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# AN EPIDEMIOLOGICAL MODEL TO AID DECISION-MAKING FOR COVID-19 CONTROL IN SRI LANKA

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25

26 **Abstract**

27 Background: Sri Lanka diagnosed its first local case of COVID-19 on 11 March 2020. The  
28 government acted swiftly to contain transmission, with extensive public health measures. At  
29 the end of 30 days, Sri Lanka had 197 cases, 54 recovered and 7 deaths; a staged relaxing of  
30 the lockdown is now underway. This paper proposes a theoretical basis for estimating the  
31 limits within which transmission should be constrained in order to ensure that the case load  
32 remains within the capacity of the health system.

33

34 Methods: We used Susceptible, Infected, Recovered model to estimate the ICU bed  
35 requirement at different levels of  $R_0$  values after lockout. We developed a web application  
36 that enables visualization of cases and ICU bed requirements with time, with adjustable  
37 parameters that include: population exposed; proportion asymptomatic; number of active and  
38 recovered cases; infectious period;  $R_0$  or doubling time; proportion critically ill; available  
39 ICU beds and duration of ICU stay.

40

41 Results: The three-day moving average of the caseload suggested two waves of transmission  
42 from Day 0 to 17 ( $R_0=3.32$ , 95% CI 1.85 - 5.41) and from Day 18 - 30 ( $R=1.25$ , 95%CI: 0.93  
43 - 1.63). We estimate that if there are 156 active cases with 91 recovered at the time of  
44 lockout, and  $R$  increases to 1.5 (doubling time 19 days), under the standard parameters for Sri  
45 Lanka, the ICU bed capacity of 300 is likely to be saturated by about 100 days, signalled by  
46 18 new infections (95% CI 15 - 22) on Day 14 after lockout.

47

48 Conclusion: Our model suggests that to ensure that the case load remains within the available  
49 capacity of the health system after lockout, transmission should not exceed  $R=1.5$ . This

50 model and the web-based application may be useful in other low- and middle-income  
51 countries which have similar constraints on health resources.

## 52 **Introduction**

53 COVID-19 is caused by a new coronavirus (SARS CoV-2) that emerged in China in  
54 December 2019. Although it causes an asymptomatic or mild infection in most instances, it  
55 can cause severe respiratory illness or even death. Transmission is mainly via droplets  
56 released into the air when an infected person coughs or sneezes. Aerosol and fomite  
57 transmission of SARS-CoV-2 is also possible (1) (2). There is no vaccine at present, nor is  
58 there any antiviral agent of proven efficacy. Thus traditional measures that control the spread  
59 of infectious diseases such as quarantine, contact tracing, isolation of positives and contacts  
60 as well as social distancing and hand-washing are of vital importance.

61

62 The basic reproduction number ( $R_0$ ) is a central concept in infectious disease epidemiology,  
63 representing the average number of new infections generated by an infectious person in a  
64 completely susceptible population. For COVID-19,  $R_0$  has been estimated by the WHO to be  
65 1.4 – 2.5. Others have placed it higher, at a median of 2.79 with an interquartile (IQR) range  
66 of 1.16 (3). For comparison, seasonal flu has a reported median  $R_0$  of 1.28 (IQR, 1.19–1.37),  
67 while measles has an  $R_0$  of 12–18 (4).

## 68 **Situation in Sri Lanka**

69 The 1<sup>st</sup> case of COVID-19 was diagnosed in Sri Lanka on 27 January 2020, in a tourist from  
70 China. The 2<sup>nd</sup> case was detected nearly 6 weeks later, on 11 March, in a tour guide who  
71 probably contracted the infection from Italian tourists. Since then, the spread of infection has  
72 been relatively slow, and mostly confined to returnees from countries with high transmission,  
73 and their contacts. However, it must be noted that in four of the 190 cases diagnosed in the  
74 30 days from 11 March to 10 April 2020, it was not possible to identify the source of  
75 infection. It took nearly a week for the caseload to double from 50 (on 19 March) to 100 on

76 (25 March). It had not yet doubled again as of 11th April, when the count was 197 cases, with  
77 54 recovered and 7 deaths (5). The epidemic has not yet reached the stage of full-blown  
78 community transmission, and almost all cases still occur in clusters where the chain of  
79 transmission can be traced.

