 5th of August. The National Healt System seems able to respond to about 70% of the infected people.

B. Egypt

The data for the cumulative numbers of confirmed infected people, of deaths, and of hospitalizations in Egypt are, respectively, illustrated in Figs. 9-11. The corresponding fit for the number of confirmed infected people shows that the GL behavior is in better agreement with data, while the initial phase is best described by an exponential growth. The number of deaths , Fig. 10

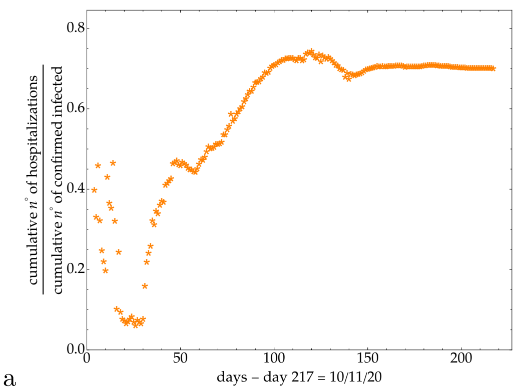

FIG. 8: Ratio between the cumulative number of infected and the cumulative number of hospitalizations in Algeria. Final day - October 11.

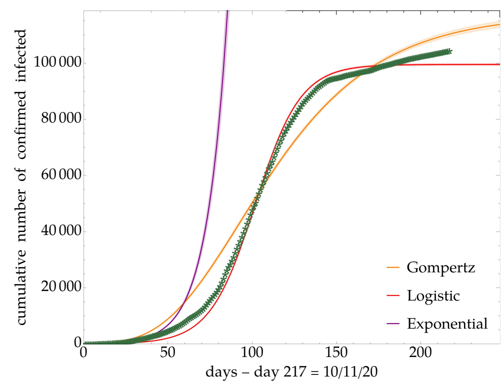

FIG. 9: Comparison of the growth laws with the data of the cumulative number of infected individuals in Egypt. Final day - October 11.

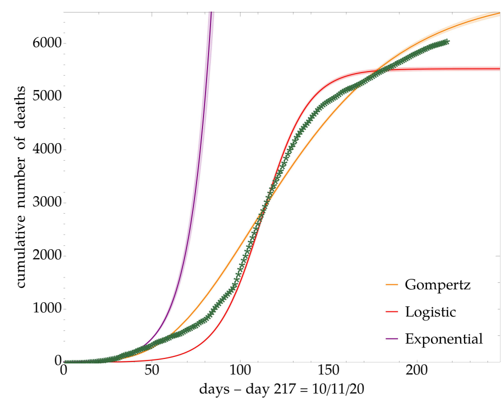

FIG. 10: Comparison of the growth laws with the data of the cumulative number of deaths in Egypt. Final day - October 11.

and the number of hospitalizations, Fig. 11, are well described by GL in all phases. No evidence for a final phase is observed in any the cumulative numbers, although a clear peak is visible in the daily number of infected people in Fig. 12, which suggests a better evolution of the spreading in the near future.

The daily number of hospitalizations, and of deaths, respectively are reported in Figs. 12 and 13. Despite the strong fluctuations, the three ensembles are likely biased. For example, registering infected individuals through medical tests is controlled by different protocols. On the other hand, the daily numbers of deaths and of hospitalizations are strongly affected by various social and institutional impacts.

Finally, the ratio, H, between the total number of hospitalization and the total number of infected people is reported in Fig. 14 and it seems to remain approximately constant. As discussed, both total number of hospitalization and total number of infected individuals are likely biased, no statistical conclusion can be drawn.

C. Morocco

The results of the containment efforts of Covid-19 in Morocco for the cumulative and daily number of infected people are in Figs. 15 and 16. The cumulative number is well described by the GL behavior, with a very fast growth rate, and the daily number shows no peak and a increasing average trend. The same behavior is observed for the total and daily number of hospitalizations (see Figs. 17 and 16). The mortality rate agrees with the GL and the LL, but with no saturation (see Figs. 18 and 19). The ratio H (Fig. 20) shows fluctuations with an average value of about the 80% of the total infected population.

