GLOBAL ACADEMIC RESEARCH INSTITUTE

COLOMBO, SRI LANKA

GARI International Journal of Multidisciplinary Research

ISSN 2659-2193

Volume: 08 | Issue: 04

On 31st December 2022

http://www.research.lk

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GARI Publisher | Pandemic | Volume: 08 | Issue: 04

Article ID: IN/GARI/ICAS/2022/114 | Pages: 62-70 (09)

ISSN 2659-2193 | Edit: GARI Editorial Team

Received: 12.07.2022 | Publish: 31.12.2022

SEIR MODEL FOR COVID 19 DYNAMICS IN SRI LANKA

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ABSTRACT

The novel corona virus infection is an ongoing threat to most of the countries in the world. We still have significant gaps in our understanding of Covid-19 epidemiology, transmission dynamics, investigation techniques and management, despite the fact that the outbreak is an unprecedented worldwide hazard. But there is currently enough knowledge about the epidemic process to allow for the development of mathematical forecasting models. Our study dealt with mathematical modeling, model verification and numerical simulation for Covid-19 dynamics in Sri Lanka. Model verification was performed to calibrate system parameters. Parameter estimation was done by least squares minimization method in Python and graphs were plotted using MATLAB. The model's capacity to predict infectious evolution is demonstrated by the results. Here we used 2 models to study dynamics of Covid-19 outbreak in Sri Lanka based on efficiency of controlling the spread of infectious disease in 2nd and 3rd waves of Covid-19 outbreak. The findings highlight the importance of governmental and individual initiatives in limiting the frequency and duration of pandemic-related critical circumstances. And two models have predicted peak points for infected population close to actual points.

Keywords: Covid 19, mathematical modeling, SEIR model, epidemiology

INTRODUCTION

The current Covid-19 pandemic is an infectious disease caused by the virus, severe acute respiratory syndrome corona virus 2 or SARS-CoV-2. It was started from Wuhan city, China in December 2019. Covid-19 symptoms include fever, cough, myalgia or tiredness, hemoptysis, diarrhea, dyspnea, lymphopenia and kidney failure (Chen, 2020). Early confirmed cases of Covid-19 were thought to have had a history with a seafood market in Wuhan (Zhou, 2020). But soon human to human transmission was detected. The transmission of SARS-CoV-2 among human beings might also occur by using three routes (Jayasena, 2020) (Cao, 2021) 1) direct transmission through inhalation of respiration droplets (coughs or sneezes via inflamed patients in close proximity), 2) touch transmission via contact of a surface or item contaminated with the virus, 3) aerosol transmission in restrained areas. This Covid pandemic has been now spread more than 200 countries around the world and would have reported 254 million cases and more than 5 million deaths. On March 11, 2020, the World Health Organization classified this new corona virus disease a pandemic (Sahoo, 2020) (Samui, 2020).

Predicting an ongoing infectious disease in common sense is not possible. So there must be a potential tool for comparing tactics for planning for an impending epidemic as well as dealing with a disease outbreak in real time. Mathematical models are using on that purpose. To analyze the pandemic researchers in different countries have developed various mathematical models (Sahoo, 2020) (Samui, 2020) (Mahajan, 2020) (Kaxiras, 2020) (Zhong, 2020). In our study we used SEIRD model (Susceptible-Exposed-Infected-Recovered-Dead) adding death compartment to the traditional SEIR model to analyze the dynamics in Covid-19 outbreak in Sri Lanka.