80

81 The government of Sri Lanka acted swiftly to contain transmission, with very stringent public  
82 health measures and social distancing: complete island-wide lockdown, contact tracing and  
83 isolation, and quarantine of all inbound passengers were all adopted almost simultaneously.  
84 The airport has been closed for inbound passengers since 19 March. The national policy with  
85 regard to testing was that all symptomatic individuals clinically suspected of infection with  
86 SARS-CoV-2, should be tested in one of seven designated laboratories, using PCR as a  
87 diagnostic tool. All positive individuals (regardless of severity of illness) are managed in one  
88 of three state hospitals, designated for management of COVID-19. These hospitals are also  
89 equipped with intensive care units and ventilators for management of the critically ill.  
90 However, the control measures have exacted a very heavy social and economic cost, and the  
91 state is now about to implement a phased relaxation of preventive measures. For economic  
92 and social reasons, the government will be forced to re-open Sri Lanka's borders in the near  
93 future, while the pandemic is still going on elsewhere.

#### 94 **Potential impact of COVID-19**

95 It has been suggested that most people infected with SAR-CoV-2 show no symptoms but are  
96 still able to infect others. Blanket testing of an isolated village of about 3000 individuals in  
97 northern Italy found that 50 – 75% of infected individuals were asymptomatic (6). Analysis  
98 of the outbreak in China found that 81% of symptomatic individuals had mild illness,  
99 whereas 14% developed severe illness (i.e., dyspnea, respiratory frequency  $\geq 30$ /min, blood

100 oxygen saturation  $\leq 93\%$ , partial pressure of arterial oxygen to fraction of inspired oxygen  
101 ratio  $< 300$ , and/or lung infiltrates  $> 50\%$  within 24 to 48 h) and another 5% became critically  
102 ill with respiratory failure, septic shock, and/or multiple organ dysfunction or failure (7). It is  
103 the provision of effective care for this last group of patients, who may require ventilation for  
104 2 – 3 weeks, that is the crucial limiting factor in any health system.

105

106 The global numbers as of 10 April were 1,617,204 cases, 364,686 recovered, and 97,039  
107 deaths, which suggests a case fatality rate of 5.5% (8). Of the first 140 patients treated for  
108 COVID-19 at the Infectious Disease Hospital in Sri Lanka, where the majority of patients  
109 have been managed, nine (6.4%) have required intensive care; a similar proportion to that  
110 reported from Wuhan. Sri Lanka's case fatality rate has been 3.7% (7/197) as of 11 April  
111 2020.

112

113 If the spread of infection is not controlled, the  $R_0$  of SARS-CoV-2 is such that it sweeps  
114 swiftly through the susceptible population, resulting in a large number of very ill persons  
115 within a short period of time, thus overloading the health system and causing it to collapse.  
116 However, it is clearly possible to slow down transmission, as has been demonstrated in Sri  
117 Lanka. The availability of beds and ventilators in hospital intensive care units (ICU), to care  
118 for critically ill patients, is the major constraining factor that has been observed in all  
119 countries with large epidemics. Sri Lanka will need to closely monitor and control the rate of  
120 spread of infection so that the requirement for ICU beds and ventilators remains within the  
121 available capacity.

122

123 This paper proposes a theoretical basis for estimating the limit within which the reproduction  
124 number should be constrained, in order to ensure that the infection spreads slowly, and the  
125 COVID-19 case load remains within the capacity of Sri Lanka's health system.

126

## 127 **Materials and Methods**

128 We used publicly available data for the analysis. The 3-day moving average of cases  
129 diagnosed each day during the period 11 March to 15 April were plotted (see Figure 1).  
130 These numbers are based on a policy of screening all symptomatic individuals clinically  
131 suspected of infection with SARS-CoV-2, using PCR as a diagnostic tool, as recorded in the  
132 daily situation reports released by the Epidemiology Unit of the Ministry of Health. It should  
133 be noted that an exception to this policy was made on 31 March, when screening was  
134 extended to contacts, and 10 of the 21 cases reported on 1 April were asymptomatic positives.  
135 Using the maximum likelihood method in the R0 package in R programming language (9),  
136 we calculated R over the first 35 days.

137

138 We used the Susceptible, Infected, Recovered (SIR) model to explore the number of new  
139 infections and estimated ICU bed requirements at different levels of  $R_0$  values after lockdown.  
140 These  $R_0$  values were selected to represent the range within which transmission may be  
141 constrained, and assuming that it will increase after lockdown (Table 1).

