Mathematical Modeling of COVID-19 Pandemic in the African Continent

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Abstract:

The present work aims to give a contribution to the understanding of the highly infectious pandemic caused by the COVID-19 in the African continent. The study focuses on the modelling and the forecasting of COVID-19 spread in the most affected African continent, namely: Morocco, Algeria, Tunisia, Egypt and South Africa and for the sake of comparison two of the most affected European country are also considered, namely: France and Italy. To this end, an epidemiological SEIQRDP model is presented, which is an adaptation of the classic SIR model widely used in mathematical epidemiology. In order to better coincide with the preventive measures taken by the governments to deal with the spread of COVID-19, this model considers the quarantine. For the identification of the model's parameters, official data of the pandemic up to August 1st, 2020 are considered. The results show that the number of infections due to the use of quarantine is expected to be very low provided the isolation is effective. However, it is increasing in some countries with the early lifting of containment. Finally, the information provided by the SEIQRDP model could help to establish a realistic assessment of the short-term pandemic situation. Moreover, this will help maintain the most appropriate and necessary public health measures after the lockdown lifting.

Keywords: COVID-19; SEIQRDP model; reproduction number; African continent.

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1. Introduction

The year 2020 is and will be forever marked by the COVID-19 pandemic caused by the highly infectious disease SARS-CoV-2. According to the World Health Organization, since its first appearance in late 2019 in the Wuhan region of China, the Covid-19 has affected more than 6 million people and has caused the death of almost 400 thousand people worldwide, during the first half of 2020. However, the spread of the disease and the damage caused by it did not happen in the same way and at the same time for all continents. Indeed, taking the case of the African continent, the COVID-19 pandemic reached a significant point by exceeding 180,000 cases in early June with more than 5,000 deaths. Although the pandemic has reached a worrying threshold, the spread of the disease in Africa has not followed the exponential path as in the rest of the world (e.g. Europe and United States). According to WHO's analysis, the relatively low mortality rate compared to other continents is likely due to the demographic nature of the continent. Indeed, demographically, Africa is considered as the youngest continent, with more than 60% of the population under the age of 25. However, the disease still represents a danger for the African population, particularly, the South and African North. In fact, according to the WHO, the above-mentioned regions account for more than 56% of the cases recorded in Africa.

To date, in the absence of an effective vaccine or treatment against COVID-19, African governments have taken several measures to limit the spread of the disease as much as possible (e.g. quarantine, social distancing, lockdown, curfew, masks, etc.). Furthermore, during this anti-COVID-19 battle, in addition to medical and biological research, theoretical studies based on mathematical models can also play an important role in understanding the pandemic dynamics (e.g. predicting the inflection point and of the end time). These models are therefore an important decision-making tool for coping with this pandemic. Since the apparition of the disease, the literature has witnessed an avalanche of work on modelling and predicting the behaviour of the COVID-19 pandemic. However, most of these works have focused on China [1-5], Europe [6-11] and the United States [7, 11-13], which is understandable because these are the regions which were the first and most affected by COVID-19. Nevertheless, studies on the African continent are practically negligible compared to those dedicated to the above-mentioned regions [14-16].

The present paper aims to present a contribution on the modelling and the forecasting of COVID-19 spread in the most affected African continent, namely: Morocco, Algeria, Tunisia, Egypt and South Africa. In addition, for the sake of comparison two European countries are considered, namely: France and Italy. Thereby, an epidemic SEIQRDP model is presented, which is an adaptation of the classic SIR model widely used in mathematical epidemiology. In the next section, we present the data and the model. Section 3 presents the results of the application of the model for the above-mentioned countries through the estimation of the epidemic parameters and the adjustment of the model. The discussion of the results obtained as well as a forecast analysis, are presented in the same section. The last section provides some future directions for using the SEIQRDP model to control and prevent the spread of the COVID-19virus.

2. Data and Model

2.1. Data

The epidemiologic data of Covid-19 were provided by the Johns Hopkins University Center for Systems Science and Engineering (JHUCSSE) [17], and derived from the official case count from the World Health Organization. The data provides the total number of confirmed, quarantined, recovered and death cases, for each country since January 22, the day that WHO announced an epidemic caused by a new coronavirus in China. Our preliminary study includes the most affected African countries and one of the main endemic foci in Europe, namely: Algeria, Morocco, Egypt, South Africa, Tunisia, France, and Italy. Figure 1 shows the cumulative reported cases of COVID-19 in the considered countries. The data refer to daily cumulative cases from January 22, 2020 until August 1st, 2020. It is important to note that these data are influenced by the capacity and strategy of countries in case detection. Some countries perform more tests than others. However, the provided data still provide indicator for tracking the trajectories of the epidemic. It can be well seen from figure 1 that the curve of newly detected cases in European countries is gradually flattening. On the other hand, there is an epidemic surge in the African countries, where the number of cumulative cases shows a different picture. Indeed, South Africa and Egypt are currently the countries with most known confirmed and deaths cases and the curve of infections still pointing mostly upwards.

