

Mathematical modeling of COVID-19 pandemic in the context of sub-Saharan Africa: a short term forecasting in Cameroon and Gabon

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Outline

- ▶ Introduction
- ▶ Motivation
- ▶ Results
- ▶ Summary



Contexte

- ▶ Initially detected in Wuhan (China) in December 2019, the outbreak caused by COVID-19 spread rapidly around the world
- ▶ Coronavirus is continuing its spread across the world, with more than 35 million confirmed cases in 188 countries and more than one million deaths¹
- ▶ The virus is surging in many regions and some countries that had apparent success in suppressing initial outbreaks are also seeing infections rise again
- ▶ Mathematical modelling can be used to understanding how a virus spreads within a population and to predict the evolution of the pandemic in a given region or country

¹Source: Johns Hopkins University, national public health agencies



Distribution of COVID-19 cases in the world²

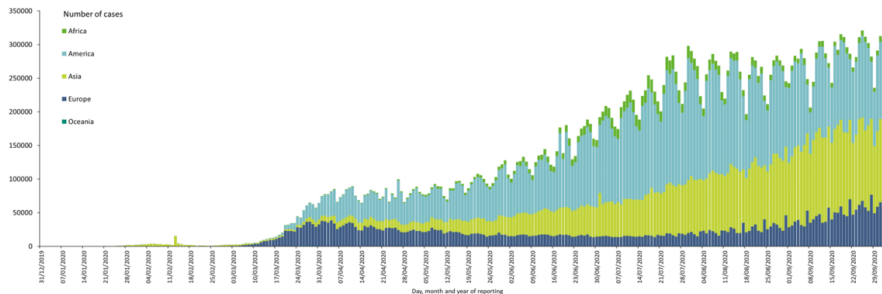


Figure: Distribution of cases of COVID-19 by continent

²European Centre for Disease Prevention and Control. <https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases>



COVID-19 confirmed cases in Africa³

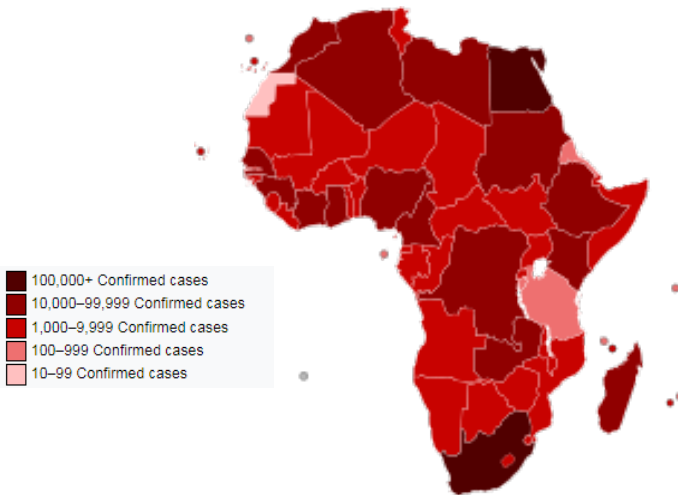
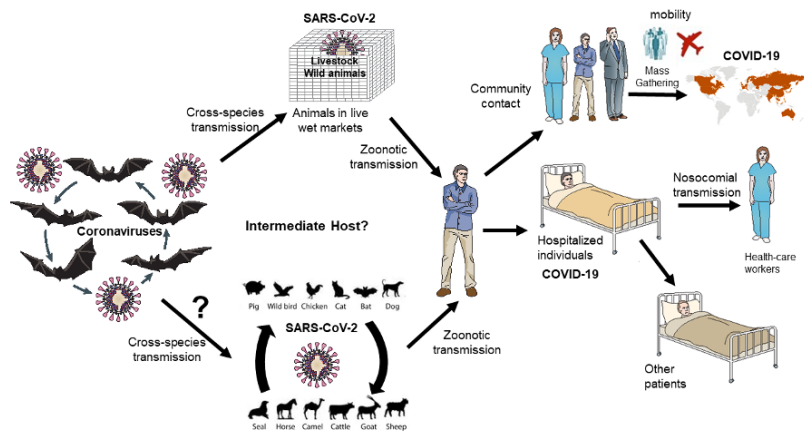


Figure: Distribution of cases of COVID-19 confirmed cases in Africa



Mode of transmission of SARS-CoV-2 virus ⁴



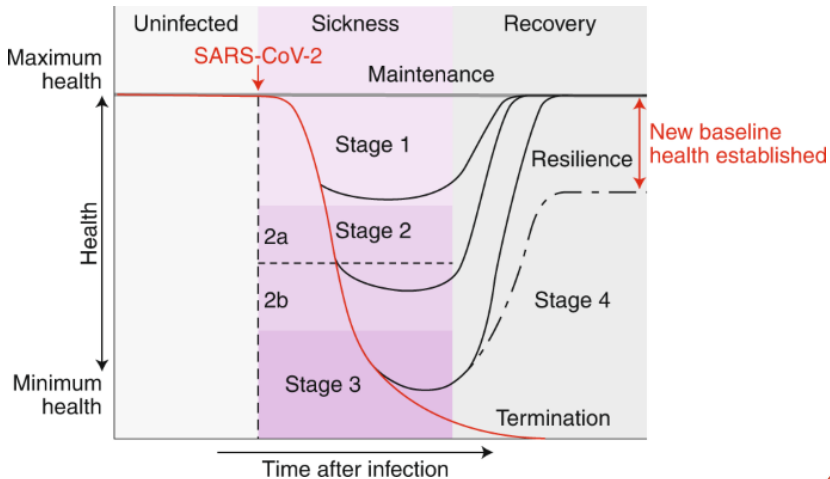
M.E. El Zowalaty and J.D. Jarhult, *One Health* 2020 <https://doi.org/10.1016/j.onehlt.2020.100124>

⁴

Mohamed E.El Zowalaty, Josef D.Jarhult, From SARS to COVID-19: A previously unknown SARS- related coronavirus (SARS-CoV-2) of pandemic potential infecting humans - Call for a One Health approach, *One Health*, Vol. 9, June 2020, 100124, <https://doi.org/10.1016/j.onehlt.2020.100124>



The disease phases of infection with COVID-19⁵



⁵J.S. Ayres , *A metabolic handbook for the COVID-19 pandemic*. Nat Metab 2, 572-585 (2020).



