PalArch's Journal of Archaeology of Egypt / Egyptology

# Modeling and data analysis for the Evolution of COVID-19 in Ethiopia

**[1]Wudneh Ketema*, [2]Worku Girma**

[1]Wudneh Ketema*, Debre Berhan University Department of Statistics, Debre Berhan, Ethiopia

[2]Worku Girma, Debre Berhan University Department of Statistics, Debre Berhan, Ethiopia

**Corresponding Author *: [1]Wudneh Ketema**

**[1]Wudneh Ketema*, [2]Worku Girma, Modeling and data analysis for the Evolution of COVID-19 in Ethiopia Palarch's Journal Of Archaeology Of Egypt/Egyptology -ISSN 1567-214x**

**Abstract**

COVID-19 is currently affecting over 215 countries worldwide and poses serious threats to public health not only the health system but also economics, education, transportation, politics. The objective of this paper was to model the evolution COVID-19 data using deterministic and stochastic models and investigates how the model parameters depend on the population sizes in Ethiopia and we extend the deterministic SEIR (Susceptible, Exposed, Infectious, Recovered) model to simulate disease outbreak scenarios and to quantify the potential impact of a host-based early warning capability to mitigate pathogen transmission during an outbreak. Here, we show that real-time predictions of COVID-19 infections are extremely complex to errors in data collection and crucially depend on the last available data. We test these ideas in both using deterministic and stochastic models (susceptible–exposed–infected–recovered) models that are currently used to forecast the evolution of the COVID-19 epidemic. Our goal is to show how uncertainties arising from both poor data quality and inadequate estimations of model parameters (incubation, infection, and recovery rates) promulgate to long-term extrapolations of infection counts.

Finally is to be better understand the evolution of COVID-19 in Ethiopia, we apply a susceptible–exposed–infected–recovered (SEIR) model to the analysis of data from the Ethiopian Department of Health. Based on systematic and numerical results, as well on the data, the basic reproduction number is estimated to $R_0$= 1.12, we have analyzed the SEIR model and concluded with saturated incidence rate and we observed that the reproduction number plays an important role to control the disease, when $R_0 <1$, disease- free equilibrium of the system is locally stable ,and if $R_0 >1$, the endemic equilibrium is locally asymptotically stable , so based on the analysis of the result was indicates the diseases was reached outbreak time, so that the responsible body will create more awareness in the society for the seriousness of the diseases

**Keywords**: SEIR, Covid 19, Compartmental model, Statistical model, Reproduction number

## 1. Introduction

The evolution of epidemics is one of the most dangerous problems for a society. The Humanity faced severe pandemics during its evolution, like the Spanish flu in 1917, the Honk Kong flu (H3N2) of 1968 and the swine flu (H1N1) in 2009.

Several efforts were done since 70's in order to understand the mathematical evolution and spreading of diseases.

Coronavirus disease-19 (COVID-19), caused by a novel coronavirus, has changed the world significantly, not only healthcare system, but also economics, education, transportation, politics, etc. Infected COVID-19 people normally experience respiratory illness and can recover with effective and appropriate treatment methods. What makes COVID-19 much more dangerous and easily spread than other Coronavirus families is that the COVID-19 coronavirus has become highly efficient in human-to-human transmissions. As the writing of this paper, the COVID-19 virus has spread rapidly in 215 countries, causing infected= 17,482,602 people, currently dead =676,835, recovered =10,942,542, currently infected =5,863,225, in mild condition= 5,796,891 and seriously or critical condition =66,334 up to July 30/07/2020.

Recently, in December, 2019, Wuhan city, the capital of Hubei province in China, became the center of an outbreak of pneumonia of unknown cause. By January 7, 2020, Chinese scientists had isolated a novel coronavirus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), from these patients with virus-infected pneumonia [3, 4], which was later designated coronavirus disease 2019 (COVID-19) in February, 2020, by World Health Organization.

The COVID-19 virus has affected socio-economic development and political environments all Over the world. For example, the scheduled Ethiopian National election, in August 2020, is Postponed creating a constitutional and political crisis.

