

Estimation of exponential growth rate and basic reproduction number of the coronavirus disease 2019 (COVID-19) in Africa

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Infectious Diseases of Poverty  BMC

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SUBJECT AREAS

Infectious Diseases

KEYWORDS

COVID-19; reproduction number; pandemic; statistical modelling.

Abstract

Background Since the first case of coronavirus disease 2019 (COVID-19) was detected on February 14, 2020, the cumulative confirmations reached 15207 including 831 deaths by April 13, 2020.

Methods We analyzed the initial phase of the epidemic of COVID-19 in Africa between 1 March and 13 April 2020, by using the simple exponential growth model.

Results We estimated the exponential growth rate as 0.22 per day (95%CI: 0.20 – 0.24), and the basic reproduction number, R_0 , to be 2.37 (95%CI: 2.22-2.51) based on the assumption that the exponential growth starting from 1 March 2020.

Conclusion The initial growth of COVID-19 cases in Africa was rapid and showed large variations across countries. Our estimates should be useful in preparedness planning.

Trial registration: NA

Introduction

Since the end of 2019, an outbreak of coronavirus disease 2019 (COVID-19), now a pandemic (2020 (World Health Organization, 2020b; Gilbert, 2020), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (World Health Organization, 2020a) has hit China severely, in particular, the epicenter, Wuhan, the capital city of Hubei province. The city has been locked down since January 23, 2020 and the lockdown has been lifted on April 8, 2020. As of the March 23, the epicenter has moved to Europe and US, after the outbreak was largely controlled in China. Many countries are facing a rapid increasing trend of confirmed cases. The case-fatality-rate varies wildly from country to country. As of 13 April 2020, about 2 million people have been infected with COVID-19 with over 117,000 death globally (out of which about 90% of the death cases were from United State and Europe) (World Health Organization, 2020a; World Health Organization, 2020c).

Africa reported its first case of COVID-19 in Egypt on 14 February 2020 (Gilbert, 2020; World Health Organization, 2020c).

As of 13 April 2020, a total of 15207 infected cases were reported, with 831 fatal cases, giving an overall case fatality rate (CFR) of 5.47% throughout Africa, among them only 3 cases with no death reported in February 2020 (World Health Organization, 2020c).

The African region has been described as one of the most vulnerable with the COVID-19 infection (Gilbert, 2020) in the initial phase, due to the fact that Africa is important commercial partner of China and as a result, large volume of business person travel to the region. Since the epicenter is now in Europe, due to the close tie between Africa and European countries, African countries face even bigger threat.

Several control measures have currently been taken by most of the African countries to prevent/reduce the spread of COVID-19, especially against case importation from the COVID-19 epicenters. Some of the measures includes travel ban to and from the most COVID-19 hit countries, school closures, temporary ban of religious gathering and so on (Gilbert, 2020; World Health Organization, 2020d; Nigeria Center for Disease Control, 2020). Nevertheless, the ability to curtail or reduce and control the local transmission after case importation depends largely with how African government are seriously sustaining the current recommended measures. Due to the fragile health care system, insufficient health workers, lack of water, and sanitizers for maintaining hygiene in the region. African countries need to find their optimal strategies to stop the spread of COVID-19 in its region.

Numerous epidemiological studies have been conducted to understand the transmission dynamics of COVID-19, which is quantified in two key parameters, the basic reproduction number (the expected number of secondary cases that may be caused by a typical primary case during his/her infectious period in a wholly susceptible population, R_0) and the serial interval (time delay between the symptom onset of a primary case and his/her secondary case, SI). High reproductive number and short serial interval imply rapid growth. In the initial phase, the epidemic (number of new cases over time) typically exhibited exponential growth. The basic reproduction number is a function of the exponential growth rate (r) and the serial interval. Studies on the basic reproduction number, exponential growth rate and serial interval (Zhao et al., 2020a; Ma, 2020; Nishiura et al., 2020; Du et al, 2020; and Zhao et al., 2020b), many of which have shown the R_0 ranges from 2.0 to 4.0, and initial under-reporting/under-detection during the early phases of the outbreak in Wuhan, China.

