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What Can We Learn from Burkina Faso COVID-19 Data? Using Phenomenological Models to Characterize the Initial Growth Dynamic of the Outbreak and to Generate Short-Term Forecasts

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Abstract: On 9 March 2020, two cases of COVID-19 were reported in Burkina Faso. As of 10 April 2020, a total number of 484 cases (404 cases in the Kadiogo province) were reported nationwide. Real-time forecasts of COVID-19 are important to inform decision-making in the country. Here, we propose an approach that tests the performance of four models (Exponential Growth model, the Generalized Growth model (GGM), the Generalized Logistic Growth, and Richards Growth model) to select the model that best fit data and to generate short-term forecasting (5-, 10-, and 15-day forecasts from 11 to 25 April 2020) in Kadiogo, the epicenter of the outbreak. Using daily number of confirmed COVID-19 cases, the results suggests that GGM performed the best out of the 4 models. Overall, our GGM predictions suggested an average total number of cumulative cases of 514 (95% CI, 464–559), 629 (95% CI, 559–691), and 750 (95% CI, 661–840) between 11 to 15 April, 16 to 20 April, and 20 to 25 April 2020, respectively. COVID-19 in this province was best approximated by sub exponential growth rather than exponential or logistic growth. Current data suggest that COVID-19 cases would continue to increase over the next 15-days.

Keywords: COVID-19; coronavirus; enhanced surveillance; real-time forecasts; phenomenological models; sub-exponential growth; Kadiogo; Burkina Faso

1. Introduction

On 31 December 2019, respiratory viral infection (Coronavirus, called COVID-19) appeared in Wuhan in Hubei province in the Popular Republic of China [1]. This infection has since spread very rapidly throughout the world. The expansion of the outbreak to all continents led the World Health

Organization (WHO), on 30 January 2020, to declare the situation as a pandemic [2] while simultaneously recommending measures to stop the spread due to the current lack of an effective treatment (either curative or preventive). By approximately three and a half months later, an estimated 1,696,588 or more cases of COVID-19 had been reported worldwide, with more than 105,952 deaths [3]—of which, more than 9728 of the confirmed cases and 44 of the deaths occurred in 54 different African countries [3]. While strategies to prevent and control the spread (e.g., staying at home as much as possible, limiting social contact, wearing protective masks, etc.) of the disease have proven successful in China and other countries in Asia and Europe [4–6], there are uncertainties as to whether they can be effectively implemented in sub-Saharan African countries [7].

Burkina Faso is currently facing this international health emergency. The first two cases (people who spent time in Mulhouse, the epicenter of the outbreak in France [8]) were reported on 9 March 2020 [7, 9]. After the COVID-19 outbreak in Ouagadougou, the capital of Kadiogo province, it spread very quickly through the other provinces [7], spreading social psychosis among the population. According to the report of the Coordinating Committee of Response against the disease, a total number of 484 cases, including 27 deaths, were recorded between 9 and 10 April 2020 (SitRep number 44 of 10 April 2020)[10], making Burkina Faso the fifth most affected country in sub-Saharan Africa after South Africa, Cameroon, Ivory Coast, and Niger [3, 11]. The government has taken a number of measures, including the implementation of hygienic measures, isolation and quarantines, closure of frontiers, postponement of commercial flights, the launch of two clinical trials, and epidemiological surveillance, with the aim of protecting the population [12, 13]. However, the social context and the economic structure of Burkinabe society, which is largely dominated by the activities of the non-formal sector [14] and which forces the population to live hand-to-mouth, make absolute isolation difficult. In addition, the country—characterized by a weak health system infrastructure [15]—would not have sufficient resources to diagnose all cases or to manage critical cases that require respiratory assistance.

In such a context, characterizing and forecasting the trend of the early outbreak growth profile appears crucial [16, 17] for an optimal allocation of prevention measures, medical resources, organization of production activities, and, eventually, maintenance of national economic development throughout the country. Phenomenological approaches in modeling the spread of the disease are particularly appropriate when substantial uncertainties interfere with the epidemiology of the outbreak, including the potential contribution of multiple transmission routes [18]. In addition, phenomenological models provide a starting point for providing early estimates of the potential spread, understanding the evolution patterns of the outbreak, and generating short-term forecasts of the trajectory of the outbreak and forecasts of the final size of the outbreak [16–18].