March 13, 2020, The Federal Ministry of Health has confirmed a coronavirus disease (COVID-19) case in Addis Ababa, Ethiopia. The case, which was announced on the 13$^{th}$ of March 2020, is the first one to be reported in Ethiopia since the beginning of the outbreak in China in December 2019. (As of 19 May 2020) 365 people are infected and five have died. (https://www.worldometers.info/coronavirus).

Yet, given the weak institutional capacity, it should be noted that Ethiopia with a total population of 109,224,559, according to the 2018 World Bank estimate has a high vulnerability to the pandemic.

The case is a 48- year old Japanese man reported to have traveled from Japan to Burkina Faso and who then arrived in Ethiopia. He developed symptoms and presented at the health center in Addis Ababa from where the rapid response team (RRT) moved him to the isolation facility in Yeka Kotebe. He is currently clinically stable, with no serious symptoms.

The WHO Country Office Ethiopia (WCO) is following up closely to ensure an outbreak in Ethiopia is quickly controlled and contained. The COVID-19 Emergency Operations Centre housed at Ethiopian Public Health Institute (EPHI) is working closely with the Ministry of Health and the WCO to respond to this case and implement firm control measures.

Dr. Boureima Hama Sambo, the World Health Organization (WHO) country representative “with the detection of this first case, it is of utmost importance for us to identify all the contacts of this case, and immediately test them. Only then can we stop the disease from spreading to the communities he visited”

To focus on containment in the narrowing window of available time, WHO, in collaboration with MOH/EPHI, immediately started working to identify the contacts of the patient, from the time he entered Ethiopia to the time of his diagnosis.

While there is still much to learn about COVID-19, people can take action to prevent the disease through simple, day-to-day measures.

These include the following safety measures:

1. Regularly and thoroughly wash your hands with soap and water and use alcohol-based hand sanitizer.
2. Maintain a physical distance of at least one meter, particularly if a person is coughing.
3. Persons with persistent cough or sneezing should stay home or keep a social distance, and not mix in crowds.
4. Make sure you are coughing into a tissue or a bent elbow, and make sure to safely dispose of the used tissue afterwards.
5. Stay home if you feel unwell with symptoms like fever, cough and difficulty in breathing. Please immediately call for medical help using the EPHI toll free number-8335- which is available day and night.
6. Stay informed on the latest developments about COVID-19 through official channels.

To prevent the spread of the pandemic, the country established a National Ministerial Committee on 16 March 2020. As the concern are mounting, the government and the parliament declared a state of emergency respectively on April 8-10 2020, and the council of minister issued regulation 11 April 2020. Furthermore, to increase the national public health preparedness and coordination capacity, the World Bank allocated an amount of $82.6 million.

A 50% loan and a 50% grant (http://www.mofed.gov.et). Recently, in December, 2019, Wuhan city, the capital of Hubei province in China, became the center of an outbreak of pneumonia of unknown cause. By January 7, 2020, Chinese scientists had isolated a novel coronavirus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), from these patients with virus-infected pneumonia [9, 10], which was later designated coronavirus disease 2019 (COVID-19) in February, 2020, by World Health Organization.

**Impacts of Covid-19 for Different Aspects**

**Economic**

The United Nations Economic Commission for Africa estimated that COVID-19 will shave 2.9 percentage points off of Ethiopia's economic growth for fiscal year 2020.

The pandemic has affected Ethiopia's flower export industry significantly. After Europe was hit with the coronavirus, the demand for flowers has plummeted and the price dropped by more than 80%. A total of 150,000 employees in this industry are also at the risk of losing their jobs.

Ethiopian Airlines, the country's flag carrier, reported that it is working at only 10% of its capacity because of the coronavirus pandemic. The CEO, Tewolde Gebremariam, reported a loss of $550 million in the months of January to April 2020.

**Educational**

More than 26 million students are affected by school closures due to the coronavirus. Consequently, school feeding programs for around 1 million children across multiple regions of the country have stopped.