Motivation

Biological question

What is the number of undetected cases in the currently COVID-19 pandemic?

Undetected cases are susceptible individuals that have been exposed to SARS-CoV-2 virus and who have not been detected or suspected by the authorities in charge of COVID-19

The appearance of COVID-19 undetected cases is due to

- ▶ Stigmatization
- ▶ Ancestral believe
- ▶ Lack of knowledge on consequences of an infection with the SARS-CoV-2 virus
- ▶ Authorities are not doing enough testing on people showing symptoms, or 'preclinical cases'
- ▶ African traditional pharmacopoeia,...



Early results on estimation of the number of COVID-19 undetected cases

Estimation the number of undetected cases has been considered recently in the following works:

- ▶ [Z. Liu, P. Magal and G. Webb](#), *Predicting the number of reported and unreported cases for the COVID-19 epidemic in China, South Korea, Italy, France, Germany and United Kingdom*, Journal of Theoretical Biology, in press, <https://doi.org/10.1016/j.jtbi.2020.110501>
- ▶ [Q. Griette, P. Magal, O. Seydi](#), *Unreported Cases for Age Dependent COVID-19 Outbreak in Japan* (June 17, 2020). Biology 9(6):132 DOI: 10.3390/biology9060132
- ▶ [A. Maugeri, M. Barchitta, S. Battiato, A. Agodi](#), *Estimation of Unreported Novel Coronavirus (SARS-CoV-2) Infections from Reported Deaths: A Susceptible-Exposed-Infectious-Recovered-Dead Model*, Journal of Clinical Medicine 2020, 9, 1350; doi:10.3390/jcm9051350.
- ▶ [L. Liu, S. Bao, T. Hu, H. Wu, Z. Peng, R. Wang, Ru](#), *Estimating Unreported COVID-19 Cases in the United States Based on Time-Varying SIR Model* (September 12, 2020). Available at <http://dx.doi.org/10.2139/ssrn.3691372>



State variables of the model

Human population

- ▶ $S_u(t)$: Number of unaware susceptible individuals at time t
- ▶ $S_a(t)$: Number of aware susceptible individuals at time t
- ▶ $I_d(t)$: Number of COVID-19 detected cases at time t
- ▶ $I_u(t)$: number of COVID-19 undetected cases at time t
- ▶ $R(t)$: Number of recovered individuals at time t

Total human population

- ▶ $N(t) = S_u(t) + S_a(t) + I_d(t) + I_u(t) + R(t)$: Total number of human population at time t

Environment

- ▶ $V(t)$: Concentration of free SARS-CoV-2 viruses in the environment at time t



Definition of state variables of the model

- ▶ **Unaware susceptible individuals** are individuals who are susceptible to COVID-19 and do not comply to preventive methods against COVID-19 or individuals who still have no knowledge about the disease
- ▶ **Aware susceptible individuals** are susceptible individuals that observe the COVID-19 preventive methods against COVID-19 such as the lockdown, the social distancing, the mask-face wearing, the use of hydro-alcoholic gel every time, the washing of hands with soap every time, the disinfection of infected surfaces every time
- ▶ **COVID-19 undetected cases** are susceptible individuals that have been exposed to SARS-CoV-2 virus and who have not been detected or suspected by the authorities in charge of COVID-19
- ▶ **COVID-19 detected cases** are susceptible individuals that has been exposed cases to SARS-CoV-2 virus and a confirmatory laboratory test has been conducted by the authorities in charge of COVID-19 to confirm that they are infected
- ▶ **Recovered individuals** are COVID-19 detected cases that recover from the infection after a treatment prescribed by the health authorities



Flowchart of the model

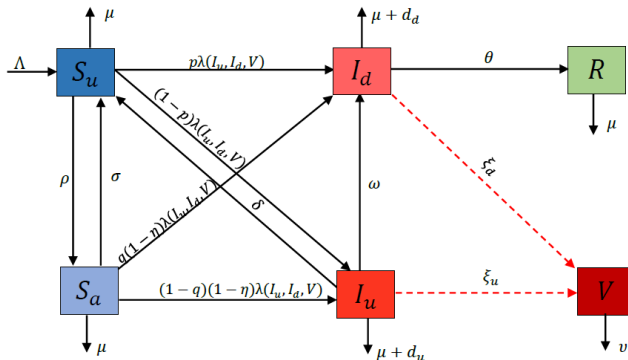


Figure: Structure of the model



The model

Equations of the model

$$\left\{ \begin{array}{l} \dot{S}_u(t) = \Lambda + \gamma S_a(t) + \delta I_u(t) - (\lambda(t) + \rho + \mu) S_u(t) \\ \dot{S}_a(t) = \rho S_u(t) - ((1 - \eta)\lambda(t) + \gamma + \mu) S_a(t) \\ \dot{I}_d(t) = [\rho S_u(t) + q(1 - \eta) S_a(t)] \lambda(t) + \omega I_u(t) - (d_d + \theta + \mu) I_d(t) \\ \dot{I}_u(t) = [(1 - \rho) S_u(t) + (1 - q)(1 - \eta) S_a(t)] \lambda(t) \\ \quad - (\delta + \omega + d_u + \mu) I_u(t) \\ \dot{R}(t) = \theta I_d(t) - \mu R(t) \\ \dot{V}(t) = \xi_u I_u(t) + \xi_d I_d(t) - \nu V(t) \end{array} \right. \quad (1)$$

