



TECHNIUM
SOCIAL SCIENCES JOURNAL

Vol. 9, 2020

**A new decade
for social changes**

www.techniumscience.com

ISSN 2668-7798



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Modeling and Forecasting Infections, Fatalities and Recoveries from COVID-19 pandemic in SSA: A case of the 10 hotspot in Sub-Saharan Africa

Momodou Mustapha Fanneh¹, Mustapha Jobarteh², John T. Mendy³, Amadou Jawo⁴

^{1 2 3 4}University of Gambia

mmfanneh@utg.edu.gm¹, mjobarteh@utg.edu.gm², jt.mendy@utg.edu.gm³, amadouessa2019@gmail.com⁴

Abstract. This paper aims to model COVID 19 infections and fatalities and how the growth paradigm of the continent will shift overtime. The study used epidemiological data of countries and two mathematical models, i.e., Logistic model growth model and modified growth model to predict number of patients (infections), number of deaths and number of recoveries from COVID-19 in the continent. In this study, it is showed that with the current state of the spread of the COVID-19, it is projected that the number of infections will reach 141,733 in the next 30 days and 986,059 patients in the next 60 days. Also, 12,972 will die in the next 30 days and 151,190 in the next 60 days and 73,590 will recover in the next 30 days and 490,547 in the next 60 days. These estimates will help countries to strengthen their policies towards COVID-19 such as lockdown, social distancing, wearing of face masks, washing of hands with water and soap and using hand sanitizers.

Keywords. COVID-19, Coronavirus, Forecasting, Logistic growth, Modified Exponential Growth

1. Introduction

There has been uncertainties everywhere regarding the COVID-19 pandemic and the increasing number of infections and deaths around the world. This fear affected production, consumption, investment, financial sector, service sector, education sector, health sector, agricultural sector and remittances among others. Health is fundamental to a prosperous productive society, whereas panic and illness can stifle production, consumption, recreation, travel, and overall well-being (Marin, 2017).

The Coronavirus Disease 2019 (COVID-19) is a respiratory illness caused by a novel coronavirus, namely severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), first detected in December 2019 in the city of Wuhan in Hubei province, China (Brüssow, 2020; Fauci, Lane & Redfield, 2020; Gentile & Abenavoli, 2020; Shang, Yang, Rao & Rao, 2020). Symptoms of the virus range from fever, flu-like symptoms such as coughing, sore throat and fatigue, and shortness of breath. There is evidence that it spreads from person to person, but good hygiene can prevent infection (Chavis & Ganesh, 2020; Chen et al, 2020; Deng & Peng, 2020).

COVID-19 is a health related issue, it is contagious and affects other sectors of the economy and all continents. Health is fundamental to a prosperous productive society, whereas panic and illness can stifle production, consumption, recreation, travel, and overall well-being (Marin, 2017; Adeola & Evans, 2018; Lawanson & Evans, 2019; Nwaogwugwu & Evans, 2019; Fourie, 2020). The impacts Ebola virus in West Africa from 2013 to 2014 cut across many sectors and undoubtedly have long-term consequences” in Guinea, Liberia and Sierra Leone (Smith et al, 2019).

Coronavirus started in China and now spreads across all the continents. Africa joined the COVID-19 bandwagon on 15th February, 2020 where Egypt reported the first case. As of the 21st of April the COVID-19 hotspots were Egypt, South Africa, Tunisia, Ivory Coast, Nigeria, Algeria, Ghana, Djibouti, Cameroon, and Morocco. The study generates 30 days and 60 days forecast of cumulative confirmed infections, fatalities and recoveries.

We used the number of cases reported from February 1st to April 21, 2020 to estimate possible spread size of COVID-19, especially in the hotspot countries. As the epidemic curve follows the rule of rising, peaking, and then decline, however, in our observed period, all the 8 countries are in their speedy rising stages but not yet reach their peak and decline stages (Zhou, Xian, et al., 2020)

The study aims to model and forecast COVID-19 pandemic in 10 hotspots in SSA. The study objectives are to:

- (a) Predict the number of patients (infections) from COVID 19 using different models (Logistic model and modified exponential growth model)
- (b) Predict the number of deaths from COVID-19 using the different models
- (c) Predict the number of recoveries from COVID-19 using the different models

Section 2 surveys the mathematical modeling of COVID-19 pandemic and section 3 discusses the methodologies used. Section 4 analyzes the results and section 5 concludes the study.