**Political**

The general elections which were set to be held on 29 August 2020 won't be held on the scheduled date, according to a statement by the National Electoral Board of Ethiopia released on 31 March. The board also stated that it has temporarily ceased all activities related to the election. Some people have been arrested for allegedly spreading false information about the COVID-19 pandemic

**Psychological**

Psychological distress is one of the major public health problems that may occur as a result of work environment [1] and different local and global incidents, like the COVID-19 pandemic. COVID-19 became a major concern for global health [2]. The disease is registered as the largest outbreak of atypical pneumonia since the severe acute respiratory syndrome (SARS) outbreak in 2003[3]. On Jan 30, 2020, WHO declared the current novel COVID-19 as pandemic disease and a Public Health Emergency of International Concern posing a high risk to countries with vulnerable health systems [4].

2.1 **Objective**

The objective of this research was to model the evolution COVID-19 data using deterministic and stochastic models and investigates how the model parameters depend on the population sizes in Ethiopia.

## 2. Data and Data Description.

The data for this analysis was obtained from the publicly available database and websites; mainly those of the Ministry of Health Ethiopia and the Department of Statistics. The data sets reporting COVID-19 among the Ethiopian population are considered the total population of N = 1 individuals on March 13, 2020, The Federal Ministry of Health has confirmed a coronavirus disease (COVID-19) case in Addis Ababa, Ethiopia. The case, which was announced on the 13th of March 2020, is the first one to be reported in Ethiopia since the beginning of the outbreak in China in December 2019.

The daily prevalence data of COVID-2019 from March 10, 2020, to July 31 last 2020 was collected from the official website of COVID-19 Health Advisory Platform by the Ministry of National Health Services Regulations and Coordination, Ethiopia. At this time coronavirus cases was= 16,615, Active cases =9,589, Serious or critical cases =134, Recovered =6,763, total test =413,397 and total number of population (N) =114,895,969.

The R-Studio software was used to build associated packages and data was analyzed by the time to predict the future state of the confirmed cases of COVID19 scenarios in Ethiopia until March 13, 2020. Countries with lower health services and facilities like Ethiopia are at great risk. Ethiopia has 10 regions and the distribution of COVID-19 for those regions shown in Table1 below, from the beginning to the end of the study period.

**Table 1: Distribution of Covid-19 in Ethiopian region**

| **Regions** | **Number of Cases** | **Number of Death** |
|---|---|---|
| Addis Ababa | 10,667 | 122 |
| Somali | 670 | 4 |
| Oromia | 960 | 6 |
| Amhara | 493 | 3 |
| Tigray | 711 | 2 |
| Afar | 257 | 1 |
| SNNPR | 177 | 0 |
| Dire dawa | 472 | 6 |
| Harari | 86 | 1 |
| Gambela | 484 | 0 |
| Benshangul Gumuz | 141 | 0 |
| Sidama | 82 | 0 |

## 3. Methodology

In this section, we discussed to better understand such a new disease, a lot of papers and preprints were published in different journals analyzing for various properties of the COVID-19, as well as modeling its evolution in many countries. Our target in this work is to perform a data analysis of the evolution of COVID-19 in Ethiopia. We collected data from the Ethiopian Department of Health institution and apply a Susceptible-Exposed-Infectious -Recovered (SEIR) model to analyze the COVID-19 dynamics.

About two types of models were used for the study of infectious diseases at the population scale. The descriptions of deterministic models and to some extent about stochastic models were discussed below. In both model families, the basic SEIR model was considered, with the assumption that the total size of the population **N** is constant and the population is open. Models are simplified representations of reality and are used in many areas of science, finance, and industry. When a model includes a probabilistic component is called a stochastic model (Lindsey; 2007). Stochastic modeling has been a very active area of research, taking into account the nature of the outcome variable and explanatory variables.

**3.1. The SEIR mathematical model.** To model the progress of infectious diseases in a certain population SEIR models place the individuals into four different compartments relevant to the epidemic. Those are:

- Susceptible (S),
    - Exposed (E),
    - Infectious (I),
    - Recovered (immune by vaccination) (R).

An individual is in the S compartment if he/she is vulnerable (or susceptible) to catching the disease. Those already infected with the disease but not able to transmit it is called exposed. Infected individuals capable of spreading the disease are infectious and so are in the I compartment and those who are immune are in the R compartment.

Since immunity is not hereditary SEIR models assume that everyone is susceptible to the disease by birth. The disease is also assumed to be transmitted to the individual by horizontal incidence, i.e., a susceptible individual becomes infected when in contact with infectious individuals. This contact may be direct (touching or biting) or indirect (air cough or sneeze). The infectious population cans either die or recover completely and all those recovered (vaccinated or recovered from infection) are considered immune.

