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Brief Report

Modelling and Prediction of the Spread of COVID-19 in Cameroon and Assessing the Governmental Measures (March–September 2020)

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Abstract: COVID-19 is an acute respiratory illness in humans caused by a coronavirus, capable of producing severe symptoms and, in some cases, death, especially in older people and those with underlying health conditions. It was originally identified in China in 2019 and became a pandemic in 2020. On 6 March 2020, Cameroon recorded its first cases of infection with COVID-19. The Government of Cameroon (GOC) took 13 barrier measures on 18 March 2020. On 1 May 2020, 19 new measures were adopted, easing restrictions and encouraging economic activity. On 1 June, schools and universities were reopened, after which massive screening began to take place throughout the country. In this study, we have modelled the COVID-19 epidemic in Cameroon in order to assess the governmental measures of response and predict the behaviour of epidemic As a result of these measures, the pandemic evolved in three phases. The first phase began on 18 March and ended on 15 May 2020. During this phase, the actual curve of cumulative positive cases based on field data closely fit the theoretical curve resulting from mathematical modelling. In the beginning of May, we predicted that nearly 3000 positive cases would be declared by mid-May 2020. The actual data confirmed these predictions: there were 2954 cases as of 15 May 2020. The second phase, beyond mid-May 2020, encompasses the period when the GOC's relaxation of measures takes effect. This phase was marked by an acceleration of the cumulative number of positive cases starting in the third week of May, postponing the expected peak by two weeks. Under Phase 2 conditions, the onset of the peak will occur in early June and extend through the first two weeks of June. However, a third phase occurs in the first week of June, with the reopening of schools and universities combined with massive screening; the peak is therefore expected in the second week of June (around 15 June). The GOC should, at this stage, strengthen its response plan by tripling the current coverage capacity to regain the first phase convergence conditions associated with the first 13 measures. The pandemic will begin its descent in the month of august, but COVID-19 will remain endemic for at least one year.

Keywords: COVID-19; calibration; basic reproduction number; evaluation; peak

1. Introduction

Mathematical modelling is a process by which a real-world problem is interpreted in terms of abstract symbols [1]. It is the entire process that allows the intervention of mathematics in a science based on experience or observation. Various steps in the modelling process can be distinguished. First, the scientist makes hypotheses about the phenomena studied, and these assumptions are translated mathematically into a model. On the basis of the model, qualitative or quantitative predictions are made and compared with experimental realities. The hypotheses are reviewed, possibly leading to modifications in the model, and the cycle continues. Mathematical modelling has been applied to several disciplines, including economics, biology agriculture, ecology, industry, and public

health [2]. In epidemiology, mathematical models help in understanding the spread of infectious agents and predicting or estimating of the impact of mitigating actions, with the major goal of allowing the system to continue to function by flattening the epidemic curve.

Departing from China in Wuhan on 31 December 2019, the coronavirus epidemic rapidly spread worldwide. After three months of the pandemic, 185 countries were affected [3]. As of 12 April 2020, the world has recorded 1.9 million confirmed cases, with more than 120,000 deaths. Italy [4], France, the United States, and Spain have paid the heaviest price in this pandemic. As of 14 April 2020, France reported more than 15,000 deaths, Spain reported more than 18,000, Italy reported more than 20,000, and the United States reported more than 23,000 deaths. As the world entered its sixteenth epidemiological week, the pandemic had become a public health problem for each affected country. Cameroon is one of the most affected countries in Africa, with nearly 1000 cases confirmed as of 15 April 2020. Coronavirus disease is a highly contagious disease, and the strain is SARS-CoV-2 [5]. It belongs to the coronavirus family, which can cause benign diseases in humans, such as a cold, and can also cause serious pathologies such as Severe Acute Respiratory Syndrome (SARS). Basic reproduction number ($R0$) is an indication of the transmissibility of a virus, representing the average number of new infections generated by an infectious person in a totally naive population. For $R0 > 1$, the number infected is likely to increase; for $R0 < 1$, the transmission is likely to die out. The basic reproduction number is a central concept in infectious disease epidemiology, indicating the risk of an infectious agent with respect to epidemic spread [6]. Considerable works can be found regarding the estimation of the reproductive number of novel coronavirus COVID-19 [6,7]. Liu et al. identified 12 studies that estimated the basic reproductive number for COVID-19 from China and overseas. The period covered was from 1 January 2020 to 7 February 2020. They found that the R0 was between 1.4 to 6.49. Several models have been used to understand the spread of COVID-19 better. According to Kathakali Biswas et al., the cumulative data can fit into an empirical form obtained from a Susceptible–Infected–Removed (SIR) model studied on a Euclidean network previously [8]. Wu et al. [9,10] introduced a susceptible–exposed–infectious–recovered $SEIR$ model to describe the transmission dynamics. The Chayu et al. model describes the multiple transmission pathways in the infection dynamics and emphasises the role of the environmental reservoir in the transmission and spread of this disease [11,12]. Dashraath et al. found that pregnant women and their fetuses represent a high-risk population during infectious disease outbreaks [9]. Some authors have studied the impact of climate on the spread of novel coronavirus [13,14]. Luo et al. discussed the role of absolute humidity on transmission rates of the novel coronavirus outbreak [15]. Baud et al. showed real estimates of mortality following COVID-19 infection [16]. Zoltan et al. studied COVID-19 epidemic outcome predictions based on logistic fitting and estimation of its reliability. Mathematical models can also be used to calculate certain parameters, such as the basic reproduction rate $R0$ [17], which corresponds (in a simplified manner) to the average number of individuals that a carrier will infect during the duration of his or her contagious period. Under certain conditions, $1 - 1/R0$ gives an indication of the proportion of the population likely to be infected during the epidemic. In general, the $R0$ of SARS-CoV-2 is estimated to be about 2.5 [7], which would suggest, applying the formula simplistically, that 60% of the world population could be infected. In Cameroon, $R0$ evolves from 1.5 at the beginning of the epidemic.

In this work, we present a mathematical model of the 2019 coronavirus disease (COVID-19) in Cameroon. The model is based on $(S\ S_m,\ P\ C_c,\ C_H,\ G_c,\ G_H,\ M_c,\ M_H)$: The susceptible compartment—(S). Susceptible individuals respecting barrier measures—(S_m). Carrier, infected person is in period of incubation; therefore, laboratory diagnosis has not been made—(P). Confirmed case undetected regardless of status (asymptomatic or symptomatic) and living in the community—(C_c). Confirmed case hospitalised—(C_H). Confirmed case recovered in community compartment—(G_c). Confirmed case recovered after hospitalisation compartment—(G_H). Novel coronavirus death in the community compartment—(M_c). COVID-19 death after hospitalisation compartment—(M_H). The

second model aims to provide a rapid, but relatively reliable, data-based estimate of the impact of the disease in the community transmission phase of the virus. We estimate the numbers of cumulative cases, active cases, deaths, and recoveries; the time of the spread of the epidemic; and the date of its probable peak. After two cases were confirmed (1 imported and 1 other contaminated) in Yaoundé on 6 March 2020, the Minister of Public Health activated the system management of public health emergencies. Subsequently, the escalation of the outbreak in the world sparked the return of several exposed people to Cameroon. The submerged entry device was only able to capture a few cases. The government has taken a series of measures to reduce the spread of COVID-19. The first 13 government measures to combat the spread of the COVID-19 pandemic have been implemented throughout the country since 18 March 2020, with the key points being the closure of all maritime and land air borders; the closure of public and private schools and universities until further notice; and the systematic quarantine of passengers arriving at the international airports of Douala, Garoua, and Yaoundé. those 13 barrier measures were applied between 18 March 2020 and 1 May 2020.

In Cameroon, more than 40 confirmed cases have been reported. At the beginning of the outbreak, we worked on the impact of undetected infected persons on the spread of the disease, coinciding with the implementation of the 13 government barrier measures [18]. This study led to three different scenarios with a compliance rate of 50%: with 50% of infectious people not detected, we had a peak around 20 May; with 20% of infectious people not detected, we had the peak around 15 June; and with 80% of infectious people not detected, we had the peak around the first week of May. On the other hand, we found out that if R_0 is around 5, we will have several waves of the COVID-19 outbreak for at least 8 years; with each new wave, the amplitude of the peak will be less than the previous one; after a few years, the COVID-19 infection will become endemic. On 1 May 2020, relaxation of the precedent measures was introduced, and later, the reopening of universities and mass screening on 1 June. The objective of this work is to highlight the impact of successive measures on the spread of COVID-19 in Cameroon during the period of March to June; some projections will also be presented. This document has ten sections.

The next Section 2 presents the epidemiological situation in May. Section 3 discusses model formulation. Basic reproduction number and disease-free equilibrium are presented in Section 4, followed by calibration in Section 5. Evaluation of the successive responses arrives in Section 7. General spread of infection and prediction of peak is described in Section 8. Section 9 discusses the dynamics of R_0 from March to September. The Discussion and conclusion are presented in Section 10.

1.1. Sources Data

We collected the daily numbers of laboratory-confirmed COVID-19 active cases, deaths, and recovered patients, released by the Cameroon Health Emergency Operations Center, from 6 March 2020 to 4 May 2020, to construct a real-time database.

1.2. Foreword

The safest way to deal with an epidemic or pandemic is to break the chain of transmission. This involves the application of personal and collective barrier measures, early detection, awareness-raising, and case management. In this work, compartmentalised models are used to predict the evolution of the COVID-19 pandemic in Cameroon. Such modelling is essential for decision making by policy makers and health authorities. We hope that it will strengthen the country's response mechanism and clarify the thinking of decision makers concerning the impact of the measures they adopt.