Force of infection

$$\lambda(t) = \beta_h(t) \frac{I_u(t) + \varepsilon I_d(t)}{N(t)} + \beta_v(t) \frac{V(t)}{K + V(t)} \quad (2)$$



COVID-19 transmission rates⁶ and initial conditions

Time dependent COVID-19 transmission rates

$$\begin{aligned}\beta_h(t) &= \beta_{h,min} + (\beta_{h,0} - \beta_{h,min})e^{-r_h t} \\ \beta_v(t) &= \beta_{v,min} + (\beta_{v,0} - \beta_{v,min})e^{-r_v t}\end{aligned}\quad (3)$$

Initial conditions

- ▶ Here $t \geq t_0$ is time in weeks, t_0 is the beginning date of the epidemic
- ▶ The model is supplemented by initial data

$$\begin{aligned}S_u(t_0) = S_u^0 > 0, \quad S_a(t_0) = S_0^0 > 0, \quad I_u(t_0) = I_u^0 > 0, \\ I_d(t_0) = I_d^0 > 0, \quad R(t_0) = R^0 > 0 \quad \text{and} \quad V(t_0) = V^0 > 0\end{aligned}\quad (4)$$

⁶B. Tang, N. L. Bragazzi, Q. Li, S. Tang, Y. Xiao, J. Wu, *An updated estimation of the risk of transmission of the novel coronavirus (2019-nCov)*. Infectious Disease Modelling 5 (2020), 248-255.



Parameters of the model

Table: Parameter of the model (1)

Symbols	Description	Method
Λ	Human recruitment rate	fixed
μ	Natural mortality rate for human	fixed
β_{h0}	COVID-19 transmission rate of infected cases without interventions	fitted
β_{v0}	COVID-19 transmission rate of free SARS-CoV-2 in the environment without intervention	fitted
r_h	Decay rate of human contacts	fitted
r_v	Decay rate of human contacts with free SARS-CoV-2 in the environment	fitted
ν	Decrease rate of free SARS-CoV-2 in the environment	fixed
ξ_d	Shedding rate of SARS-CoV-2 detected cases in the environment	fixed
ξ_u	Shedding rate of SARS-CoV-2 undetected cases in the environment	fixed
η	Efficacy of preventive methods against COVID-19	fixed
ρ	Rate at which unaware susceptible individuals become aware susceptible individuals	fixed
γ	Rate at which aware susceptible individuals become unaware susceptible individuals	fixed
d_u	COVID-19 induced mortality rate of undetected cases	fixed
d_d	COVID-19 detected induced mortality rate of detected cases	fitted
K	Positive constant	fixed
θ	Recovery rate of COVID-19 detected cases	fitted
p	Proportion of unaware susceptible individuals that become newly COVID-19 detected cases	fitted
q	Proportion of aware susceptible individuals that become newly COVID-19 detected cases	fitted
ω	Detection rate of COVID-19 undetected cases	fitted
ε	Modification factor of infectiousness for undetected cases	fixed



Basic Properties

Positivity of solution and boundedness of trajectories

The model (1) is a dynamical system on the biologically feasible compact domain:

$$\Omega = \left\{ (S_u, S_a, I_d, I_u, R, V) \in \mathbb{R}_+^6, N(t) \leq \frac{\Lambda}{\mu}, V(t) \leq \frac{(\xi_d + \xi_u)\Lambda}{\nu\mu} \right\} \quad (5)$$

Disease free equilibrium (DFE)

$$X^* = (S_u^*, S_a^*, 0, 0, 0, 0)^T, \quad (6)$$

where

$$S_u^* = \frac{(\gamma + \mu)\Lambda}{(\rho + \gamma + \mu)\mu} \quad \text{and} \quad S_a^* = \frac{\rho\Lambda}{(\rho + \gamma + \mu)\mu}.$$



Basic reproduction number

Basic reproduction number

The basic reproduction number \mathcal{R}_0 is the average number of secondary cases produced by a single infective individual which is introduced into an entirely susceptible population

When all parameter values are constant, the basic reproduction of the model is

$$\mathcal{R}_0 = \mathcal{R}_{0h} + \mathcal{R}_{0v}, \quad (7)$$

where

$$\mathcal{R}_{0h} = \frac{\beta_h}{N_0} \left[\frac{\varepsilon S^*}{d_d + \theta + \mu} + \left(\frac{\omega \varepsilon}{d_d + \theta + \mu} + 1 \right) \frac{C^*}{\delta + \omega + d_u + \mu} \right]$$

and

$$\mathcal{R}_{0v} = \frac{\beta_v}{(d_d + \theta + \mu)Kv} \left(\xi_d S^* + \frac{(\xi_u(d_d + \theta + \mu) + \xi_d \omega)C^*}{\delta + \omega + d_u + \mu} \right),$$

with $S^* = pS_u^* + q(1 - \eta)S_a^*$, $C^* = (1 - p)S_u^* + (1 - q)(1 - \eta)S_a^*$.



