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The SIR Model: Spread of Disease (COVID-19) in Ethiopia

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ABSTRACT

The recent emergence of COVID-19 a pandemic is the top of the issues in the Globe. The spread of disease is more and there are several phases of Outbreaks and propagandas to aware their people by the Government and various public interested organizations. Even the daily reports on this Pandemic increased with respect to times or days. In Ethiopia, the Government announced State of Emergency (SOE) to protect the people. After observing these situations, the thrust of analysis of Spread of disease leads this article. Based on the daily reports from the authorized concern bodies that is Ministry of Health (MOH) , Ethiopia providing daily reports and it was recorded by the authors and the data were made. Conclusion: There is no any special significance of spread of diseases (COVID-19) in Ethiopia; it has the same pattern in spread of diseases as like the overall world. By maintain the practice of Hygiene and social distance the spread may reduce in Ethiopia.

Keywords: *COVID-19, SIR Model, Spread of Diseases, Pandemic, Ethiopia*

1. INTRODUCTION

The recent emergence of COVID-19 a pandemic, the spread of disease became more and more from day to day reports overall the global scenario. There are many pharm companies doing trials to eradicate the disease from the globe. The spread of disease is more and there are several phases of Outbreaks and propagandas to aware their people by the Government and various public interested organizations. Even the daily reports on this Pandemic increased with respect to times or days. In Ethiopia, the government announced State of Emergency (SOE) to protect the people. After observing this situation, the thrust of analysis of Spread of disease leads this article.

Infectious diseases have a substantial impact on society of human being, it affects the public health, healthcare, economic and society. Any infectious diseases must be control and prevent the emergence, expansion or resurgence of pathogens warrants continuous evaluation using different methods.

To better predict the spread of COVID-19, it needs to capture these different transmission modes into a model. Hence here the authors use the help of epidemic model to find the spread of disease as SIR model. This model is the basic and simple to carry out the spread and other dimensional activities of the communicable diseases such as COVID-19. Our goal of this article is to develop a simple mathematical model that to capture the spread of disease COVID-19 in Ethiopia at the given period of time.

1.1 Main Objective

To fit a model of spread of disease on COVID-19 in Ethiopia under reference period of time

1.2 Specific Objectives

1. To find the descriptive of the given model
2. To estimate the optimized parameter
3. To obtain the estimated S,I,R of the given model under the given period of time
4. To find the peak point of the spread of the COVID-19 over time

2. METHOD

To check the above mentioned objectives by using SIR model with the help of ordinary differential equation method. This data is a secondary sources data from Ministry of Health, Ethiopia. The reason is that the SIR model used is, many existing mathematical models of diseases spread require a large number of equations and it is also complex when the number of days becomes more.

3. ASSUMPTIONS

The SIR Model is used in epidemiology to compute the amount of susceptible, infected, recovered people in the given population. This model is an appropriate one to use under the following assumptions:

(a) The population is fixed.
(b) The only way a person can leave the susceptible group is to become infected. The only way a person can leave the infected group is to recover from the disease. Once a person has recovered, the person received immunity.
(c) Age, sex, social status, and race do not affect the probability of being infected.
(d) There is no inherited immunity.
(e) The member of the population mix homogeneously (have the same interactions with one another to the same degree)

4. DATA

Based on the daily reports from the authorized concern bodies that is Ministry of Health (MOH), Ethiopia providing daily reports and it was recorded by the authors and the data were made. To analysis the spread of diseases were taken between the day one of the spread and 10 of June 2020.

Some Basic equations of the SIR model

Differential Equation Model: The SIR Model for Spread of Disease

As the first step in the modeling process, we identify the independent and dependent variables. 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:
S = S(t) is the number of susceptible individuals, I = I(t) is the number of infected individuals, and R = R(t) is the number of recovered individuals.