2. Epidemiological Situation in May, Two Months after the Beginning of Outbreak

2.1. Evolution of COVID-19 Total Cases in Cameroon from February to May 2020

Cameroon registered its first case of COVID-19 on 6 March 2020. Two months later, in the early morning hours of 22 May 2020, there were 4156 total cases, released by

the Cameroon Health Emergency Operations Center of Yaoundé (figure according to http://coronavirus.politologue.com/coronavirus-Cameroun.cm [19]) (Accessed on 1 June 2021). The number of active cases is also rising sharply. This means that community transmission is very intense. The number of deaths also follows this trend, with a fairly low slope; after two months of outbreak, Cameroon had less than 500 deaths from COVID-19 (see Appendix A.3)

2.2. Geographical Distribution of COVID-19

During the month of May 2020, the epidemic was in its rising phase; consequently, the activities related to the commemoration of the national day (20 May) were cancelled. More than 3500 cases in total were reported by May 20 (Figure 1). The epicentre of the pandemic started in the central and coastal regions of Cameroon. Gradually, the pandemic spread to the western; eastern; southwestern; and lastly, the far north regions (Table 1).
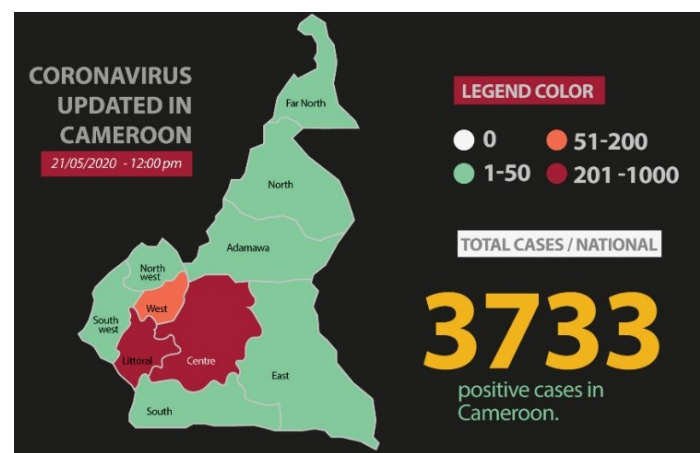

Figure 1. Total cases reported by 21 May.

Table 1. Regional distribution of COVID-19 cases in Cameroon in early May.

Regions	Cases/Cumul	Dead/Cumul	Recovered/Cumul	Type of Transmission
Adamoua	7	0	2	cluster
Centre	1787	73	960	community
East	179	3	10	community
Far North	36	1	0	cluster
Littoral	1101	61	675	community
North	54	1	2	community
Northwest	44	4	10	community
West	177	11	94	community
South	68	0	9	community
Southwest	63	2	20	community
Total	3516	156	1782	

Cluster = Point source of infection; Community = Human to human transmission in community; Cumul = cumulative.

3. Model Formulation

Epidemiologists are currently developing, testing, and adjusting models to simulate the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [16,20–22] in order to better understand the COVID-19 pandemic and optimise interventions to control it. The most common models are those derived from the famous S.I.R model developed

in 1927 [23] by Kermack and McKendrick, which describes the transition between Susceptible (S), Infectious (I), and Recovered (R) populations of individuals. Susceptible individuals are those not immune to the contagious agent. Infectious individuals are those currently infected; without necessarily being symptomatic themselves, they may infect susceptible individuals. Recovered individuals are immune to the disease after having fought it. This model is too simple to take into account all the subtleties of the reality of human exchanges. In the case of SARS-CoV-2, it would better reflect reality to add compartments to the basic model. In this work, we propose a compartmental model ($S \ S_m \ P \ C_c \ C_H \ G_c \ G_H \ M_c \ M_H$) based on the disease's clinical progression and the epidemiological status of individuals. Specifically, the population is subdivided into several compartments: The susceptible compartment—(S). Susceptible individuals respecting barrier measures—(S_m). Carrier, infected person is in period of incubation; therefore, laboratory diagnosis has not been made—(P). Confirmed case undetected regardless of status (asymptomatic or symptomatic) and living in the community—(C_c). Confirmed case hospitalised—(C_H). Confirmed case recovered in community compartment—(G_c). Confirmed case recovered after hospitalisation compartment—(G_H). COVID-19 death in the community compartment—(M_c). COVID-19 death after hospitalisation compartment—(M_H). Our model includes a net inflow of susceptible individuals into the region at a rate of λ per unit time. This parameter includes new births, immigration, and emigration. The susceptible population is reduced by the ϕ rate—the proportion of susceptible population that applies barrier measures. Moreover, the susceptible population decreases after infection, acquired through interaction between a susceptible individual and a Confirmed case hospitalised person or Confirmed case in community person at a rate of β. Despite the respect of barriers measures, the (S_m) population remains susceptible to some extent and decreases after infection, acquired through interaction between a susceptible individual and a Confirmed case hospitalised person or Confirmed case recovered in community person at a rate of ($\theta \ \beta$). A newly infected susceptible individual from group S or S_m becomes a carrier individual, and the rate of infection is given by $\beta(C_c + C_H)$ for S and $\theta\beta(C_c + C_H)$ for (S_m), where β, $\theta \ \beta_2$ are the rate of transmission of compartments S and S_m, respectively. Carriers individuals are infected individuals that have not been exposed to the community. Once a carrier, individuals progress through the Confirmed case hospitalised person (infectious) or Confirmed case in community person (infectious) stages with an average δ. A fraction p ($0 \leq p \leq 1$) of carrier individuals progress to the confirmed case hospitalised stage, while a fraction $1 - p$ of carrier individuals progress to the confirmed case in the community stage. μ_c is the disease-caused death rate for C_c compartment, and μ_h is the disease-caused death rate for C_H compartment. The recovery rate of the confirmed case in the community (C_c) is σ_c and the recovery rate of the confirmed case hospitalised (C_H) is σ_h. The confirmed case in the community population is reduced by the α rate, which is the proportion of patients who leave the community for the hospital. The abovementioned biological descriptions lead to the following compartmental scheme (flow diagram) Figure 2 and a system of nonlinear differential Equation (1), whose state variables and parameters are displayed in Table 2.
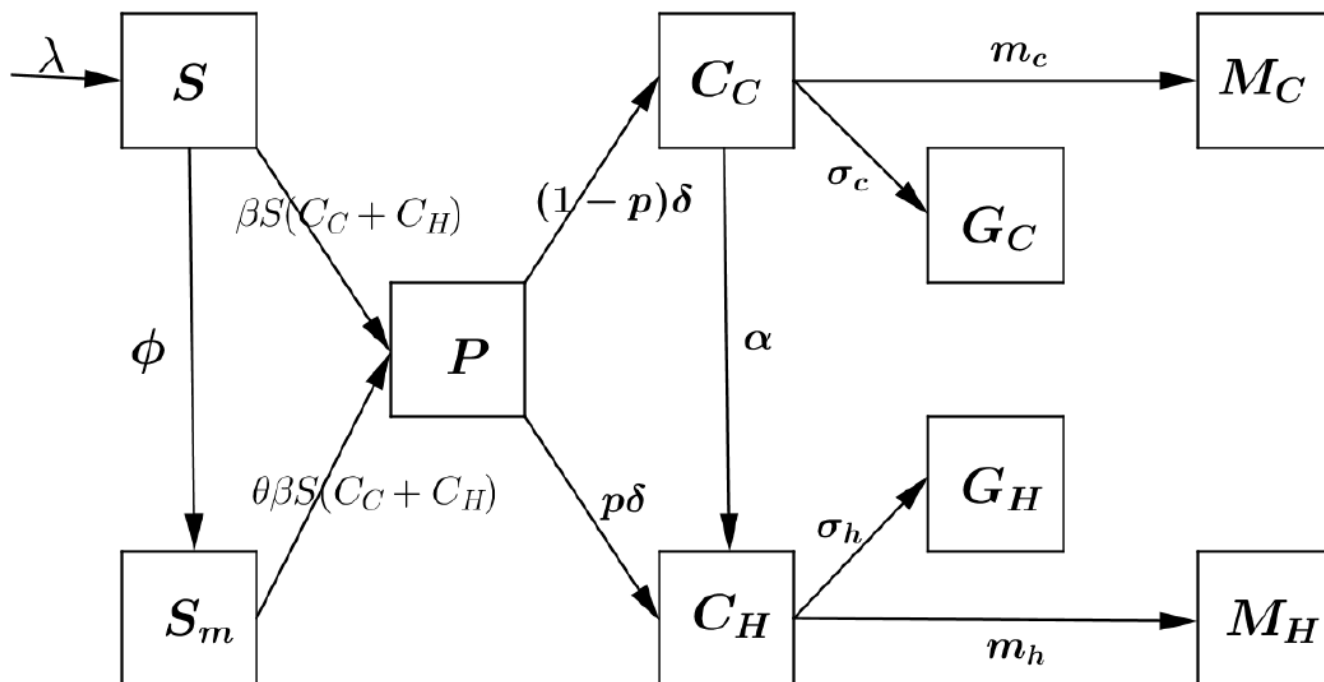
Figure 2. Scheme of the compartmental model.

