International Journal of Current Research and Modern Education (IJCRME)
Impact Factor: 6.925, ISSN (Online): 2455 - 5428
(www.rdmodernresearch.com) Volume 5, Issue 1, 2020

SIR MODEL BASED ANALYSIS ON COVID-19 DYNAMICS IN ETHIOPIA

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Cite This Article: Abere Wondimu Kassie & Assefa Legesse Sisay, "SIR Model Based Analysis on Covid-19 Dynamics in Ethiopia", International Journal of Current Research and Modern Education, Volume 5, Issue 1, Page Number 21-26, 2020.

Abstract:

The COVID-19 pandemic rapidly spread out worldwide and has caused a serious crisis affecting the public health systems, with many negative effects on the countries' social, economic and cultural aspects in the world. Thus the main focus of the study is to assess the distributing pattern of COVID-19 pandemic by estimating the transmission rate of disease and to predict the future spread of disease in Ethiopia. The data on COVID-19 daily confirmed cases report is taken from Mistry of health, Ethiopia, since the outbreak started on March, 13 2020 to May 27, 2020. The SIR model has used to analyze the dynamics of COVID-19 pandemic. The optimized SIR model parameters are estimated and the contact rate, $\beta = 0.53$and recovery delay, $\gamma = 0.47$ from the daily confirmed cases. The basic reproductive number, R_0 could also be estimated as 1.2. While, the predicted SIR model parameters were considerably taken as $\beta = 0.35, \gamma = 0.14$ and , $R_0 = 2.5$ with other previous studies. The result of the study revealed that the spread of COVID-19 pandemic in Ethiopia indicated that the number of infection will peak on July08, 2020, where 23.4 per cent of the total population could be potentially infected. Hopefully, the actual number will be lower than predicted number of infections.As our predicted SIR model is based on the epidemic progression as it currently has beenthat it doesn't account additional measures put in place to curb the spread of the virus like social distancing, school closure, lockdown etc. As a conclusion from this study, the SIR model on COVID-19 pandemic in Ethiopia shows that the infection could spread at an exponential rate unless proper and effective measures will be taken to reduce its transmission due safety practice such as social distancing, lockdown and large scale testing of suspected cases in all part of the country.

Key Words: Basic Reproduction Number, COVID-19, Pandemic, SIR Model & Transmission Rate

1. Introduction:

The pandemic of coronavirus disease (COVID-19) occurred in lastDecember,2019 in Wuhan, province of Hubei, People's Republic of China (Fauci, Lane et al. 2020). The infectious agent was identified and termed as severe acute respiratory coronavirus 2 (SARS-CoV-2), responsible of the "coronavirus disease 19" (COVID-19). Its typical clinical symptoms include fever, dry cough, myalgia, pneumonia, and may cause progressive respiratory failure due to alveolar damage and death (Huang, Wang et al. 2020). As of May 27th 2020, the virus has infected more than5 million people and killed about 351,667 people (https://www.coronatracker. com/analytics). The World HealthOrganization (WHO) has declared COVID-19 a pandemic and the health systems of all countries are making their best efforts to prevent the spread of COVID-19, to control and counteract its burden and effectively treat patients.

The COVID-19 pandemic has caused a serious crisis affecting the public health systems, with many negative effects on the countries' social, economic and cultural aspects. Due to the lack of effective vaccines or drugs that can be used to prevent and treat COVID-19, respectively, public health policy and decision-makers in many countries have implemented various policies some of which totally unprecedented to reduce the effects of the disease, such as quarantine, self-restriction, social distancing, use of face masks, school and university closures, and travel restrictions(Prem, Liu et al. 2020), (Raoofi, Takian et al. 2020).

In Ethiopia, the first case of coronavirus infection was reported on March 13, 2020 in Addis Ababa, which was animported case from Wuhan city of China. Initially, the spread of the virus was relatively slow as compared to now a time in Ethiopia and other countries in Africa. However, the spread is highly increasing after April up to the study conducted. Currently, the confirmed COVID-19 infected cases in Ethiopia have reached 731with 6 deaths and 187recoveries as reported onMay 27, 2020. At present, there is neither a treatment nor a vaccination for the COVID-19 infection. Currently, it is a major health crisis around the world. Since Ethiopia has been implementing its public health policies and those declared by World Health Organization. In this situation, the only option is to prevent the occurrence of infection and improving our healthcare system for the probable up-comings.