In this present study, four phenomenological models (Generalized Growth, Generalized Logistic Growth, Exponential Growth, and Richard Growth), been validated in previous outbreaks [17, 19–23] (Ebola virus, influenza, smallpox, plague, measles, HIV/AIDS, severe acute respiratory syndrome, Zika virus, COVID-19, etc.), were applied to the data to identify the best model to adequately fit the data, which was then used to characterize the early ascending phase of the outbreak and to assess short-term forecasts in Kadiogo province, the epicenter of the outbreak in Burkina Faso.

2. Methods

2.1. Data sources

COVID-19 confirmed cases: From the beginning of the outbreak, the Operations Center for Health Emergency Response of Burkina Faso has published daily reports on the situation of the Coronavirus outbreak (*SitRep n° xx*). This published report includes primarily the number of daily confirmed new cases, of daily cumulative confirmed cases, of daily and total deaths, and of daily and total recoveries, among others. These reports and/or the number of cases are freely available on several sites, namely, the Ministry of Health website and the World Health Organization website [18, 24, 25].

For the purpose of our study, we collected data regarding the number of daily confirmed new cases covering the period from 09 March to 10 April, 2020. These data were aggregated at the national and provincial level. For our study, we focused on the province of Kadiogo, which concentrated more than 83.5% of the cases, and we did not consider the other provinces in order to avoid the effect of demographic noise of small outbreaks (less than 100 cases) [26].

2.2. Statistical methods

2.2.1. Models

We tested four phenomenological models in order to select the model that best fit our data. These growth models are defined by differential equations as follows:

$$\frac{dC(t)}{dt} = C'(t) = rC(t) \quad (1)$$

$$\frac{dC(t)}{dt} = C'(t) = rC(t)^p \quad (2)$$

$$\frac{dC(t)}{dt} = C'(t) = rC(t)^p \left(1 - \frac{C(t)}{K}\right) \quad (3)$$

$$\frac{dC(t)}{dt} = C'(t) = rC(t) \left(1 - \left(\frac{C(t)}{K}\right)^\alpha\right) \quad (4)$$

Formulas (1)–(4) represent the Exponential Growth, the Generalized Growth, the Generalized Logistic Growth, and Richard Growth models, respectively. In these formulas, $C'(t)$ is the incidence curve over time t , the solution $C(t)$ describes the cumulative number of cases at time t , r is a positive parameter denoting the growth rate, p is a "deceleration of growth" parameter, and α represents an exponent that measures the deviation from the symmetric s-shaped dynamics of the simple logistic curve. K is the final epidemic size or carrying capacity.

After testing, the generalized growth model (GGM) appeared to best fit the Kadiogo Province COVID-19 data (Figure S1, Figure S2 and Figure S3). The GGM (with two parameters— r and p) is an extension of the simple logistic growth model, in which an incremental parameter, p , was added to allow for scaling of growth. The GGM assumes an exponential growth dynamic of the outbreak in the absence of control interventions; this implies that there is an exponential increase in the cumulative number of COVID-19 cases, $C(t)$. To smooth the exponential growth assumption, we considered a simple generalized model [19, 27, 28], according to the formula (2) described above.

In the GGM, the deceleration of growth parameter p varies between 0 and 1, whose variation enables the model to fit sub-exponential or early polynomial growth [19, 27, 28]. For instance, the model predicts an early exponential growth when the value of parameter p is equal to 1, whereas a value of 0 suggests a constant growth of incidence over time.

2.2.2. Data fitting, calibration, and Short-term forecasts

For the data fitting, we used the number of daily new confirmed cases covering a period of 30 days from 12 March to 10 April 2020, because, we noted that it was four days after the first notification date (09 March 2020) that cases began to be regularly (suspected cases tested) reported on a daily basis, We used nonlinear least squares fitting to fit the data and to obtain the initial appropriate parameters (r and p) capable of minimizing the sum of squared errors between the model and the data.