Therefore, Morocco shows a growth in the total and daily number of infected people in the last weeks, with possible new outbreaks.

D. Tunisia

Tunisia is a typical example of different phases in the control of Covid-19 spreading.

Indeed, the Government initially adopted comprehensive prevention policy since the early stages of the SARS-CoV-2 epidemic. As early as

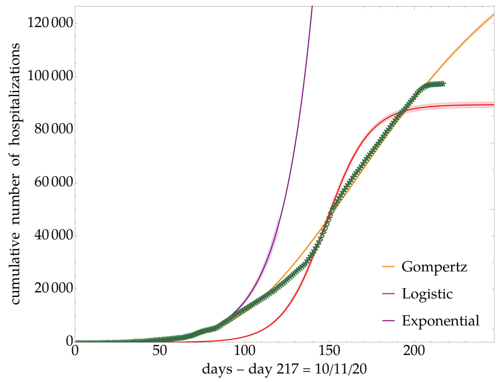

FIG. 11: Comparison of the growth laws with the data of the cumulative number of hospitalizations in Egypt. Final day - October 11.

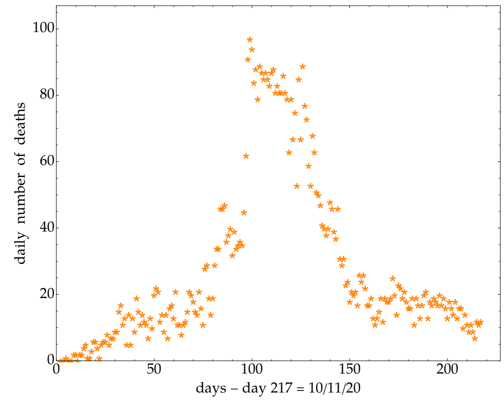

FIG. 13: Daily number of deaths in Egypt. Final day - October 11.

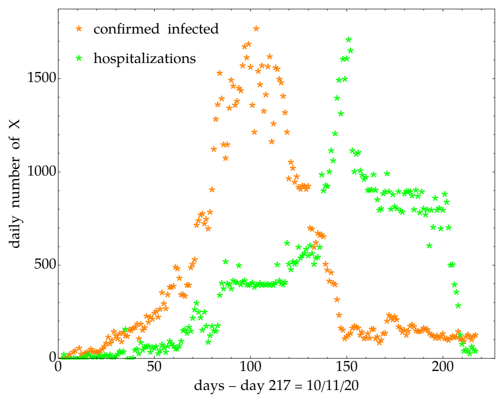

FIG. 12: Daily number of infected individuals and of hospitalizations in Egypt. Final day - October 11.

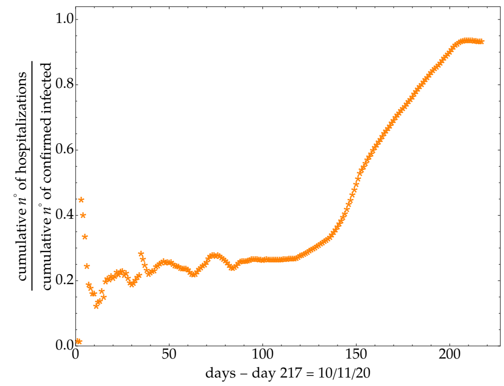

FIG. 14: Ratio between the cumulative number of infected and the cumulative number of hospitalizations in Egypt. Final day - October 11.

22 January 2020, authorities implemented upstream containment measures, including screening at border entry points and systematic quarantine for travelers from high-risk areas. Additional preventive measures have been decided after the first confirmed case. On March 12, 2020, the closure of schools and universities was announced followed by the closure of all sea and air borders. A national curfew was enforced from 18 March 2020, subsequently supplemented by a national lockdown with a ban on transport between the governorates. The government of Tunisia clearly adopted the lockdown strategy by reducing case numbers by social distancing the entire population, closing schools and universities, and halting all non-essential economic activities to protect the population. All these measures, including isolation of infected individuals and active contact tracing, allowed the initial control of the spread.