2. Mathematical modelling of the Covid-19 pandemic

Epidemics affect the population and the economy in various ways. It is crucial to model the COVID-19 pandemic (using epidemiological data) and provide mathematical models to predict infections, deaths and recoveries in Sub-Saharan Africa (SSA). This will help to provide solutions to governments in dealing with health sector challenges and how to address or plan for future pandemics.

“Mathematical modeling of an epidemic has an important role in understanding the various complexities associated with an infectious disease and its control. It is beneficial in understanding the mechanisms underlying observed epidemiological patterns and assessing the effectiveness of control strategies and also predicting epidemiological trends. Mathematical modeling of human diseases has been from long times. The first mathematical model in epidemiology was prepared by Daniel Bernoulli, a Swiss Mathematician on the effect of variolation against smallpox in increasing life expectancy. His work had idea of differential mortality for estimation of the rate of deaths attributable for a given disease. This has been used to estimate disease death rates of past epidemics like 1918 influenza pandemic. R. A. Ross (1897) did modeling on malaria transmission and showed that malaria was indeed transmitted through mosquitoes and hence developed model to describe the spread of malaria. He concluded from his model that by reduction in the mosquito population could control malaria in a given region. Then in 1927 Kermack WO and Mckendrick AG (1927), published paper on contribution to the mathematical theory of epidemic. A simple deterministic/compartamental model of susceptible – infectious – recovered (SIR) model was first used for explaining the behaviour of the plague and cholera epidemics e.g. Cholera epidemic in London 1865. The

important concepts in modeling outbreaks of infectious diseases are the a) basic reproductive number, universally denoted by R_0 , and b) the generation time i.e. the average time from onset of symptom in a primary case to onset of symptom in a secondary case. This will determine the likelihood and speed of epidemic outbreaks. - Mutalik (2017)

A lot of efforts have been made in estimating the basic reproduction number R_0 and predict the future trajectory of the coronavirus (COVID-2019) outbreak in the first quarter of 2020. In this paper, we focus on using phenomenological models without detailed microscopic foundations, but which have the advantage of allowing simple calibrations to the empirical reported data and providing transparent interpretations. This simple and top-down method can provide straightforward insights regarding the status of the epidemics and future scenarios of the outbreak. Usually, an epidemic follows an exponential growth at an early stage (following the law of proportional growth), peaks and then the growth rate decays as countermeasures to hinder the transmission of the virus are introduced.” – Mutalik (2017)

“Coronaviruses are a large family of viruses that have been identified since 1965 and so far 7 species of them have been discovered and reported to affect humans. These viruses have three genotypes of alpha, beta and gamma. The natural reservoirs of these diseases are mammals and birds, and therefore are considered as zoonotic diseases. The virus is believed transmitted mostly via contact or droplets. individuals are all generally susceptible to the virus. The mean incubation period was 5.2 days, and the basic reproductive number (R_0) in china was 2.2 at the onset of the epidemic. COVID-19 is an emerging disease, with an incubation period of 1 to 14 (mostly 3 to 5) days. The mortality rate has been reported to be 2-3%.” (source and year)

3. Methodology

The study uses secondary data from worldometer (www.) and 2 types of mathematical models: Logistic model and Modified Exponential growth model to forecast infections, fatalities and recoveries from COVID-19. This data contains the daily infections, fatalities and recoveries from the virus and will be used to predict number of cases.

Recovery rate and fatality rate for COVID-19

The mean time to recovery for this virus is known to be 14 days, hence making the recovery rate $\frac{1}{14} d^{-1}$. Recovery depends on the hospital facilities and the location of hospitalized patient. Pan et.al. (year) have measured this number to be 17 ± 4 , which is consistent with Wu et.al (2020).