The second set of dependent variables represents the fraction of the total population in each of the three categories. So, if N is the total population is in Ethiopia , we have s(t) = S(t)/N, the susceptible fraction of the population, i(t) = I(t)/N, the infected fraction of the population, and r(t) = R(t)/N, the recovered fraction of the population.

It may seem more natural to work with population counts, but some of our calculations will be simpler if we use the fractions instead. The two sets of dependent variables are proportional to each other, so either set will give us the same information about the progress of the epidemic.

As SIR model is with components of Susceptible, infected and Removed (Recovered, Death), there are several differential equation.

The susceptible Equation: This equation used to explain the component of susceptible subjects. The equation is,

$$\frac{dS}{dt} = -bs(t)I(t) - - - - - (1)$$

The Infected Equation: This equation used to explain the component of infected subjects. The equation is,

$$\frac{di}{dt} = bs(t)I(t) - ki(t) - - - - - (2)$$

The Recovered Equation: The other name is also removed and it is the component of removed from the model. The equation is

$$\frac{dr}{dt} = ki(t) - - - - - (3)$$

where k is the recovery rate (with greater or equal to zero), b is the average number of transmissions from an infected person in a time period (with b greater or equal to zero), and

$$S(t) + I(t) + R(t) = N - - - - - - - - (4)$$

From these equations it is possible to discover how the different groups will act as Susceptible from equation (1), that the susceptible group will decrease over time and approach zero. From equation (3), gives the recovered group increase and will approach N over time. How the infected group behaves is more complicated. It is good to start by taking the integral of equations (3) from 0 to t.

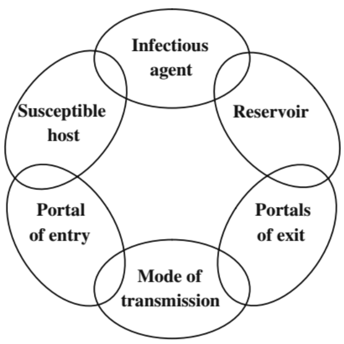


Fig. 1: The chain of infection

Spread of Diseases

Most of the human diseases are contagious, means that affected with diseases from someone already infected. Contagious diseases are of many kinds, COVID-19 also belongs to this diseases category. Figure 1 shows the chain of infection. Like COVID-19, many other diseases have the potential to affect large group of population is called epidemics. An epidemic is a complex to deal, to carry out this situation its essential to describe in mathematical functions and it is called MODEL. After construction of this mathematical model insights and methods of analyze the model. Any inference about the model will be interpreted to in the form of reality. Thus a Model with low complex and easy process work is SIR model Epidemiology Sample Activity (2003).

The SIR Model

The SIR model is a compartment model with three compartment as Susceptible(S), Infectious(I) and Removed (R) with two events as Recovered and death. This model describes the dynamics of different states of individuals in the population in terms of a system of ordinary differential equations. The mathematical model provides a precise description of the movements in and out of the three compartments. The movements are birth as flow into the compartment of susceptible individuals, death is the flow out of all compartments, transmission of infections as from S compartment to the I and recovery is the flow from I into R. This is showed in the figure 2 as the flow chart of the SIR model.

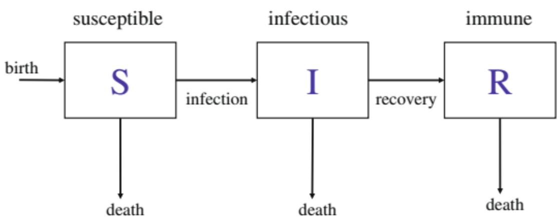


Figure 2: The flow chart of SIR model

Transitions between compartments are governed by rates, which is the simplest of this model and it is assumed to be a constant in time. (Meghan, A.B. (1998))

Initial Setup

Any epidemic disease will entail the following three quantities and their rates of change

S : number of susceptible individuals S_0 : rate of change of *S*

I : number of infected individuals *I 0* : rate of change of *I*

R : number of recovered individuals *R 0* : rate of change of *R*

Data analysis

In this analysis part there are some six segments of calculations produced by using r code.