$$\begin{cases} \dot{S} & = & \lambda - \beta p_v S(C_c + C_H) - \phi S - d_S S \\[2mm] \dot{S}_m & = & \phi S - \theta \beta p_v S(C_c + C_H) - d_{S_m} S, \\[2mm] \dot{P} & = & \beta p_v (C_H + C_c)(S + \theta S_m) - \delta P - d_P P, \\[2mm] \dot{C}_c & = & (1 - p)\delta P + \pi_c - C_c p_r(\sigma_c + \mu_c), \\[2mm] \dot{C}_H & = & p\delta P + \pi_H - C_H p_r(\sigma_H + \mu_H), \\[2mm] \dot{G}_c & = & \sigma_c C_c, \\[2mm] \dot{G}_H & = & \sigma_H C_H, \\[2mm] \dot{M}_c & = & \mu_c C_c, \\[2mm] \dot{M}_H & = & \mu_H C_H, \end{cases} \qquad (1)$$

In order to assess the successive governmental response strategies, we will focus on the part of model concerning the confirmed cases and the deaths declared at hospital. The Global model (1) is then reduced to the following system of nonlinear Equation (2); this last model (2) has the same basics properties as the *S V E I R* model, where global stability analysis and has been performed on [24].

$$
\begin{cases}
\dot{S} &= \lambda - \beta p_v S \left(C_H + C_H \right) - \phi S - d_S S \\[6pt]
\dot{S}_m &= \phi S - \beta \theta p_v S_m \left(C_H + C_c \right) - d_{S_m} S_m \\[6pt]
\dot{P} &= \beta (C_H + C_c)(S + \theta S_m) - \delta P - d_P P \\[6pt]
\dot{C}_H &= p \delta P + \pi - C_H p_r (\sigma_H + \mu_H) \\[6pt]
\dot{G}_H &= \sigma_H C_H \\[6pt]
\dot{M}_H &= \mu_H C_H
\end{cases}
\tag{2}
$$

Table 2. Description of state variables and parameters of model (1).

Variables	Description		
S	Susceptible individuals		
S_m	Susceptible individuals respecting barrier measures		
P	Carrier—infected person is in period of incubation		
C_c	Confirmed cases in the community		
C_H	Confirmed cases hospitalised		
M_c	COVID-19 death in the community		
M_H	COVID-19 death after hospitalisation		
G_c	Recovered individuals from the community		
G_H	Recovered individuals after hospitalisation		
Parameters	**Description**	**Values (Range)**	**Source**
λ	Recruitment of susceptible individuals	5000 (2500, 10,000)	Assumed
β	Transmission rate of undetected	$0.001 \, (10^{-5}, 5 \times 10^{-3})$	Estimated
θ	$\theta = 1 - e_c$, where e_c is the effectiveness of containment	$0.0001 \, (10^{-6}, 5 \times 10^{-3})$	Estimated
δ	Incubation rate	$1/7 \, (1/14, 1/2)$	[25]
p	Fraction of carriers who become confirmed cases hospitalised	0.8262 (0, 1)	Estimated
μ_c	Community infectious case fatality rate	0.05 (0.03, 0.07)	[19]
μ_H	Inpatient infectious case fatality rate	0.05 (0.03, 0.07)	[19]
π_H	Confirmed infectious case imported	5 (1, 10) per day	Assumed
p_v	Proportion of effective susceptible population	0.4 (0.1, 0.6)	Assumed
p_r	Time to be recovered or to death per day	$1/15 \, (1/17, 1/12)$	[25]
α	Proportion of patients who leave the community for the hospital	0.05 (0.03, 0.07)	[19]
$d_J \, J \in \{S, \, S_m, \, P\}$	Specific death rate in population J	0.0098	Cameroon
σ_c	Recovery rate in the community infectious individuals	0.5 (0.1, 0.10)	[25]
σ_H	Recovery rate in the hospital	0.5 (0.1, 0.10)	[25]

4. Disease-Free Equilibrium and Basic Reproduction Number

It is easy to check that model (2) always has a disease-free equilibrium (DFE): P_0

$$
P_0 = (S_0, S_{m0}, 0, 0, 0, 0)
\tag{3}
$$

$$S_0 = \frac{\lambda}{d_S + \phi} \tag{4}$$

$$S_{m0} = \frac{\lambda\phi}{d_{S_m}(d_S + \phi)} \tag{5}$$

which is obtained by setting the right-hand side of system (2) to zero.

A key quantity in classic epidemiological models is the basic reproduction number, denoted by $\mathcal{R}_0$. It is a useful threshold in the study of a disease for predicting a disease outbreak and for evaluating control strategies. Following [1], the next-generation approach is used to calculate $\mathcal{R}_0$.

Let us consider just the equations describing the dynamic of infected subpopulation compartments.

$$\begin{cases} \dot{P} &= \beta(C_H + C_c)(S + \theta S_m) - \delta P - d_P P \\ \dot{C}_H &= p\delta P + \pi - C_H p_r(\sigma_H + \mu_H) \end{cases} \tag{6}$$

The Jacobian matrix of system (6) at the DFE P_0 is

$$J(DFE) = F + V = \begin{pmatrix} -(\delta + d_p) & \beta\, p_v\,(S_0 + \theta\, S_{m0}) \\ p\,\delta & -(p_r\sigma_H + \mu_H) \end{pmatrix}.$$

where F and V are, respectively, the Jacobian matrix of transmission (next-generation infected) and the Jacobian matrix of migration. The Jacobian matrix of $\mathcal{F}$ and $\mathcal{V}$ at the DFE P_0 are

$$F(DFE) = \begin{pmatrix} 0 & \beta\, p_v\,(S_0 + \theta\, S_{m0}) \\ 0 & 0 \end{pmatrix}.$$

and

$$V(DFE) = \begin{pmatrix} -(\delta + d_p) & 0 \\ p\,\delta & -p_r(\sigma_H + \mu_H) \end{pmatrix}.$$

From the conclusion by [1], the associated basic reproduction number $\mathcal{R}_0$ of (2) is the spectral radius of the next-generation matrix $-FV^{-1}$. That is,

$$\mathcal{R}_0 = -FV^{-1} = \frac{p\,\beta\, p_v\,\delta\,(S_0 + \theta\, S_{m0})}{(\delta + d_p)p_r(\sigma_H + \mu_H)}. \tag{7}$$

5. Model Calibration

5.1. Calibration

For the results of a prediction model to be reliable, it is essential that they be calibrated against data from the real world [26]. This requires comparing model results with data gathered in the field to identify points of divergence between the two. The reasons for any discrepancies must be determined, and the necessary adjustments made to calibrate the model properly. In the present study, we collected day-by-day the numbers of laboratory-confirmed cases, confirmed deaths due to COVID-19, and recoveries from 6 March to 27 May 2020, as provided by the Centre National des Operations Durgences Sanitaires (see Appendix A). The calibration of the model using total case data is shown in Figure 3.

5.2. Total Cases Predicted Two Weeks Earlier

Cameroon recorded its first case of COVID-19 on 6 March 2020. In the early morning hours of 15 May 2020, there were 3000 cumulative cases reported. This is in line with Figure 4, predicted by the model, and the trend of the spread of COVID-19 in Cameroon's

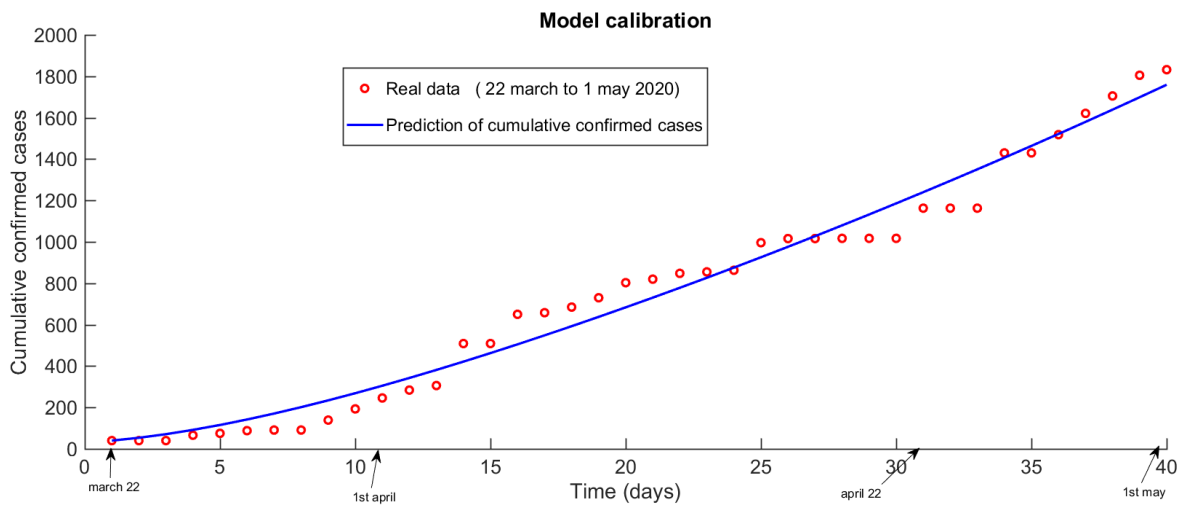simulation was performed on 1 May 2020. The proposed model is therefore reliable and reproducible.