In this paper from different compartment model we only used **SEIR** compartmental model a model in which they considered an open population with only four compartments. These are **Susceptible, Exposed, Infection** and **Recovered.**

**N (t) =S (t) +E (t) +I (t) +Q (t) +R (t)+D(t)…………………………………………Eq₁**

- **S (t) =**the number of **s**usceptible individuals. When a susceptible and an infectious individual come into "infectious contact", the susceptible individual contracts the disease and transitions to the infectious compartment.
- **E (t) =** individuals who are in the incubation phase, they have been exposed to the pathogen, but are not yet showing symptoms and are not infectious.
- **Q (t) =**Restricting the movement of, or isolating, people who might have been exposed to an infection but who aren’t yet sick. Usually, quarantine restricts a person’s movement to their home.
- **I (t) =**the number of **i**nfectious individuals. These are individuals who have been infected and are capable of infecting susceptible individuals or the number of individuals who are infectious but not quarantined.
- **R (t) =R** for the number of **r**emoved (and immune) or deceased individuals. These are individuals who have been infected and have either recovered from the disease and entered the removed compartment, or died. It is assumed that the number of deaths is negligible with respect to the total population. This compartment may also be called "**r**ecovered" or "**r**esistant".

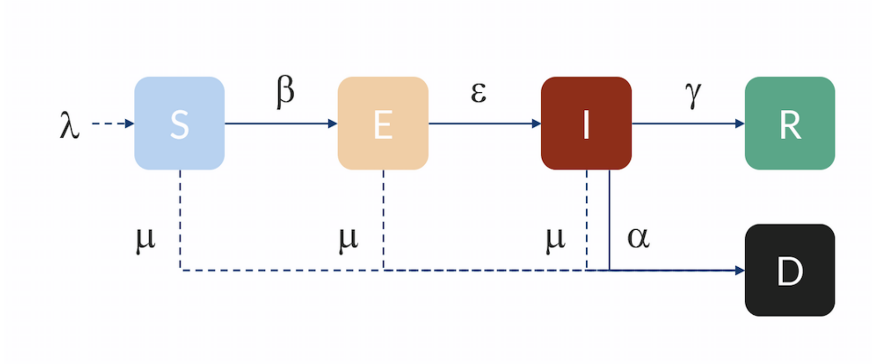


*Figure 1. Diagram of the model adopted in the study for simulating the novel coronavirus (2019-nCoV) infection. Interventions including intensive contact tracing followed by quarantine and isolation are indicated.*

*Compartmental model: Individuals flow from the S to the E compartment with a rate β, from E to I with a rate ε, and from I to R with a rate γ. Individuals can also flow from I to D (dead) with a rate α. Individuals in R are here assumed to be immune and do not return to S for the duration of the model.*

Based on the compartmental structure of the SEIR model may be described by the following ODE equations:

$$\frac{dS}{dt} = -\beta IS$$
$$\frac{dE}{dt} = \beta IS - \varepsilon E$$
$$\frac{dI}{dt} = \varepsilon E - \gamma I - dI - qI$$
$$\frac{dQ}{dt} = qI - qtQ - dQ$$
$$\frac{dR}{dt} = \gamma I + qtQ$$
$$\frac{dD}{dt} = dI + dQ$$

With the initial condition S(0)≥0,E(0)≥ 0,I(0)≥ 0, $Q(0) \geq 0$ *and* $R(0) \geq 0$, *where N is the total population of the region.*

From the Figure 1 compartmental graph, the Parameters are as:

- N=Population
- $\beta = R_{0\,\gamma}$
- $R_{0=Basic\ reproductive\ number}$
- $\varepsilon = \frac{1}{incubation} period$
- $\gamma = \frac{1}{infectious} period$
- *d=death*
- *q=fraction of active cases quarantined*
- *qt=time period of quarantine*

**Stability and Numerical Analysis**

Disease Free Equilibrium (DFE)

The disease free equilibrium of equation 1 can be obtained easily by setting S=E=I=R=0

So, from equation1, we get $\frac{dS}{dt}$=0 which gives us that S=$\frac{\pi}{\delta 1}$

