Journal of Applied and Natural Science
14(2), 469 - 476 (2022)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Mathematical Modeling on the transmission of COVID-19 and its reproduction numbers (R) in SAARC countries

Mohammed Nizam Uddin
Department of Applied Mathematics, Noakhali Science and Technology University, Bangladesh
Sofi Mahmud Parvez
Department of Applied Mathematics, Noakhali Science and Technology University, Bangladesh
H. M. Shahadat Ali
Department of Applied Mathematics, Noakhali Science and Technology University, Bangladesh
Muhammad Samsuddin
Department of Applied Mathematics, Noakhali Science and Technology University, Bangladesh
A.N.M. Rezaul Karim*
Department of Computer Science & Engineering, International Islamic University Chittagong, Bangladesh

*Corresponding author. E mail: zakianaser@yahoo.com

Article Info
https://doi.org/10.31018/jans.v14i2.3398
Received: March 21, 2022
Revised: May 27, 2022
Accepted: June 3, 2022

How to Cite
Uddin, M. N. *et al.* (2022). Mathematical Modeling on the transmission of COVID-19 and its reproduction numbers (R) in SAARC countries . *Journal of Applied and Natural Science*, 14(2), 469 - 476. https://doi.org/10.31018/jans.v14i2.3398

Abstract
In the middle of December 2019, a virus known as coronavirus (COVID-19) generated by severe acute respiratory syndrome corona virus 2 (SARC-CoV-2) was first detected in Wuhan, Hubei Province, China. As of the 9th of March, 2022, spread to over 212 countries, causing 429 million confirmed cases and 6 million people to lose their lives worldwide. In developing countries like the South Asian area, alarming dynamic variations in the pattern of confirmed cases and death tolls were displayed. During epidemics, accurate assessment of the characteristics that characterize infectious disease transmission is critical for optimizing control actions, planning, and adapting public health interventions. The reproductive number (R), or the typical number of secondary cases caused by an infected individual, can be employed to determine transmissibility. Several statistical and mathematical techniques have been presented to calculate (R) across the duration of an epidemic. A technique is provided for calculating epidemic reproduction numbers. It is a MATLAB version of the EpiEstim package's R function estimate R, version 2.2-3. in the South Asian Association for Regional Cooperation (SAARC) countries. The three methodologies supported are 'parametric SI,' 'non-parametric SI,' and 'uncertain SI.' The present study indicated that the highest reproduction number was 12.123 and 11.861 on 5th and 14th March 2020 in India and Sri_Lanka, whereas the lowest reproduction number was the lowest was 0.300 and 0.315 in Sri_Lanka and India. The Maximum and minimum reproductive number of Bangladesh was 3.752 and 0.725. In this study, we have tried to point out the worst, best and current situation of SAARC countries.

Keywords: COVID-19, Estimate, Reproduction number, Transmission

INTRODUCTION

SARC-CoV-2 (severe acute respiratory syndrome corona virus 2) caused by COVID-19 (corona virus disease) turned into a public health emergency of worldwide concern on the 31st of January, 2020, and a pandemic on the 11th of March, 2020, owing to its fast spread and widespread loss. (Rabi *et al.,* 2020; Guan *et al.,* 2020, Sohrabi *et al.,* 2020; Wu *et al.,* 2020; Rahman *et al.,* 2020 and Malik *et al.,* 2020) The corona virus disease 2019 (COVID-19) has turned into a pandemic that is endangering people's lives. Because of differences in policy-making and resource mobilization, epidemic trajectories in various nations varied significantly. (Xu *et al.,* 2020) the 17th of February, 2022, 419,986,713 cases of COVID-19 are confirmed and 5,880,462 people