We calibrated each of the models to the daily case incident reported for Kadiogo province for five days (12 to 21 March 2020), 15 days (12 to 26 March 2020), 20 days (12 to 31 March 2020), and 25 days (12 to 05 April 2020), respectively. We implemented simulation approaches to generate the outbreak trajectories for short-term forecasting based on the uncertainty in the parameter estimates [29]. Based on the best fitting model, the GGM, we performed a short-term forecast for 5 days (11 to 15 April), 10 days (16 to 20 April), and 15 days (21 to 25 April). To generate the confidence intervals at 95% level (95% C.I.) of uncertainty associated with the model estimates, we used parametric bootstrap simulation (M = 500) datasets, assuming a Poisson error structure [30].

To assess the performance of our modeling, we used the Root mean square error (RMSE) as performance metric.

3. Results

As of 10 April 2020, i.e., 33 days after the COVID-19 outbreak, 15 out of the 45 provinces in Burkina Faso have reported at least one confirmed case of COVID-19. In terms of the number of cases, Kadiogo (which includes the political capital, Ouagadougou) is the most affected province with 404 (83.5% of all cases) cases, followed by Houet province (which includes the economical capital Bobo-Dioulasso) with 42 cases (Figure 1).

Figure 1. Distribution of total confirmed COVID-19 cases in Burkina Faso by province on 10 April 2020.

It is noticeable that the majority of the population of the country is concentrated in these two major provinces (22.8% of the whole population). However, since COVID-19 has not reached all the provinces, it should be pointed out that it is the western part of the country, followed by the central area, that were affected, if we consider the geographical distribution.

Figure 2 shows the evolution of the daily confirmed cases notified between 09 March and 10 April 2020, as well as their copulation in the whole country and Kadiogo province on its own.

Figure 2. The cumulative number of confirmed and daily confirmed cases in the whole of Burkina Faso and in Kadiogo province alone. The Cross stitches represent the number of new cases per day.

The results showed an increase in the cumulative number of cases in the whole country, with an average of 14 cases carried over per day. However, we noted that it was four days after the first notification date (09 March 2020) that cases began to be regularly (suspected cases tested) reported on a daily basis. Since that date, in Kadiogo province, an average of 13 cases have been reported per day. Due to the relatively small number of cases in the other provinces of the country, we focused our analysis only in the Kadiogo province, seeing as it represents the vast majority of the cases in the country.

As mentioned in the section 2, after testing the four phenomenological models, it was found that the generalized growth model (GGM) was best adapted to the Burkinabe COVID-19 data. The results of the training of GGM are presented in Figure 3 and Figure S1. The results of the training of the other models namely, the exponential Growth, the Generalized Logistic Growth, and Richard Growth models are presented in Figure S2, Figure S3 and Figure S4. The values of the different parameters of the GGM model and the RMSE for the calibration and forecasting period are also presented in Table 1. As the number of epidemic days increases, the value of the growth rate (r) increased whereas the value of the "deceleration of growth" parameter (p) decreases, indicating a decrease in exponential growth.

Table 1. Parameters of the model (r and p) and the root mean square error (RMSE) values for the training and the forecasting during Generalized Growth model fitting

Model	r (95% C.I.)	p (95% C.I.)	RMSE	RMSE Prediction
10 days	1.5 (0.7–2.8)	0.54 (0.31–0.81)	3.12	7.48
15 days	2.0 (1.1–3.0)	0.45 (0.32–0.61)	6.94	9.54
20 days	2.6 (1.5–4.1)	0.37 (0.25–0.49)	6.44	8.57
25 days	3.2 (2.0–4.9)	0.30 (0.20–0.40)	6.58	7.10

For the performance metrics of the modeling, the results for the training after days 10, 15, 20, and 25 based on an GGM model are presented in Figure 3. In the Figure 3 below, we can clearly see that the GGM model fitted very well all of the data from the day 20 outbreak days. For the complete model with 30 outbreak days (Figure S5), the parameters were estimated as $r = 2.9$ (95% C.I., 1.9–4.2) and $p = 0.33$ (95% C.I., 0.25–0.41), and the performance metrics as $RMSE = 7.09$. The complete model of the Exponential Growth, Generalized Growth, Generalized Logistic Growth, and Richard Growth models with 30 outbreak days are presented in Figure S6, S7 and S8 respectively.