Unlike the last ones, the curve of cumulative cases is increasing less rapidly in Algeria and Morocco. Although Algeria has the highest number of deaths ahead the African countries. While, the curve of newly detected cases in Tunisia quickly flattened. Infection numbers have, however, also shown some signs of slowing down. It should be noted that the African continent is the last to be affected by the coronavirus. Indeed,

The epidemic spread to Africa a few weeks after Europe, allowing its leaders to adopt preventive measures well in advance. South Africa, Tunisia, Morocco and Algeria imposed the lockdown and curfews before the epidemic had had time to spread. In addition, the low population density has considerably limited the transmission of the virus. Indeed, the inhabitants are generally concentrated in the capitals.
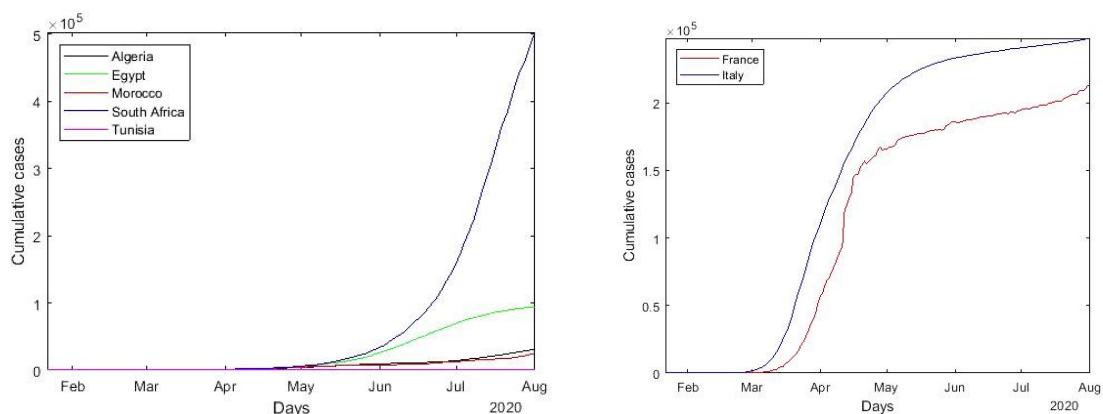

Figure 1 Cumulative reported cases of COVID-19 disease.

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103   **2.2. SEIQRDP Model**

104   Using a pandemic modeling makes it possible to understand, describe and forecast its behavior
105   and its spread. Indeed, the mathematical models assess hypotheses, indicate trends, and help
106   develop public health responses by estimating risks, in real time, during an epidemic.
107   Nevertheless, modeling is a simplified representation of reality. Its precision is limited here by
108   the ignorance of certain factors and mechanism of propagation of COVID-19.

109   In this work, the SEIQRDP epidemiological model with seven different components, proposed
110   by [2] is used. The model is an adaptation of the classic SEIR model [18, 19], widely used to
111   study the COVID-19 pandemic in many countries with variations in components and
112   parameters for adaptations to regions and study period [16, 19-23]. The present model
113   considers the effect of quarantine adopted by many countries as an effective means of
114   preventing the spread. The stochastic SEIQRDP model is specified by the following system of
115   differential equations:

116
$$\begin{cases} \dfrac{dS_t}{dt} = -\beta \dfrac{S_t I_t}{N} \\[2mm] \dfrac{dP_t}{dt} = \alpha S_t \\[2mm] \dfrac{dE_t}{dt} = \beta \dfrac{S_t I_t}{N} - \gamma E_t \\[2mm] \dfrac{dI_t}{dt} = \gamma E_t - \delta I_t \\[2mm] \dfrac{dQ_t}{dt} = \delta I_t - \lambda_t Q_t - \kappa_t Q_t \\[2mm] \dfrac{dR_t}{dt} = \lambda_t Q_t \\[2mm] \dfrac{dD_t}{dt} = \kappa_t Q_t \end{cases} \tag{1}$$

117   Where the different component at time t, i.e, $S_t, P_t, E_t, I_t, Q_t, R_t, D_t$ are respectively, the number
118   of susceptible cases (individuals who can contract the disease), the number of protected cases,
119   who have become insensitive to the disease, mainly by following the recommended protective
120   measures, the number of exposed case (individuals that have contracted the disease but not yet
121   infectious), the number of infectious cases (infectious individuals but not yet quarantined), the
122   number of quarantined cases, i.e active cases (confirmed and infected), the recovered and death
123   cases (individuals removed from the chain of transmission), respectively. The component of
124   protected part of people, namely, P_t, was introduced to reflect the growing awareness of the
125   population while respecting the lockdown. It should be noted that the total population N is
126   assumed to be homogenous, i.e. there is no birth or death and recovered people remain immune
127   once they recover from the disease where, $N = S_t + P_t + E_t + I_t + Q_t + R_t + D_t$.

128   The protection rate α, represents the population that takes into consideration security measures
129   and the actions of health authorities, it was introduced assuming that the sensitive population
130   decreases steadily. Moreover, beside the parameter α, all the remaining parameters depend on

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131 the evolution of the epidemic, the health care and the screening capacities and are calculated
132 based on the daily numbers of confirmed, recovery and death cases. The infection rate β,
133 represent the average number of contacts per-capita per time, multiplied by the probability of
134 successfully getting infected when coming into contact with an infected individual. While, the
135 latent rate γ^{-1}, represent the average time for a latent individual to become infectious, which is
136 estimated within several days [4, 24]. Furthermore, the quarantined rate δ^{-1} represent the
137 average time for an infectious individual to enter in quarantine, which is considered to be
138 between 2 and 14 days [2]. Finally, to consider the measures taken by the different countries in
139 this study, we assume that the recovery rate λ_t and the death rate κ_t are time dependent
140 function, as confirmed by [2, 21].

141 In case of a new disease as the COVID-19, the medical staff must learn new therapeutic
142 procedures and treat patients with new symptoms every day. Hence, the time of recovery,
143 cannot be a constant, because the recovery time at the start of the disease is longer, this means a
144 slower recovery rate which gradually increasing with time, considering the measures taken by
145 the governments. Consequently, we will assume that the recovery rate is modeled by following
146 function,

$$\lambda_t = \lambda_0 \left[1 - \exp\left(-\lambda_1 t\right) \right], \tag{2}$$

148 where λ_0 and λ_1 are the fitted coefficients [2].