The Ensemble Kalman filter approach (*EnKf*) ⁷

Consider the following system of ordinary differential equations:

$$\begin{cases} \dot{x}(t) &= g(x(t), \phi(t)) \\ \mathcal{Y}(t) &= h(x(t), \phi(t)) \end{cases} \quad (8)$$

- ▶ $x(t) \in \mathbb{R}^n$ is the state variables
- ▶ $\phi(t) \in \mathbb{R}^m$ is the vector of unknown parameters
- ▶ $\mathcal{Y}(t) \in \mathbb{R}^p$ is the vector of system output

Implementation with the Ensemble Kalman filter

For the implementation of the Ensemble Kalman filter, the evolution of the state and observation of measurements can be described by the following stochastic system:

$$\begin{cases} x_{t+1} &= f(x_t, \phi_t) + w_t \\ \mathcal{Y}_t &= h(x_t, \phi_t) + \psi_t \\ \phi_{t+1} &= \phi_t + \sigma_t \end{cases} \quad (9)$$

- ▶ x_t is the true state vector at time t
- ▶ $w_t \in \mathbb{R}^n$ is a Gaussian distributed model error (zero mean and covariance Q_t)
- ▶ $\psi_t \in \mathbb{R}^p$ is the representation error (zero means and covariance Z_t)
- ▶ $\sigma_t \in \mathbb{R}^m$ is the uncertainty at time t given by a Gaussian white noise (zero means and covariance T_t)



Ensemble Kalman filter (EnKf) approach

The filter equations for this system are summarized as follows. The superscript f and a refer to forecasted and analyzed entities, respectively, while the bar and n stand for the means and the number of ensemble members

Forecast

- ▶ Calculation of predicted state variables x_{t+1}^{fi} and observed states y_{t+1}^{fi}

$$x_{t+1}^{fi} = f(x_t^{ai}, \phi_t^a) + w_t^i \quad \text{and} \quad y_{t+1}^{fi} = h(x_{t+1}^{fi}, \phi_t^a), \quad i = 1, 2, \dots, n \quad (10)$$

- ▶ Calculation of the forecasted values of state variables and observed states

$$\bar{x}_{t+1}^f = \frac{1}{n} \sum_{i=1}^n x_{t+1}^{fi} \quad \text{and} \quad \bar{y}_{t+1}^f = \frac{1}{n} \sum_{i=1}^n y_{t+1}^{fi} \quad (11)$$

- ▶ Calculation of the covariance matrix of observations

$$R_{t+1} = \frac{1}{n-1} \sum_{i=1}^n v_{t+1}^i (v_{t+1}^i)^T \quad (12)$$

- ▶ Calculation of the estimate of covariance matrix of errors of states and observations

$$P_{x^f, y^f, t+1} = \frac{1}{n-1} \sum_{i=1}^n E_{x, t+1}^{fi} (E_{y, t+1}^{fi})^T \quad \text{and} \quad P_{y^f, t+1} = \frac{1}{n-1} \sum_{i=1}^n E_{y, t+1}^{fi} (E_{y, t+1}^{fi})^T, \quad (13)$$

where $E_{x, t+1}^{fi} = x_{t+1}^{fi} - \bar{x}_{t+1}^f$ and $E_{y, t+1}^{fi} = y_{t+1}^{fi} - \bar{y}_{t+1}^f$



Ensemble Kalman filter (EnKf) approach

Analysis

- ▶ Calculation of analyzed states

$$x_{t+1}^{ai} = \bar{x}_{t+1}^{fi} + K_{t+1}(\mathcal{Y}_{t+1} + v_{t+1}^i - \mathcal{Y}_{t+1}^{fi}), \quad i = 1, 2, \dots, n \quad (14)$$

$$K_{t+1} = P_{x^y, t+1} (P_{y^y, t+1} + R_{t+1})^{-1} \quad (15)$$

- ▶ Calculation of the estimate state of x_{t+1}

$$x_{t+1}^a = \frac{1}{n} \sum_{i=1}^n x_{t+1}^{ai} \quad (16)$$

The next step is to estimate ϕ_{t+1}^a from the equation $\phi_{t+1} = \phi_t + \sigma_t$ and $\mathcal{Y}_t = h(x_t, \phi_t) + \psi_t$ using the estimate of x_{t+1}^a . We use the same procedure described above.



States space formulation with *EnKf*

System outputs of the model

- ▶ Newly COVID-19 detected cases
 $\mathcal{Y}_1(t) = (pS_u(t) + q(1 - \eta)S_a(t))\lambda(t) + \omega I_u(t)$
- ▶ Newly recovered individuals: $\mathcal{Y}_2(t) = \theta I_d(t)$
- ▶ Newly deceased: $\mathcal{Y}_3(t) = d_d I_d(t)$

System output vector of the model

$$\mathcal{Y}(t) = \begin{pmatrix} (pS_u(t) + q(1 - \eta)S_a(t))\lambda(t) + \omega I_u(t) \\ \theta I_d(t) \\ d_d I_d(t) \end{pmatrix} \quad (17)$$

Unknown parameters of the model

- ▶ $\phi = (\beta_{h0}, \beta_{v0}, r_h, r_v, d_d, \theta, p, q, \omega)^T$



Study case of Cameroon

- ▶ March 06, 2020: Appearance of the first COVID-19 case
- ▶ March 17, 2020: Lockdown and announcement of more than 13 drastic measures to limit the transmission of COVID-19 within the population by the Cameroonian government
- ▶ May 01, 2020: Partial lifting of lockdown of liquor store and trade
- ▶ June 01, 2020: Total lifting of partial lockdown and Resumption of face-to-face school and universities with maintaining restrictions



Epidemiological situation of COVID-19 on April 30, 2020 in Cameroon⁸

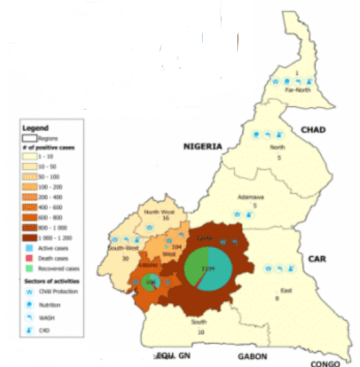
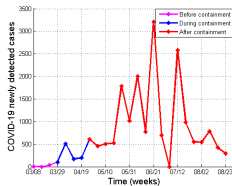


Figure: Epidemiological situation of COVID-19 on April 30, 2020 in Cameroon.