142

143

144 Table 1:  $R_0$  values and doubling time of infections

$R_0$	Doubling time of active infections
1.3	32 days
1.4	24 days
1.5	19 days
1.6	16 days
1.7	14 days
1.8	12 days

145

146

147 We developed a web-based interactive application using an R Shiny package (available  
 148 through this link: [bit.ly/COVID19\\_ICU](https://bit.ly/COVID19_ICU)) that enables visualization of cases and ICU bed  
 149 requirements with time under different values of  $R$ , with the following adjustable parameters  
 150 that include the total population exposed; the proportion of asymptomatic individuals among  
 151 those infected; the number of active cases; the number of recovered cases; the infectious  
 152 period in days;  $R_0$  or doubling time in days; the percentage who are expected to become  
 153 critically ill; the available number of ICU beds; the average duration of ICU stay in days; and  
 154 uncertainty of projection.

155

156 We calculated the scenarios that emerge at different values of  $R$ , in terms of active infections  
 157 and ICU requirements subsequent to lockout on 20 April 2020, under the following  
 158 assumptions:

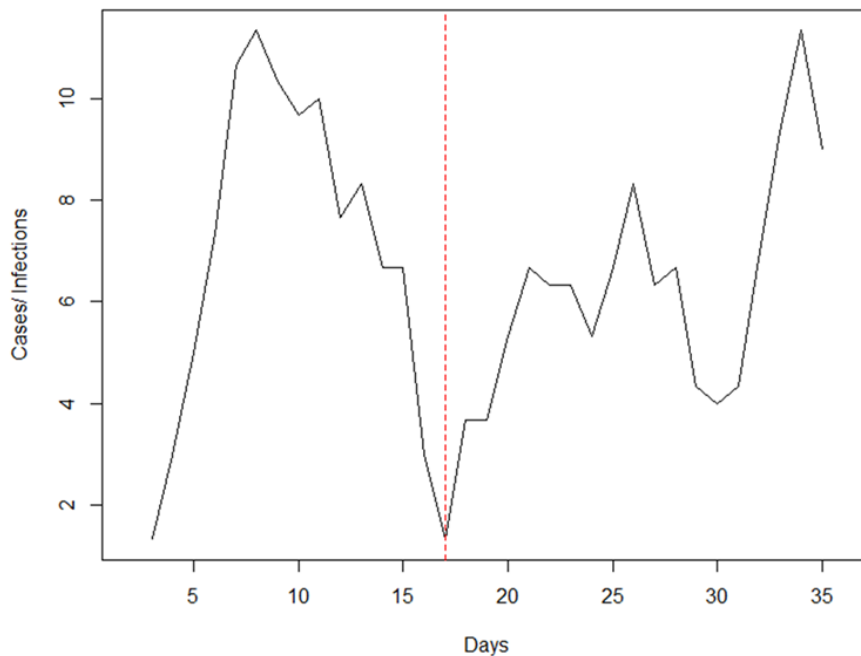
- 159 1. the entire population of Sri Lanka (22 million) is susceptible to infection,
- 160 2. there are 156 active cases, and 91 recovered (as recorded by the Epidemiology Unit of
- 161 the Ministry of Health on 19 April),
- 162 3. 50% of all infections are asymptomatic or pre-symptomatic and therefore
- 163 undiagnosed,
- 164 4. the average infectious period is 14 days,
- 165 5. 5% of symptomatic patients will require ICU care,
- 166 6. the average duration of ICU stay is 2 weeks,
- 167 7. maximum critical care capacity = 300 ICU beds and ventilators

168 At present, the state hospitals in Sri Lanka have a total of about 670 functional ICU beds with  
169 ventilators. While retaining capacity for management of patients with other illnesses, we  
170 assumed that up to 300 of these ICU beds may be made available for management of  
171 COVID-19 patients at the peak of the epidemic.

172

173 **Results**

174 The three-day moving average of daily new cases over the first month (Figure 1) is  
175 suggestive of two waves of transmission, and so we calculated R separately for these two  
176 periods. The first wave, from Day 0 to Day 17 was largely due to infections among foreign  
177 returnees ( $R_0 = 3.32$  [95%CI: 1.85 - 5.41]). The second wave was largely due to local  
178 transmission among their contacts ( $R_2 = 1.25$  [95%CI: 0.93 - 1.63]).