149 Unlike the recovery rate, the mortality rate quickly decreases over time. This is due to the
150 medical assistance, the adaptation of the pathogen and the development of new treatments.
151 Hence, we will assume that the mortality rate is modeled by an exponential decay function
152 given as follows,

$$\kappa_t = \kappa_0 \exp\left(-\kappa_1 t\right), \tag{3}$$

154 where κ_0 and κ_1 are the fitted coefficients [2].

155 However, one of the most discussed parameters in the current COVID-19 pandemic is the basic
156 reproductive number [2, 24-26]. Biologically, this number, represented by R_0, corresponds to
157 the number of new infections caused by an infected individual in a susceptible population. One
158 of the main reasons of the importance of the basic reproduction number is that it determines the
159 fraction of the population that needs to be immunized for the epidemic to start to decline. The
160 reproductive number will vary during an epidemic for two reasons. On the one hand, the public
161 health measures are put in place, like the lockdowns, social distancing, and other mitigation
162 strategies to keep the case count and death toll low in this pandemic. On the other hand, the
163 epidemic spreads and people who have recovered are protected against reinfection (at least in
164 the near future). Thus, the population becomes immune.

165 If the R_0 is above 1, each infection breeds more, and the outbreak will continue to grow. When
166 it falls below 1, the outbreak will continue but at a lower death rate.

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167 In this study, the R_0 is calculated by the next generation matrix method [22], based on a
168 endemic equilibrium, given by : $S = N, P = E = I = Q = R = D = 0$. We must solve the
169 equation, $R_0 = \rho(FV^{-1})$, where F and V are, respectively, the derivatives of the new
170 infections matrix $\mathcal{F}$ and the transition matrix $\mathcal{V}$, evaluated at the endemic equilibrium and is
171 given by, $R_t = \beta * \delta^{-1}(1 - \alpha)^t$, where t represent the number of days.

172 The nonlinear system of the SEIQRDP model given by (1.1) can only be solved using
173 numerical methods to observe the dynamics of the model. Firstly, we estimated the parameters,
174 namely, $\alpha, \beta, \gamma^{-1}, \delta^{-1}, \lambda_t, \kappa_t$. In this step, we search the unknown parameters for the SEIQRDP
175 model by global optimization. This is done automatically by implementing the nonlinear least
176 square regression method. The optimization of the model parameters to describe the
177 experimental results was performed via the minimization of the sum of the squared errors
178 between the epidemiologic and the modeling data, during successive iterations, which finally
179 gives the best parameters for data fitting. It should be noted that the use of the cumulative data
180 should be avoided, since the cumulative incidence data are highly correlated, and the least
181 squares approaches relies on the fitting of independent data. Therefore, the use of daily new
182 data should be preferred, since these data are independent. Once all the parameters are known,
183 we can solve the system of differential equations (1.1).

3. Results and Discussion

185 The estimated parameters for the considered countries are given in Table 1, where we consider
186 the mean values of the recovery rate and deaths rate, λ_t and κ_t, respectively .

187 **Table 1.** Parameter estimation of the SEIQRDP model

Country	N	α	β	γ	δ	λ_t	κ_t
Morocco	36e+6	0.017	0.524	0.475	0.175	0.057	0.003
Algeria	43e+6	0.017	0.448	0.332	0.136	0.051	0.008
Tunisia	12e+6	0.055	0.675	0.407	0.139	0.038	0.001
Egypt	100e+6	0.032	0.379	0.0.249	0.0.479	0.003	0.007
South Africa	56e+6	0.008	0.424	0.461	0.169	0.049	0.002
France	65e+6	0.022	0.799	0.349	0.173	0.015	0.009
Italy	60.48e+6	0.028	0.954	0.347	0.174	0.028	0.006

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189 The estimated parameter values are strongly linked to the discipline of the local population,
190 public health systems and the severity of the lockdown measures. Although there is so far no
191 gold standard for assessing the accuracy of the model parameters, the values of the obtained
192 parameters are in good agreement with the estimates given by [4, 27, 28]. The protection rate is
193 expected to remain very close to zero since there is currently no vaccine against COVID-19
194 [20] . It can be seen from table 1 that Tunisia shows the highest protection rates, which reflects
195 the increase of people infected with the new coronavirus after the opening of the country's
196 borders. The infection rate β values are in the range of the recent estimate by [4]. The lower it

197 is, the less an infected individual will be able to infect healthy individuals. However, Tunisia
198 shows a high infectious potential of the disease, compared to other African countries, which
199 confirms the result of the protection rate. The obtained latent rates (Table 1) are, also, in
200 agreement with the existing report [24], where Egypt has the longest latency period, which
201 explains the number of infected people exceeding 94,000 cases. This may be due the delay in
202 taking control and prevention measures against COVID-19. Notes that the latent period for
203 COVID-19 is limited to $\gamma \in [0.2 : 0.5]$, so a latency period between 2 and 5 days [24]. While,
204 Diekmann, Heesterbeek [22] notes that the average incubation period $\gamma^{-1} + \delta^{-1}$ for COVID-19
205 is between 2.1 and 11.1 days, this implies an infection rate limited to $\delta \in [0.1 : 1]$. Therefore, a
206 quarantine period between 1 and 10 days. The estimation values obtained are within this
207 estimation range, where the smallest quarantine period is recorded in Egypt. However, the
208 parameters λ_t and κ_t governing, respectively, the recovery rate and the mortality rate of the
209 disease, seems quite similar in the different countries, except for Egypt and Algeria. It is
210 interesting to note that the smallest value of λ_t is recorded in Egypt compared to other
211 countries, which coincides with the results of the quarantine time obtained (Table 1). This is
212 probably due to an overload of the health system which implies a shorter average quarantine
213 period. This reflects the poor control of virus spreading by the low testing capacity and the non-
214 compliance with health security measures against coronavirus, especially in the most affected
215 areas of the country. On the other hand, Algeria has the highest value of the parameter κ_t,
216 probably due to prevention and control measures as well as the dramatic improvement in
217 medical conditions, such as the use new treatment protocol as well as the strict compliance with
218 lockdown. The use of the quarantine considered by the current SEIQRDP model is based on the
219 separation of the healthy population from the asymptomatic population in order to prevent the
220 spread of the virus more quickly.