Modeling of infectious diseases like COVID-19 pandemic is a tool that has been used to study the mechanisms by which measure the diseases of spread, to predict the future cause of an outbreak and to evaluate strategies to control an epidemic(Shanmugam 2005).A predominant method of modeling the spread of infectious disease is to categorize individuals in thepopulation as belonging to one of several distinct compartments, which represent their health status withrespect to the infection. The dynamics of an epidemic can then be analyzed as the rates of transfer between these compartments. One of the most fundamental compartmental models is the Susceptible Infection and Removed (SIR) model, which forms the basis of much of infectious disease modeling(Duggan 2016).In the SIR model the population is divided into three compartments, S(susceptible), I(infected), and R(removed). Individuals in the population may exist in any one of these three compartments at a given time.The main objective of this study was to assess the pattern of COVID-19 pandemic by estimating the transmission rate and to predict the future spread of disease in Ethiopia.

2. Materials and Methods:

Data:

The study data is collected from daily reports on official website of Ministry of health, Ethiopia from March 13, 2020 to May 27, 2020 in (http://www.moh.gov.et/ejcc/).Since March 13th, 2020 has been chosen as the starting date for this early evolution study because it is the first COVID-19 case was identified in Ethiopiaand up to 27 May, 2020 the total confirmed COVID-19 cases, recoveries and deaths are 731, 181, and 6respectively. The total population of Ethiopia since the outbreak of Covid-19 in Ethiopia started on March, 13, 2020 was 114, 102,082.

The independent variable is time t, measured in days. We consider two related sets of dependent variables. The first set of dependent variables counts people in each of the groups, each as a function of time. The second set of dependent variables represents the fraction of the total population in each of the three categories.

The SIR Model:

There are many epidemiological modelsfor infectious diseases modeling; this study used one of the most common models, which are SIRmodel. The *SIR* model can be complexities to incorporate more specificities of the virus outbreak like COVID-19 pandemic. The model is composed with three compartments that represent different categories of individuals within a population; the susceptible (S), infected (I), and removed (R).Here susceptible is meant by people exposed to this COVID-19, infected comes after COVID-19 is confirmed in a person and removed means that either the person is recovered or death due to COVID-19 pandemic.The scheme of SIR model with the transmission of infection through the contact of susceptible individuals with an infected host is shown in Figure 1.

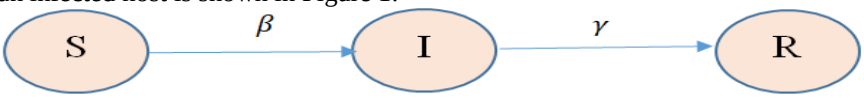

Figure 1: SIR Model Compartment

The model is very basic and has important assumptions. The first being the population is closed and fixed, in other words, no one it added into the susceptible group (no births), all individuals who transition from being infected to recovered are permanently resistant to infection and there are no deaths. Second, the population is homogenous (all individuals are the same) and only differ by their disease state. Third, infection and that individual's "infectiveness" or ability to infect susceptible individuals, occurs simultaneously.

Based on these assumptions, the SIR model can be written as the following ordinary differential equation (ODE):

$$\frac{dS}{dt} = -\frac{\beta SI}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\frac{dI}{dt} = \frac{\beta SI}{N} - \gamma I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\frac{dR}{dt} = \gamma I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where, β is transmission rate (effective contact rate), $\gamma$is the recovery rate (removal rate) andN=S+I+R is the total population.In modelling infectious disease like coronavirus, one of the important parameters is basic reproductive number (R_0), it tells us whether the susceptible population is at risk and it affected by the infection and recovery rate(Hackborn 2008). It can be obtained as:

$$R_0 = \frac{\beta}{\gamma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where, $R_0 > 1$ the occurrence of the disease will increase known as pandemic and $R_0 < 1$, disease will decrease is known as endemic, whereas $R_0 = 1$ the spread of disease become constant. Based onsome reviewedliteratures, it was observed that the values of basic reproductive number for the prediction process. Some of the studies conducted on COVID-19 cases,in these studies the average estimated basic reproductive number $R_0$was found to be between 1.4 and 2.65with the average recovery rate of 0.14 (Liu, Gayle et al. 2020, Syed and Sibgatullah 2020). For simple models, the proportion of the population that needs to be effectively immunized to prevent sustained spread of the disease, known as the "herd immunity threshold", has to be larger

than$1-1/R_0$ (Fine, Eames et al. 2011).The daily COVID-19 cases data was registered using Excel sheet and exported into R version 4.0.0 software for analysis.