Sri Lanka reported its first case on January 27, 2020 (Erandi, 2020) and more than 646,000 confirmed illnesses and 16,000 deaths have been reported during the past period of the epidemic. On March 11, 2020, (Erandi, 2020) local media outlets reported the first confirmed locally acquired case of corona virus in a Sri Lankan person. This person works as a tour guide for Italian tourists. After that Sri Lanka was implemented contact tracing and broad screening measures at international airports to identify and isolate individuals with Covid-19 symptoms (Jayasena, 2020) (Ranasinghe, 2020). The availability of locally developed rapid antigen tests with results available within 24 hours aided in the early identification of infected individuals. And government took necessary control measures like face masks are mandatory to wear outside in proper way and limiting public gatherings (Jayasena, 2020). With strict rules implemented by government and the support from people obeying the rules, Sri Lankans could come back to normal life when at the beginning of October 2020. And it was considered as the end of the 1st wave of Covid-19 outbreak in Sri Lanka.

But again the number of Covid confirmed cases were rised and started 2nd wave of Covid in Sri Lanka. Number of cases per day got increased than 1st wave (Wickramaarachchi, 2020) . Even at the end of the year 2020, Sri Lanka was struggling to free from the virus. The Covid 19 problem has thrown Sri Lanka's economy and people into a loop. Due to island wide curfews and travel restrictions hold for a long time by government, many people lost their daily income and also their jobs. Due to that reason government released the lockdowns so as to start the normal day to day activities for people. But misbehave of people and violating health instructions, caused to rise the number of people infected in April.

The Ministry of Health in Sri Lanka issued a risk alert level 3 in April due to an increase in the number of Covid patients in hospitals. According to data, the 3rd Covid wave in Sri Lanka began on April 15 2021. Sri Lanka had the highest number of deaths due to Covid 19 as of August 30th 2021. Since August 2021, the exceedingly contagious delta variant has been blamed for the country's significantly high death rate. Sri Lanka lifted all travel bans as of 31st October 2021 but some rules were not lifted due to the risk. The government, on the other hand, had focused its efforts on making vaccination cards required for entering public places such as stores and restaurants. When the Ministry of Health reports that roughly 70% of the overall population has been vaccinated against Covid-19 by the beginning of November 2021, and the population over 30 years old has been fully vaccinated.

Sri Lanka as a middle-income country, faces its own socioeconomic challenges due to limited resources and finance. When a global epidemic was thrown into the mix, it was predicted that Sri Lanka would plummet. At the time, Sri Lanka is able to keep its head above water. Covid-19 is still a threat, and the war is far from done.

In our study we used modified SEIRD model to analyze the dynamics in Sri Lanka during the 2nd and 3rd Covid outbreaks.

RESEARCH METHODOLOGY

For these two models we have done model verification and model simulations. So for that we needed actual data for number of exposed, infected, recovered and dead people for the considerable period. Those data were obtained from Epidemiology unit, Ministry of Health website of Sri Lanka. For model 1 and 2 we collected daily data for 30 days duration. For model 1 we considered a time period during 2 nd wave of Covid in Sri Lanka, 4th October to 3rd November 2020. In model 2nd , we used 3rd wave data starting from 15th April to 15th May 2021.

To verify the models we have done a model fitting with actual data . For that parameter estimation was done by least squares minimization method using python and all the plots were gained through MATLAB. Then we have simulated the model 1 and 2 for 5 months period.

Mathematical models

To analyze the dynamics of Covid 19 outbreak in Sri Lanka we used modified SEIR model. Here we developed 2 models;

- Model 1: Basic SEIRD model
- Model 2: SEIRD model considering government and individual actions in controlling the spread of virus

All these models subdivided the total human population N into susceptible (S), exposed (E), infected (I), recovered (R) and dead (D) compartments. Here we considered death rates for S, E and R compartments. And assumed the deaths in I compartment were only due to virus infection. New births were added to the susceptible population. Other than new births and natural deaths, there were no inflows and outflows. By adding the term $\mu 1N$, it balanced natural deaths and births in the population. So for model, we assumed total population is constant for any time t. [N = S + E + I + R + D]