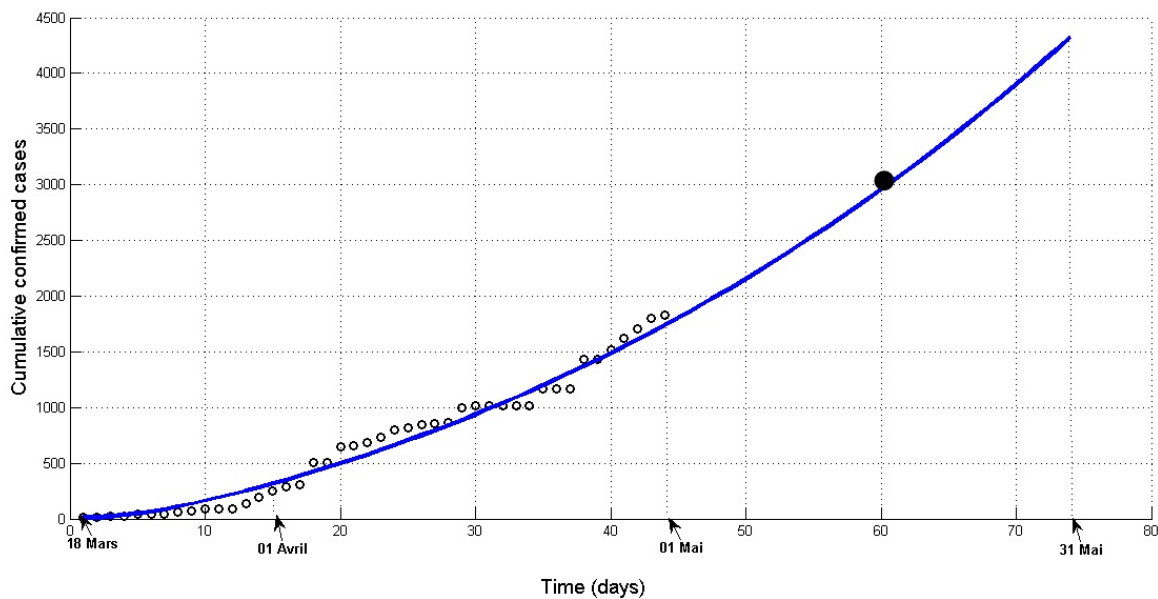**Figure 3.** Calibration of the COVID-19 propagation model in Cameroon.

Figure 4. Prediction of cumulative cases since 1 may. Solid curve—model; Dots—observations.

6. The Three Key Periods of Outbreak in Cameroon (Phase 1, Phase 2, and Phase 3)

In this work, we are focused on the spread of COVID-19 in Cameroon during six months (March, April, May, June, July, and September). We have observed three key periods:

- Phase 1: From 18 March 2020 to the first week of May.
  Phase 1 is defined here as the period when the 13 barrier measures (closure of borders, schools and universities, churches, bars, etc.) see Appendix A, decrees by the Cameroonian government were in full effect. Phase 1 took place between 18 March and early May.

- Phase 2: First week of May to first week of June 2020. Phase 2 is the period when the original measures were being eased by the gradual reopening of borders, drinking establishments, churches, mosques, etc. On 30 April 2020, the government of Cameroon established 19 other measures to relax the first 13 measures and support the national economy; measures were applied from 1 May 2020. The influence zone of its new

measures began after the first week of May 2020. Phase 2 runs from the second week of May to early June.

- Phase 3: Third week of June to September. In Cameroon, on 1 June 2020 rang with the reopening of schools and universities that had closed in March.

In the following section, we assess the impact of each response level in the spread of COVID-19 in Cameroon.

7. Evaluation of Different Response Strategies (Level) on the Spread of Infection

All the measures taken have resulted in different levels of response.

- Application of the 13 barrier measures = response level 1;
- Relaxation of the 13 measures = response level 2;
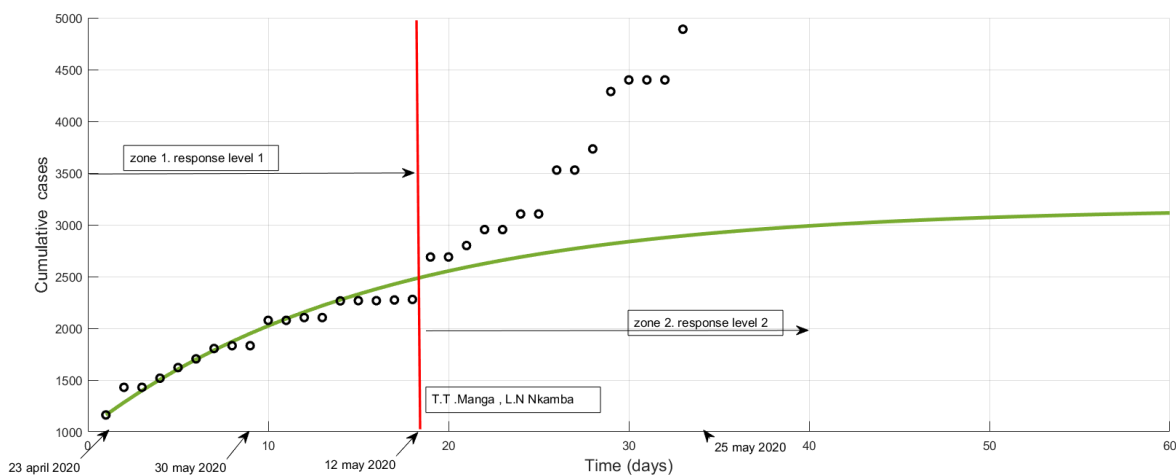- Reopening of schools and universities = response level 3.

To evaluate the different strategies, we compare the curves of the real data and the predictive curves obtained from the calibrated model. If, at a given time, the observational data rise above the projection curve, then the level of response has dropped; if they fall below the curve, it has been reinforced. Every two weeks, the parameters must be re-estimated to make good predictions and evaluate the response strategy.

7.1. Potential Impact of Original Measures and Effective Impact of Relaxing Measures in the Behaviour of Outbreak during the Month of May
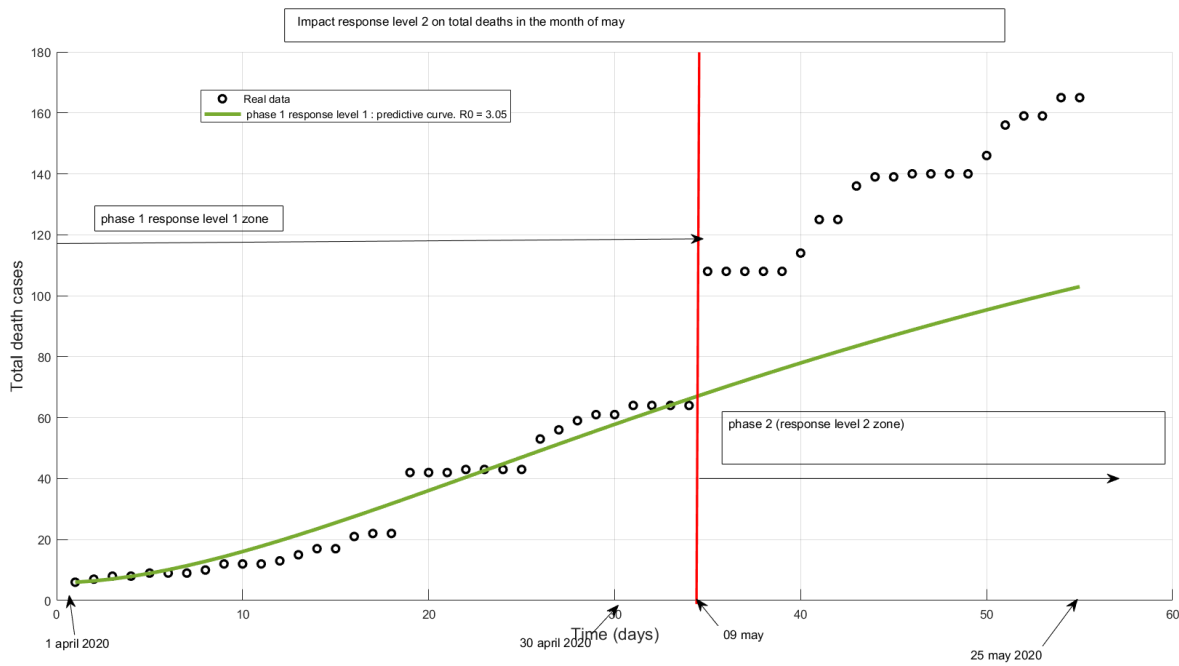
Impact on Total Cases

Solid line shows predictions, dots are observations. Zone 1 = zone of influence of the 13 barrier measures (phase 1). Zone 2 = zone of influence of the relaxation measures (phase 2).