3. Results:

Initially, the daily reported confirmed cases and the cumulative cases were plotted against time (in day) to observe the trajectory on the number of cases for a period of 77 days which is obtained from Ethiopian Ministry of Health reports. Since, the data on the number of daily COVID-19 cases is highly increasing after 50 days when the first case started on March 13, 2020as Figure 2 reflects. From Figure 3, it reveals that the cumulative cases suggests that an exponential increment in the number of infected cases overtime.

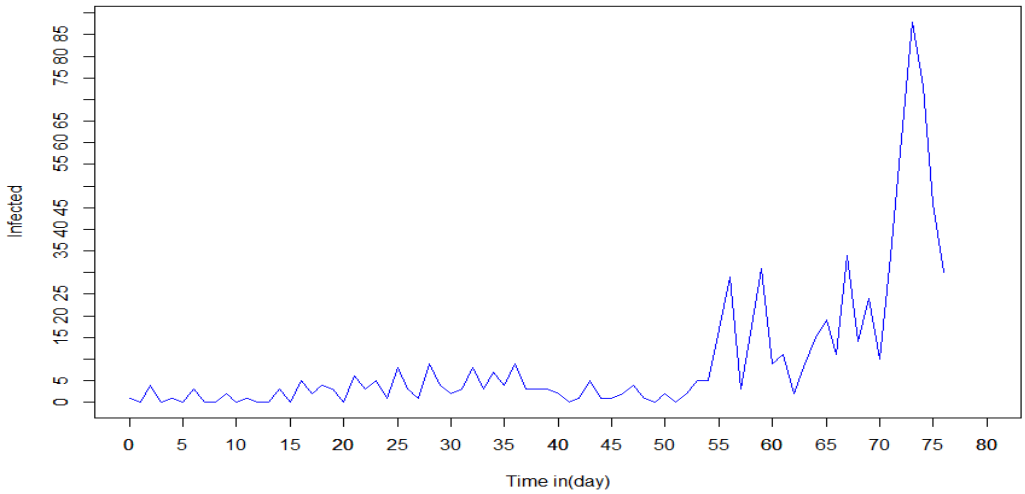

Figure 2: Daily confirmed COVID-19 Cases in Ethiopia since outbreak began on March, 13, 2020

Figure 2, shows the number of COVID-19 pandemic confirmed cases highly increased after about fifty days for the 77-days data extracted from the Ministry of Health, Ethiopia daily case reports. On first day of the epidemic the numbers of cases was only one person and then after 88 infected people were reported on May 24, 2020.But the rate of increment rapidly decline for next days that about 73, 46, 30 cases reported on May 25, 26 and 27, 2020 respectively.The x-axis corresponds to the days which number of cases recorded, whereas the y-axis corresponds to the number of cases.