221 Figure 2 shows the effective reproduction number (R_t) as a function of time for the different
222 modeled countries for the same period. Analyzing the effective reproduction number (R_t) can
223 give us more information about how the pandemic dynamics unfolded and detecting in real
224 time the climax or turning point. Moreover, this figure is an indication of the speed and the
225 severity of the preventive measures as well as quarantine, adopted to reduce the average
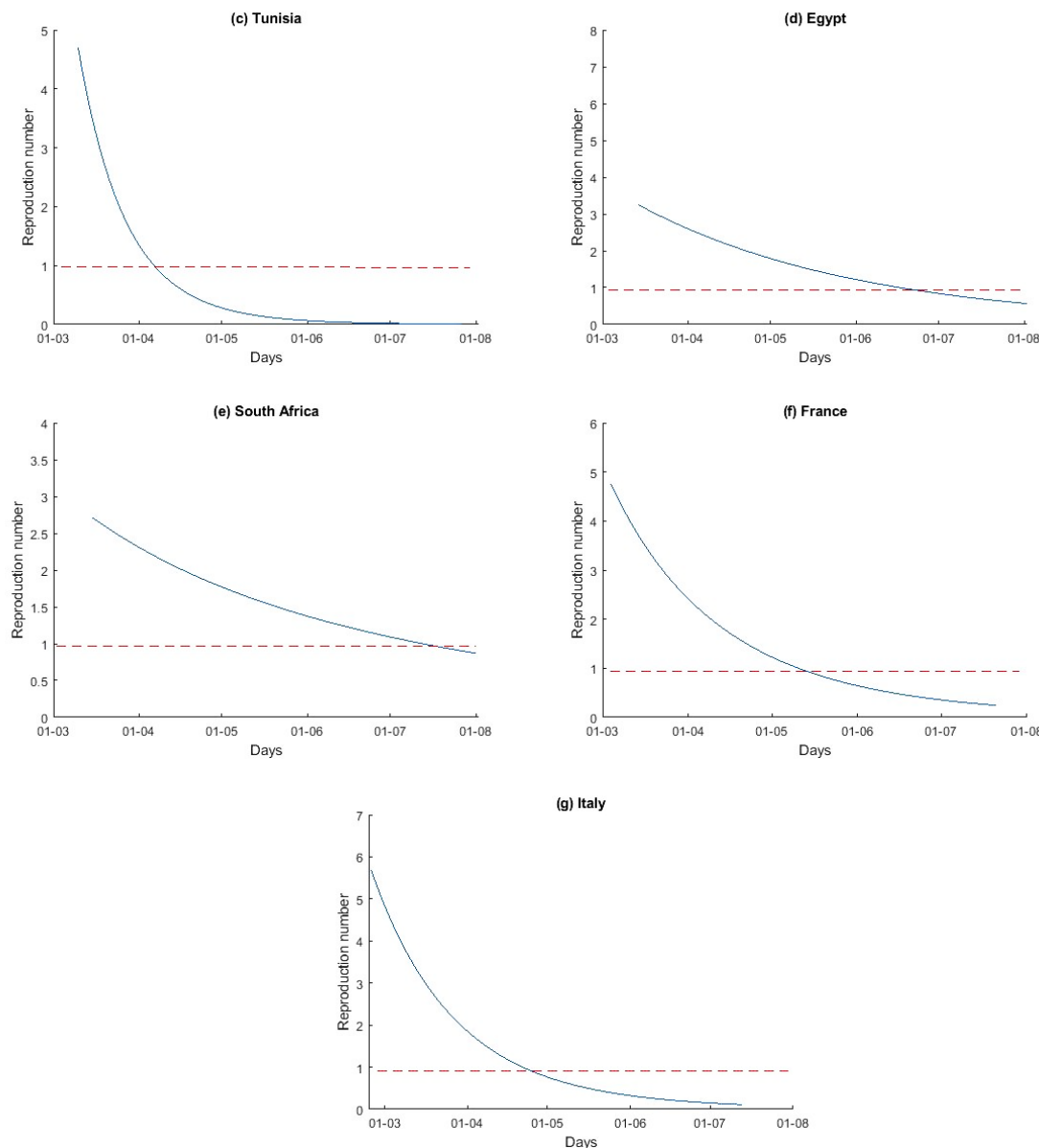226 infectious period by isolating certain infectious, so that they do not transmit the infection.

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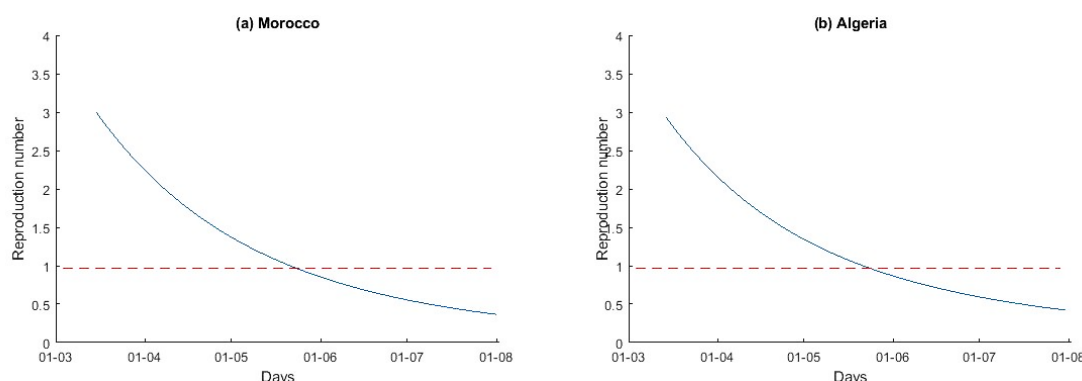
Figure 2 Estimated effectif reproduction number over time