Figures 5 and 6 show how the easing measures implemented on 1 May 2020 have affected the epidemic. Figure 5 clearly demonstrates that, as of mid-May, the easing of restraints has had the effect of accelerating the epidemic. Figure 6 shows that, without the relaxation of the measures, there would have been fewer than 120 deaths at the end of May, but with the arrival of the relaxation measures, there were nearly 160. We have accordingly revised our projections to account for this acceleration. The result seems to be quite accurate. On 25 May, the new, steeper curve predicted nearly 206 deaths by 6 June 2020; the actual data as of 5 June shows 205 deaths (Figure 6).
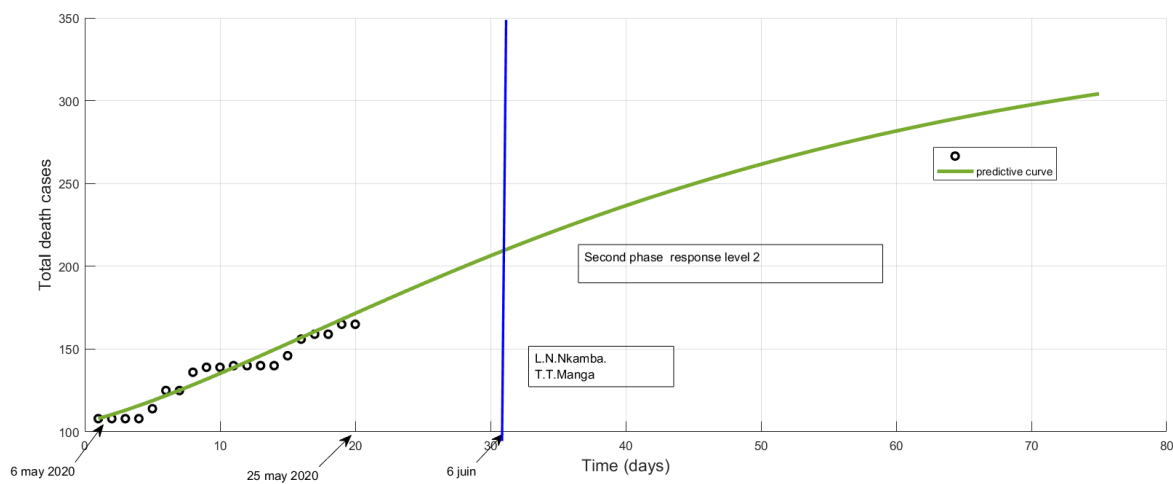

Figure 5. Potential impact of response level 1 and effective impact of response level 2 on cumulative cases after 12 May 2020. Solid line shows predictions, dots are observations. Zone 1 = zone of influence of the 13 barrier measures (phase 1). Zone 2 = zone of influence of the relaxation measures (phase 2). from 12 May, the observation curve goes above the prediction curve, which denotes a deterioration in response level.

Figure 6. Potential impact of response level 1 and effective impact of response level 2 on total deaths in May 2020. From 9 May, the observation curve goes above the prediction curve, this shows the decline in government response.

We have accordingly revised our projections to account for this acceleration. The result seems to be quite accurate. On 25 May, the new, steeper curve predicted nearly 206 deaths by 6 June 2020; the actual data of 5 June show 205 deaths (see [19] or the Synoptic table of Daily cumulative death cases from March to September 2020, Appendix A.3). Revised predictive curve of the evolution of confirmed deaths from COVID-19. Dots are observations through 25 May (Figure 7).
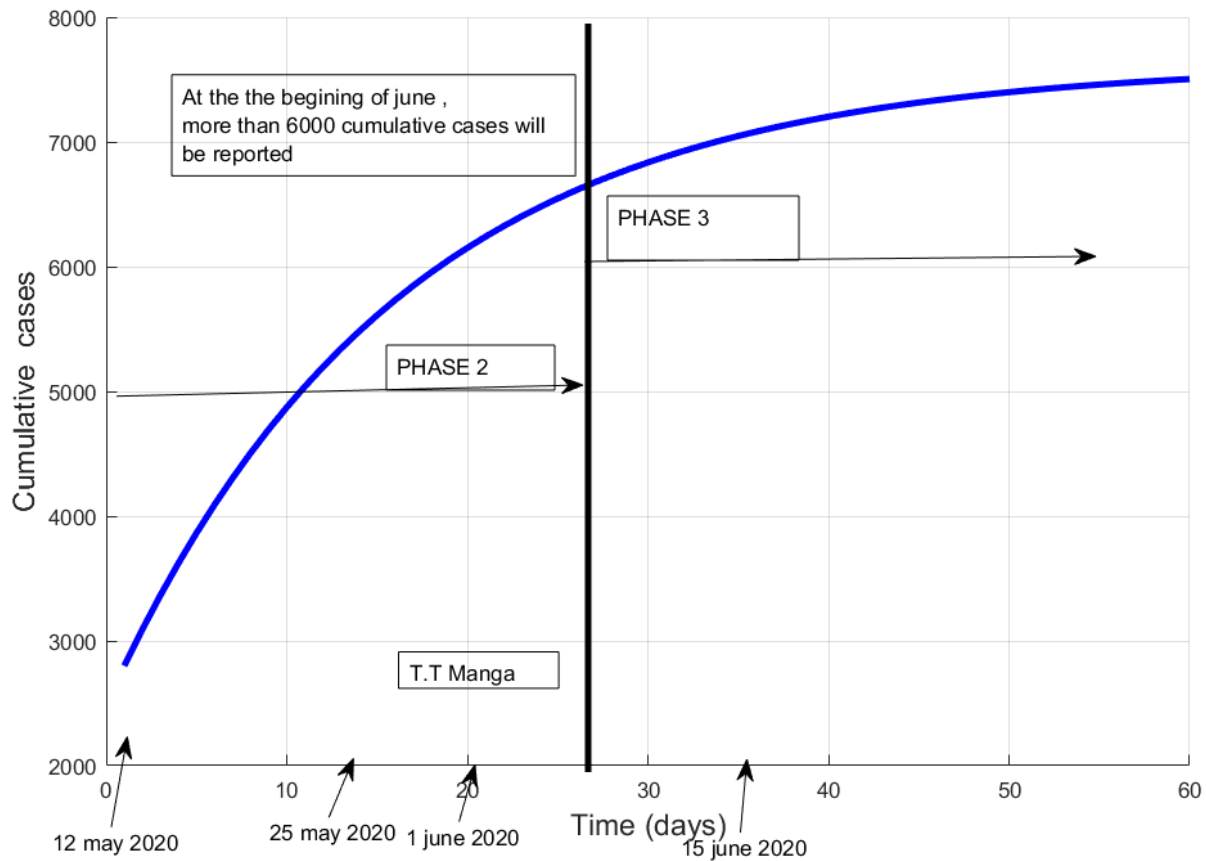

Figure 7. Potential impact of response level 2 on total deaths in June 2020. By the end of the first week of June, if the level of response remains the same, we will have slightly over 200 declared deaths.

7.2. Potential Impact of Relaxing Measures and Effective Impact of Reopening Schools and Universities in the Behaviour of Outbreak during the Month of June

7.2.1. Potential Impact of Relaxing Measures

The official total number of cases at the end of May will probably be more than 6000. By 10 June, it will rise to 7000 if there is no new accelerator of the epidemic (Figure 8).

There will be nearly 4000 active cases in the official counts in the first week of June (active cases = total cases—total death cases—total recovered cases). If schools and universities open, there will be an acceleration, and more than 5000 active cases will have been reported by around 10 June.
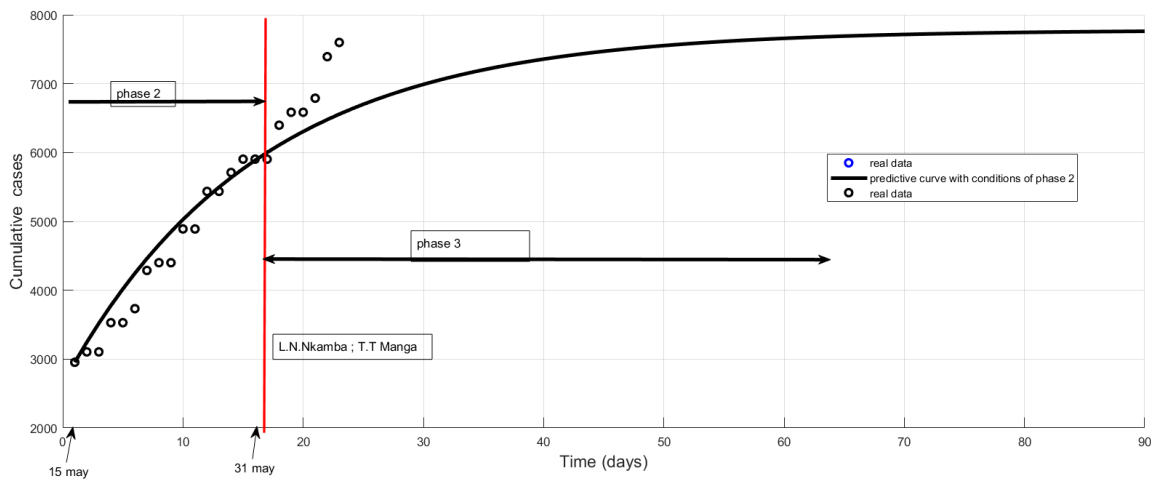

Figure 8. Potential impact of response level 2 on total cases in the month of June 2020. Relaxation of the 13 measures = response level 2. The official total number of cases at the end of May will probably be more than 6000. By 10 June, it will rise to 7000 if there is no new accelerator of the epidemic.

7.2.2. Effective Impact of the Reopening of Schools, Universities and Mass Screening on the Spread of Infection in the Month of June

Phase 3 runs from the first week of June to July. It is characterised by mass screening and the reopening of schools and universities. The government of the Republic decided to reopen schools and universities, effective from 1 June 2020, and also to conduct a mass screening campaign.

By the end of the first two weeks of June, there was an epidemic boom, with an average of 200 new confirmed cases per day. This is illustrated by a shift in the actual data above the prediction curve at the beginning of June (Figure 9).