Mathematical model 1: Basic SEIRD model

Other than the common assumptions mentioned above, we assumed there was an equal probability of infection for every individual in the population. Proposed model 1 denoted by,

$$\frac{dS}{dt} = \mu_1 N - \frac{\beta SI}{N} - \mu_1 S \quad (1)$$

$$\frac{dE}{dt} = \frac{\beta SI}{N} - \text{б}E - \mu_1 E \quad (2)$$

$$\frac{dI}{dt} = \text{б} E - \gamma I - \mu I \quad (3)$$

$$\frac{dR}{dt} = \gamma I - \mu_1 R \quad (4)$$

$$\frac{dD}{dt} = \mu I \quad (5)$$

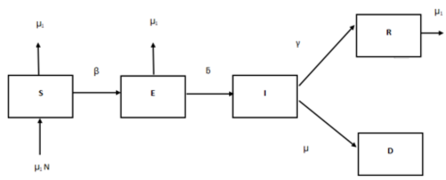


Figure 1- Schematic representation of model 1

Table 1- Description of model variables

variable	description
S	Susceptible population (individuals who have no immunity to virus, so may become infectious if exposed)
E	Exposed population (individuals who has had close contacts with an individual with Covid 19 who has symptoms)
I	Infected population (individuals who has had clinically tested positive for corona virus)
R	Recovered population (individuals who are immune to the disease and have no effect on the transmission dynamics when they interact with others)
D	Dead population
N	Total population

Table *2- Description of model parameters*

parameter	Description
β	Transmission rate from susceptible population to an infected population which has not been detected
б	Transmission rate from susceptible population to an infected population which has been detected
γ	Recovery rate
μ	Death rate due to Covid 19
μ_1	Natural death rate

Mathematical model 2: SEIRD model considering government and individual actions in controlling the spread of virus

Although Sri Lanka was successful in dealing with the first wave of the pandemic, the government and individual actions efficiency affected for the increase in confirmed and death cases in 2nd and 3rd waves. In model 2, we considered the efficiency of control measures followed by Sri Lankan government and individuals in handling the 3rd wave. The assumptions were same as in model 1.

$$\frac{dS}{dt} = \mu_1 N - \frac{(1-u)\beta SI}{N} - \mu_1 S \qquad (6)$$

$$\frac{dE}{dt} = \frac{(1-u)\beta SI}{N} - \text{б}E - \mu_1 E \qquad (7)$$

$$\frac{dI}{dt} = \text{б}E - \gamma I - \mu I \qquad (8)$$

$$\frac{dR}{dt} = \gamma I - \mu_1 R \qquad (9)$$

$$\frac{dD}{dt} = \mu I \qquad (10)$$

u - Efficiency of control measures

RESULTS AND DISCUSSION

Using the 2nd wave data, we graphed actual data with model 1 data. The initial values and estimated parameter values are as follows.