died around the world because of COVID-19 in accordance with the data from https://www.worldomet ers.info/coronavarius/. COVID-19 has been blasted as a global health issue, producing a big calamity globally, regardless of a country's economic situation, whether it is developed or developing, and without a border. (Nisan, 2020). Though the COVID-19 virus began as an epidemic, it swiftly expanded into a worldwide public health disaster that swept around the globe in a short amount of time, devastating devastation regardless of a country's economic standing, whether developed or developing, and without respect for national borders. (Malik *et al.,* 2020) COVID-19 is a directly transmissible disease that can be spread by the respiratory (aerosol), droplet, orofaecal, or fomite pathways **(**Siordia, 2020). Although different types of vaccines are being given to protect against the coronavirus, and to help prevent infection, it is difficult to fully control the infection. In the present study, the reproduction number of Covid-19 was calculated for the South Asian Region (Uddin *et al.,* 2020). The reproduction number R represents the average number of infections that occur due to the primary infection caused by a single infected person over their contagious period. This statistic is widely used to characterize pathogen transmissibility during an epidemic and is temporal and circumstance specific. Given that the control efforts aimed to lower R below the threshold value of 1 and as near to 0 as feasible, the monitoring of Rover time offers feedback on the success of treatments as well as the need to strengthen control efforts (Anderson *et al.,* 1992; Ferguson *et al.,* 2006; Fraser *et al.,* 2004 and Anderson *et al.,* 1982). The infectious disease dynamics model is commonly used to estimate and forecast the number of infections of contagious diseases such as SARS and the COVID-19 outbreak. (Cori *et al.,* 2009; Fukutome *et al.,* 2007; Fang *et al.,* 2006; Read *et al.,* 2020 and Viegas *et al.,* 2020). This study provides a technique for calculating epidemic reproduction numbers. It is a MATLAB version of the R function estimate R from the EpiEstim package, version 2.2-3(Cori *et al.* 2022). 'Parametric SI', 'non-parametric SI', and 'uncertain SI' are the three approaches presently supported (Milan, 2022). The South Asian Association for Regional Cooperation (SAARC) is a prominent intergovernmental organization and geopolitical union in South Asia (Abdi, 2020; Vickers, 2017; Waris *et al.,* 2020; Bhutta *et al.,* 2020; Jahan *et al.,* 2020; Subbaraman, 2020 and LeVine *et al.,* 2020) Its secretariat is situated in Nepal's Kathmandu. Overall, the SAARC nations account for 3% of the global land area, 21% of the global population, and 4.21 percent (US$3.67 trillion) of worldwide economic output (https://www.officeprimebelem.com.br/blog/3e4690-saarc-chairman). South-East Asian countries reported fewer COVID-19 cases and deaths in 2020 than developed and Western countries (World Health Organization, 2020). The main goal of the present study was to discover the most persuasive demographic parameters linked to COVID-19 and estimate real-time reproduction numbers in the South Asian Association for Regional Cooperation (SAARC).

MATERIALS AND METHODS

Data source

The daily COVID-19 infection case data was collected for South Asian Association for Regional Cooperation (SAARC) nations from the publicly accessible data collection from March 2020 to March 2022 for the present study. The data were collected from https://www.worldometers.info/coronavarius/, a reference website that provided counters and real-time statistics on different topics. The required data was also from https://ourworldindata.org/coronavirus-source-data.

Calculation of reproduction number

Estimate R is a MATLAB translation of elements of the R package EpiEstim, which calculates and estimates the reproduction number of contagious diseases (https://cran.project.org/web/packages/EpiEstim/index.html). The basic structure of the functions was kept as far as practical in the translation, allowing the EpiEstim reference manual to be utilized (Cori *et al.*2022). 'parametric SI', 'non-parametric SI', and 'uncertain SI' are the three techniques now supported. The software was downloaded for free at https://www.mathworks.com/matlabcentral/fileexchange/78760-epidemicr.

In the method "non-parametric SI," the user sets the discrete spreading of the serial interval. In the approach "parametric SI," the user specifies the mean and standard deviation of the serial interval. The serial interval's mean and standard deviation are calculated using truncated normal distributions with values chosen by the user in method "uncertain SI."

RESULTS

The present study showed that India recorded the highest number of infected and death people (427,54,315 and 5,10,413) till 5 March 2022, followed by 14,94,293 and 29,917 in Pakistan, 19,23,031and 28,887 in Bangladesh, 1,71,519 and 7,513 in Afghanistan, 9,74,493 and 11,905 in Nepal, 1,62,169 and 289 in the Maldives, 6,31,816 and 15,899 in Sri-Lanka and 8,297 and 5 in Bhutan respectively and are shown in Table 1. Bhutan is the only country among the SAARC countries that seems to control the COVID-19 epidemic. The highest number of infected people per day in South Asian countries is 4,14,433 in India and 16,230 in Bangladesh (Fig.1) According to country-by-country research, the Maldives had a higher coronavirus affected population

Table 1. Different parameters of COVID-19 cases and deaths of SAARC nations as on the 9th of March, 2022 (https://ourworldindata.org/coronavirus-source-data)