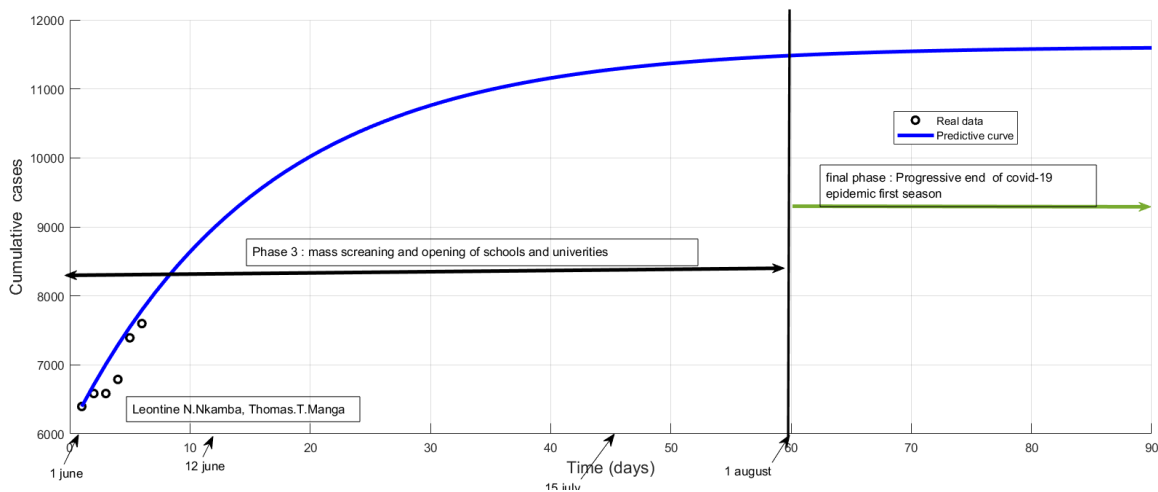**Figure 9.** Effective impact of response level 3 on total cases in the month of June 2020. Reopening of schools and universities = response level 3. By the end of the first two weeks of June, there was an epidemic boom, with an average of 200 new confirmed cases per day. This is illustrated by a shift in the actual data above the prediction curve at the beginning of June.

7.2.3. The End Prediction of the First Epidemic Season

The new predictive curve from simulations based on June data indicates probable extinction of the epidemic in August, see Figure 10.
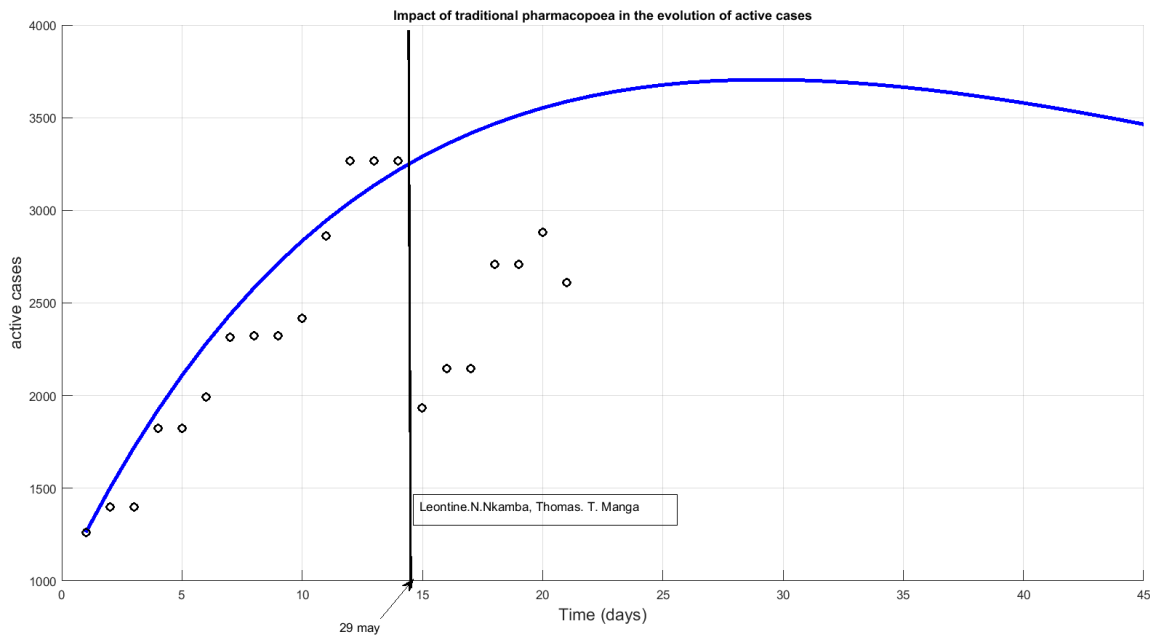

Figure 10. Prediction of total cases based on earlier data of June. The new predictive curve from simulations based on June data indicates probable extinction of the epidemic in August, at which point a plateau will have been reached with almost 12,000 total confirmed cases.

7.3. Impact of the Traditional Pharmacopoeia on the Evolution of Active Cases

The response against COVID-19 has brought to the surface the importance of traditional pharmacopoeia. On the evening of 29 May, more than 1000 people were declared cured by Mgr Kleda Bishop. Samuel Kleda is a Cameroonian phytotherapist, who has set up two products constituting a treatment against COVID-19 (Elixir COVID and ADSAK COVID). These inventions are registered with the African Intellectual Property Organization (OAPI). The products are available in different Catholic hospitals across Cameroon (e.g., Notre Dame de Logpom, St Albert le Grand de Bonaberi) We observed that some patients healed by traditional pharmacopoeia were not reported progressively but the total was added officially only on 29 May. This made the number of active cases fall dramatically from 3265 to 1933. From then on, the data on active cases deviate from the predictive curve,

as shown in Figure 11. This indicates a higher level of response. This does not have a great impact on the evolution of total confirmed cases.

Figure 11. Impact of the traditional pharmacopoeia on the evolution of active cases from 29 May 2020 onward.

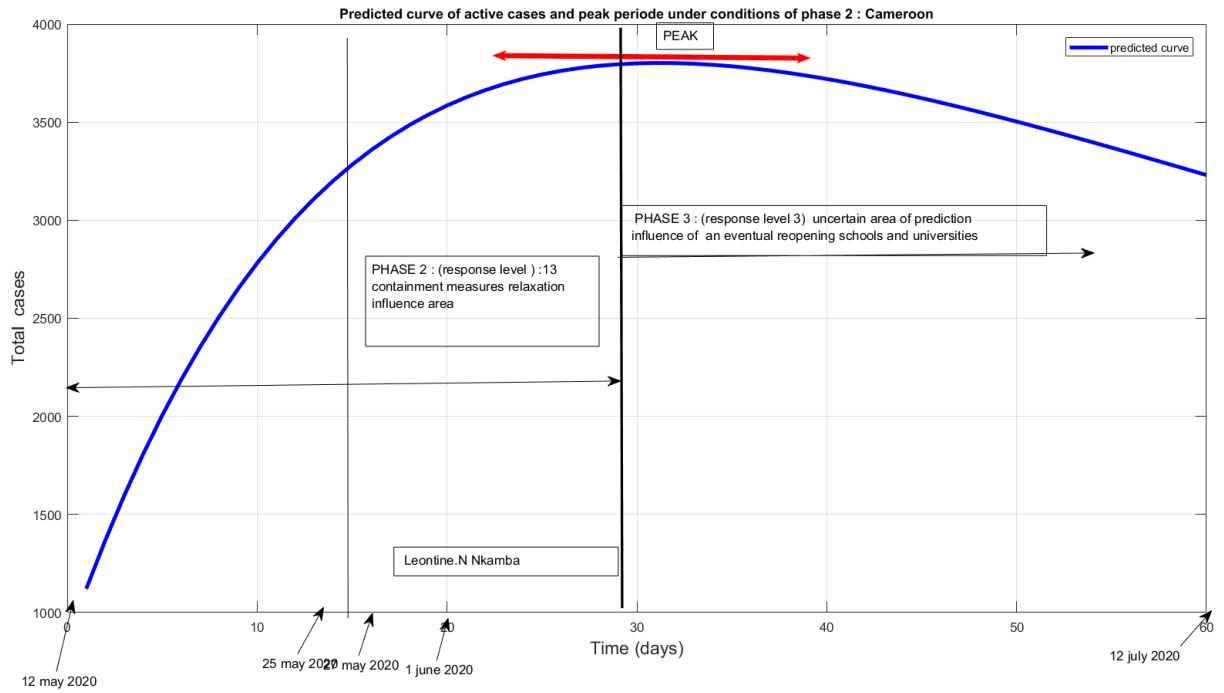## 8. General Spread of Infection and Prediction of Peaks

The simulations started on 3 April indicated that active cases would peak around 20 May. Those launched on 6 May confirmed a peak around 24 May. With the easing of restrictions, the beginning of the peak has been postponed by one week, until the end of May. Finally, based on conditions of response level 2, the peak will probably be reached in the middle of June and the epidemic will be in full swing around 15 June. The peak will last at least two weeks (Figure 12) and the epidemic will begin to decline by the end of June or the beginning of July. With the current level of response, if there is no bifurcation or acceleration of the epidemic at the beginning of June, the curves indicate an end of the epidemic towards the end of July and August. Whatever the dates on which the simulations were carried out, all converge towards an extinction of the first wave of epidemic at the beginning of August, see Figure 13.