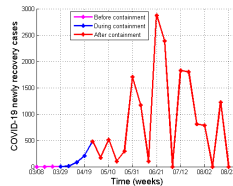


⁸Cameroon: COVID-19 situation

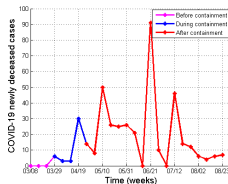
Reported data of COVID-19 in Cameroon⁹



(a)



(b)



(c)

Figure: Reported data of COVID-19 from 06-03-2020 to 23-08-2020 in Cameroon. (a) Newly detected cases, (b) Newly recovered individuals and (c) Newly deceased.

⁹Pollitologue, <https://coronavirus.politologue.com/coronavirus-cameroun.CM>



Numerical simulation

Parameter values used for numerical simulation

Symbols	Value	Symbols	Value	Symbols	Value
v	$1/2 \text{ week}^{-1}$	ξ_d	$0.01 \text{ cells. (week. indiv)}^{-1}$	ξ_u	$0.5 \text{ cells. (week. indiv)}^{-1}$
η	0.9180	ρ	0.0255 week^{-1}	γ	0.015 week^{-1}
K	10^6 cells	δ	$1/2 \text{ week}^{-1}$	$\varepsilon = 0.1$	

Start time of simulation

- ▶ $t_0 = \text{March 08, 2020}$

Initial conditions

- ▶ $S_u(t_0) = 26371000$, $S_a(t_0) = 0$, $I_u(t_0) = 1$, $I_d(t_0) = 50$, $R(t_0) = 0$ and $V(t_0) = 700$

Initial conditions of unknown parameters

- ▶ $\beta_{h0}(t_0) = 0.00123$, $\beta_{v0}(t_0) = 0.0051$, $r_h(t_0) = 0.074$, $r_v(t_0) = 0.0765851$, $d_d(t_0) = 0.01138$, $\theta(t_0) = 0.02$, $p(t_0) = 0.3$, $q(t_0) = 0.5$ and $\omega(t_0) = 0.0035$

Covariance matrice of white noises

- ▶ $Q_t = \text{diag}(100, 5, 7, 5, 5, 10)I_6$, $T_t = 10^{-5}I_9$ and $Z_t = 0.0015I_3$ where I_9 and I_3 are the identity matrix of dimension 9 and 3, respectively.



Estimate of state variables of the model

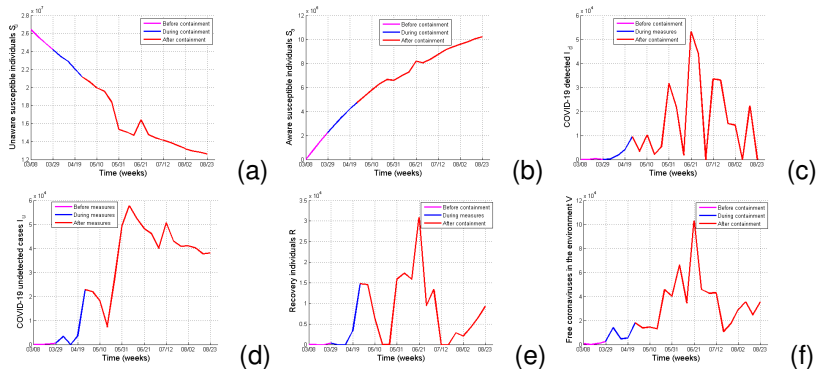
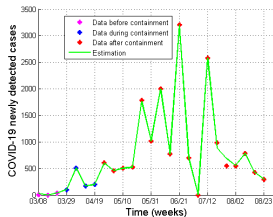


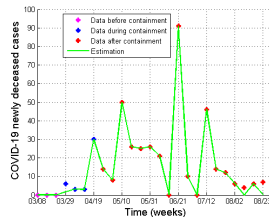
Figure: Estimate of state variables of the model (1). (a) S_u ; (b) S_a ; (c) I_d ; (d) I_u ; (e) R and (f) V



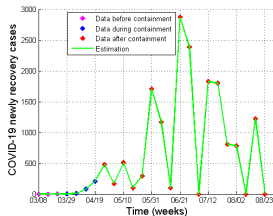
Fitting results of the current COVID-19 pandemic from March 08, 2020 to August 23, 2020 in Cameroon



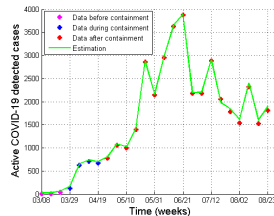
(a)



(b)



(c)



(d)

Figure: Fitting results of the current COVID-19 pandemic from March 08, 2020 to August 23, 2020 in Cameroon when $\mu = 3.261037118722394 \cdot 10^{-4}$ and $\Lambda = 17562$