On the other hand, as shown in Figs. 21-26, the situation is now completely different with a fast growth after a stationary condition (plateau). In the last weeks in Tunisia there is an increasing, exponential, trend of the infected people which signals a new dangerous phase and, moreover, the number of hospitalizations shows an anomalous jump with a corresponding step in H.

III. COMPARATIVE ANALYSIS

A comparative analysis among the different Countries can be done on the basis of cumulated parameters, because the daily numbers show strong fluctuations.

In Fig. 27 the total number of confirmed infected individuals clearly shows the different be-

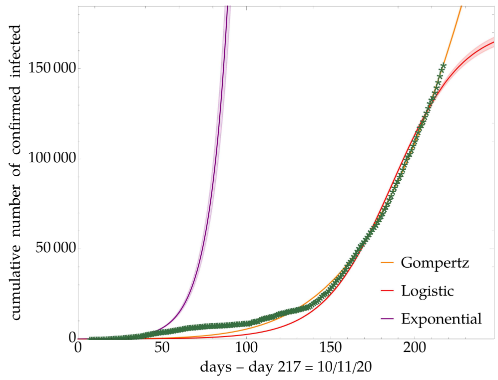

FIG. 15: Comparison of the growth laws with the data of the cumulative number of infected individuals in Morocco. Final day - October 11.

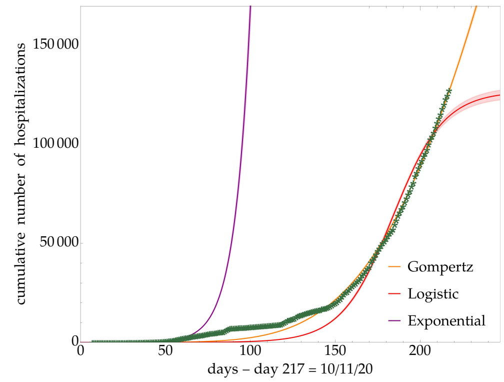

FIG. 17: Comparison of the growth laws with the data of the cumulative number of hospitalizations in Morocco. Final day - October 11.

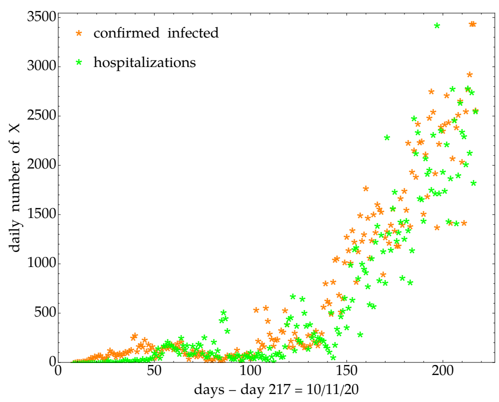

FIG. 16: Daily number of infected individuals and of hospitalizations in Morocco. Final day - October 11.

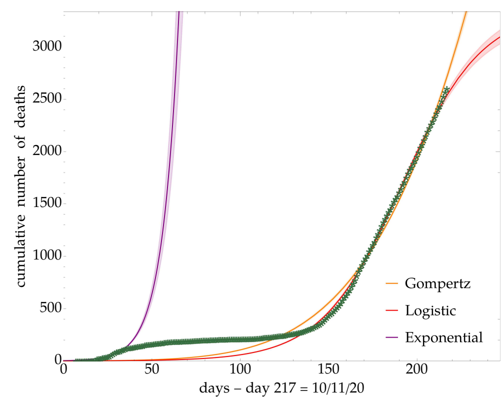

FIG. 18: Comparison of the growth laws with the data of the cumulative number of deaths in Morocco. Final day - October 11.

haviors. Algeria and Egypt started with a weak level of control of the spreading with respect to Morocco and Tunisia. Recently, the analysis suggest a quite different situation in North Africa with Algeria and Egypt enforcing a more severe control and a rather fast growing rate of Covid-19 in Tunisia and Morocco.