1. Distribution of spread
2. Spread of COVID-19 in Ethiopia
3. Estimating Beta and Gamma
4. Fitted data for given COVID-19 data set
5. Predicted Cases Covid-19 in Ethiopia
6. SIR Model

As on date the Ethiopian population is 114102082, the data set contains Date, Days, Confirmed, Recovered, Deaths, Removed Cummalitive.I, s, I, r variables. An important way to minimize the spread of a disease within a area is to have people stay at home. The spread of the diseases from one area to another based on the transportation. Today the spread of the disease across the globe takes only hours or days because spread is largely tied to transportation with inter-intra area limits. Additionally, the demographic factors, the virulence of the disease itself have to be taken into accounts in models of disease spread.

5. RESULTS

Interpreting a SIR model Graphs

This section involved with the Graphs of the compartments of SIR model and the SIR graph.In the beginning the daily records from the Ministry of Health, Ethiopia shows very low confirmed cases. Gradually, the spread of disease increased, observing this the Government declared State of Emergency in the country with strict rules. Based on the observed data from MOH, Ethiopia the analysis were made with SIR model. The analysis involved between 13 March,2020 and 10 June2020.

The first diagram is on Cases that are confirmed as on the 10 June 2020. The figures are a graphical output of a typical model

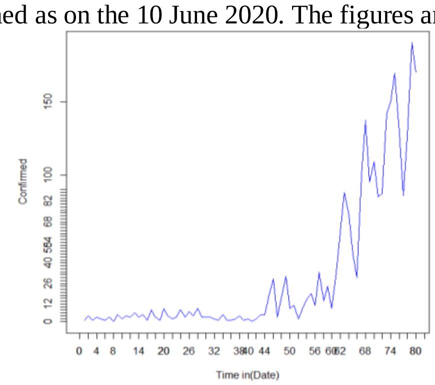


Fig. 3: Confirmed over time (Date)

From the figure 3, the x axis shows the time in date and y axis shows the cases that are confirmed. By observing the graph the day 1 is less and the cases were increased when the days increases. This shows the spread of the diseases were more when the day increased. Figure 3; depict the confirmed cases with respect to the date as time. Again from the Figure 3 the number of COVID-19 on the very first day, the epidemic shows the number of cases was exactly one person and further there were least amount of cases were recorded. It is observed that from the day 45 (06-May, 2020) the spread started increased after these days the spread of disease gradually started increase and it is continued till. The severity of spread of diseases occurred 23 May 2020 onwards. On this day, there were 61 newly confirmed cases identified.

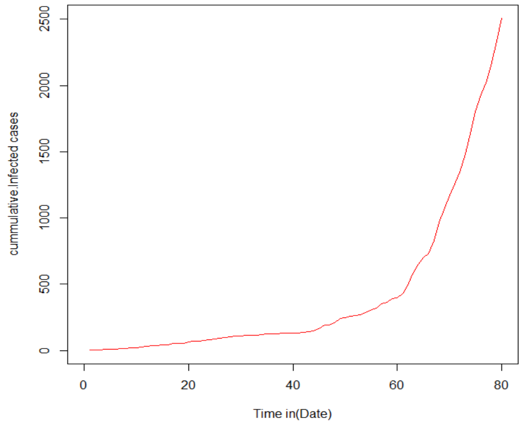


Fig. 4: Cumulative infected cases with respect to Time

Figure 4, depict the cumulative records of infected cases from day 1(3 May, 2020) to day 80 (10 June 2020). The diagram shows an exponential growth of spread of diseases within the study duration. From the diagram the cumulative infected cases gradually increase with respect to the day or time. On 62th day the curve started increase and it shows the spread of disease is more from this date (23 may 2020). The spread of disease on 67 th day the conformed cases took exactly 100 people.