Under the conditions of phase 3, we found out that the disease will remain at least one year, see Figure 13.
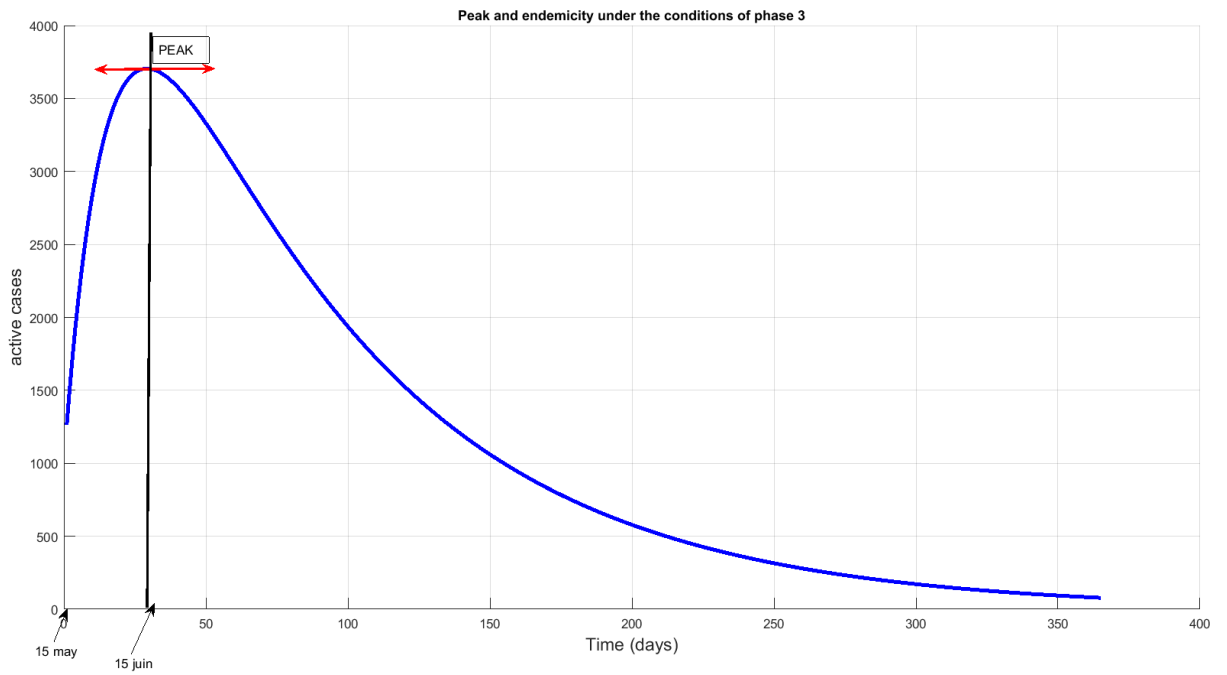
Predicted Peak in June Confirmed

Data reported during March, April, and May had allowed us to predict a peak in the month of June see Figure 13, those reported during July, August, and September (see Table 3) allowed us to confirm it (see Figure 14); Synoptic table of Daily cumulative confirmed cases and death cases from march to September 2020 and Appendix A, Figures A1 and A2). From the month of September, the real data confirm a trend towards the endemicity of the epidemic (Figure 14) as predicted since the month of May.
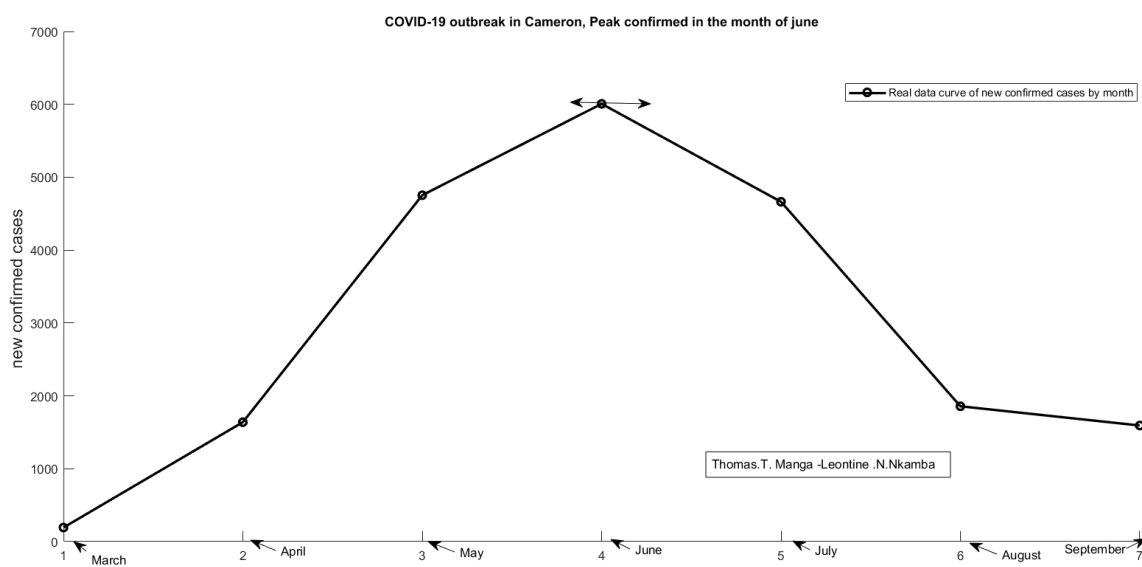
Figure 12. Predicted curve of active cases and peak period under the conditions of phase 2: Cameroon.

Figure 13. Predicted curve of active cases and peak period under the conditions of phase 3: Cameroon.

Table 3. New confirmed cases reported by month from March to September.

Months	New Confirmed Cases
March	193
April	1639
May	4753
June	6007
July	4663
August	1857
September	1593

Figure 14. COVID-19 outbreak in Cameron. Peak confirmed cases in the month of June.

9. Evolution of R_0 from March to September

We compute the value of Ro for four periods.

- Period 1: 15 March to 30 April 2020 (15 March to 30 March; 1 April to 30 April).
- Period 2: 1 May to 31 May 2020 (1 May to 15 May; 16 May to 30 May).
- Period 3: 1 June to 30 June 2020.
- Period 4: 1 July to 30 September (July, August, September).

$$R_0 = \frac{p\,\beta\,p_v\,\delta\,(S_0 + \theta\,S_{m0})}{(\delta + d_p)\,p_r\,(\sigma_H + \mu_H)}$$

To compute R_0, some parameters have been estimated, as shown i Table 4.

To compute the numerical average value of R_0 for each chosen period, we feed. first the predictive curve with real data curve corresponding; then we obtain the estimated parameters. Bellow, we have a simulation of the first two weeks of April. Here, $R_0 = 1.99$, see Figure 15. The same exercise should be performed for each period. Table 5 provides the successive average value of R_0 from March to September (see Figure 16). The basic reproduction number R_0 varies from 0.42 to 4.22 in Cameroon.

Table 4. Table of parameters.

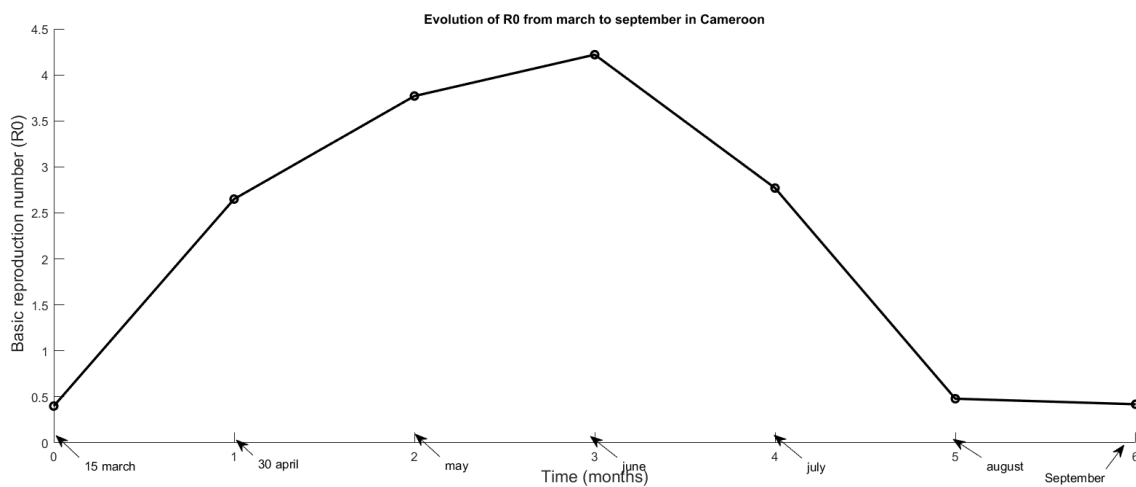| Parameters	Description	Values (Range)	Source
λ	Recruitment of susceptible individuals	$200, 600$	Assumed
β	Transmission rate	$0.15; 0.35$	Estimated
θ	$\theta = 1 - e_c$, where e_c is the effectiveness of containment	$0.0001\ (10^{-6}, 5 \times 10^{-3})$	Estimated
δ	Incubation rate	$1/5; 1/14$	Estimated
p	Fraction of carrier who become confirmed cases hospitalised	$0.15; 0.3$	Estimated
μ_c	Community infectious case–fatality rate	$0.05\ (0.03, 0.07)$	[19]
μ_H	Inpatient infectious case–fatality rate	$0.05\ (0.03, 0.07)$	[19]
π_H	Confirmed infectious case imported	$5\ (1, 10)$ per day	Assumed
p_v	Proportion of effective susceptible population	$0.001\ (0.1, 0.0009)$	Assumed
p_r	time to be recovered or to be died per day	$1/21\ (1/17, 1/21)$	Estimated
$d_J J \in \{S,\ S_m,\ P\}$	Specific death rate in population J	0.0098	Cameroon
σ_c	Recovery rate in the community infectious individuals	0.8	Estimated
σ_H	Recovery rate in the hospital	$0.8\ (0.1, 0.10)$	Estimated

Figure 15. R0 Value estimated in the middle of April 2020.