Figure 3. Five-day ahead forecast provided by the Generalized Growth Model (GGM) when the model is fitted to an increasing amount of outbreak data: (A) 10, (B) 15, (C) 20, and (D) 25 outbreak days. The vertical dashed lines separate the calibration and the forecasting periods. The median (solid red line) and 95% C.I. (dashed red lines) of the model fit ensembles are plotted. The blue points represent the real observations.

Finally, we performed a short-term forecasting at 5-, 10-, and 15-days based on the GGM. The results are presented in the Figure 4. Overall, our predictions suggested that the COVID-19 outbreak would continue to increase over the next 15 days. Our model (GGM) suggested an average total number of cumulative cases of 514 (95% C.I., 464–559), 629 (95% C.I., 559–691), and 750 (95% C.I., 661–840) on 15 April, 20 April, and 25 April 2020, respectively.

Figure 4. Forecasting at 5- (A), 10- (B), and 15 (C) days based on the GGM model (25 days of training). The median (solid red line) and 95% CI (dashed red lines) of the model fit ensembles (blue curves) are plotted. The black points represent the real observations.

4. Discussion

In this study, our findings showed that cases of the COVID-19 in Burkina Faso are concentrated in areas where the population mix is enormous. Moreover, it is easy to observe that from the areas where the number of cases is higher, the neighboring provinces are also beginning to register cases. This shows that population movements increase the transmission of the COVID-19 [31, 32], which provides support for the government's strategy to place provinces with very high cases loads into lockdown and to avoid the "non-essential" movement of people. This strategy, aiming at reducing population movement and increasing physical distance or reducing the frequency of meetings in high-density community settings, such as schools, prayer halls, markets, or workplaces, plays a crucial role in outbreak control [33, 34]. While maintaining continuous surveillance in all of the provinces (if possible, disaggregated into health districts and municipalities) of the country, the "non-essential" movements (in and out) from the epicenter province must be controlled as a matter of priority. Based on the available data, if these measures are well implemented and are followed by the population, the situation of COVID-19 could change in a matter of a few days.

We applied phenomenological models to COVID-19 to characterize the early outbreak growth profile in the most affected province in Burkina Faso and to provide short-term forecasts. The COVID-19 pattern in Kadiogo province was best approximated by sub-exponential growth rather than exponential or logistic growth models. Overall, our forecasted values suggested that the outbreaks have progressed slowly and will continue to increase for the next 15 days. Several factors could explain the slower than expected exponential growth pattern in Kadiogo, Burkina Faso: 1) the age and structure of the population, 2) the levels of tests currently performed in Burkina Faso.

The first—and probably most important—factor related to demographics and the population pyramid; that is, the median age is 17.9 years [35], and the life expectancy is 63 years [36]. Large-scale epidemiological studies in China, Europe, and the USA have shown that the median age of COVID-19 patients is approximately 45 years [37, 38], but the severity of the disease and the risk of death increase exponentially with age—with patients aged above 65 years being at higher risk [39]. In this context of a relatively young population, it is likely that part of the population is infected but only present limited symptomatology and do not seek medical consultation; in the absence of a systematic screening campaign, such cases are not reported. It has also been previously suggested that cold temperature and low humidity might provide conducive environmental conditions for prolonged viral survival or for other types of SARS-CoVs [40]; the hot climate in Burkina Faso could, therefore, be a protective factor. We could also hypothesize that, due to the highly infectious terrain and the low level of healthcare management, responsible for a high child mortality rate, only individuals with higher resistance to infectious diseases survive.