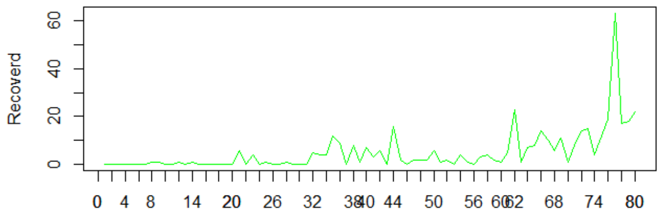


Figure 5a: Recovered individuals from COVID-19

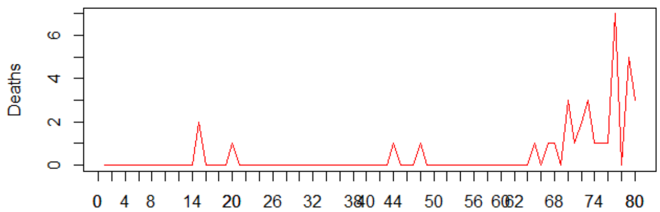
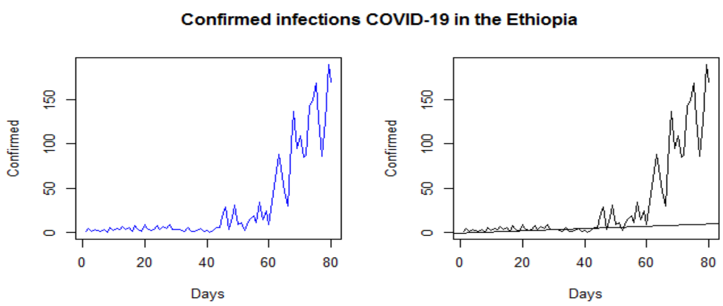


Figure 5b: Number of deaths from COVID-19

Fig. 5: Recovered cases from COVID-19 5a Recovered individuals from COVID-19 and5b Death occurred due to COVID-19

In SIR Compartment model, the third component is Removed, in this compartment the event of recovered (Cured/immunized) and Death will be counted. Thus figure 5 , shows two diagrams figure 4a as recovered and 4b as death cases. In Figure 5a, 76th day (07 June 2020) the recovered is 63 cases were recorded out of the 80 days study this was the highest recovered case. From 5b shows the death recorded on day wise. Out of 80 days, the first death was occurred on 15th day(05 April 2020) as two death occurred, further as the highest death occurred day was (07 June 2020) as 7 cases were found.



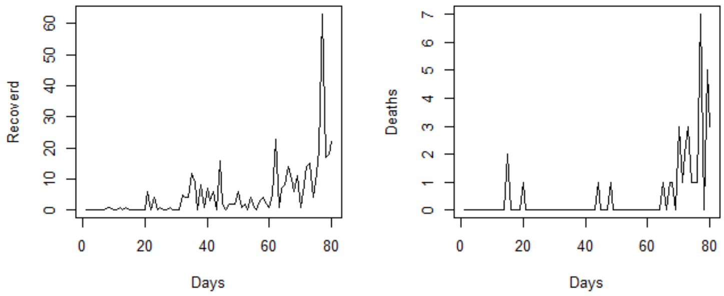


Fig. 6: SIR Model Compartment (Cases Confirmed, Recovered and Deaths)

Figure 6, shows some compartments such as cases confirmed with trend line, cases that are recovered and deaths of Removed compartment. It is clearly observed that there is more deviation on the trend of confirmed and the spread of death also the spread is more after 60 days out of 80 days of study. Likewise, the Recovered and the deaths are also occurred more after the 60 days and it rose up to the end of the study.