As can be seen, R_t becomes less than 1 between early April and early June, about four to seven weeks after the lockdown in the Maghreb countries (figure 2a-c). In fact, this shows the effects of the lockdown, the quarantine and the strict curfews adopted to reduce the effect of virus transmission, while for Egypt and South Africa, the R_t has not crossed the line $R_t = 1$ (mitigation phase), till end of June for Egypt and mid-July for South Africa. However, the lowest infection kinetics is recorded in Tunisia and has generated a first $R_0 = 4.690$, much lower than those of other African countries and that of Italy especially. For Egypt, the number R_t decreased more slowly due to relative delayed lockdown compared to the other countries and an early lifting of the lockdown. However, the number of effective reproduction number depends on the parameter δ, which governs the rate of transfer from the infectious class to the quarantine class. Therefore, the use of quarantine to control the disease not only decreases the size of the endemic infectious class, but also reduces the reproduction number R_t below 1, so that the disease vanishes.

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247 The estimation results (Table 1 and Figure 2) indicate that the measures taken to prevent, and
248 control the epidemic taken by the governments have strengthened over time. Indeed, the
249 admission and follow-up of suspect cases, quarantine and treatment of confirmed cases
250 significantly affect the parameters values. As a result, the number of active (quarantined),
251 suspect, cured cases and the deaths predicted by the SEIQRDP model tend to decrease over
252 time. On the other hand, the accuracy of long-term forecasts will also decrease.

253 Figure 3(a-g) present the forecasts of actives (quarantined), recovery and death cases of the
254 COVID-19 pandemic in the considered African countries and European depending on
255 quarantine policy considered by the SEIQRDP model. While, Figure 4 presents the forecasts of
256 the COVID-19 pandemic for France, Algeria, Morocco and Tunisia for the period after the
257 lifting of the lockdown.