Table 3- *Initial values of SEIRD model 1*

parameters	Initial value
N	20,000,000
μ_1	1/ (77*365)
E_0	42
I_0	8
R_0	4
D_0	0

Table 4- *Estimated model parameters*

parameter	value
β	0.3135
б	0.1562
γ	0.0651
μ	0.0025

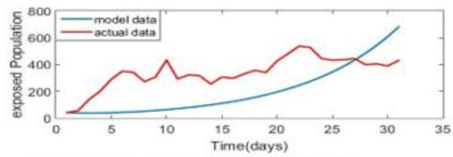


Figure 2-Model 1 fitting for exposed population

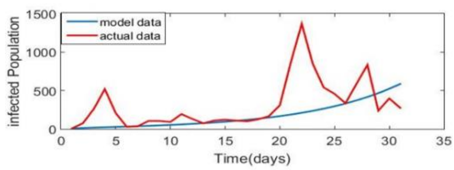


Figure 3- Model 1 fitting for infected population

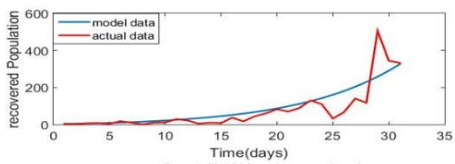


Figure 4- Model 1 fitting for recovered population

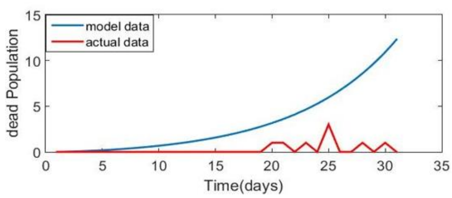
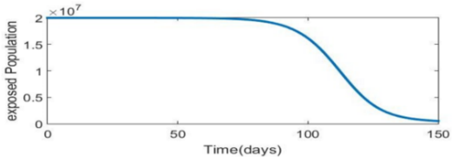


Figure 5 - Model 1 fitting for dead population

Model 1 simulations were done for 5 months starting from 3rd of October 2020 for exposed, infected, recovered and dead populations.



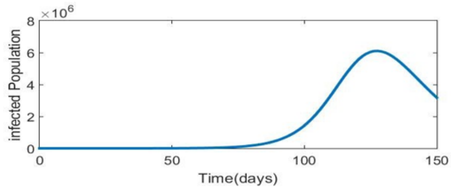


Figure 7- *Model 1 simulation for infected population*

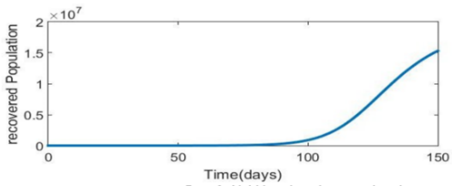


Figure 8 - Model 1 simulation for recovered population

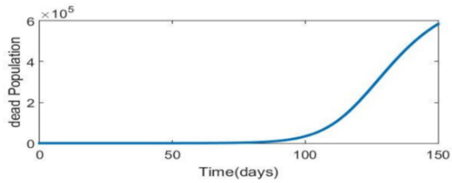


Figure 9 - Model 1 simulation for dead population

According to the simulation for model 1, nearly after 118 days (around 30th of January 2021), the infected population curve attains its peak. And also from January 2021 onwards, the number of deaths will be increased if the government still takes no implementation of curfews and other control measures to avoid the spread of the disease.

Although Sri Lanka was successful in dealing with the first wave of the pandemic, the government and individual actions efficiency affected for the increase in con- firmed and death cases in 2nd and 3rd waves. In model 2, we considered the efficiency of control measures followed by Sri Lankan government and individuals in handling the 3rd wave. The assumptions were same as in model 1.

Following tables show initial values and estimated parameters for model 2.

Table 5- *Initial values for model 2*

Parameter	value
N	20,000,000
μ_1	1/(77*365)
u	0.75
E_0	202
I_0	117
R_0	157
D_0	2

Table 6 - *Estimated model parameters for model 2*

parameter	value
β	0.8045
б	0.2450
γ	0.0464
μ	0.0033

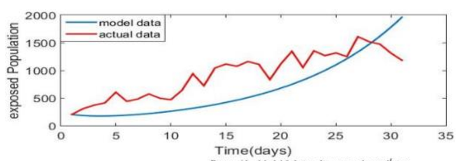


Figure 10 - Model 2 fitting for exposed population

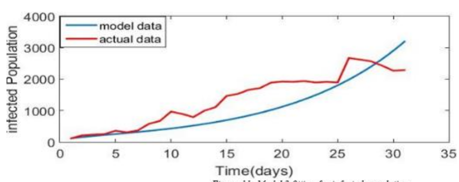


Figure 11- Model 2 fitting for infected population

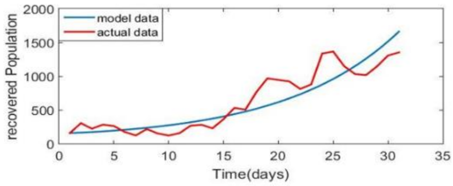


Figure 12 - Model 2 fitting for recovered population

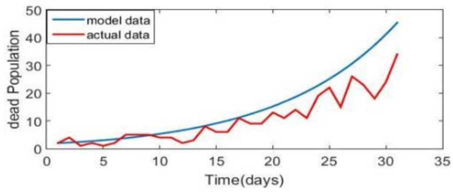


Figure 13- Model 2 fitting for dead population

Model 2 simulations were done for 5 months starting from 15th of April 2021 for exposed, infected, recovered and dead populations.