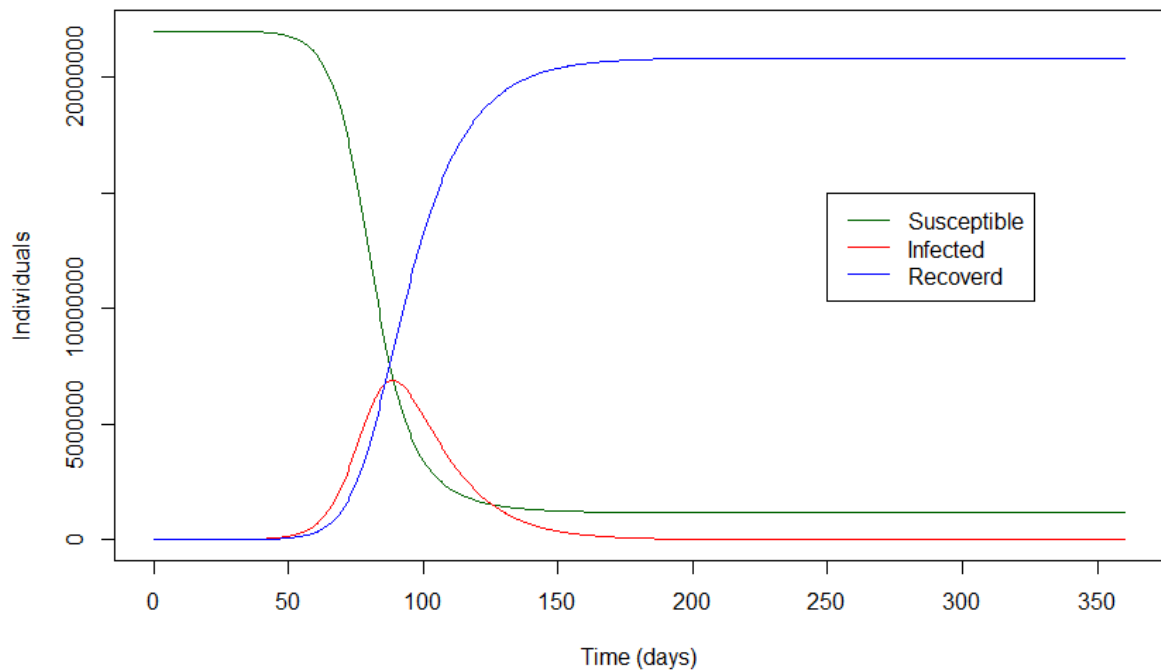


179

180 Fig 1. Three-day moving average of new cases, 11th March to 15th April. Red dashed line  
181 indicate day 17.

182

183 Figure 2 shows the possible course of the epidemic if transmission remained at the initial  
184 level seen during the first wave of transmission ( $R=3.32$ ). This model suggests that the  
185 epidemic would have peaked in about 3 months, with more than 5,000,000 affected  
186 individuals at the peak of the epidemic.



187

188

Fig 2. Natural progression of COVID-19 epidemic when  $R=3.32$ .

189

190

Figure 3 shows the interface of the web-based application. This web-based application plots

191

the expected epidemic curve under the user input parameters and provides projections on