258 Figure 3 and Figure 4 show the potential of the SEIQRDP model to predict the trend of
259 pandemic dynamics. As can be seen from Figure 3, the curves follow roughly the same trend
260 except for the two most affected African countries, namely, Egypt and South Africa. From
261 Figure 4, we note that the curves follow the same trend to those of Figure 3, where we notice
262 some non-homogeneity of the data. The curves show the potential of the model to predict the
263 trend of pandemic dynamics. Consequently, for the forecasts of the pandemic dynamics of
264 Algeria, Morocco, Tunisia and France, we consider the results appearing in Figure 4.
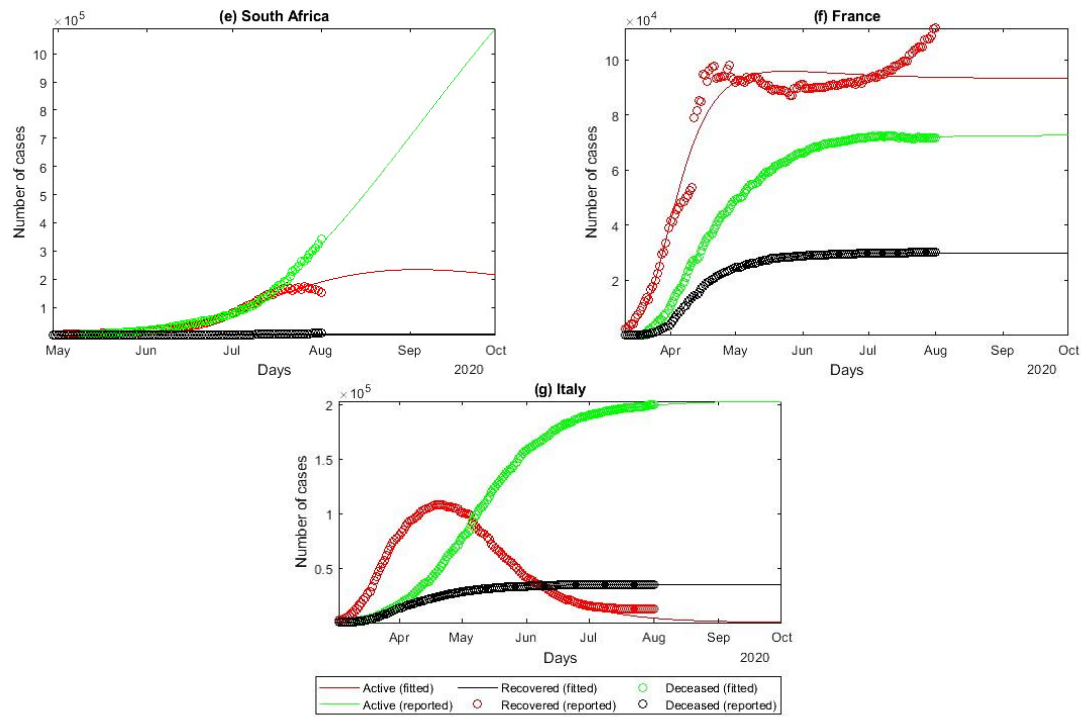
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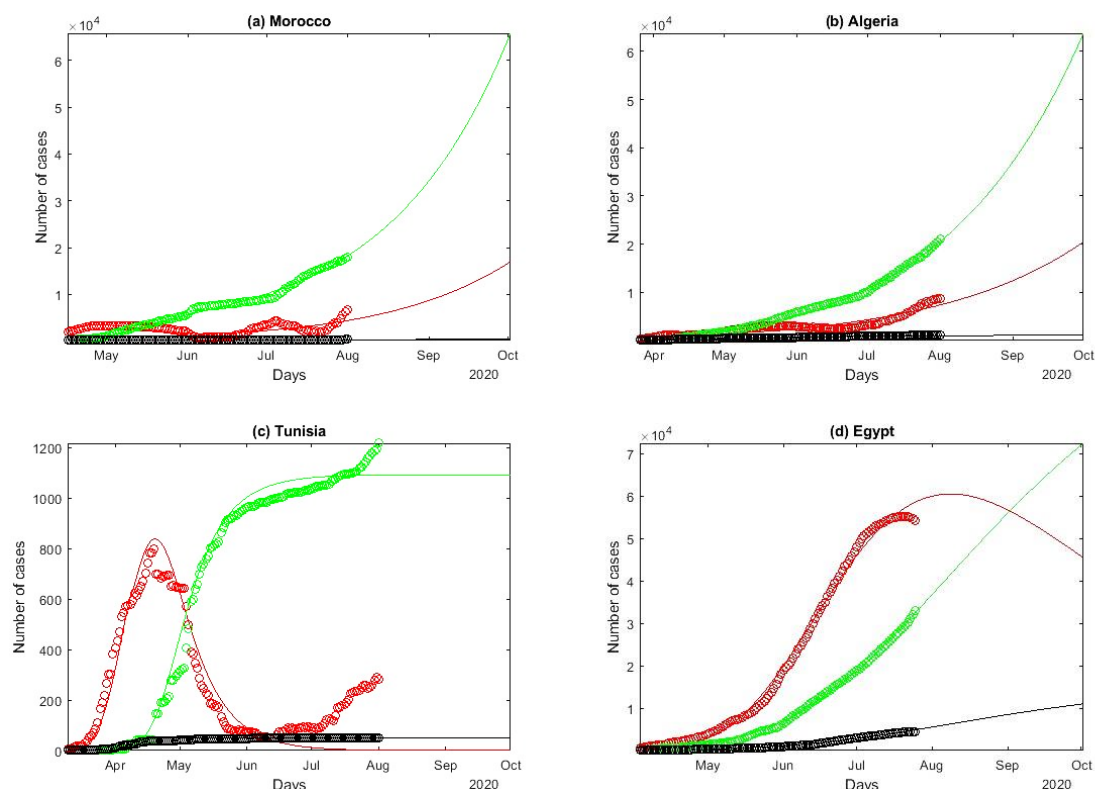
269 **Figure 3** COVID-19 epidemiologic data reported and fitted by SEIRQDP model
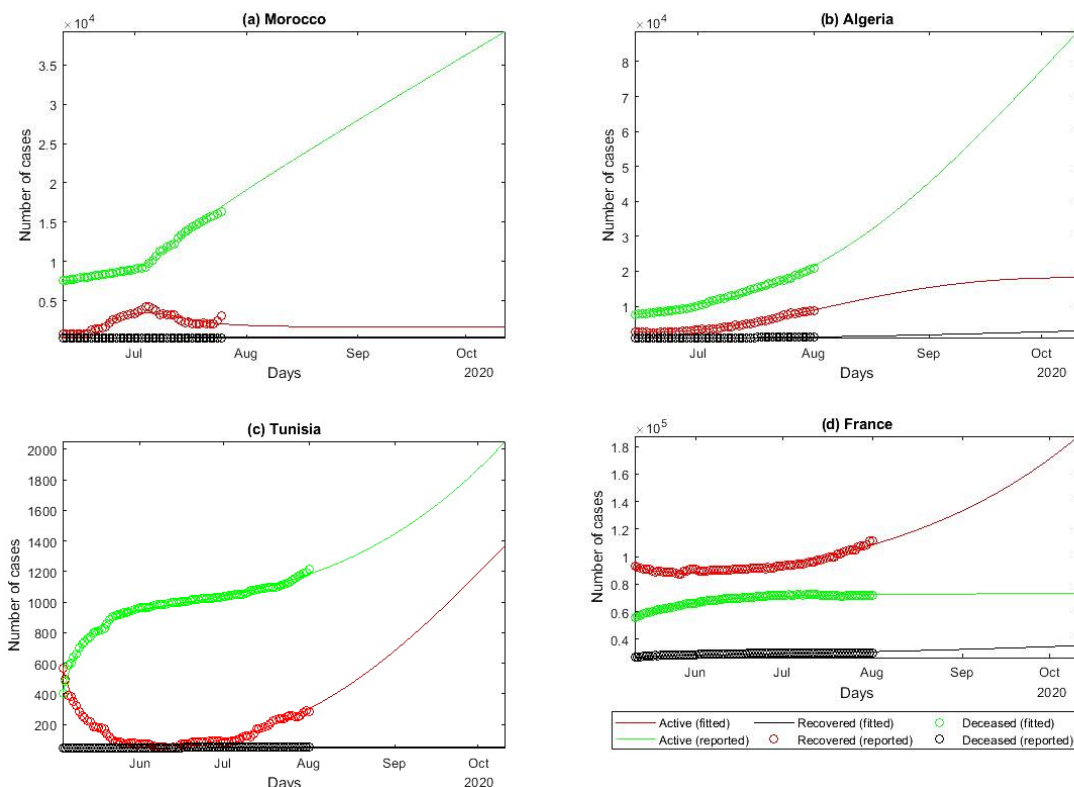
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Figure 4 COVID-19 epidemiologic data reported and fitted by SEIRQDP model after the lockdown lifting.