The aim of this study is to estimate the exponential growth rate and the basic reproduction number of the COVID-19 pandemic in Africa at the early stage, which should be valuable in informing the official and public in the preparedness against COVID-19 spread, forecasting the trend, and highlighting the importance of sustaining strict measures in order to curtail the spread.

Methods

We obtained the daily number of COVID-19 cases time series data in Africa from World Health Organization (WHO) from 1 March to 19 March 2020

(<https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports/>). Although there were 3 confirmed cases throughout Africa from 14 February to 29 February 2020, we did not include them as there were no additional case reported until 1 March 2020. In this work, we considered the situation from 1 March 2020 as the number of cases and death started a steady increasing trend.

Referring to recent studies (Zhao et al., 2020a; Ma, 2020), we model the epidemic curve by employing the exponential growth proposed by Ma et al. (Ma, 2020). The Poisson likelihood framework is adopted for data fitting and parameter estimation. The intrinsic growth rate (λ) was estimated, and the basic reproduction number R_0 computed via $R_0 = \lambda / \mu$ with 100% susceptibility for COVID-19 presumed (Wallinga and Lipsitch, 2007). The function $\phi(s)$ represents the Laplace transform and the moment generating function of the probability distribution, for the generation interval (GI, the time between the timing of infections of two successive cases) of the COVID-19 (Zhao et al., 2020a; Ma, 2020, Wallinga and Lipsitch, 2007). Note that since GI is not observable, we follow conventional approach to use serial interval (timing between symptom onset of two successive cases) as a proxy of GI. Since the transmission chain of COVID-19 in Africa is yet to be fully uncovered, we adopted the SI estimated in Zhao et al. (2020c). We modelled the distribution of COVID-19 GI as Gamma distributions with a mean of 4.7 days and standard deviation (SD) of 2.9 days previously estimated by Zhao et al. (2020b).

Additionally, we quantified the instantaneous transmissibility of the outbreak by the time-varying effective reproductive number. We adopted previous study by Zhao et al. (2020c) to estimate the

effective reproductive number following the SI technic. By employing the renewal equation methods as described by Zhao et al. (2020c), we showed the effective reproductive number of some African countries with reported data for at least 20 days after exceeding 20 cumulative cases in order to show the potential of COVID-19 to spread across the region.

Results And Discussion

The exponential growth fitting results are depicted in Figure 1. The fitting results matched the observed daily number of cases, which implies that the early outbreak data in Africa were largely following the exponential growth rate estimated at 0.22 per day (95%CI: 0.20 - 0.24), which is slightly larger than previous estimates (Zhao et al., 2020a; Nishiura et al., 2020; Li et al., 2020). Our analysis and estimation of R_0 rely on the accuracy of the SI of COVID-19 estimated previously based on cases from Hong Kong by Zhao et al. (2020b). We estimated the basic reproduction number R_0 to be 2.37 (95%CI: 2.22 - 2.51), which is also depending on the estimates of the SI during the early epidemics. Our basic reproduction number R_0 estimates is significantly larger than 1 and broadly consistent with recent studies (Zhao et al., 2020a; World Health Organization, 2020e; Li et al., 2020; Wu et al., 2020; Zhao et al., 2020d; Li et al., 2020b; Riou and Althaus, 2020). We suggested that the current COVID-19 outbreaks in Africa could increase rapidly if the measures were not strictly sustaining, which includes temporary bans of international travels, religious gathering, avoid social distancing and so on.

We reported that the mean R_0 of COVID-19 in Africa is likely to be 2.37 which could vary from 2.22 to 2.51 and is consistent with the previous estimates, (World Health Organization, 2020e, Zhao et al., 2020a; Imai et al., 2020; Read et al., 2020).