Therefore the DEF of eq1 is $E_0$=($\frac{\pi}{\delta 1}$, 0,0,0)

Endemic Equilibrium Point (EEP)

To derive the endemic equilibrium points of eq1 we get

$$\frac{dS}{dt} = \frac{dE}{dt} = \frac{dI}{dt} = \frac{dR}{dt} = 0$$

**3.2. The Reproductive number ($R_0$)**

Comparing with the basic reproductive number, the effective reproductive number can be used to measure the number of secondary cases generated by one primary case in a population in which there is partial immunity or some intervention measures have been implemented .It changes during the progress of the disease outbreak. As the population size is much larger than the resulting size of the outbreak, i.e. $S(t)/_N$, the effective or control reproductive number of our model is given by the following formula.

$R_0$ is also the number of secondary cases which one case would produce in a population which is completely susceptible. It depends contact rate(c), rate of transmission ($\beta$) and duration of infectiousness.

Table 2: Table of Assumption about the parameter

| **Parameter** | **Value** |
|---|---|
| Incubation period | Mean=5.1 days |
| Infectious period($\gamma$) | Mean =7 days |
| Basic reproductive number | 1.1208 |
| Mean death rate | 0.8% |
| Period of quarantined | 14 days |
| Number of cases in quarantined | 9,589 |
| Number of Recovered | 6,763 |
| Number of death | 263 |
| Number of critical cases | 134 |
| Population of Ethiopia(N) | 114,895,969 |
| Exposed population | 413,397 |
| Probability of transmission($\beta$) | 0.75 |

4. **Result and Discussion**

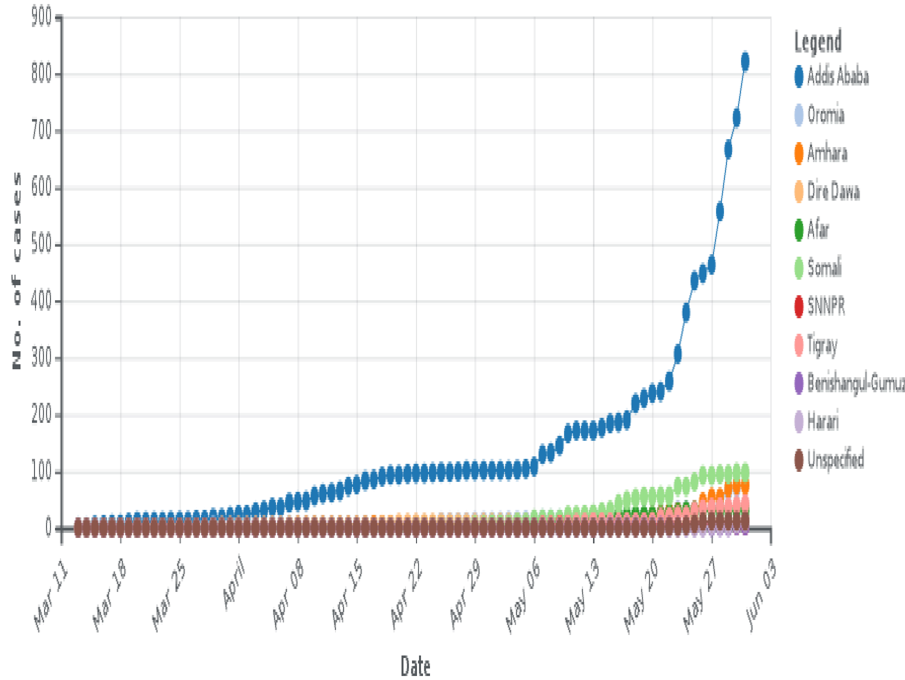


**Figure 1: Total confirmed cases Covid-19 in Ethiopia by Region**

From the above Figure 1, we observed that the number of Covid -19 cases increased from time to time and when the diseases have happened in Ethiopia to a certain duration of time the number of cases was small, progressively nowadays the number of cases were increased by regions.