The second point is that, the data on COVID-19 in Kadiogo, Burkina Faso change daily and only take into account people who are sick and who are rushing to be diagnosed or whom the health center has the capability to test. In fact, screening is not generalized and only concerns specific populations: hospitalized patients, suspected people, and health care staff with suspected symptoms. Therefore, we cannot determine if the low number of observed cases, compared to other countries worldwide and in North African countries or in South Africa [41], are under-reported and diagnostic due to the lower testing capacities. Indeed, over the last month, covering our period of analysis, about 1192 tests were performed in Burkina Faso, among which 29% were positive [42]. This percentage of positive test results is relatively similar to European countries, where this value appears to oscillate between

20% and 30% [43]. This would suggest that if the Burkina Faso health system had the capacity to screen widely like they do in other countries, the number of actual cases could far exceed the number of cases currently reported.

A last point is that the higher prevalence of infectious diseases (e.g., malaria) in the Sub-Saharan population could explain a lower sensitivity to this virus.

5. Conclusion

Our study provided insight into the early spread of the outbreak, which could allow optimal planning of prevention measures and medical resources, as well as organization of production activities throughout the province. Our results suggest that the confirmed COVID-19 cases data in Kadiogo, Burkina Faso exhibits a slower growth pattern that can be best approximated by a sub-exponential growth model rather than exponential or logistic functions. The findings indicate that COVID-19 cases are likely to continue to increase for the next two weeks.

However, by following the recommendations of the authorities (i.e., reducing social contacts), we can expect an inversion of the evolution curve in the number of infected cases and in the duration of the outbreak. Further works and continuous analysis of any newly reported cases are fundamental to control the progression of the disease and to ensure that growth is limited, as is currently the case.

Supplementary Materials:

Figure S1. Five-day ahead forecast provided by the Exponential Growth Model when the model is fitted to an increasing amount of outbreak data: (A) 10, (B) 15, (C) 20, and (D) 25 outbreak days. The vertical dashed lines separate the calibration and the forecasting periods. The median (solid red line) and 95% C.I. (dashed red lines) of the model fit ensembles are plotted. The blue points represent the real observations.

Figure S2. Five-day ahead forecast provided by the Generalized Logistic Growth Model when the model is fitted to an increasing amount of outbreak data: (A) 10, (B) 15, (C) 20, and (D) 25 outbreak days. The vertical dashed lines separate the calibration and the forecasting periods. The median (solid red line) and 95% C.I. (dashed red lines) of the model fit ensembles are plotted. The blue points represent the real observations.

Figure S3. Five-day ahead forecast provided by the Richard Growth Model when the model is fitted to an increasing amount of outbreak data: (A) 10, (B) 15, (C) 20, and (D) 25 outbreak days. The vertical dashed lines separate the calibration and the forecasting periods. The median (solid red line) and 95% C.I. (dashed red lines) of the model fit ensembles are plotted. The blue points represent the real observations.

Figure S4. Evolution of performance metric values, the mean square error (RMSE) for the training and the forecasting during model fitting.

Figure S5. Generalized Growth model with all dataset (30 outbreak days). The vertical dashed lines the end date of the collected data. The median (solid red line) and 95% C.I. (dashed red lines) of the model fit ensembles are plotted. The blue points represent the real observations.

Figure S6. Exponential Growth model with all dataset (30 outbreak days). The vertical dashed lines the end date of the collected data. The median (solid red line) and 95% C.I. (dashed red lines) of the model fit ensembles are plotted. The blue points represent the real observations.

Figure S7. Generalized logistic Growth model with all dataset (30 outbreak days). The vertical dashed lines the end date of the collected data. The median (solid red line) and 95% C.I. (dashed red lines) of the model fit ensembles are plotted. The blue points represent the real observations.

Figure S8. Richard Growth model with all dataset (30 outbreak days). The vertical dashed lines the end date of the collected data. The median (solid red line) and 95% C.I. (dashed red lines) of the model fit ensembles are plotted. The blue points represent the real observations.

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