Denote the infection attack rate (final size of infected) as z , then $z=1-\exp(-R_0z)$, one may solve z given R_0 (Ma and Earn 2006) showed this equation is true when the homogeneous mixing assumption holds.

Brauer (2019) showed that the actual infection attack rate could be low due to public behavior change and heterogeneity in mixing, for instance in the Ebola outbreak, the actual infection attack rate was

much smaller than the theoretical estimates in ideal situation. With an R_0 at 2.37, the theoretical infection attack rate will be as large as 87%, namely 87% of Africa will be infected. However, we need to point out that the classical final size overestimated the infection attack rate in the influenza pandemic 1918 and influenza pandemic 2009. These two influenza pandemics had R_0 around 2 and 1.5, respectively. The observed infection attack rate was round 20% in England and Wales and 10% in Hong Kong. Theoretically, the infection attack rate could be 80% and 58%, respectively. The case-fatality-rate (CFR) of 1918 was around 2% (Paulo, 2010), and thus the situation of panic and governmental action was similar to COVID-19 pandemic. While the CFR of 2009 influenza pandemic was relatively low, there was virtually little-scale or insufficient control. For these two examples, the expected infection attack rate could be close to the 1918, namely 25%. Thus, we need to be prepared and strict action needs to be taken.

In Figure 2, we examined the publicly available materials published by the WHO (WHO, 2020a) to show the potential of COVID-19 to spread without sustaining strict health measures. We observed the daily confirmations of the COVID-19 cases in 19 African countries that reported data for at least 20 days after exceeding 20 cumulative cases. Thus, we fitted the cumulative confirmations of 19 African countries starting from the date when cumulative exceeded 20. In Figure 3, we showed the changing patterns of reproductive number (R) based on the daily confirmations of COVID-19 cases time series in Africa. We used the R package EpiEstim (Cori et al 2013) to calculate the instantaneous effective reproductive number of 19 African countries in order to show the potential of COVID-19 to spread across the region. After an initial rapid growth in COVID-19 confirmed cases driven by imported cases in the whole Africa, the reported cases showed steady pattern (with decreased reproductive number) in many Africa countries which could be due to limited testing.

We suggested that the likely factors responsible for the rapid increase in the number of confirmed cases in these countries is presumably linked with proportion of population in Africa doing international trade with foreign countries (e.g., China, Germany, Italy and US), also the level of vulnerability of African countries as described by Gilbert et al. (2020), i.e., countries with the highest

importation risk (such as Egypt, Algeria, and South Africa) followed by countries at moderate risk (such as Nigeria, Ethiopia, Sudan, Angola, Tanzania, Ghana, and Kenya) and then others. This further shows that Africa is one of the highest vulnerable region for the COVID-19 pandemic, indicating that there is a need of taking more serious control measures based on the recommendation of WHO and other health related bodies to curtail the spread of COVID-19 in Africa.

Conclusion

We estimated the exponential growth rate as 0.22 per day (95%CI: 0.20 – 0.24). We estimated that the mean R_0 of COVID-19 in Africa to be 2.37 (95%CI: 2.22 – 2.51) with a constant testing effort assumed. We highlighted the importance of sustaining strict health measures in order to contain the virus within a shortest possible time.

Declaration

Ethical Approval and Consent to participate

Not applicable. All data used are from public domain.

Consent for publication

Not applicable. All data used are from public domain

Availability of data and materials

All data used are from public domain

Competing interests

DH was supported by an Alibaba (China) - Hong Kong Polytechnic University Collaborative Research project. Other authors declare no conflict of interest.

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Authors' contributions

MSS and SZ conceived the project. MSS, SZ and DH conducted the research and wrote the draft. MHW, AGH and UTM critically revised the manuscript, and all authors approved the submission.