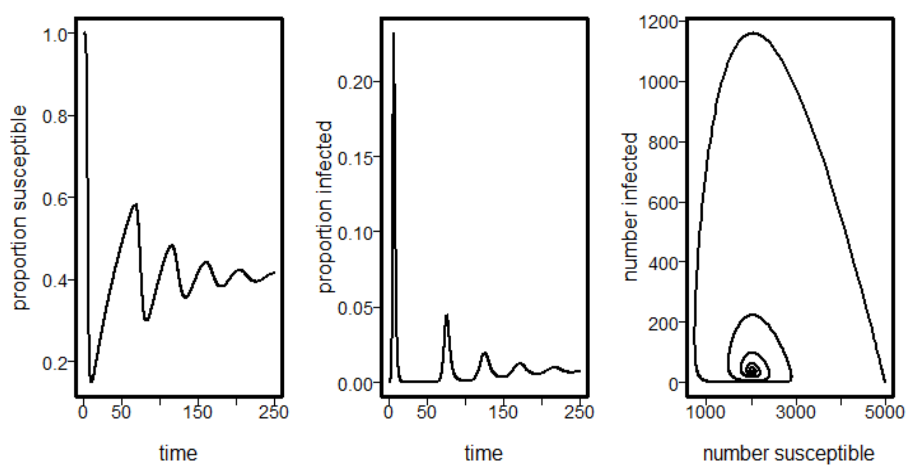


**Figure 2: Susceptible and Infected**

From the above Figure 2, we examined (observed) that the susceptibility is not constant increased or decreased due to open population that means there are natural death and natural birth, and also when the value of beta has increased the susceptibility of the Outbreak point value and the infected proportion value is increased, while the transmission rate beta is decreased susceptible of the Outbreak point value and the infected proportion value is decreased. This implies that the transmission rate of beta, susceptible and infected is directly proportional.

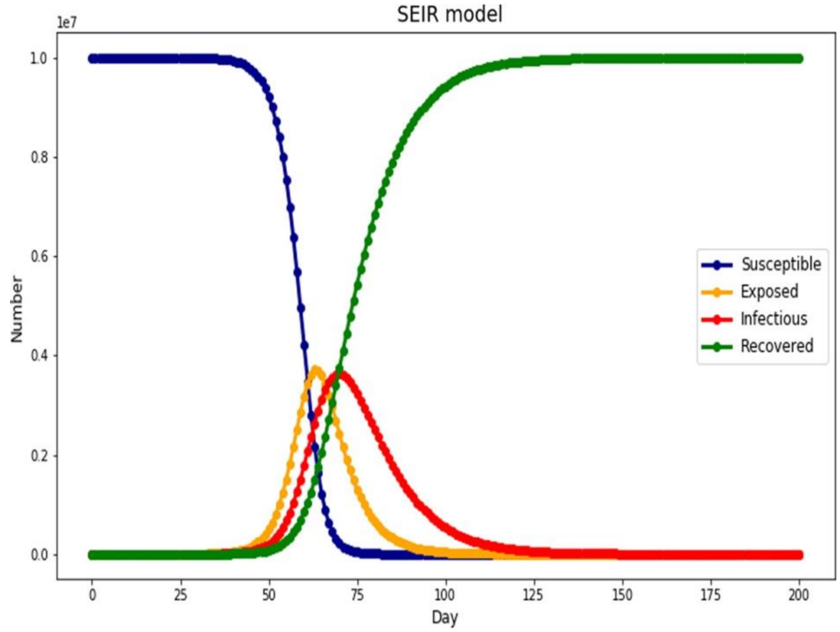


**Figure 3: SEIR model prediction of NOVEL Corona virus outbreak in Ethiopia**

From the Figure 3, we observed that an example output of the full SEIR model. Here, we begin with a population of N = 114,895,969 people and consider a scenario where 413, 397 individuals are exposed from the beginning the incidence of the diseases up the end of my study then, some pathogen at time, $t$ = 0 ($S_{t=0}$ =114,482,572, $E_{t=0}$ =413,397,$I_{t=0}$ =9589,$R_{t=0}$ =6,763) If we assume a particular infectious pathogen has a contact rate, $\beta = 0.75$, with an incubation period of two days, $\delta$= 0.5, and an infectious period of five days, $\gamma$=7 days (similar properties to a highly contagious flu virus), the solution to the SEIR model shows that nearly the entire population will contract the disease over a month and also we considered the standard SEIR model, which describes disease spread without any public health interventions. To quantitatively evaluate an outbreak scenario with additional measures, the parameters and compartments of the SEIR model can be modified to reflect policy choices or new early warning technologies.