192

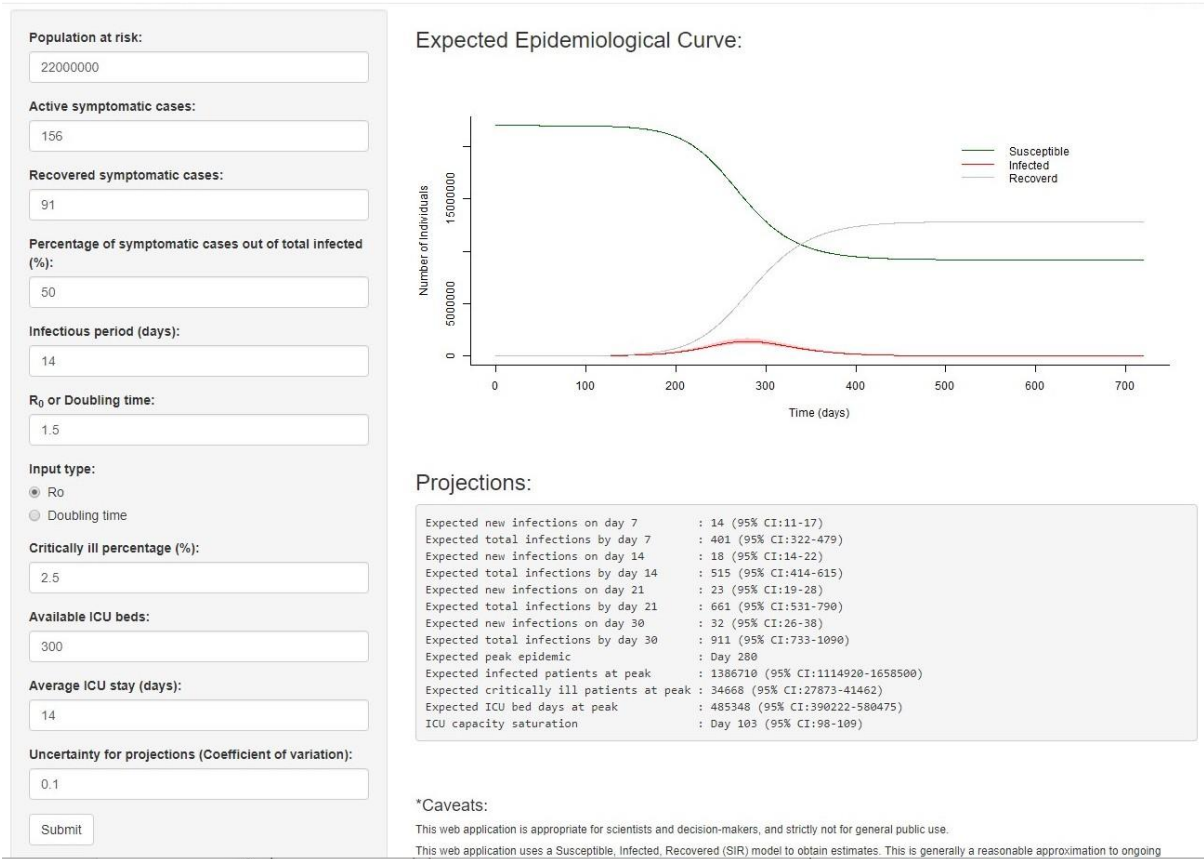
expected new infections on day 7, 14, 21 and 30, new infections by day 7, 14, 21 and 30, day

193

of the peak epidemic, infected patients at peak, critically ill patients at peak, required ICU

194

bed days at peak and the day of the ICU saturation under each scenario.



195

196

197

198

199

200

201

Fig 3. Interface of the web-based application (URL: [bit.ly/COVID19\\_ICU](https://bit.ly/COVID19_ICU))

Figure 4 shows how the spread of infection could progress at each of the selected levels of  $R_0$ . It can be seen that as the value of  $R_0$  decreases, the curve becomes flatter: the peak arrives progressively later, and affects a smaller number of individuals at any one time.