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Figures

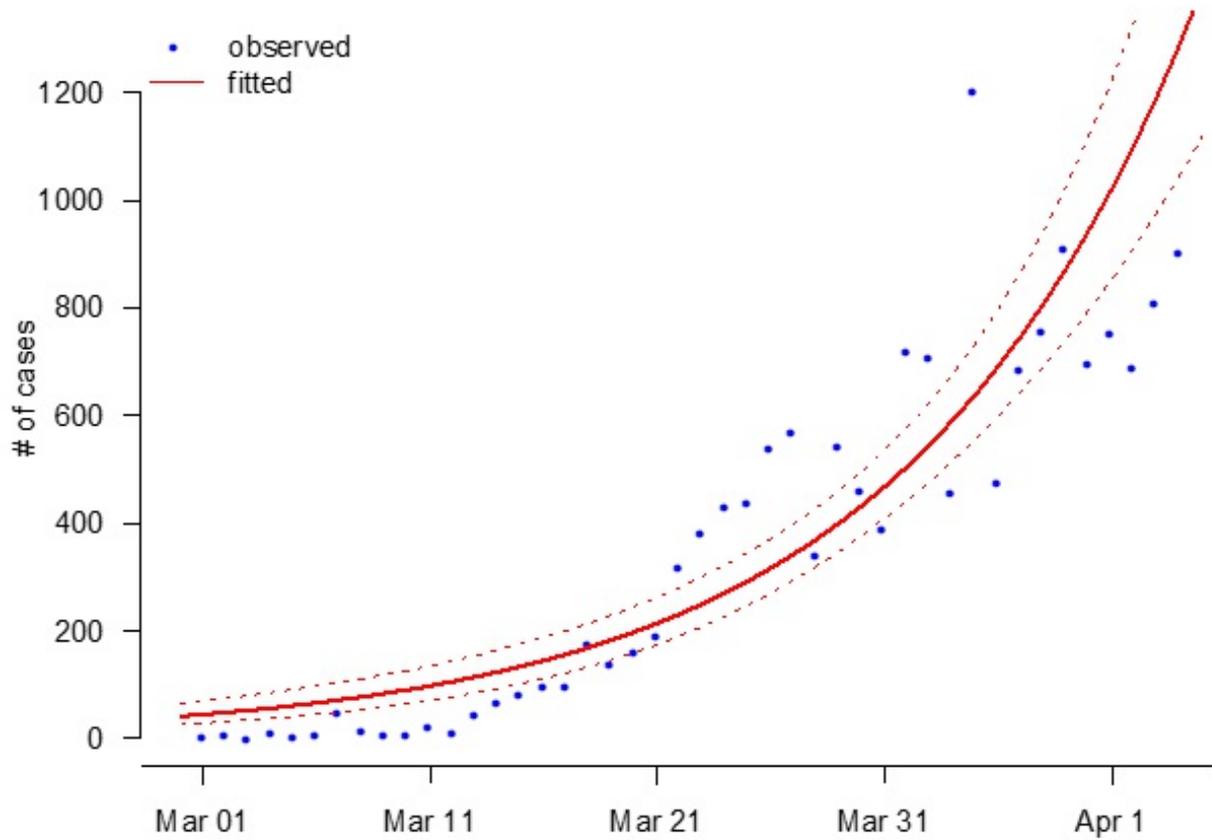


Figure 1

The observed (dots) and fitted (curves) daily number of COVID-19 cases time series in Africa. The blue dots are observations, and the curves are fitting results. The red bold curve represents the mean fitting result, and the red dashed curves are the 95% confidence intervals. Multiple R-squared: 0.756.