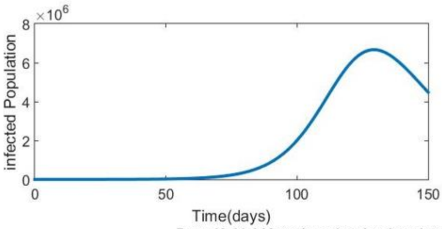


Figure 15 -Model 2 simulation for infected population

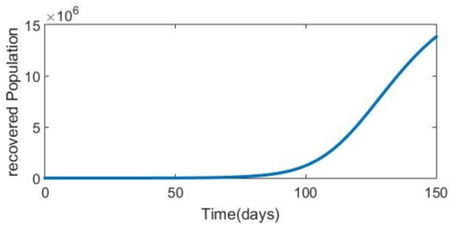


Figure 16- Model 2 simulation for recovered population

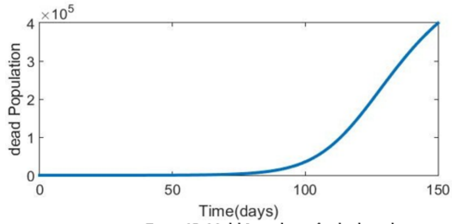


Figure 17- Model 2 simulation for dead population

According to the simulation of model 2, infected population curve attains its peak after 128 days (last week of August) from April 15th 2021. After 3 months from April, the number of deaths will be increased due to Covid virus infection.

The goal of this model 2 was to evaluate the efficacy of control measures; however, the timing of control measures was not simulated. We changed the control parameter u to account for the combined influence of government social distancing control efforts and individual actions. It could be observed that when the efficacy of the control measure grows, the epidemic curve flattens out and additionally, the peak of the outbreak can be delayed so that the national health system can treat patients without becoming overwhelmed.

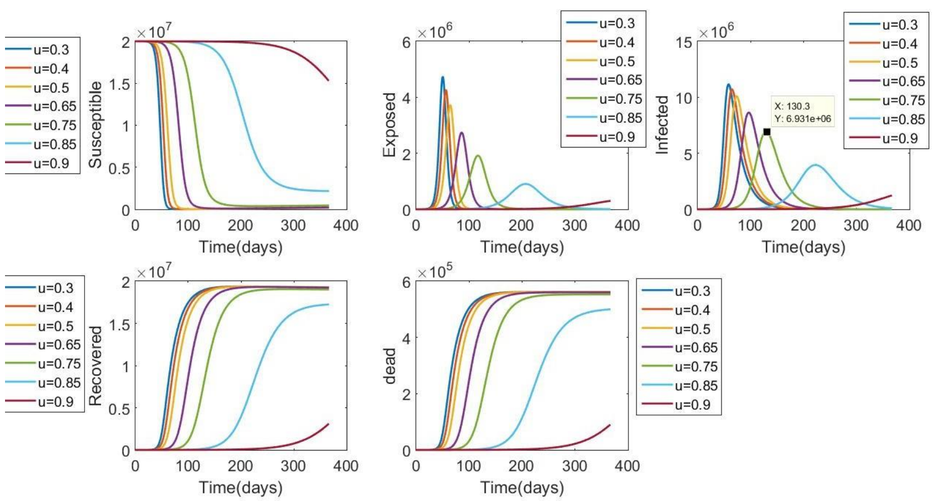


Figure 18- Sensitivity analysis on Control parameter effect when u = 0.3, 0.4, 0.5, 0.65, 0.75, 0.85, 0.9

Below graph shows how peak changes with respect to the control efficiency for infected and dead populations.