Reconstruction of unknown parameters in Cameroon

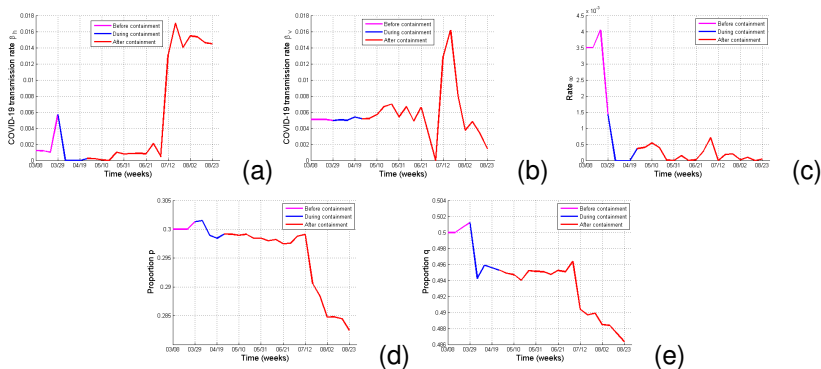
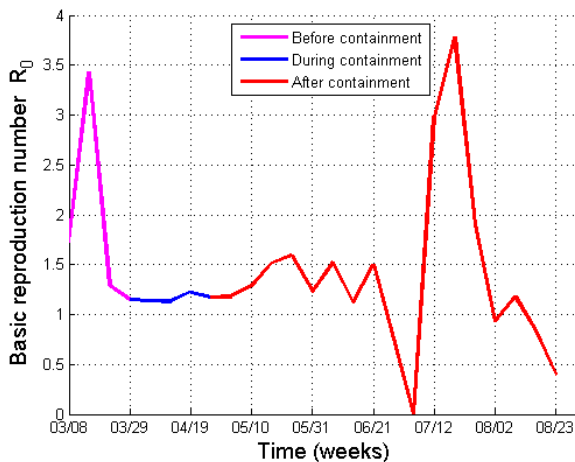


Figure: (a) Transmission rate from infected cases β_h ; (b) Transmission rate from free SARS-CoV-2 in the environment β_v ; (c) detection rate ω ; (d) proportion p and (e) proportion q



Reconstruction of basic reproduction number in Cameroon



Situation of COVID-19 pandemic on August 23, 2020 in Cameroon

Estimated of mean parameter values of the COVID-19 pandemic in Cameroon on August 23, 2020

Parameters	Values	Parameters	Values
β_{h0}	0.004978840618071	β_{v0}	0.005781517016911
r_h	0.001348902213412	r_v	0.000810871905941
d_d	0.003483016040501	θ	0.045117926388403
ρ	0.295930213087618	q	0.494168486139734
ω	0.000637292241936	β_h	0.004978840618071
β_v	0.005781517016911	\mathcal{R}_0	1.338553757883551

Estimate of COVID-19 cases in Cameroon on August 23, 2020

Detected cases		Undetected cases		Total cases	
Active	Cumulative	Active	Cumulative	Active	Cumulative
1 814	18 762	23 064	43 060	24 878	61 822



Reconstruction of COVID-19 undetected cases in Cameroon

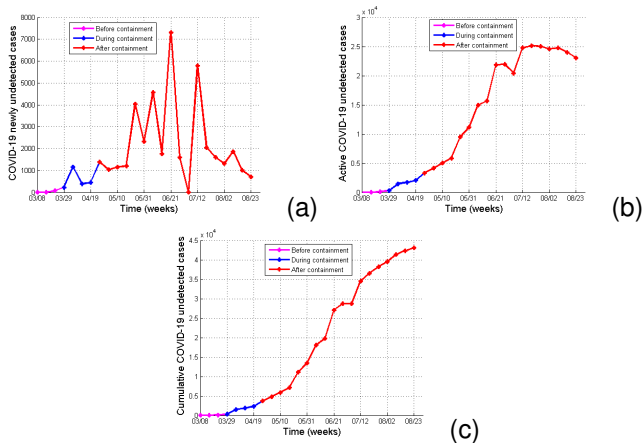


Figure: Reconstruction of COVID-19 undetected cases in Cameroon. (a) Newly undetected cases, (b) Active undetected cases and (c) Cumulative undetected cases



Short term forecasting of COVID-19 pandemic in Cameroon

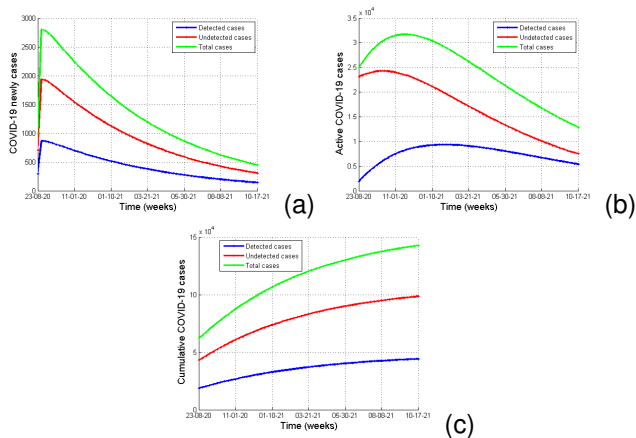


Figure: (a) COVID-19 newly detected cases; (b) COVID-19 infected cases and (c) COVID-19 cumulative cases.



Study case of Gabon

- ▶ March 12, 2020: Appearance of first COVID-19 case
- ▶ March 20, 2020: The first death was confirmed
- ▶ April 10, 2020: Lockdown imposed by the authorities
- ▶ May 11, 2020: Lifting of the lockdown with maintaining restrictions follow government directives



Epidemiological situation in Gabon on Monday, October 5, 2020¹⁰

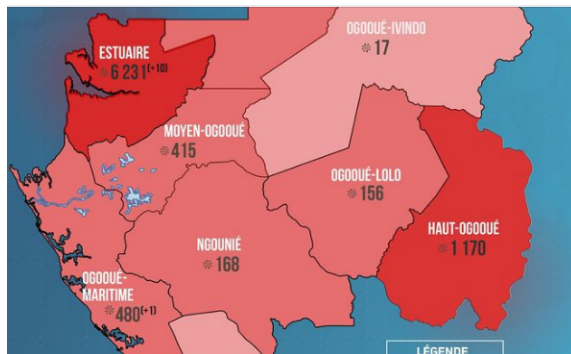


Figure: Epidemiological situation in Gabon on Monday, October 5, 2020

¹⁰<https://info-covid19-gabon/situation-%C3%A9pid%C3%A9miologique-au-lundi-5-octobre-2020/10223958266922775/>