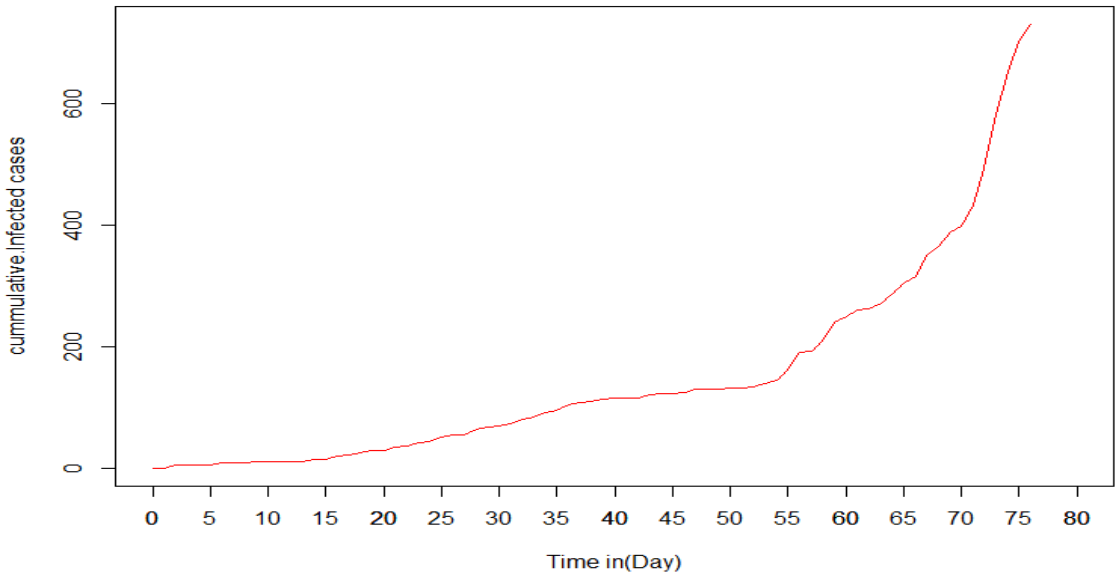

Figure 3: The Cumulative COVID-19 Cases in Ethiopia since outbreak began on March, 13, 2020

Figure 3, depicts an exponential growth pattern for the 77-days data extracted from the Ministry of Health Ethiopia case daily reports. After outbreak started, the firstcase was only 1 individual and on Day 77 of the epidemic, the numbers of cases were recorded 731 people. The x-axis corresponds to the days which number of cases recorded, whereas the y-axis corresponds to the number of cases.

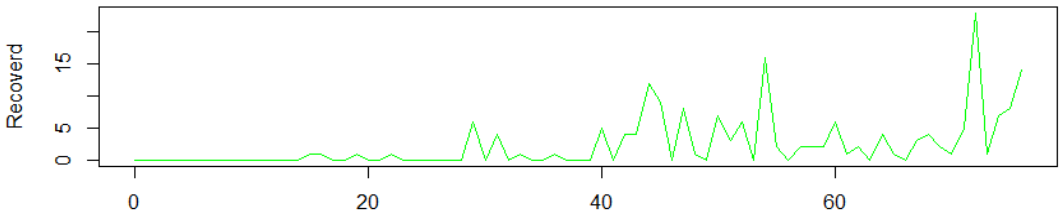

Figure 4a: Recovered individuals from COVID-19

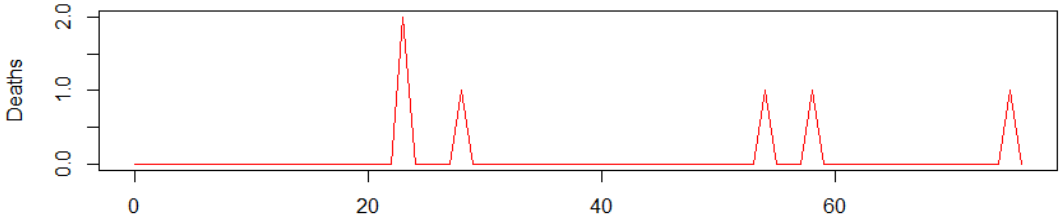

Figure 4b: Number of deaths from COVID-19

Figure 4: The removed COVID-19 cases per day

Figure 4a shows that the number of recovered individuals becomes slowly increasing and Figure 4b shows that the two deaths due to the virus after 22 days of the outbreak on April 5, 2020 in Ethiopia were recordedand the other four persons were also died in different time up to this study completed.

In the SIR model, the expected amount of people that an infected person infects per day i.e. estimated transmission rate (β) and recovery rate (γ) was found to be 0.53, 0.47 respectively from the daily recorded data on COVID-19 cases in Ethiopia. Then, the basic reproductive number (R_0) found to be 1.2 using equation (4).