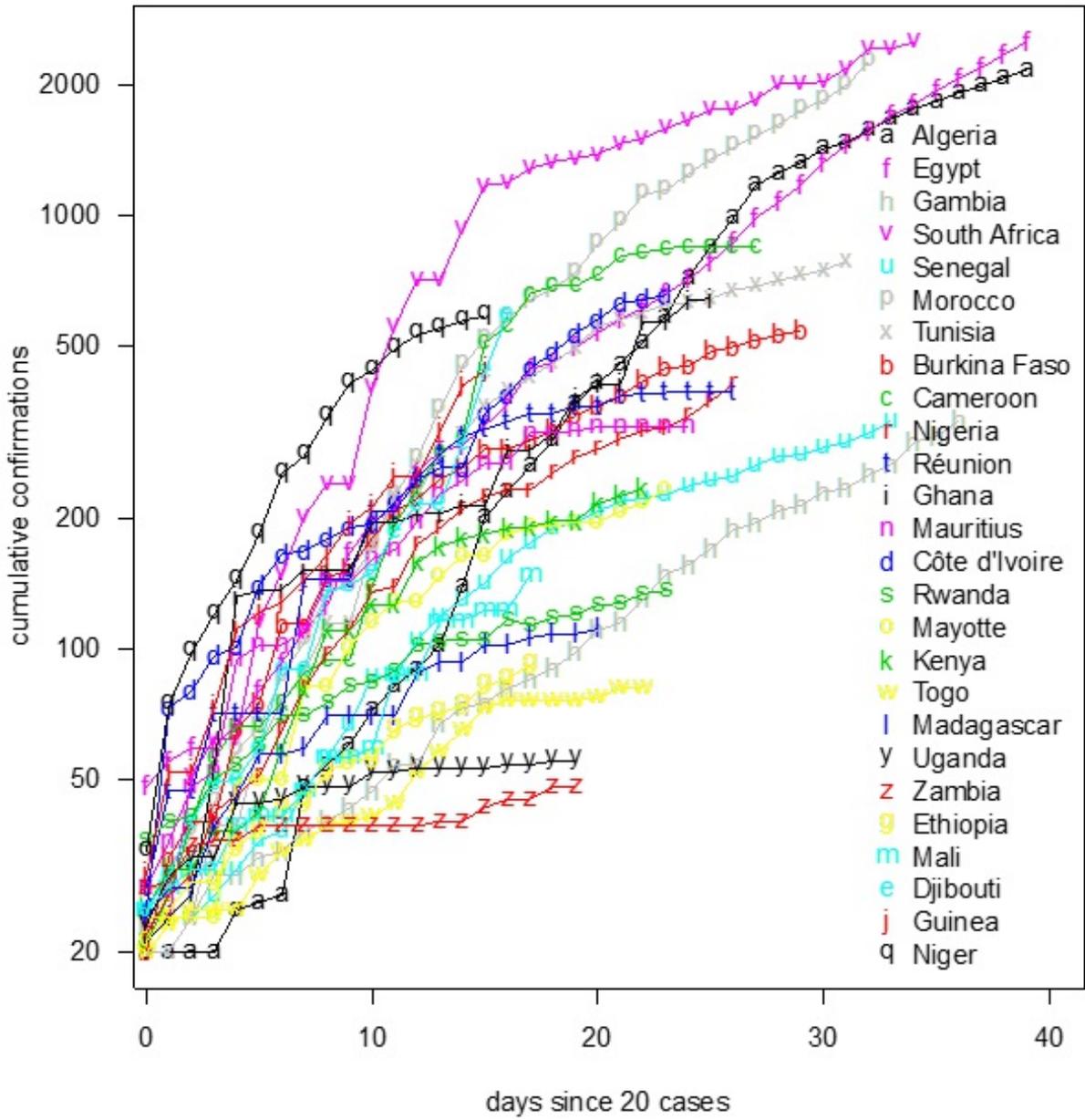


Figure 2

The reported cumulative confirmations of COVID-19 in 19 African countries exceeding 20 cases. The x axis shows the days since the cumulative exceeded 20 in a country.