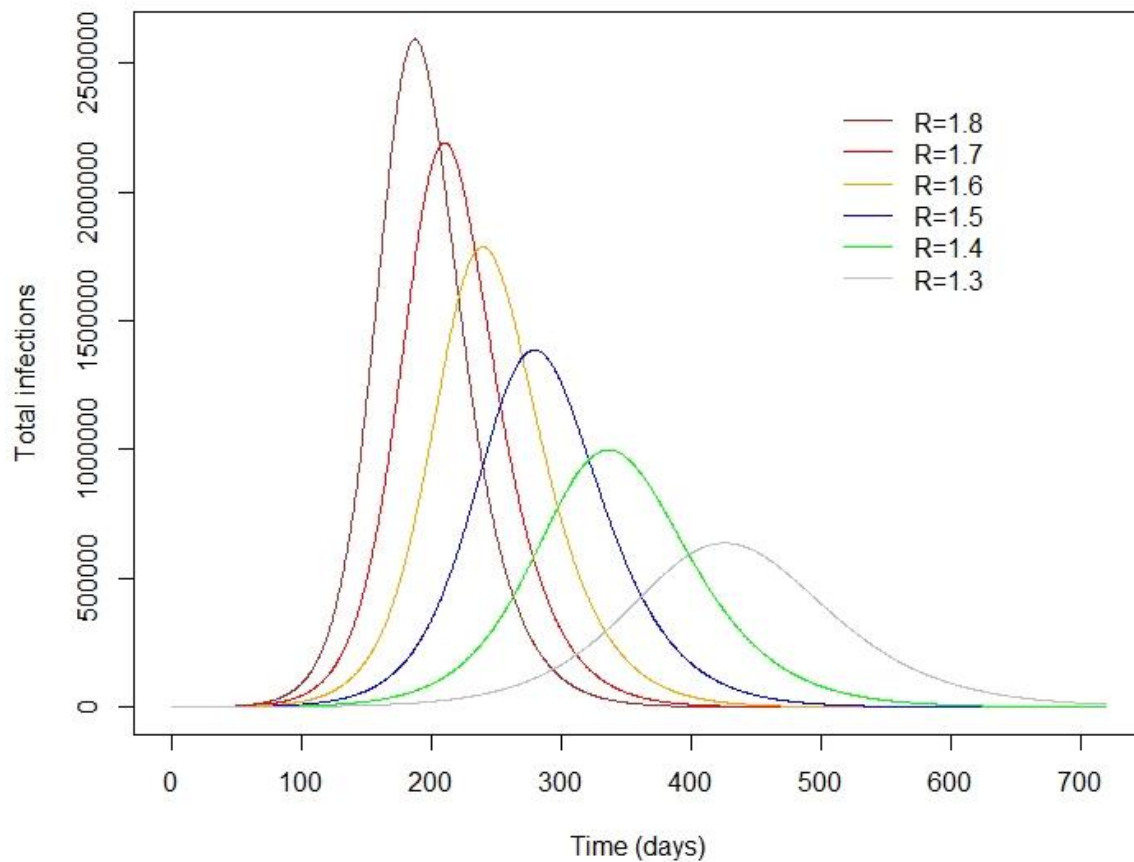
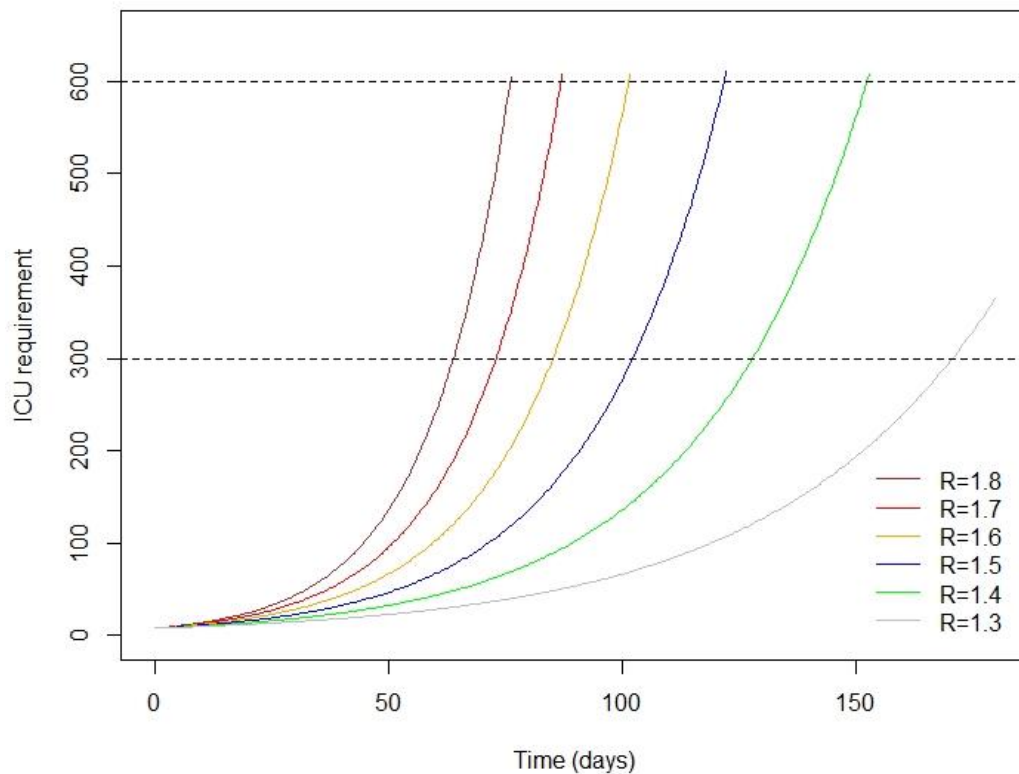


Fig 4. The epidemic curve over time at selected values of R

202  
 203  
 204  
 205  
 206  
 207  
 208  
 209

Figure 5 shows how saturation of ICU bed capacity (300 beds) could be delayed, as the value of R becomes lower. The curves suggest that while saturation of ICU bed capacity would not occur until about 6 months have elapsed at the lowest value of R selected (R=1.3), this would happen in about 2 months if R=1.8, the highest value selected.