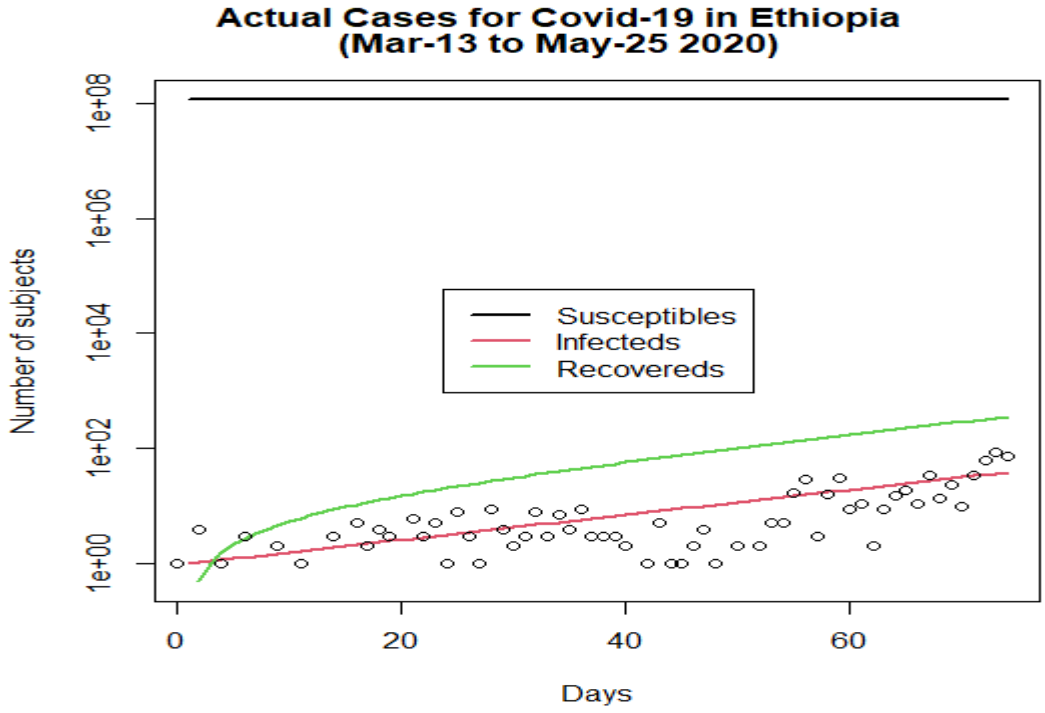

Figure 5: SIR model plot for actual COVID-19 cases in Ethiopia

In Figure 5, the susceptible population didn't become decreasing and seemed to be constant over time. But this doesn't mean that the COVID-19 pandemic is not serious problem in Ethiopia rather the infected population currently smaller as compared to total population. Again from Figure 5, it also observed that the

infected cases increase across time. Similarly, the number of recoveries improved over time up to date May 27, 2020 that the study end (green line).

While in the predicted SIR model (Figure 6), the spread of COVID-19 in Ethiopia indicates that the number of infection will peak on 90th Day, where 26,666,170 individuals could be potentially infected. And then the number of infections will rapidly decrease on the 138th day (July, 26, 2020), the number of infected cases will stand at 514,935.7, whereas, 101,146,795 cases will be recovered which isapproximately 88.65 per cent of the Ethiopia population.

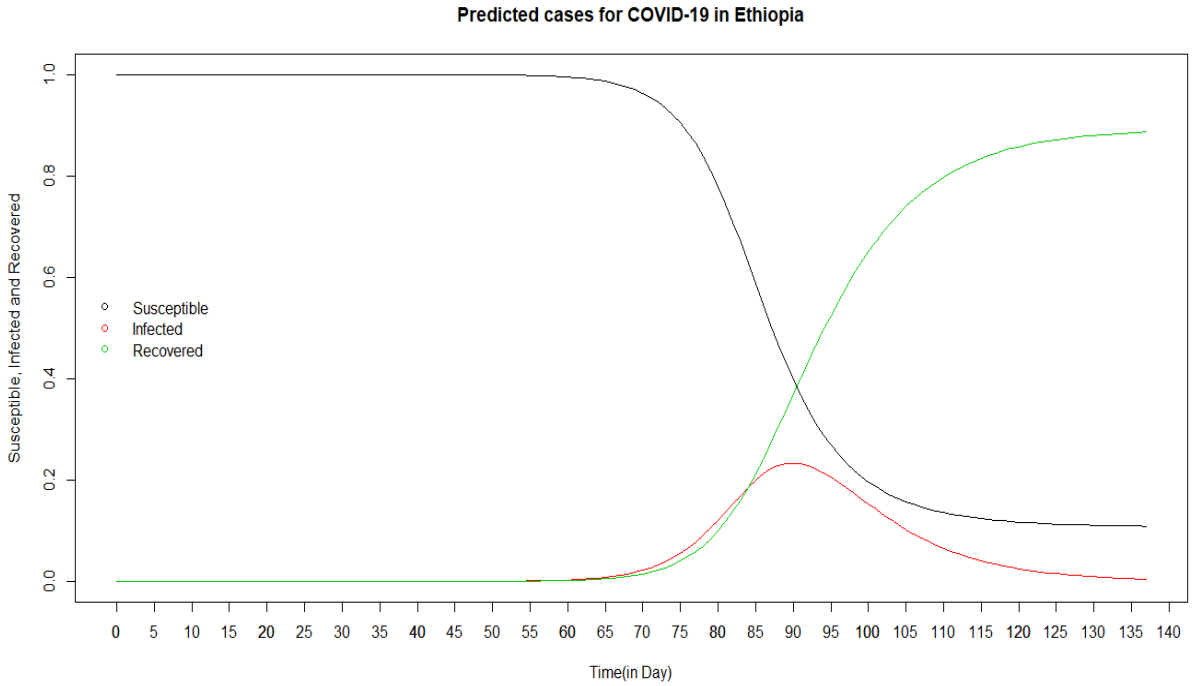

Figure 6: Predicted SIR model graph over 138 Daysfor COVID-19 Epidemic in Ethiopia