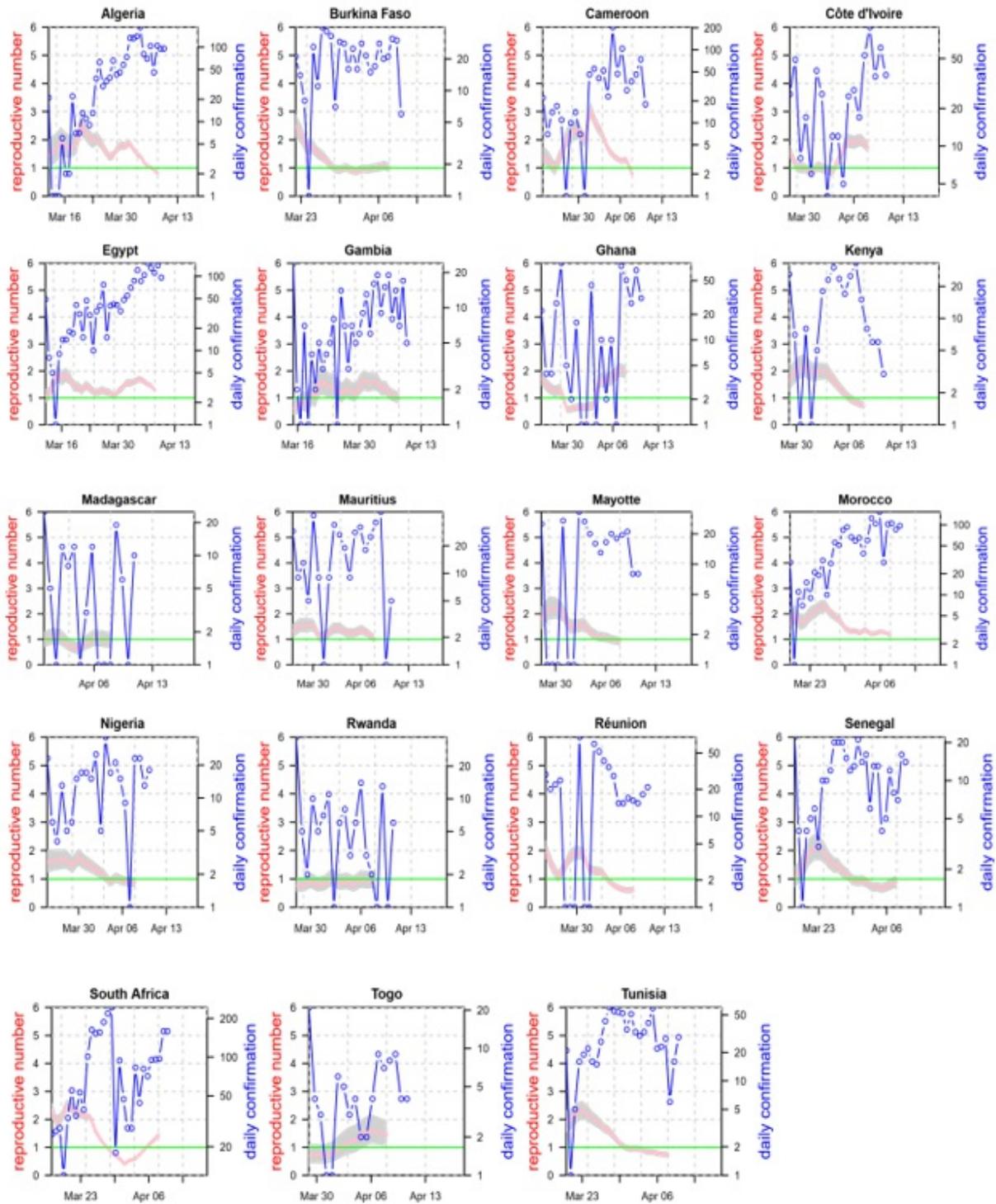


Figure 3

The reported cases (blue circle line) and reproductive number (the three solid lines are the median and 95% CI) based on the daily confirmations of COVID-19 cases time series in 19 African countries.