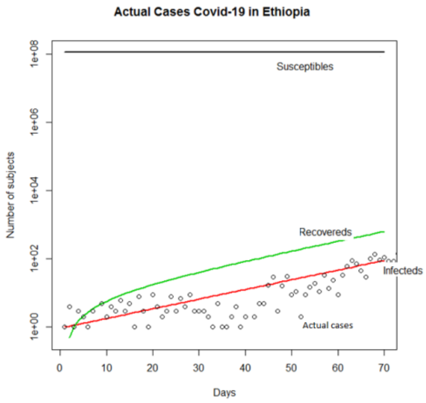


Fig. 7: SIR Model plot for Actual COVID-19 cases in Ethiopia

In figure 7, the Predicted COVID-19 cases in Ethiopia depicted, as in x axis the days were recorded and y axis recorded the number of subjects (Cases). From the figure 7 the susceptible cases not decreased and it shows a constant increase over time that is when the time increases the cases also increased. Based on this it might be able to conclude that the spread of diseases COVID-19 is a series issue in Ethiopia. It is also be able to observe that the infected population is very small as compared with the total population in Ethiopia. With respect to the infected cases, the observation is evident that there is an increase over time of the study and finally the recovered cases also increased over time under the duration of this study.

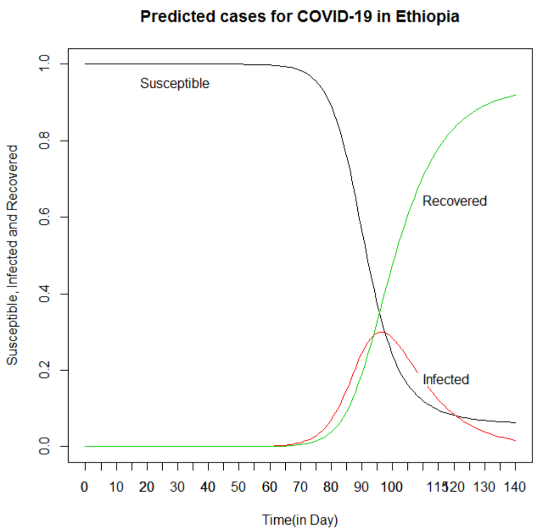


Fig. 8: Predicted SIR Model (100 days of prediction) in Ethiopia

The figure 8 shows the predicted cases of COVID-19 for 140 days of diseases of spread. In the graph the x axis plots time, specifically the number of days is from the day of beginning of the outbreak. The y axis plots the number of people in each three categories for each day. The line named susceptible, the number of people who have not yet been infected. It indicates that the diseases are very contagious, with pretty much every susceptible person being infected by day 2. The line for a less infectious disease would slope more gently to the right.

The next line is infected; the daily number of infected people and it is essentially the epi-curve for the diseases. It has changes rapidly up to a maximum about 34230624.6 (Approx) people on day 120 and then decline slowly until the day 140 when nearly everyone has recovered. The reason is the prediction shows an overall decline in day 100. The slop of the right side of the infected line reflects the recovery rate.

The final line is Recovered, the number of people who have been removed from this model, typically by recovering, steadily increases, leaving off near day 100, the reason is no more infected people who need to recover.

6. DISCUSSION

In the SIR model, there are three components are available, susceptible individuals are uninfected and susceptible to the diseases (S), infected individuals are infected and can infect susceptible (I) and finally recovered individuals have recovered from the infection and are immune to the re-infection (R). This component R is sometimes replaced as Removed and it includes cured and died. Still the day this model is used to modelling epidemics of infectious diseases (A.R.Muralidharan,2020). Based on this In sir model, the expected amount of population that an infected is estimated with the transmission rate(β) and recovery rate(γ). These two rates are important to determine the reproductive number (R_0) , $R_0 = \frac{\beta}{\gamma}$. 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. Several review made on some 75 literatures about 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 2.65 with the average recovery rate of 0.14 (Howard Weiss (2013)). Below are some of the observation based on this study were displayed.