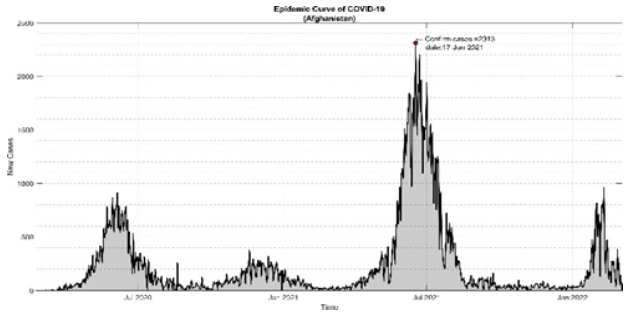
Country	Population	Density	Total COVID-19 cases	Total deaths	Cases per million	Deaths per million	GDP per capita
Afghanistan	39835428	54.422	175000	7626	4393.074	191.438	1803.987
Bangladesh	166303494	1265.036	1947702	29089	11711.732	174.915	3523.984
Bhutan	779900	21.188	15119	7	19385.819	8.976	8708.597
India	1393409033	450.419	42971308	515210	30838.976	369.748	6426.674
Maldives	543620	1454.433	173064	297	318354.733	546.338	15183.616
Nepal	29674920	204.43	977567	11948	32942.532	402.63	2442.804
Pakistan	225199929	255.573	1515392	30281	6729.096	134.463	5034.708
Sri_Lanka	21497306	341.955	650802	16339	30273.654	30273.654	11669.077

Table 2. Current, maximum and minimum reproduction number of Covid-19 and dates of SAARC countries as the 5th of March 2022 (Calculations done by MATLAB using the R package EpiEstim)

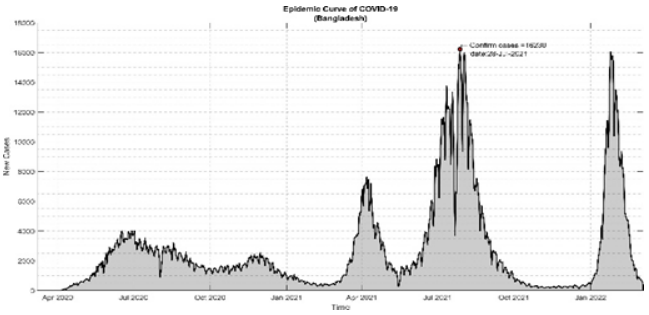
Country Name	Current Reproduction number (R) (95% CI)	Date of Current Reproduction number (R)	Maximum Reproduction number (R)	Date of Maximum Reproduction number (R)	Minimum Reproduction number (R)	Date of Minimum Reproduction number (R)
Afghanistan	0.77839 (CI 0.752213 - 0.804943)	5- Mar-2022	3.212531088	17-Mar-20	0.535482635	26-Aug-21
Bangladesh	0.521055 (CI 0.514541 - 0.527605)	5- Mar-2022	3.751980064	10-Apr-20	0.516294466	4-Mar-22
Bhutan	1.01686 (CI 0.993111 - 1.04084)	5- Mar-2022	12.12329919	5-Mar-20	0.315442953	1- Mar-2020
India	0.570676 (CI 0.568291 - 0.573065)	5- Mar-2022	12.1232992	5-Mar-20	0.315442954	1-Mar-20
Maldives	0.796477 (CI 0.782209 - 0.810853)	5- Mar-2022	5.835846008	20-Apr-20	0.523110124	16-Jun-20
Nepal	0.567612 (CI 0.548069 - 0.587442)	5- Mar-2022	9.987429042	24-Mar-20	0.467940925	25-Feb-22
Pakistan	0.645879 (CI 0.637507 - 0.654297)	5- Mar-2022	8.343200126	17-Mar-20	0.645879145	5-Mar-22
Sri_Lanka	0.881478 (CI 0.869538 - 0.893487)	5- Mar-2022	11.8612048	14-Mar-20	0.300617943	27-Jul-20

cases and fatalities per million populations than other nations. On the other hand, Bhutan had the fewest COVID-19 instances and fatalities compared to other nations, with only 19 cases and deaths (Table 1). Bhutan reported the fewest COVID-19 instances (n = 8297) whereas India reported the most (n = 427, 54,315). Nepal had the lowest number of illnesses and fatalities per million people among the countries that imposed the countrywide lockdown.