As Figure 3 shows, we find that there is a good fit between the model fitting results and the actual COVID-19 data in each country under the optimized SEIQRDP model. Therefore, it could be considered relatively reasonable to use the optimal model to predict the current epidemic situation in other countries. In addition, it is estimated that countries lockdown and closure strategies would have avoided considerable loss and millions of infections. These results show that these measures are important and necessary to respond to this serious public health emergency.

For some countries, namely, France, Algeria, Morocco and Tunisia, we notice a bad adjustment between the results of the SEIQRDP model and the actual COVID-19 data, after the lockdown lifting given by the following dates, 11 / 05, 14/06, 11/06, 04/05/2020, respectively. This can be explained by the ignorance of health security measures after the lockdown lifting. In addition, the present model, namely the SEIQRDP model, does not take into account such shocks or changes in the situation, given the very limited testing capacity, infected people can spread the virus if they do not comply with health security measures and they are not quarantined, remember that this component is very important in the model, and ignorance of the latter can affect the results of the model. Therefore, we only consider the data after the lockdown lifting to plot the forecasts of the countries in question. Figure 4 present the forecasts of active cases, recovery and death from the evolution of the COVID-19 pandemic by the SEIQRDP model adapted after the lockdown lifting.

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295 Based on this model, the epidemic in Italy is in its final phase and should end by September.
296 Other countries like Morocco and Algeria are expected to get rid of COVID-19 by the end of
297 October. States like Egypt, South Africa must wait until the end of this epidemic until
298 November. While for Tunisia and France they experience a considerable increase in the number
299 of infected cases and an end to the epidemic is not predictable at this time. However, these
300 forecasts would still be accurate over a short period, given the sensitivity of the model to the
301 value of β, which in turn also depends on the number of contacts per person and per unit of
302 time. This implies that the number of cases in the future could decrease or increase
303 considerably depending on the health security measures and the respect of these measures by
304 the population.

305 The Maghreb has been relatively spared by the pandemic of the new coronavirus, compared to
306 Europe, especially, the most affected (France and Italy).

307 These Maghreb countries took precautionary measures very early on with border closings,
308 general lockdown, social distancing or the wearing of protective masks. These proactive
309 measures, dictated by the fragility of the hospital system in each country, have so far prevented
310 the epidemic tsunami noted in France but also in Italy, as shown in Figure 3(f-g), where the
311 peak of infected people reached around 10E6 infected in France and Italy, compared to the
312 epidemiological situation is generally reassuring in the Maghreb nevertheless hides trajectories
313 which diverge appreciably, after having been similar for a long time. Indeed, with more than
314 30.900 confirmed and 1.200 deaths cases, Algeria is the country with the most worrying
315 situation in the Maghreb. Indeed, from Figure 3b, the number of cases confirmed daily begins
316 to decrease after reaching its maximum. We note that there was a slight decrease in daily cases
317 in April which seems to be explained by a low number of tests and the random rules of the
318 lockdown. With approximately 6.500 tests performed, only cases with advanced symptoms
319 appear to be counted. After this plateau of active cases in April, there was a worrying return
320 until the end of May. However, according to Algerian COVID-19 forecasts by the SEIQRDP
321 model (Figure 4b), the situation will begin to stabilize. the number of recovery cases will
322 increase exponentially, and the number of death cases will also stabilize despite the fact that it
323 has not grown significantly compared to the European countries. The gradually flattening in
324 deaths is may be due to the use of the chloroquine treatment protocol [29].

325 However, Morocco will soon cross the threshold of 25.015 positive cases with more than 360
326 deaths. After a peak around early May, a decline in late May, the resumption of daily cases in
327 early May worried the health authorities. This can be explained by the non-compliance with the
328 rules of social distancing rules and sanitary rules during groupings, it should be noted that most
329 new cases were attributed to contact cases. Regarding the forecast for Morocco (Figure 4a), the
330 curves of the recovered cases seem to increase contrary to the curves of infected after the
331 lockdown lifting. Indeed, the country has allowed the reopening of cafes, restaurants and sports
332 halls as well as the resumption of domestic tourism and interurban travel. On the other hand,
333 the death curve tends to zero. This encouraging result may be explained by a better knowledge
334 of the disease [30].

335 With just over 1.550 cases tested positive and around 51 deaths, Tunisia is the least affected
336 country of the three Maghreb countries by the pandemic. According to Figure 3c and Figure 4c,
337 there is a decrease in active cases after a peak in mid-April, followed by a second significant

338   peak predicted approximately in mid-October, due to the lockdown lifting. The curve of active
339   cases (Figures 3c and 4c) describes well this reassuring trend, with a peak in mid-April and a
340   drop which accelerated at the beginning of May to reach 0. This confirms the adequacy of the
341   proposed SEIQRDP model. In addition, we notice a lower mortality rate compared to other
342   countries as well as a significant recovery rate coupled with the low number of new cases
343   which have eased the pressure on the hospital system. As for its Maghreb neighbors, Tunisia
344   resorted to a treatment based on chloroquine [31]. However, according to the result of forecasts
345   by the SEIQRDP model, the results are encouraging and confirms the end of the health crisis
346   with a few scattered daily cases by the early August. However, for Egypt and South Africa
347   (Figure 3d-f), the disease manifests itself in different ways compared to the Maghreb. Indeed,
348   we note that the trend of the curves is almost the same from mid-March to July. Nevertheless,
349   the two countries already stood out with a higher number of cases than the other countries
350   during this same period.