A. Logistic growth model

Logistic growth model is used in epidemiology to model and predict the probability of occurrence of diseases. In the advent of the COVID-19, it can be used to predict the number of infections, number of fatalities and number of recoveries. The logistic regression is stated as follows:

$$P(t) = \frac{a}{\{1 + (b * e^{c*t})\}} \dots \dots \dots 1$$

Where P represents the number of individuals in each population, a and b are the model parameters, c is a constant and t represent the number of days. The model assumes that the COVID-19 epidemic trend follows a logistic growth curve.

B. Modified Exponential Model or Curve

The modified exponential model or curve results when a constant is added to the exponential curve equation, used to estimated trend in a nonlinear time series. It can be used to forecast the number of infections, fatalities and recoveries from COVID-19 pandemic. The modified exponential model is stated as follows:

$$P = a + b * e^{c*t} \dots\dots\dots(2)$$

Where *P* represents the number of individuals in each population, a and b are the model parameters, c is a constant and t represent the number of days.

4. Analysis of results

According to the data from worldometers (<https://www.worldometers.info/coronavirus/>), the COVID-19 first appeared in Africa around 15th February, 2020, when it was identify in Egypt, Northern Africa. The results showed the short term forecast for COVID-19 infections, fatalities and recoveries in the Infection hotspots in Africa. The models are compared using coefficient of determination (R-squared) to estimate the best fit model. The higher the R² the better the goodness of fit.

4.1. Descriptive Statistics of COVID-19 hotspots in Sub-Saharan Africa

Table 1 below shows the descriptive statistics of cumulative infections, cumulative fatalities and cumulative recoveries for the 10 counties. The study used 67 days (15 February to 21 April). The number of infections in the selected countries reached 18724 patients; number of deaths reached 989 and number of recovered patients reached 10393.

Table 1: Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
Cumulative infections (all countries)	67	3938.045	5431.329	1	18724
Cumulative fatalities (all countries)	67	203.6866	307.0584	0	989
Cumulative recoveries (all countries)	67	2167.373	2954.756	0	10393

The countries with the highest number of infections or cases of COVID 19 are Egypt followed by South Africa and Tunisia. The tenth highest is Guinea Conakry. Each of the regions happens to have at least a country that is in the hotspot.

As shown in Table 2 below, the country with the highest number of infections of COVID-19 recorded as of 21st April, 2020 is Egypt with 3490 infections and the lowest in the top 10 hotspots is Nigeria with 782 infections. Algeria presented the highest number of fatalities ensuing from the COVID-19. Djibouti had the lowest number of aggregate fatalities as well as the lowest number of recovered cases. South Africa presented the highest number of recovered cases of 3407.

Insert Table 2: Minimum and maximum infections, fatalities and recoveries by country

Cases by country	Min	Max
Cumulative infections	782 Nigeria	3490 Egypt
Cumulative fatalities	2 Djibouti	392 Algeria