The previous conclusion is supported by the total number of hospitalizations (see Fig. 28) and the total number of deaths, in Fig. 29.

IV. SHORT TERM PREDICTIONS

The previous analysis for the different Nations indicates that the cumulative indices (confirmed infected, deaths and hospitalizations) are, in general, well described by the GL, although some fast linear growth has been observed in the last weeks.

The most important and difficult aspect of the data analysis is the possibility of predictions of the spread evolution. In general, long term predictions are unreliable since the underlying dynamics is unknown. However, macroscopic growth laws, with the small number of parameters fitted by data, permit an estimate of the short time evolution, by extrapolating the GL or the steep linear (in the last weeks) fits.

We have done about four months of study of the short term predictions in the different North Africa Nations (see www.northafricacovid.org) and one can indeed consider that the short term predictions (say, for less/about than a week) are, in general, reliable within few percent.

As an example, the prediction for the cumulative number of confirmed infected, hospitalizations and deaths from 12 to 16 October are in the Tables I-IV, where, however, there is a problem

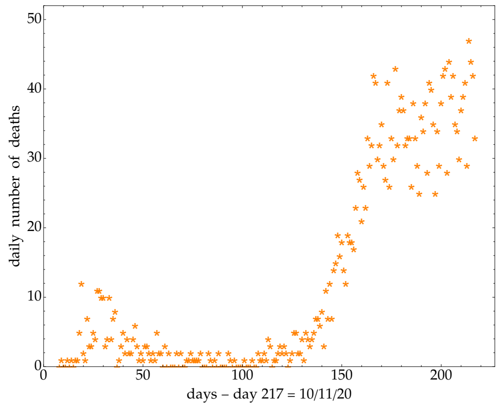

FIG. 19: Daily number of deaths in Morocco. Final day - October 11.

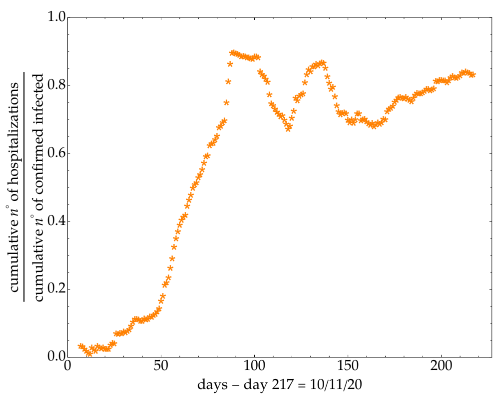

FIG. 20: Ratio between the cumulative number of infected and the cumulative number of hospitalizations in Morocco. Final day - October 11.

in hospitalization data for Tunisia, which show an anomalous, huge, jump in the previous weeks.

The ex-post verification of the short term predictions, weekly done for about five months (June-October 2020) for the cumulative numbers, shows the agreement with the observed data within $5-10\%$, as depicted in fig. 30 for

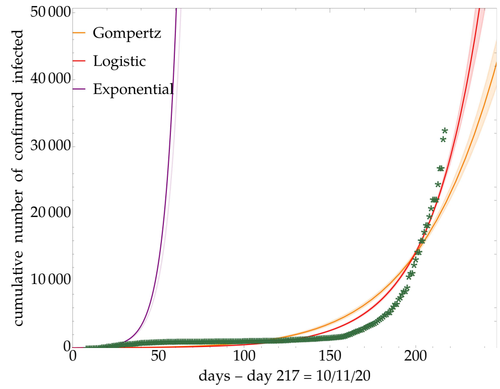

FIG. 21: Comparison of the growth laws with the data of the cumulative number of infected individuals in Tunisia. Final day - October 11.