Table 1: Initial values of SIR model

S. No	SIR Model	
1	N (Total Population)	114102082
2	S (Susceptible)	114102081
3	I (Infected)	1
4	R (Removed)	0
5	β* (Transmission rate)	0.5313152
6	γ* (Recovery rate)	0.4686848
7	R_0	1.13

*optimum values

From table 1 the Initial values of SIR model is displayed, the total population of Ethiopia is 114102082 (N) , by assumption Susceptible (S) is approximately equal to N or N-1 thus the Susceptible is 114102081 and the infected (I) is 1 and Removed or recovered (R) is zero. The optimum rate for transmission and recovery are obtained as 0.5313152 and 0.4686848 respectively. Hence the Recovery rate R_0 is 1.13 as compared with the average recovery rate (0.14), the optimum recovery rate is very near to that recovery rate. This shows this study is on the way of the previous studies.

Table 2: Sample output of SIR model (General Solver for Ordinary Differential Equations)

Days	S	I	R
1	1.0000000	8.76E-09	0.00E+00
2	1.0000000	1.09E-08	1.09E-09
3	1.0000000	1.36E-08	2.44E-09
4	1.0000000	1.67E-08	3.95E-09
5	1.0000000	2.04E-08	5.81E-09
6	1.0000000	2.49E-08	8.07E-09
7	1.0000000	3.04E-08	1.08E-08
8	0.9999999	3.72E-08	1.42E-08
9	9 0.9999999	4.55E-08	1.83E-08
10	10 0.9999999	5.56E-08	2.34E-08

Table 2 shows the estimated value of the compartments of the SIR model about 15 days, it was predicted for 100 days of the duration of the study on COVID-19. It is evident to observe that the components fit with the basic assumptions of SIR model. It shows the decrease on the compartments as a whole.

The main focus of this study is to fit a model of spread of disease on COVID-19 in Ethiopia under reference period of time. The data was taken from Ministry of Health, Ethiopia. This study is a secondary data analysis; the duration of the study is between 13 March 2020 and 10 June 2020 with a daily report observed from the ministry records.

In this article, the study reveals that the cases were showing increase over time as an exponential growth of spread of diseases. It is also observed that the late part of the data shows an increase on the spread of the diseases and it is implying that the COVID-19 as a serious issue in Ethiopia. Impact of this the government declared the entire country in state of emergency act.

Further, in this analysis part there are some six segments of calculations produced by using r code.

1. Distribution of spread
2. Spread of COVID-19 in Ethiopia
3. Estimating Beta and Gamma
4. Fitted data for given COVID-19 data set

5. Predicted Cases Covid-19 in Ethiopia
6. SIR Model

By the performance of above tasks, several observations were made and in short the observations are:

- The day 45 (06-May, 2020) the spread started increased after these days the spread of disease gradually started increase and it is continued till
- An exponential growth of spread of diseases within the study duration.
- On the76th day (07 June 2020) the recovered is 63 cases were recorded out of the 80 days study this was the highest recovered case. From 5b shows the death recorded on day wise. Out of 80 days, the first death was occurred on 15th day(05 April 2020) as two death occurred, further as the highest death occurred day was (07 June 2020) as 7 cases were found.
- It is clearly observed that there is more deviation on the trend of confirmed and the spread of death also the spread is more after 60 days out of 80 days of study
- The infected cases, the observation is evident that there is an increase over time of the study and finally the recovered cases also increased over time under the duration of this study.

7. CONCLUSION

In the current scenario of COVID-19, there were many studies occupied in the literature in various dimensions. This article attempted the spread of diseases in Ethiopia. This COVID-19 a pandemic is an infectious diseases family. There are several trials going on over the Globe. As mentioned earlier, Infectious diseases have a substantial impact on society of human being, it affect the public health, healthcare, economic and society. Any infectious diseases must be control and prevent the emergence, expansion or resurgence of pathogens warrants continuous evaluation using different methods. To better predict the spread of COVID-19, it needs to capture these different transmission modes into a model. Hence here the authors use the help of epidemic model to find the spread of disease as SIR model. Finally, as a whole, there is no any special significance of spread of diseases (COVID-19) in Ethiopia, it has the same pattern in spread of diseases as like the overall world. By maintain the practice of Hygiene and social distance the spread may reduce in Ethiopia.

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