Cumulative recoveries	112 Djibouti	3407 South Africa
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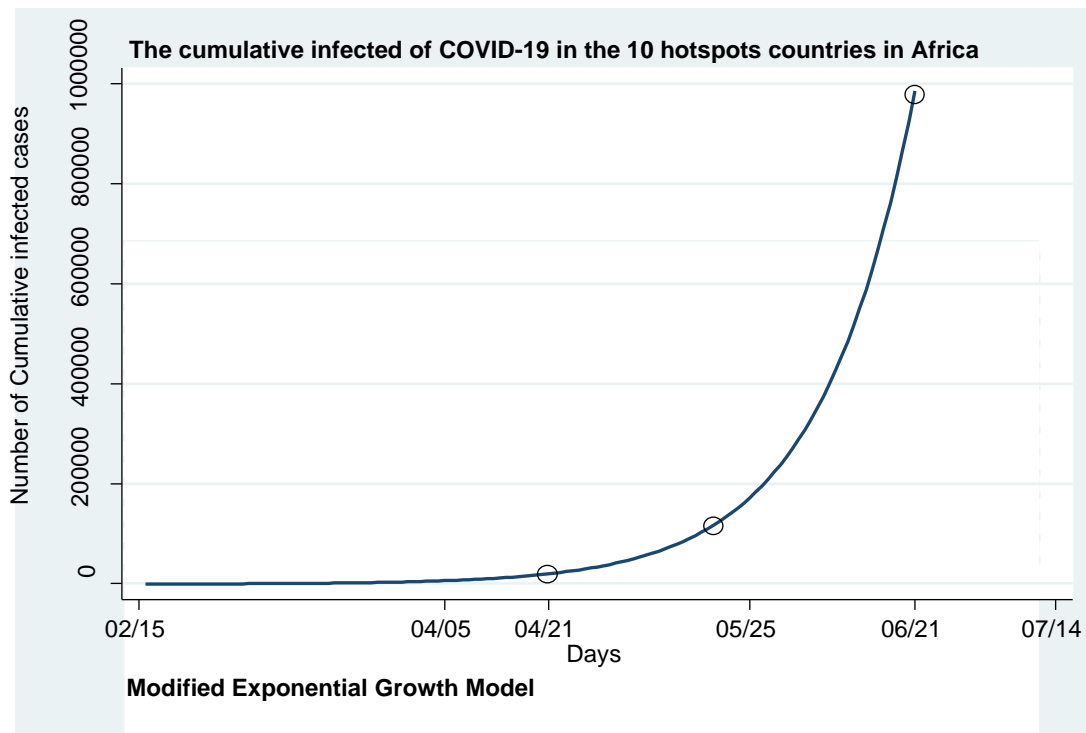
Note: The reference date is from 15 February to 21 April.

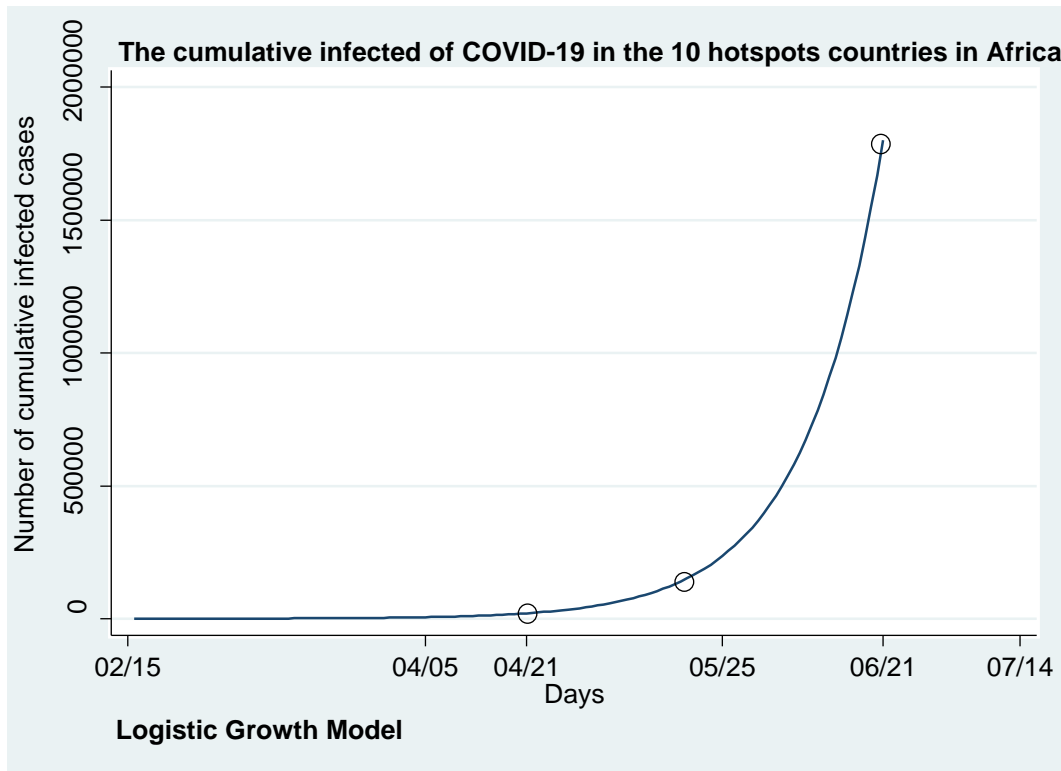
4.2. Logistic Growth Model and Modified Exponential Growth Model