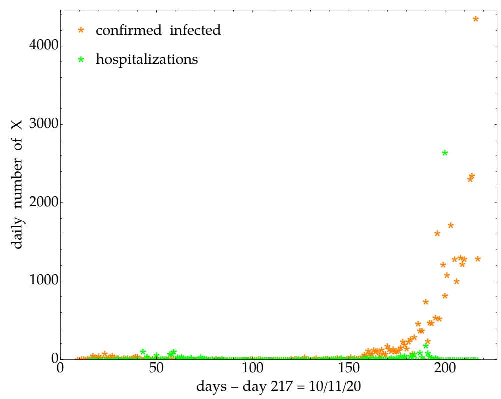

FIG. 22: Daily number of infected individuals and of hospitalizations in Tunisia. Final day - October 11.

Morocco (with similar figures for the other countries).

Day	Infected	Hospitalizations	Deaths
11 October	53070	37221	1800
12 October	53205	37311	1807
13 October	53340	37401	1813
14 October	53474	37491	1819
15 October	53609	37581	1825
16 October	53744	37670	1831

TABLE I: Algeria

Day	Infected	Hospitalizations	Deaths
11 October	104513	97833	6050
12 October	104634	97933	6060
13 October	104756	98033	6070
14 October	104877	98133	6081
15 October	104999	98234	6091
16 October	105120	98334	6101

TABLE II: Egypt

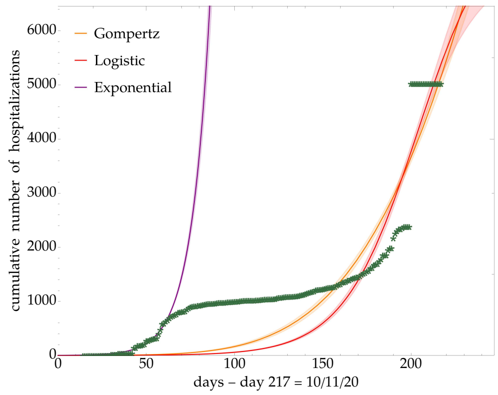

FIG. 23: Comparison of the growth laws with the data of the cumulative number of hospitalizations in Tunisia. Final day - October 11.

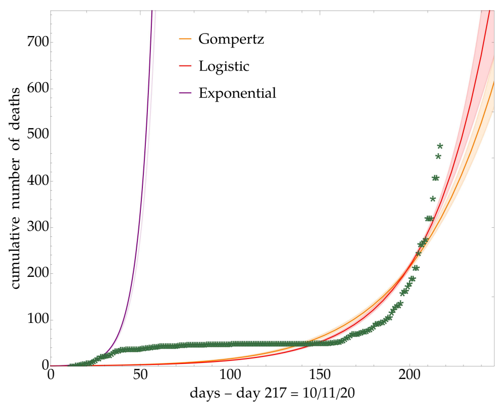

FIG. 24: Comparison of the growth laws with the data of the cumulative number of deaths in Tunisia. Final day - October 11.

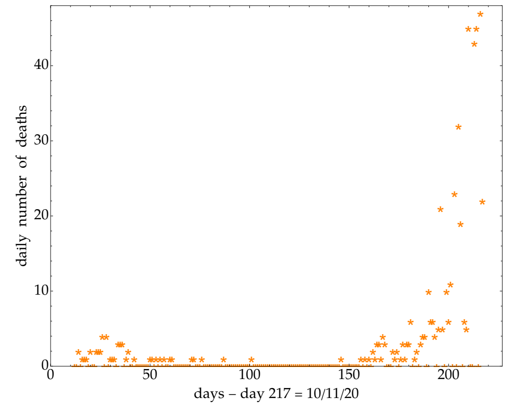

FIG. 25: Daily number of deaths in Tunisia. Final day - October 11.