351   was in the first place in terms of death until mid-July when the south of Africa is now the
352   country most affected by the coronavirus in terms of death

353   Egypt currently has nearly 94.320 cases and around 4.830 deaths for a population of 100
354   million inhabitants. Until mid-July, the Egypt recorded the highest number of deaths,
355   afterwards, South Africa became the most affected country in terms of deaths, despite the
356   rigorous preventive measures. The situation in Egypt may be explained by the poor health
357   system [32] and the wave of patients COVID-19 which is growing day after day. However, the
358   results of the SEIQRDP models correspond very well to the provided data. Regarding the
359   forecasts of the pandemic in Egypt (Figure 3d), the results show that the number of infected
360   cases continues to increase rapidly to reach the peak around the end of August. While, the
361   number of recovered cases will increase less rapidly, whereas, the number of deaths cases
362   remains high compared to the Maghreb and continue to increase. This stabilization in death
363   cases may be explained by the recent use of the drug Remdesivir to treat the patients [33]. This
364   treatment was authorized a few days ago in the United States and Japan, based on a positive
365   American clinical trial[34].

366   South Africa tops the list of countries most affected by coronavirus (in terms of contamination).
367   To date, there have been more than 503.290 cases of COVID-19 and around 8.153 deaths.
368   From Figure 3e, we note that infected cases have experienced significant increase since the
369   beginning of May and continues to increase. This is due to the lockdown lifting for certain
370   industrial sectors, with a 1.5 million people who have been authorized to return to work, under
371   strict health protection. Whereas, before these, the situation was under control because the very
372   strict measures taken from the beginning made it possible to slow the progression of the
373   pandemic of coronavirus. However, the curve of restored cases continues to grow and exceeds
374   the infected cases since mid-May despite that the latter continues to increase. This can be
375   explained by the community screening and testing (CST) operation in working-class
376   neighborhoods. This massive campaign made it possible to isolate infected people as quickly as
377   possible and trace their contacts. This massive campaign partially explains South Africa's
378   success in the very slow development of the epidemic compared to other African countries for
379   the same period (Figure 3a-e). Regarding the number of deaths, we note that it is stable so far,
380   this stability is explained using the treatment protocol with chloroquine and the CST. In
381   addition, the experience of the Ebola epidemic in South Africa which taught caregivers and

382 populations the best practices in place, such as, isolation of the sick, precautions during care
383 and basic hygiene such as hand washing. For the forecast of the COVID-19 pandemic in South
384 Africa by the SEIQRDP model (Figure 3e), the situation will stabilize in terms of infected and
385 recovered cases, while the dead experienced a certain increase in mid-July, due to the lifting of
386 the lockdown of certain economic [35].

387

4. Conclusion

389 In this paper, mathematical model for the coronavirus COVID-19 epidemic development is
390 performed for the most affected African countries based on an epidemiological SEIQRDP
391 model, which is an adaptation of the classic SIR model widely used in mathematical
392 epidemiology. The SEIQRDP model takes quarantine into account to match with the medical
393 security measures adapted by many countries as an effective way of preventing the spread of
394 the coronavirus COVID-19. Furthermore, considering all major parameters of the progression
395 of the coronavirus, several analytic results established, while proving all the necessary
396 properties for epidemiological relevance. This model allowed us to estimate the main epidemic
397 parameters and forecast the evolution of the reproduction number of the disease over time in
398 order to assess the epidemic situation and the effect of the applied preventive health measures.
399 An acceptable agreement between the statistical data and the curves of the model was
400 established. This indicates the suitability of the SEIQRDP in modelling the spread of the
401 COVID-19 disease for the considered countries.

402 On the other hand, according to the statistical, fitted and predicted curves, we noticed that the
403 epidemic peaks are between mid-April and mid-August, after which the epidemic declines.
404 This situation can be explained by the policy adopted by African countries, aimed at effectively
405 combating this virus. In addition, this confirms the effectiveness of the lockdown measures and
406 curfews taken early enough to slow the spread of the disease. Most countries have implemented
407 these measures as soon as the first case is detected. In France, it took 52 days after the first case
408 to take such measures. In addition to this factor, there are many other factors that contribute to
409 the robust and rapid response of these countries. The other main explanation is the youth of the
410 African population, around 60% of the population under 25 years of age. In addition, the
411 population density is lower in Africa, thus limiting the spread of the virus, as is the low
412 mobility of African populations in comparison with Western populations, where most of the
413 cases remain concentrated in the capitals and large cities.

414 However, caution should probably follow. A general lockdown lifting seems unlikely, while
415 the gradual lifting of lockdown experienced by the countries under study by city, depending on
416 the mortality rate and the number of new infections observed, may be reasonable in compliance
417 with the measures of security. However, Algeria and Tunisia may experience new peaks
418 expected mid-October, due to the lifting of lockdown, where countries have allowed the
419 reopening of cafes, restaurants and gymnasiums as well as the resumption of tourism domestic
420 and interurban. Nevertheless, the three Maghreb countries will have to strengthen the control of
421 health measures, to avoid the epidemic resumption. The crucial element will remain the
422 generalization of tests which will remain one of the main ingredients in the fight against
423 epidemics in the country. All these precautions will effectively reduce the number of basic

424 reproductions at each interaction, which is considered a crucial parameter during a pandemic
425 used to estimate the risk of an outbreak of COVID-19 and assess the effectiveness of the
426 measures implemented.

427 Finally, the epidemiological situation is reassuring in the three Maghreb countries, while for
428 South Africa, the situation seems controllable, mainly due to the CST operation. However, in
429 Egypt the number of infected cases continues to increase, the situation comes mainly from
430 ignorance of physical distancing measures and the violation of curfews after the last relaxation
431 of the restrictions in mid-March. In fact, without control of the population and lack of effective
432 treatment and vaccine, there will be no way to prevent the death of many people. Furthermore,
433 hospitals will be flooded and will never be able to manage the pandemic.

5. References

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