Logistic growth model and modified exponential growth models are used to do a 30-day and a 60-day ahead forecast of infections, fatalities and recoveries in the selected hotspots in Africa. The 10 highest infected countries represent the hotspots.

Infections

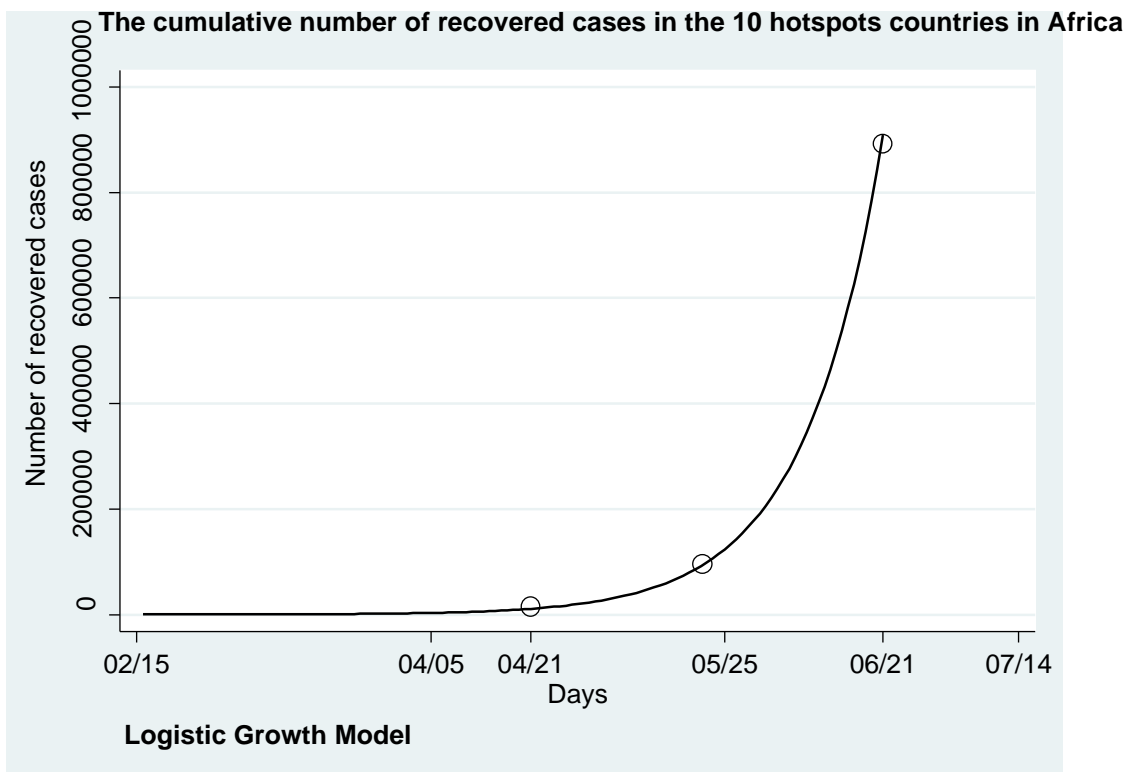
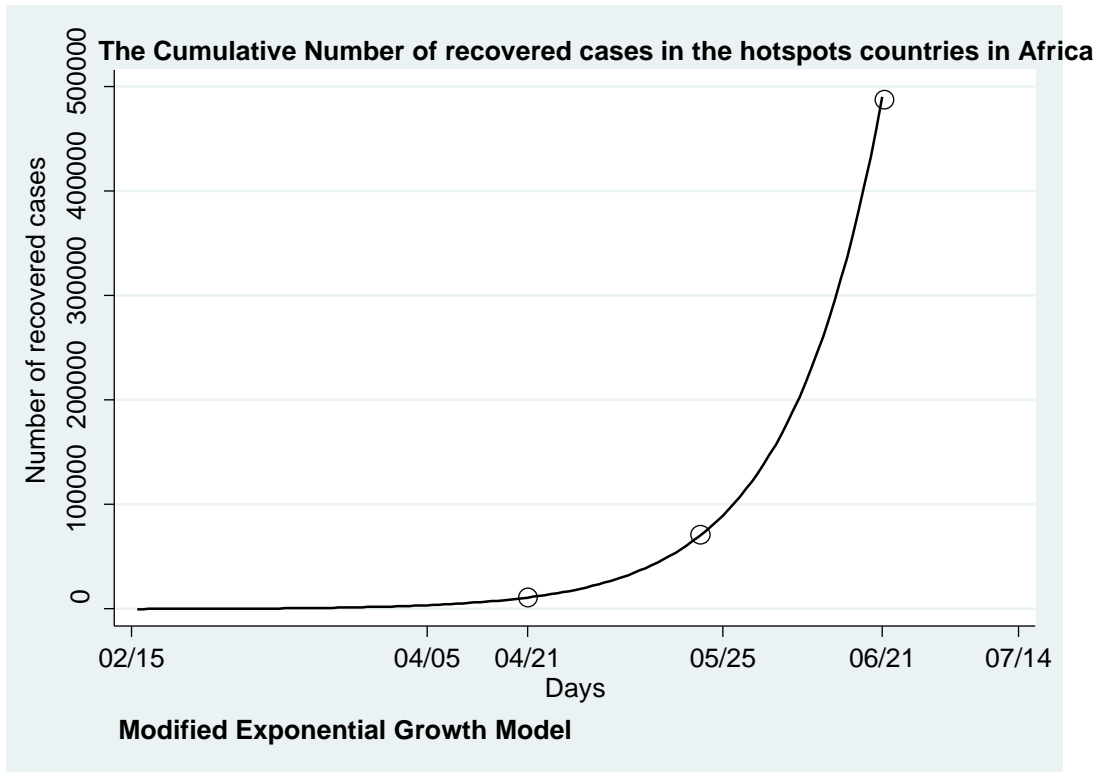
Two models were used, namely, modified exponential model and the logistic model, in order to obtain viable forecasts of infections, recoveries and deaths from the COVID-19 in the 10 most affected countries in Africa. Based on the modified exponential model the number of infected cases in the 10 hotspots country about 21st may, 2020 and 21st June, 2020 is estimated to have been 141,733 patients and 986,059 patients, respectively. The logistic model estimated the infected cases as at stated dates to be 188,824 and 1,801,637, respectively.