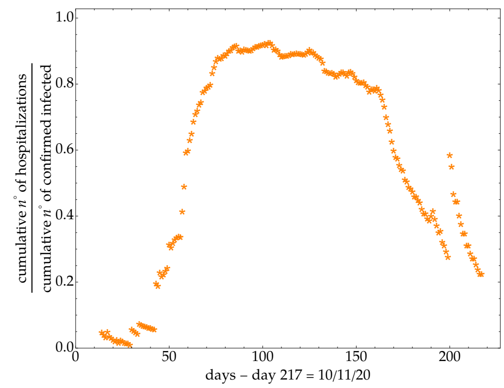

FIG. 26: Ratio between the cumulative number of infected and the cumulative number of hospitalizations in Tunisia. Final day - October 11.

V. CORRELATION WITH MEDITERRANEAN SEA IMMIGRATION

Another interesting question is the possible correlation between the spread of Covid-19 in North Africa and the sea immigration in other Mediterranean Nations, which can be studied by the monthly data of United Nations [28].

In Figs. 31, 32, and 33 is shown the different trend among 2017-18-19 and 2020. In 2020 there is an increase starting in June with respect to

Day	Infected	Hospitalizations	Deaths
11 October	152440	127423	2608
12 October	155464	129783	2648
13 October	158489	132144	2688
14 October	161513	134504	2728
15 October	164538	136865	2768
16 October	167562	139225	2808

TABLE III: Morocco

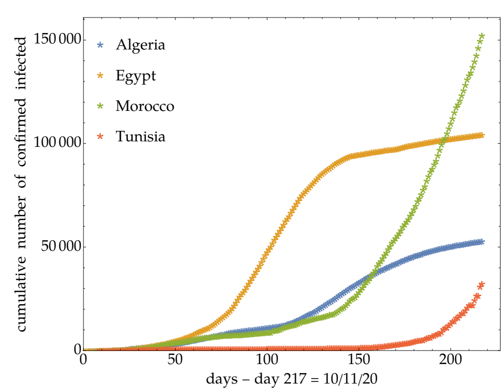

FIG. 27: Comparison of the total number of confirmed infected. Final day - October 11.

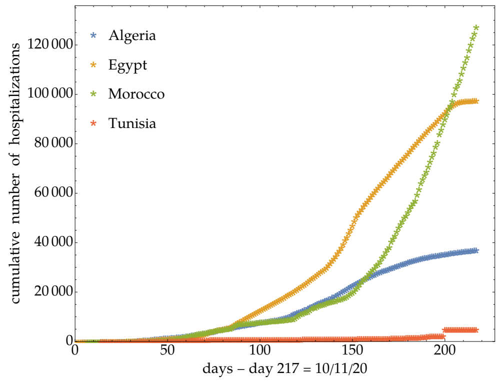

FIG. 28: Comparison of the total number of hospitalizations. Final day - October 11.

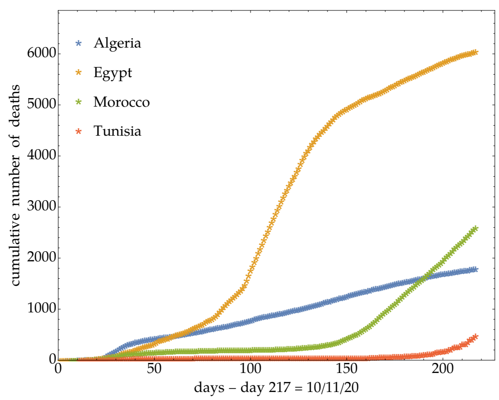

FIG. 29: Comparison of the total number of deaths. Final day - October 11.

2019, which is partially due to the end of lock-down phase. Indeed, during the lock-down phase in the European Mediterranean Countries, the immigration has been essentially blocked by the Governments. Moreover the first lock-down was from March to May 2020. The combined effects of the reopening and of the summer season increased the number of sea immigrants.