Table 5. Evolution of R0 value from March to September.

Period	Value of R0
15 March to 30 March	0.43
April	2.34
1 May to 15 May	2.65
June	4.22
July	2.87
August	0.48
September	0.42

Figure 16. Curve of evolution of Ro from March to September.

10. Discussion and Conclusions

10.1. Discussion

10.1.1. Impact of Management and Application of Barrier Measures on the Spread of Infection

The level of care has a significant impact on the future of the epidemic. Here, care is measured in terms of the recovery rate. If the recovery rate is at least 50%, the peak arrives earlier and has a lower amplitude. According to our simulations, the rate of implementation of barrier measures does not sufficiently influence the rate of the epidemic, even if the measures are implemented by more than 50% of the population. On the other hand, the effectiveness of these measures has a strong impact on the spread of the infection. When the effectiveness is more than 80%, even if the measures are applied by only 30% of the population, the magnitude of the epidemic is reduced.

10.1.2. Projections of COVID-19 Outbreak under the Conditions of Phase 2 and Recommendations

On the assumption of phase 2 response-level conditions, we used our model to predict the course of the disease in the first two weeks of June 2020. It was expected that the official cumulative number of cases around 1 June would be more than 6000, and by 8 June, around 7000, if there were no new accelerators of the epidemic at the beginning of June (Note that the number of cases in the community is approximately triple the number given officially.). We anticipated that there would be nearly 4000 active cases in the official counts in the first week of June and that if schools and universities opened, there would be an acceleration: we would be at more than 5000 active cases around 10 June. Before the easing measures, the start of the peak was expected in the third week of May, but the new measures pushed

this back by one week. The peak would now extend over two weeks, the first two weeks of June, assuming the level of response remained the same and there was no new accelerator. The peak amplitudes would be higher. The epidemic could begin to regress after the third week of June. In this scenario, support resources need to be made ready immediately. By the end of the first week of June, hospital capacity should be brought up to at least 4000 beds. Moreover, at least 50,000 tests need to be available, as in the community there are about 25,000 cases not officially counted. Decentralisation of care could be achieved by allocating beds and all other logistical necessities according to the incidence rate by Region, Departments, and Districts.

10.1.3. Projections of COVID-19 Outbreak under the Conditions of Phase 3

When the level of response changed at the beginning of June, simulations were carried out on 6 June, and the above picture changed somewhat. At the end of the first week of June, there was an epidemic boom with an average of 200 new confirmed cases per day. This is illustrated by a shift in the actual data above the prediction curve at the beginning of June, visible in Figure 9. With the introduction of the traditional pharmacopoeia at the end of May (Figure 11), an increase in the number of recoveries was observed; this would reduce the number of active cases to less than 4000 during the peak. However, the position of the peak itself had not shifted. The epidemic woulds be at its worst (in terms of recorded cases) from the second week of June because widespread testing would elevate the peak to about 120,000 cumulative cases. The disease would start to decline from the end of June but remain endemic for at least one year, see Figure 13.

10.2. Conclusions

At the end of September, 7 months after the COVID-19 outbreak, Cameroon reported around 20,000 confirmed cases, with less than 500 deaths and a cure rate of over 80%. The peak was reached in June with around 6000 new cases. The epidemic curve observes a symmetry around the month of June, from March to August only. The month of September suggests the endemicity of the disease (Figure 14), this means that the disease could remain in the population for a long period. We could fear the arrival of a second wave of the epidemic in October, due first to the 2020/2021 school reopening and second to the resurgence of the epidemic in Europe (12,845 new cases confirmed on September 30 in France); so, it would be prudent to strengthen the governmental response throughout the month of October to avoid a second boost of outbreak in Cameroon.

Appendix A

Appendix A.1. 13 Barrier Measures

(source: https://www.prc.cm/fr/actualites/4151-coronavirus-mesures-instruites-par-le-president-paul-biya (Accessed on 1 June 2021)).

As from Wednesday 18 March 2020, till further notice:

1 Cameroon's land, air, and sea borders will be closed; consequently, all passenger flights from abroad will be suspended, with the exception of cargo flights and vessels transporting consumer products and essential goods and materials, whose stopover times will be limited and supervised. Cameroonians who wish to come back home should contact our diplomatic representatives.

2 The issuance of entry visas to Cameroon at the various airports shall be suspended.

3 All public and private training establishments of the various levels of education, from nursery school to higher education, including vocational training centres and professional schools, will be closed.

4 Gatherings of more than fifty (50) persons are prohibited throughout the national territory.

5 School and university competitions, such as the FENASSCO and University games, are postponed.

6 Under the supervision of administrative authorities, bars, restaurants, and entertainment spots will be systematically closed from 6 p.m.

7 A system for regulating consumer flows will be set up in markets and shopping centres.

8 Urban and interurban travel should only be undertaken in cases of extreme necessity.

9 Drivers of buses, taxis, and motorbikes are urged to avoid overloading—law enforcement officers will ensure they comply.

10 Private health facilities, hotels, and other lodging facilities; vehicles; and specific equipment necessary for the implementation of the COVID-19 pandemic response plan in Cameroon may be requisitioned as required by competent authorities.

11 Public administrations shall give preference to electronic communications and digital tools for meetings likely to bring together more than ten (10) people.

12 Missions abroad of members of Government and public and para-public sector employees are hereby suspended.

13 The public is urged to strictly observe the hygiene measures recommended by the World Health Organization, including regular hand washing with soap, avoiding close contact such as shaking hands or hugging, and covering the mouth when sneezing.

Appendix A.2. Synoptic Table of Daily Cumulative Confirmed Cases from March to September 2020

Synoptic table of Daily cumulative confirmed cases from march to september 2020

Days	March	April	May	june	July	August	September
1	0	246	1832	6789	12592	17255	19409
2	0	284	2077	6940	12592	17255	19460
3	0	306	2077	7144	12592	17255	19604
4	0	509	2104	7392	12592	17718	19604
5	0	509	2104	7599	12592	17718	19604
6	1	650	2265	7708	13711	17718	19604
7	1	658	2267	7860	14960	17718	19604
8	2	685	2267	8112	14960	18042	19848
9	2	730	2274	8112	14960	18042	19848
10	2	803	2279	8481	14960	18042	20009
11	2	820	2689	8743	15173	18213	20009
12	2	848	2689	9013	15173	18263	20009
13	2	855	2800	9196	15173	18308	20167
14	2	863	2954	9572	16157	18462	20228
15	2	996	2954	9864	16157	18469	20271
16	4	1016	3105	10140	16157	18469	20303
17	10	1016	3105	10355	16157	18582	20303
18	10	1017	3529	10638	16757	18599	20371
19	10	1017	3529	11281	16157	18624	20431
20	20	1017	3733	11610	16157	18762	20431
21	27	1163	4288	11892	16522	18762	20598
22	40	1163	4400	12041	16522	18762	20598
23	40	1163	4400	12270	16522	18762	20690
24	40	1430	4890	12592	16708	18762	20690
25	66	1430	4890	12592	16708	18973	20712
26	75	1518	5436	12592	16708	18973	20712
27	88	1621	5436	12592	17110	19142	20735
28	91	1705	5711	12592	17179	19142	20838
29	91	1805	5904	12592	17255	19142	20838
30	139	1832	6397	12592	17255	19142	20838
31	193		6585		17255		20838

Figure A1. Synoptic table of daily cumulative confirmed cases from March to September 2020.

Appendix A.3. Synoptic Table of Daily Cumulative Death Cases from March to September 2020

Synoptic table of Daily cumulative death cases from march to september 2020

Days	March	April	May	June	july	August	September
1	0	6	61	199	328	391	414
2	0	7	64	200	328	391	415
3	0	8	64	203	328	391	415
4	0	9	64	205	328	391	415
5	0	9	64	206	328	391	415
6	0	9	108	206	359	391	415
7	0	9	108	206	359	391	415
8	0	10	108	208	359	395	415
9	0	12	108	208	359	395	415
10	0	12	114	208	359	398	415
11	0	12	125	271	359	398	415
12	0	13	125	273	359	401	415
13	0	13	136	276	359	401	415
14	0	14	139	277	359	401	415
15	0	17	139	277	373	401	415
16	0	22	140	277	373	401	415
17	0	22	140	277	373	403	415
18	0	42	140	282	373	406	416
19	0	42	140	300	373	406	416
20	0	42	146	301	382	408	416
21	0	43	156	303	382	408	416
22	0	43	159	308	382	408	416
23	0	43	159	312	382	408	416
24	0	43	163	313	385	408	418
25	0	53	171	313	385	410	418
26	0	56	175	313	385	410	418
27	0	58	175	313	391	411	418
28	2	58	175	313	391	411	418
29	6	61	185	313	391	411	418
30	6	61	191	313	391	411	418
31	6		197		391		418

Figure A2. Synoptic table of daily cumulative death from March to September 2020.

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