210

211

212 Fig 5. Saturation of ICU bed capacity: changes with time at selected values of R

213

214 We then estimate active infections predicted on Days 7, 14, 21 and 30 after lockout and the  
 215 day of ICU saturation (300 beds) at different values of R (see Table 2), and the predicted new  
 216 infections over this same period (see Table 3). This suggests that a R value of 1.5 or above  
 217 would result in saturation of ICU capacity within about 3 months of lockout, and this would  
 218 be likely if the number of active infections reaches 515 (95% CI 414 - 615) and  
 219 approximately 18 (95% CI 14 - 22) new infections on Day 14 after lockout. Based on our  
 220 assumption that 50% of infections are asymptomatic, this means the number of active  
 221 symptomatic cases on Day 14 after lockout would have increased to about 255 and the  
 222 number of new symptomatic cases would be about 9.

223 Table 2. Predicted active infections and ICU bed saturation at selected values of R after  
 224 lockout

R value (Day of the expected peak)	Active infections after 7 days (95% CI)	Active infections after 14 days (95% CI)	Active infections after 21 days (95% CI)	Active infections after 30 days (95% CI)	ICU saturation on day (95% CI)
1.3 (Day 426)	363 (291-434)	421 (339-504)	489 (394-585)	594 (477-710)	171 (163-181)
1.4 (Day 337)	381 (306-456)	466 (374-557)	569 (457-680)	736 (591-880)	128 (122-136)
1.5 (Day 280)	401 (322-479)	515 (414-615)	661 (531-790)	911 (733-1090)	103 (98-109)
1.6 (Day 240)	421 (339-504)	569 (457-680)	768 (617-918)	1129 (908-1351)	86 (81-91)
1.7 (Day 210)	443 (356-530)	629 (505-752)	892 (717-1067)	1399 (1125-1674)	74 (70-78)
1.8 (Day 187)	466 (374-557)	695 (559-831)	1037 (833-1240)	1734 (1394-2074)	64 (61-68)

225

226

227 Table 3. Expected new infections on day 7, 14, 21 and 30 at selected values of R

R value (Day of the expected peak)	New infections on day 7 (95% CI)	New infections on day 14 (95% CI)	New infections on day 21 (95% CI)	New infections on day 30 (95% CI)
1.3 (Day 426)	8 (6-9)	9 (7-11)	10 (8-12)	13 (10-15)
1.4 (Day 337)	11 (9-13)	13 (10-16)	16 (13-19)	21 (17-25)
1.5 (Day 280)	14 (11-17)	18 (14-22)	23 (19-28)	32 (26-38)
1.6 (Day 240)	18 (14-21)	24 (19-29)	32 (26-38)	47 (38-57)
1.7 (Day 210)	22 (17-26)	31 (25-37)	44 (35-52)	68 (55-82)
1.8 (Day 187)	26 (21-31)	39 (31-46)	58 (46-69)	96 (78-115)

228

229

## 230 **Discussion**

231 Our findings suggest that the multiple control measures adopted in Sri Lanka during March  
232 2020, which includes prompt contact tracing and isolation, border closure and complete  
233 lockdown, have enabled reduction in transmission from an initial level ( $R=3.0$ ) that would  
234 have almost certainly overwhelmed Sri Lanka's health system within a month, peaking in  
235 about 3 months, with well over 5 million active infections at that point.

236 The simple SIR model we developed enables visualization of how different levels of control  
237 would affect the speed at which ICU capacity in our country reaches saturation and the  
238 number of cases that would signal the likelihood of this occurring in 2-3 months. Our  
239 projections suggest that transmission should be controlled so that  $R$  does not exceed 1.5 for  
240 any prolonged length of time, in order to avoid overloading the ICU capacity. The model can  
241 also be used to envisage the impact of varying levels of control in different areas within Sri  
242 Lanka, such as in the 6 districts in Sri Lanka categorized as having a high risk of transmission  
243 compared to the other 19 districts which have a lower risk. This could inform healthcare  
244 decision making at a more local level.

245 It may be argued that the SIR model is not applicable in the Sri Lankan context, because there  
246 is, as yet, no full-blown community transmission. However, it is likely that the COVID-19  
247 epidemic in Sri Lanka will move into this phase, as has happened in many other countries  
248 over the past three months, and the SIR model is widely accepted as a means of  
249 conceptualizing the spread of an infectious disease through a population over time (10).