**Basic reproduction number DFE and EEP**

The average number of people that each person infects is called the basic reproductive number. Assuming that the basic reproductive is 1.1208 so this indicates that the basic reproduction number $R_0$is an indicator of the occurrence of an outbreak of Covid 19 in Ethiopia.

It is defined to be the number of secondary infections produced by one primary infection in a population where everyone is susceptible and is denoted by$R_0$. If $R_0$ >1, one primary infection can produce more than one secondary infection. This implies that the disease-free equilibrium (DFE) is unstable. As a result, an epidemic breaks out. If $R_0$ <1 the situation is thought to be under control. In this case, the disease-free equilibrium (DFE) will be locally asymptotically stable and the disease cannot persist in the population. So, when a pandemic breaks out, an effective strategy should be developed so that the reproduction number reduces to less than 1 as soon as possible [8].

**The stochastic SEIR model**

When insight is limited and compartmental models are not well-matched, phenomenological statistical models provide a starting point for estimation of key transmission parameters, such as the reproduction number, and forecasts of epidemic impact. One of the simplest ways to model the epidemics is to observe that the function C(t) is a sigmoid function and perform a statistical fit of the data to extrapolate the long-term behavior of the epidemics. Among all the possible sigmoid functions, two have recognized useful in fitting epidemic growth: the generalized logistic distribution and the generalized Gompertz distribution, since our considerations are independent of the sigmoid function used, we will present results for the generalized logistic model only. The model reads

$$C(t) = {}^{a}\!/_{(1 + b.\exp(-C.t))}$$

Where *a*, *b*, and *c* are parameters of the model. They are linked in a non-explicit way to the solution of the SEIR model. Logistic fits are performed with the R-studio nonlinear least-squares solver constraining objective function with incline. At first sight, one can be tempted to use $R^2$ is approximately 0.89 as a quality indicator of the fit. However, we stress that $R^2$ is not an appropriate measure for nonlinear regression models.

**5. Discussion**

In this work, we have discussed the compartmental and statistical asymptotic estimates of the COVID-19 pandemic in Ethiopia. The number of confirmed cases of COVID-19 in Ethiopia is growing exponentially fast. Based on the data, we considered a Susceptible- Exposed -Infectious -Recovered (SEIR) on a fully-connected population. Despite the simplicity of the model, we can make estimates of the infection rate, the rate at which individuals are isolated from the population and some others, as well as the basic reproduction number and the doubling time of the epidemics, based on fitting data available at the site of the Ethiopian Minister of Health.

In this study, we conducted statistical modeling analyses on widely available data to explain the asymptomatic proportion, along with the time of infection among the COVID-19 cases. This estimate should be taken as a first caution in fitting an SEIR model to infer COVID-19 epidemics evolution in other countries as results may be largely under/overestimated. Then, we have shown that statistical fits often used to generalize the long-term behavior of the epidemics are greatly affected by the magnitude of the last data point, despite values of close to one, leading to unrealistic or overconfident estimates of confidence intervals on the forecast of the total number of infections. Finally, we have investigated whether this compartmental and statistical asymptotic reproduced with an SEIR model, where parameters are considered stochastic processes. Standard epidemic SEIR-type models implement a compartmental description under the assumption of homogeneous mixing of individuals [7]. More realistic modeling approaches require spatial heterogeneity due to time-varying disease onset times, regionally different contact rates, and the time-dependence of the contact rates due to the implementation of containment strategies.

**6. Conclusion**

In this paper, the Compartment models are useful to describe the individual movements in a system especially for the disease transmission dynamics in an epidemic, so we have analyzed the SEIR model with saturated incidence rate and we observed that the reproduction number plays an important role to control the disease, when $R_0$ <1, disease free equilibrium of the system is locally stable and if $R_0$ >1, the endemic equilibrium is locally asymptotically stable, so based on the analysis of the result was indicates the diseases was reached outbreak time so that the responsible body will create more awareness in the society for the seriousness of the diseases.

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