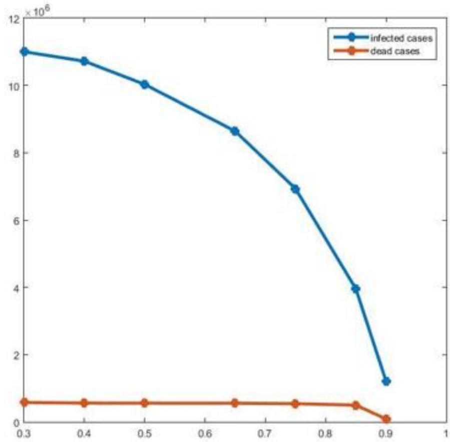


Figure 19: *Change in peak with respect to control parameter for infected and dead cases*

Limitations

- All of the presented models were primarily concerned with the direct human to human transmission. It was widely assumed that Covid 19 can be transferred through direct contact between human hosts, and that both symptomatic and asymptomatic individuals can infect others (Mwalili, 2020) (Kampf, 2020) (Van Doremalen, 2020). The indirect transmission pathway from the environment to human hosts, on the other hand, is a plausible source of virus propagation but is not explored in this thesis.
- These models didn't consider about the disease severity with different variants of SARS-CoV-2.
- There is no evidence that individuals get lifetime immunity after they recover. But due to model complexity and data unavailability, we assumed that recovered individuals won't become susceptible again.

CONCLUSION

We proposed 2 models for analyzing the dynamics of Covid 19 outbreak in Sri Lanka. We saw that model 1 and 2 projected the peak for infected population around exact dates in the real scenario.

Model 1, which assumed the homogeneity of individuals in population and no control over the spread of the virus in 2nd wave of Covid attained its peak for infected cases at the end of January 2021. According to actual data peak was at the beginning of the first week of February 2021. So model 1 is better to predict the behavior of 2nd wave and take safety precautions for health authorities prior to worst case scenario.

If the government and individual's maintained 75% efficiency in controlling the spread of the virus, model 2 suggested that the peak for confirmed cases occurs during the last week of August. In actual scenario it occurred at 30th of August 2021. Model 2 was best fitted for describing the behavior of 3rd wave of Covid in Sri Lanka.

And Model 2 highlighted the importance of government control efficiency and individual control measures such as social separation, mask wearing in public, frequent hand washing, and limiting non-essential travel to avoid Covid 19 epi- demic. If policymakers were tightened control measures, they can postpone the peak and thereby flatten the curve.

It is critical to define and assess the current efficacy level of average aggregated combined social distancing as a percentage in Sri Lanka. Final results are highly based on these values. At the very beginning of the pandemic government and individuals paid more attention to follow Covid 19 safety precautions. But in 2nd and 3rd wave period of Covid 19 government didn't take necessary lockdowns and travel restrictions island wide even though health authorities requested to do like that. And even people didn't wear masks and follow health guidelines even though they have to. The efficacy level of restricted mobility will never be ideal and consistent throughout time.

Acknowledgements

First and most heartfelt thanks go to my supervisor Dr P.D. Dilruk Gallage for his outstanding supervision, mentoring and support. His extensive engagement in mentoring, constructive feedback, friendly encouragement and guidance is deeply appreciated. Also, I would like to thank Dr S.S.N Perera, head of the Department of Mathematics at the University of Colombo for all of his assistance throughout my research. As well as academic staff of University of Colombo for their wonderful feedback, support, and guidance. Thank you very much. I need to thank Mrs Hasitha Erandi, who is a researcher in epidemiology area for sharing her knowledge on this subject.

I'd also like to thank all of my colleagues for their ongoing encourages and support.

Last but not least, I want to express my heartfelt gratitude to my family for their unwavering support and hope. This research work would not have been conceivable without such hope. Thank you all for your support.

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