Reported data of COVID-19 from 12-03-2020 to 08-2020 in Gabon¹¹

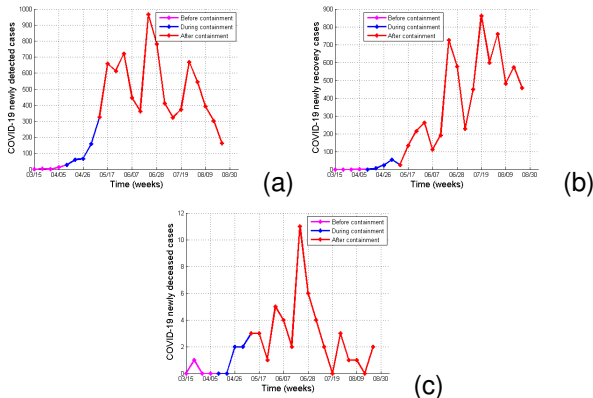


Figure: Reported data of COVID-19 from 12-03-2020 to 08-2020 in Gabon. (a) Newly detected cases, (b) Newly recovered individuals and (c) Newly deceased

¹¹Politologue, <https://coronavirus.politologue.com/coronavirus-gabon.GA>



Numerical simulation

Parameter values used for numerical simulation

Symbols	Value	Symbols	Value	Symbols	Value
v	$1/2 \text{ week}^{-1}$	ξ_d	$0.01 \text{ cells. (week. indiv)}^{-1}$	ξ_u	$0.5 \text{ cells. (week. indiv)}^{-1}$
η	0.9180	ρ	0.0255 week^{-1}	γ	0.015 week^{-1}
K	10^6 cells	δ	$1/2 \text{ week}^{-1}$	$\varepsilon = 0.1$	

Start time of simulation

- ▶ $t_0 = \text{March 15, 2020}$

Initial conditions

- ▶ $S_u(t_0) = 2183590$, $S_a(t_0) = 0$, $I_u(t_0) = 1$, $I_d(t_0) = 20$, $R(t_0) = 0$ and $V(t_0) = 700$.

Initial conditions of unknown parameters

- ▶ $\beta_{h0}(t_0) = 0.00123, 0.0051$, $\beta_{v0}(t_0) = 0.074, 0.0765851$, $r_h(t_0) = 0.01138$, $r_v(t_0) = 0.02$, $d_d(t_0) = 0.01138$, $\theta(t_0) = 0.02$, $\rho(t_0) = 0.3$, $q(t_0) = 0.5$ and $\omega(t_0) = 0.0035$

Covariance matrix of white noises

- ▶ $Q_t = \text{diag}(10, 5, 7, 5, 5, 10)I_6$, $T_t = 10^{-5}I_9$ and $Z_t = 0.0015I_3$ where I_9 and I_3 are the identity matrix of dimension 9 and 3, respectively



Estimation of state variables of model

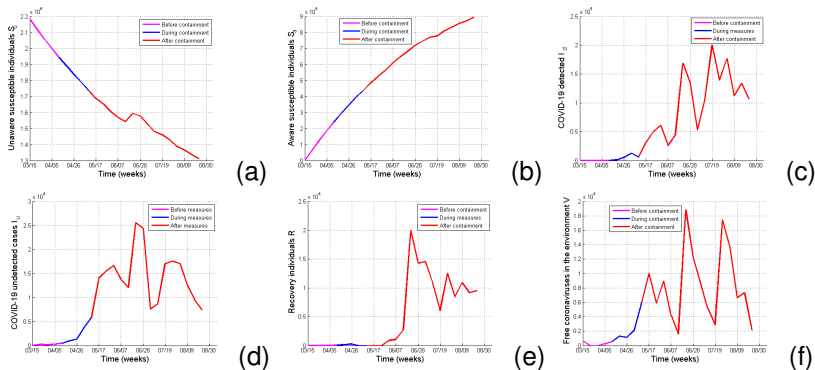
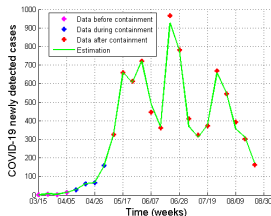


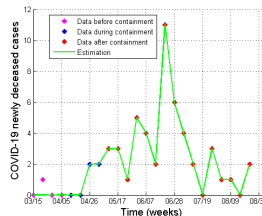
Figure: Estimate of state variables of the model (1). (a) S_u ; (b) S_a ; (c) I_d ; (d) I_u ; (e) R and (f) V



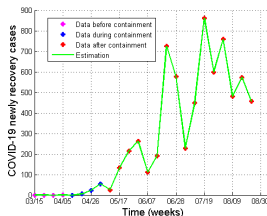
Case of Gabon: from March 15, 2020 to August 23, 2020



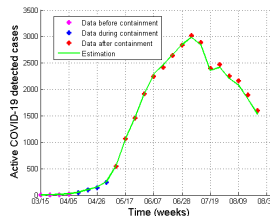
(a)



(b)



(c)



(d)

Figure: Fitting results of the current COVID-19 pandemic in Gabon when $\mu = 1/(66.47 * (365/7))$ and $\Lambda = 1312$