Recoveries

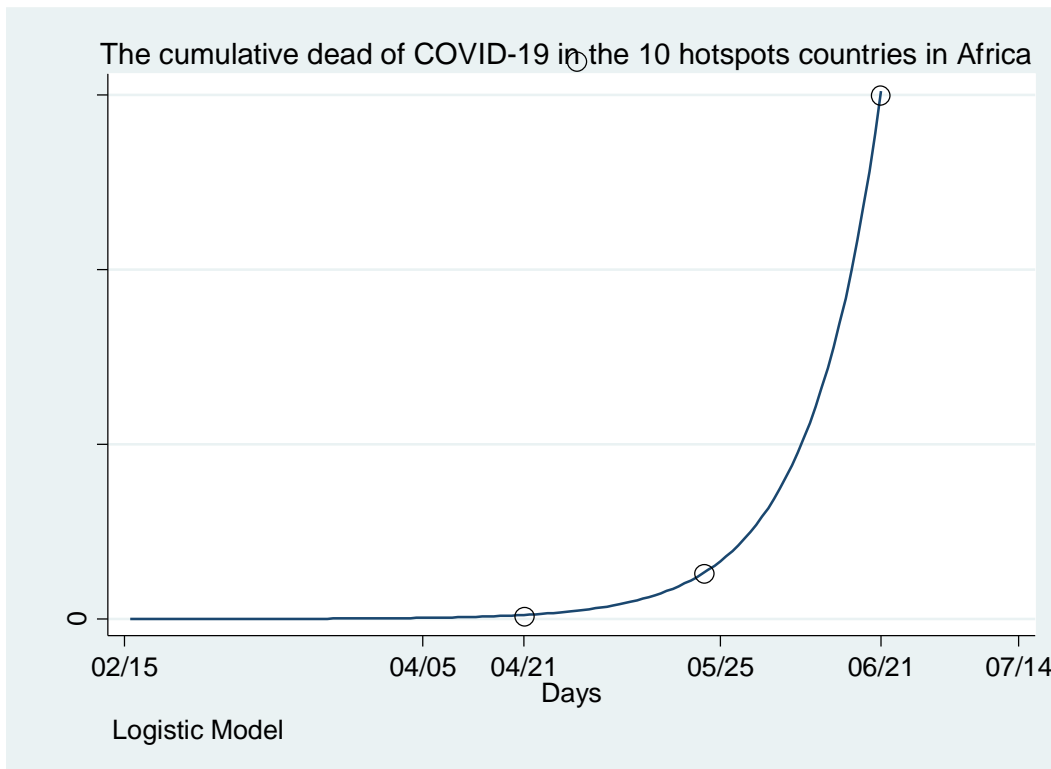
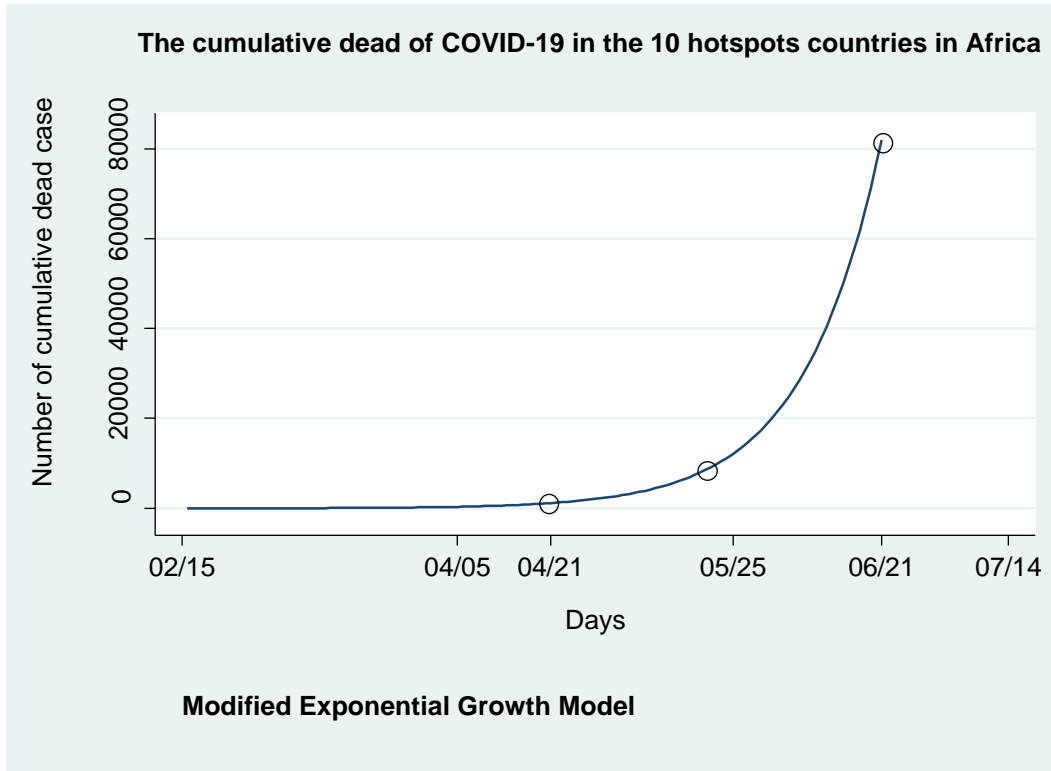
Again, the modified exponential model estimate the recovered patients to be 73,590 and 490,547 as of 21st May and 21st June, 2020, respectively; similarly, the logistic model presented the recovered patients to be 98,853 and 908,810, as of 21st May and 21st June, 2020, respectively.