Day	Infected	Hospitalizations	Deaths
11 October	32166	5032	478
12 October	34001	5032	506
13 October	35837	5032	534
14 October	37672	5032	562
15 October	39508	5032	591
16 October	41343	5032	619

TABLE IV: Tunisia

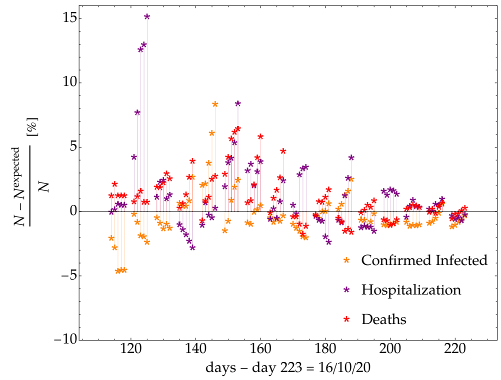

FIG. 30: Comparison of the expected number of confirmed infected, of hospitalizations and of deaths with the observed values for Morocco.

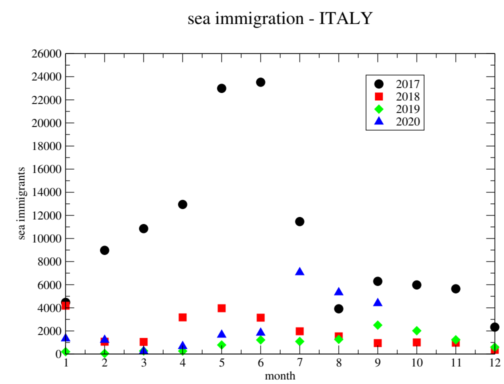

FIG. 31: Number of sea immigrants per month in Italy-2017-2018-2019-2020

VI. COMMENTS AND CONCLUSIONS

The proposed analyses for the single Nations and the comparative study indicate that macroscopic growth laws are a useful tool for describ-

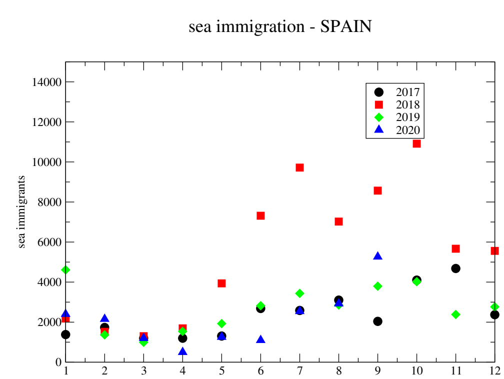

FIG. 32: Number of sea immigrants per month in Spain - 2017-2018-2019-2020

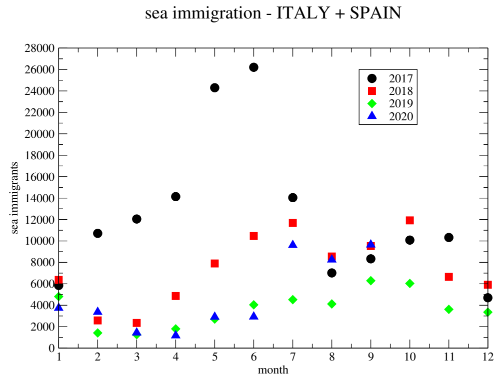

FIG. 33: Number of sea immigrants per month Italy and Spain - 2017-2018-2019-2020

ing the most important indices of the Covid-19 spreading.

Moreover, the corresponding short term predictions are reliable and one easily visualizes possible deviations from the trend of the epidemic evolution, due, for example, to some new outbreaks.

Of course, the data fits have to be updated (the weekly study is in the web site www.northafricacovid.org), in such a way to follow the time evolution of the infection and its impact on the National Health Systems.

We conclude that stable (or unstable) condition of the spreading in North Africa can quickly change due to a stronger or weaker application of the lockdown measures. Tunisia and Egypt are clear examples of different phases, which produce strong effects on the National Health Systems. Indeed, in our opinion , the suggested approach has to be extensively used to evaluate (although for short time interval) the impact of the spread on the National Health systems.

The correlation between sea immigration and Covid-19 spreading follows, in a broad sense, the lockdown period of the European Countries, although there is a clear overlap with the political agreements among the European and North Africa Nations (Spain-Italy anti-correlation).

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