Figure 6 shows that the numerical simulation for the SIR model $\beta = 0.35$, $\gamma = 0.14$ and initial conditions S(t=0) = 114102081/114102082, I(t=0) = 1/114102082 and R(t=0) = 0. In the initial of the epidemic the number of infectious individuals increases exponentially through time.As the disease propagate the concentration of susceptible population decreases eventually causing the incidence rate of disease to become diminished. The predicted graph also reveals that the peak infection will fall at 90th Day. And the epidemic might have resolved at 137thDay, correspondingly the highest number of recovery will be recorded.

4. Discussion:

The main focus of our study was to assess the pattern of COVID-19 disease by estimating the transmission rate and to predict future spread of disease in Ethiopia. The data was taken from Ethiopian Mistry of health COVID-19 daily confirmed case reports during the first outbreak started on March 13 to May 27, 2020.

In the result of the study, after the outbreak started on March 13, 2020, the number of daily COVID 19 pandemic cases were increasing slowly more than about a month and then after the number of cases growth rapidly. As a consequence, the cumulative COVID-19 also exponentially grows for about 77 days of data extracted from Ministry of Health website, Ethiopia.Surprisingly the number of recoveredpersons also increases in parallel to infected patients for a certain days. Two deaths were occurred on April 5, 2020 in Ethiopia and the other four people were also died in different time up to this study completed.

With optimized values for effective contact rate or transmission rate (β) which is the amount of people that an infected person infects per day was estimated to be 0.53 in our SIR model. And the recovery delay (γ) considered based on the average infectious period for COVID-19 was 0.47. From the SIR model parameters, we can plug these values into equation (4) to estimate the basic reproduction number $R_0 = 1.2$. Here the basic reproductive number is larger than unity, which implied that the COVID-19 disease is considered to be pandemic disease. In addition, the value 1.2implied almost about two individuals could be secondary infected by one infected person per day.This estimate of $R_0$is on the low side of published estimates, with the World Health Organization estimating R_0 between 1.4 and 2.5 (Liu, Gayle et al. 2020). Furthermore, in some literatures, it has been estimated the reproduction number for COVID-19 were 1.4 with $\beta = 0.58$ and $\gamma = 0.42$ (https://www. statsandr.com/blog/covid-19-in-belgium/) to 2.65with $\beta = 0.21$ and $\gamma = 0.14$(Syed and Sibgatullah 2020). The reproduction number beinglower is mainly due to the fact that the number of confirmed cases stayed

constant and equal to 1 at the beginning of the pandemic.In addition, the basic SIR model doesn't take into account interventions that have taken place that would reduce the infection curve.

Whereas the predicted SIR model was considerably used parameters, $R_0 = 2.5$ and $\gamma = 0.14$ taken in the range of pre-specified literatures of basic reproductive numbers and rate of recoveries. And then the transmission rate conversely obtained as $\beta = 0.35$ using Equation (4).It is observed that the peak of infectious would be on July08, 2020 with morethan 26 million infected individual at the same time (Figure 6).Hopefully, the actual number will be lower than predicted number of infections. As our predicted SIR model is based on the epidemic progression as it currently has been that it doesn't account additional measures put in place to curb the spread of the virus like social distancing, school closure, lockdown etc.

Based on the "herd immunity threshold", our reproduction number, 1.2 suggested that the proportion of effective immunity given the formula $1 - 1/1.2$is 0.167, which 16.7% of the population should be immunized to stop the spread of theinfection, among the total population ofEthiopia approximately 114.1 million, this translates about 19.1 million people.

As an overall conclusion, the SIR model of COVID-19 pandemic in Ethiopia showed that the infection could spread at an exponential rate unless proper and effective measures are taken to reduce its transmission due safe practice such as social distancing, lockdown and large scale testing of suspected cases in all part of the country.

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