Reconstruction of unknown parameters in Gabon

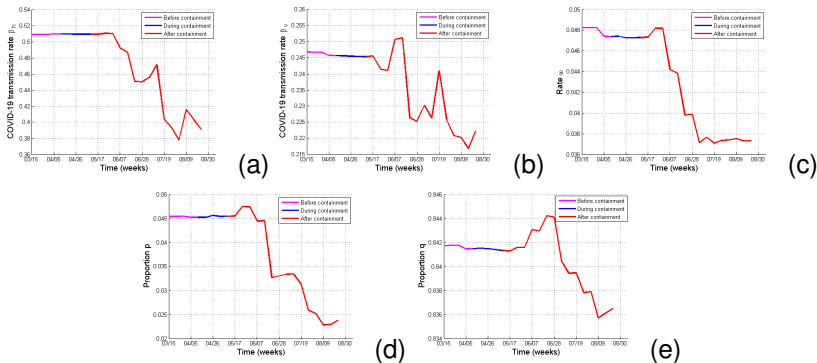
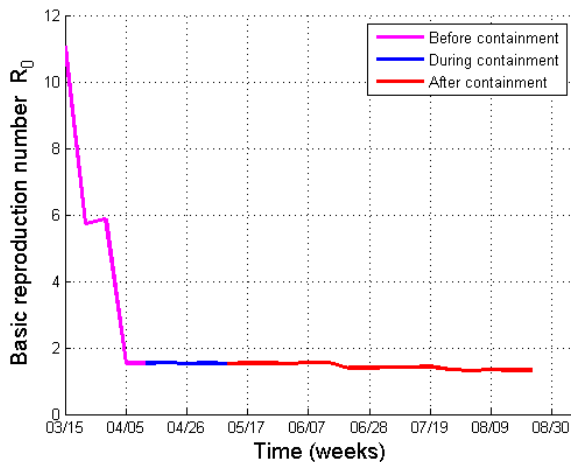


Figure: (a) Transmission rate from infected cases β_h ; (b) Transmission rate from free SARS-CoV-2 in the environment β_v ; (c) detection rate ω ; (d) proportion p and (e) proportion q



Reconstruction of the basic reproduction number \mathcal{R}_0 in Gabon

Situation of COVID-19 pandemic on August 23, 2020 in Gabon

Estimate of mean parameter values of the COVID-19 pandemic in Gabon on August 23, 2020

Parameters	Values	Parameters	Values
β_{h0}	0.509360347677284	β_{v0}	0.243484334897228
r_h	0.005667056736739	r_v	0.001739955970803
d_d	0.000083827451995	θ	0.003909065108489
p	0.038433354239025	q	0.840674799591183
ω	0.043291171389538	β_h	0.509360347677284
β_v	0.243484334897228	\mathcal{R}_0	1.551353148244056

Estimate of COVID-19 cases in Gabon on August 23, 2020

Detected cases		Undetected cases		Total cases	
Active	Cumulative	Active	Cumulative	Active	Cumulative
1 349	8 468	8 024	114 285	9 373	122 753



Reconstruction of COVID-19 undetected cases in Gabon

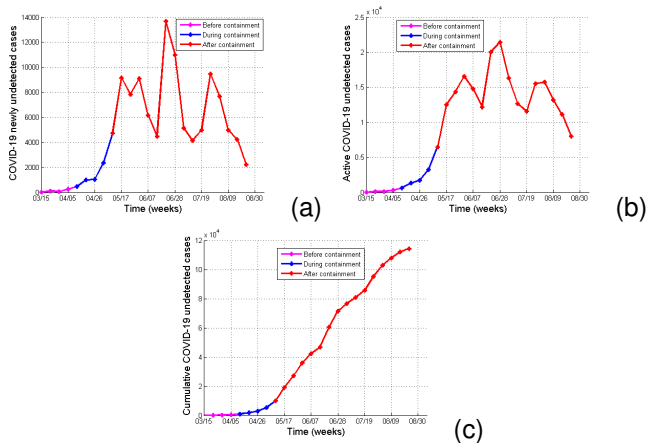


Figure: Reconstruction of COVID-19 undetected cases in Gabon. (a) Newly undetected cases, (b) Active undetected cases and (c) Cumulative undetected cases



Short term forecasting of COVID-19 pandemic in Gabon

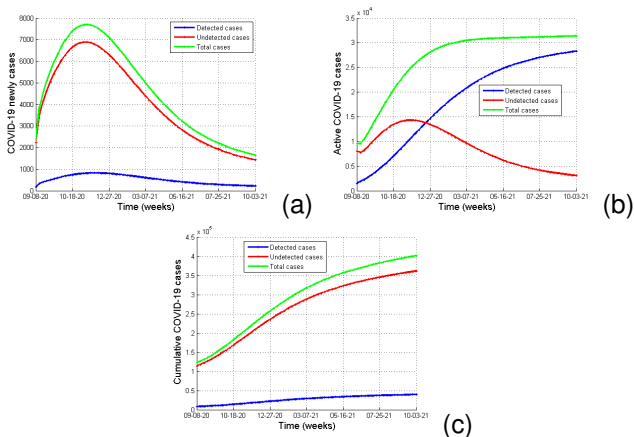


Figure: (a) COVID-19 newly detected cases; (b) COVID-19 active cases and (c) COVID-19 cumulative cases



Summary

- ▶ A mathematical model for COVID-19 transmission in the context of Sub-Saharan Africa is presented
- ▶ We computed the DFE and derived the basic reproduction ratio \mathcal{R}_0
- ▶ Using available data on COVID-19, the *EnKf* approach has been used to estimate state variables that are not accessible to measurements and unknown parameters of the model
- ▶ We found that
 - ▶ Transmission of COVID-19 from infected individuals is more important than the transmission from free SARS-CoV-2 virus in the environment
 - ▶ On August 23, 2020, $\mathcal{R}_0 \approx 1.33$ in Cameroon, while $\mathcal{R}_0 \approx 1.55$ in Gabon
 - ▶ The majority of COVID-19 cases fear stigmatization, and prefer to stay home for self-treatment
 - ▶ The number of undetected cases remains high in both countries, which could be the source of a next COVID-19 outbreak as observed in many countries



Thank you for your attention and Take care!