Fatalities

To forecast the number of COVID-19 deaths in the 10 hotspots countries we also used the same models that is the modified exponential and the logistic. The results of the modified exponential model estimated that the number of deaths on 21st May, and 21st June, 2020 is 9754 and 82,056

individuals, respectively whilst the logistic model predicted the number of deaths as of 21st May and 21st June, 2020 to be 12,972 and 151,190 individuals, respectively.



Moreover, The Adjusted R-Square was used to determine the best model for forecasting. For the infection cases the modified exponential model was the best for estimation since it had higher adjusted R-Square than the logistic model which is 99.06% compare to 98.90% and in the case of recoveries the modified exponential was also the a better fit as it had a slightly higher Adjusted R-Square of 98.94% as compare to 98.82% in the case of logistic growth model. In the case of deaths from the COVID-19, forecasting was far more realistic in the logistic model simply because it had an Adjusted R-Square of 97.74% compare to 97.55% from the modified exponential growth model.

This study is basically monitoring the trend of COVID-19 in the ten (10) most affected countries in Africa. The forecasts may be associated with random errors, because it was made with assumptions about the past trend of COVID-19 epidemic which was used to forecast the future trend of COVID-19 epidemic in the ten (10) most affected countries in Africa. Aside from the random errors in the data two most important factors that may change our estimates is the Public behavior and government intervention in Africa.

5. Conclusion and recommendation

The trend of COVID-19 infections, fatalities and recoveries forecasted using the modified exponential growth model and logistic growth model. The cases of infections and fatalities has been increasing and expected to continue due to public behavior toward Covid-19 such as social distancing, washing hands with soap and using hand sanitizers, lockdown and stay at home measures. Also government measures towards COVID-19 not adhered to.

The modified exponential model showed that the number of infected cases in the 10 hotspots country is expected to increase to 141,733 patients on 21st May, 2020 and to 986,059 patients on 21st June, 2020. It also revealed the recovered patients to increase from 73,590 to 490,547 on 21st May and 21st June, 2020, respectively. The logistic model forecasted that the number of deaths will rise to 12,972 on 21st May 2020 and to 151,190 on 21st June, 2020. Finally, whenever the epidemic is not ended, there is still a possibility of future outbreaks if governments loosen the interventions with people returning back to close social distances. Zhou, Xian, et al. (2020)

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Annex 1: Cumulative infections, fatalities and recoveries

	Growth models	
COVID-19 cases	Modified Exponential Model	Logistic Growth Model
Cumulative Infections	15 th February 2020 = 19694.46	15 th February 2020 = 20212.66
	21 st May 2020 = 141733	21 st May 2020 = 188828.4
	21 st June 2020= 986058.9	21 st June 2020 = 1801637
	Adj R-squared = 0.9906	Adj R-squared= 0.9890
Cumulative Fatalities	15 th February 2020 = 1121.043	15 th February 2020 = 1146
	21 st May 2020 = 9754.198	21 st May 2020 = 12972
	21 st June 2020= 82056.18	21 st June 2020 = 151190
	Adj R-squared = 0.9755	Adj R-squared= 0.9774
Cumulative Recoveries	15 th February 2020 = 10660.43	15 th February 2020 = 10956.63
	21 st May 2020 = 73590.43	21 st May 2020 = 98853.63
	21 st June 2020= 490546.7	21 st June 2020= 908810.1
	Adj R-squared = 0.9894	Adj R-squared= 0.9882