250 The validity of the projections derived from our model depend a great deal on the accuracy of  
251 the assumed parameters, such as the proportion of asymptomatic individuals, the average  
252 period of infectiousness, the proportion of symptomatic individuals who require ICU care, the  
253 duration of ICU stay, etc. The estimates presented here are based on data reported from other  
254 countries where the epidemic is more advanced, and may not necessarily be appropriate in

255 the Sri Lankan context. However, the availability of the app enables the user to change the  
256 parameters as required as more data becomes available.

257 Other web-based applications have been developed, such as the Epidemic Calculator  
258 available at <https://gabgoh.github.io/COVID/index.html>. This application uses a SEIR  
259 (Susceptible, Exposed, Infectious, Removed) model, and although it does not enable  
260 calculation of the saturation of ICU bed capacity, the results produced by our model in terms  
261 of active infections, susceptible individuals and recovered patients are on par with the  
262 Epidemic Calculator under no intervention scenario. We chose not to use a SEIR model  
263 because the data available at this stage in Sri Lanka was insufficient to estimate all the  
264 parameters necessary for such a model.

265 Another web-based app developed at the London School of Hygiene & Tropical Medicine is  
266 available at [https://cmmid-lshtm.shinyapps.io/hospital\\_bed\\_occupancy\\_projections/](https://cmmid-lshtm.shinyapps.io/hospital_bed_occupancy_projections/), to  
267 estimate projected hospital bed occupancy in the UK. However, this app can be used to  
268 forecast COVID-19 bed requirements in a given location for only up to 21 days (e.g. a  
269 healthcare facility, a county, a state) and our estimates were similar to this app.

270 We believe that the model and web based app, which we developed primarily for use in Sri  
271 Lanka, may also be appropriate for use in other low and middle income countries that have  
272 similar constraints for ICU care of COVID-19 patients, but are unable to enforce stringent  
273 lockdown measures for a prolonged period of time due to social and economic reasons.

274

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279

## 280 **References**

- 281 1. COVID-19 Basics [Internet]. Johns Hopkins University & Medicine. 2020 [cited 2020  
282 Apr 1]. Available from: <https://coronavirus.jhu.edu/#covid-19-basics>
- 283 2. van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson  
284 BN, et al. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-  
285 CoV-1. *N Engl J Med*. 2020;
- 286 3. Liu Y, Gayle AA, Wilder-Smith A, Rocklöv J. The reproductive number of COVID-19  
287 is higher compared to SARS coronavirus. *Journal of travel medicine*. 2020.
- 288 4. Lake MA. What we know so far: COVID-19 current clinical knowledge and research.  
289 *Clinical medicine (London, England)*. 2020.
- 290 5. Epidemiology Unit Ministry of Health Sri Lanka [Internet]. Epidemiology Unit  
291 Ministry of Health Sri Lanka. [cited 2020 Apr 15]. Available from:  
292 <http://www.epid.gov.lk/web/index.php?lang=en>
- 293 6. Day M. Covid-19: identifying and isolating asymptomatic people helped eliminate  
294 virus in Italian village. *BMJ*. 2020;
- 295 7. Wu Z, McGoogan JM. Characteristics of and Important Lessons From the Coronavirus  
296 Disease 2019 (COVID-19) Outbreak in China. *JAMA*. 2020;
- 297 8. COVID-19 Dashboard [Internet]. Johns Hopkins University & Medicine, Coronavirus  
298 Resource Centre. 2020 [cited 2020 Apr 6]. Available from:

299 <https://coronavirus.jhu.edu/map.html>

300 9. Obadia T, Haneef R, Boëlle PY. The R0 package: A toolbox to estimate reproduction  
301 numbers for epidemic outbreaks. BMC Med Inform Decis Mak. 2012;

302 10. White PJ. Mathematical Models in Infectious Disease Epidemiology. In: Infectious  
303 Diseases [Internet]. 4th ed. Elsevier; 2017. p. 49-53.e1. Available from:

304 <https://linkinghub.elsevier.com/retrieve/pii/B9780702062858000058>

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308 **Conflict of Interest Statement**

309 All authors have completed the ICMJE uniform disclosure form at  
310 [www.icmje.org/coi\\_disclosure.pdf](http://www.icmje.org/coi_disclosure.pdf) and declare: no support from any organization for the  
311 submitted work; no financial relationships with any organizations that might have an interest  
312 in the submitted work in the previous three years; no other relationships or activities that  
313 could appear to have influenced the submitted work.

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