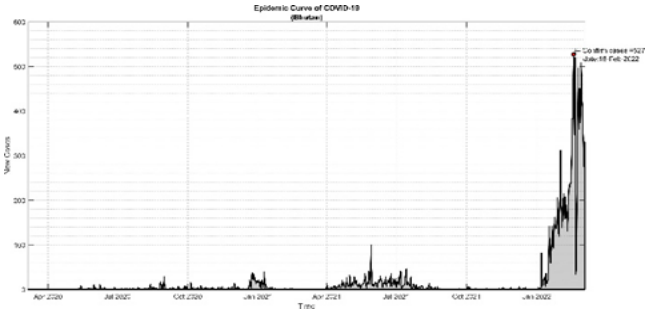
Limited lockdowns have been implemented in Pakistan, Bangladesh, Afghanistan, and the Maldives, while a countrywide lockdown had been imposed in India and Nepal. On the 30th of January, 2020, India announced its first positive case of SARS-CoV-2, prompting a countrywide lockdown on the 25th of March, 2020. Sri Lanka, an island nation, had imposed quarantine and curfews. The reproduction rate decreased and increased for several periods among the SAARC countries. In the early stages of the pandemic in SAARC countries, the highest reproduction number R detected in India was12.1233 The current value is 0.570676 The highest reproduction number for Bangladesh was 3.752 and current value is 0.77839 (Table 2, Fig. 2). The current value of the reproduction number of Afghanistan, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka is 0.77839, 1.01686, 0.796477, 0.567612,



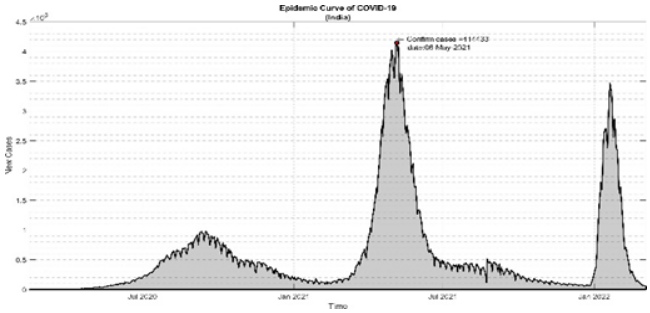
1.1. *Cases of Covid-19 in SAARC countries confirmed daily of Afghanistan as of the 5th of March, 2022. Redpoint indicates the highest confirmed cases 2313 in one day and it was 17-Jun-2021*



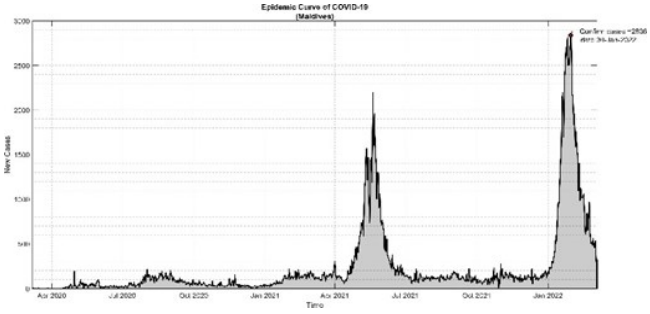
1.2. *Cases of Covid-19 in SAARC countries are confirmed daily in Bangladesh as of the 5th of March, 2022. Redpoint indicates the highest confirmed cases 16230 in one day and it was 28-Jul-2021*



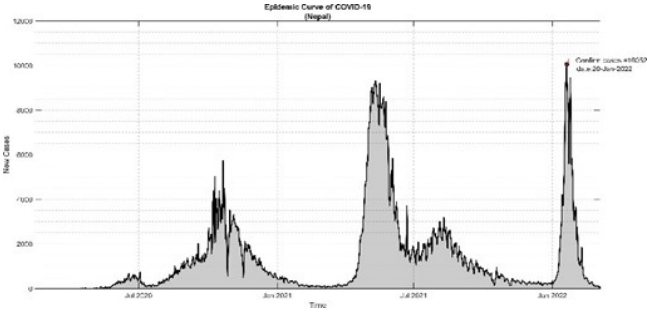
1.3. *Cases of Covid-19 in SAARC countries are confirmed daily in Bhutan as of the 5th of March, 2022. Red point indicates the highest confirmed cases 527 in one day and it was 18-Feb-2022.*



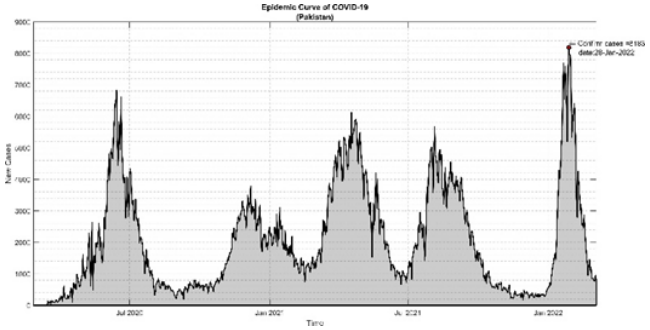
1.4. *Cases of Covid-19 in SAARC countries are confirmed daily of India as of the 5th of March, 2022. Red point indicates the highest confirmed cases 414423 in one day and it was 06-May-2021*



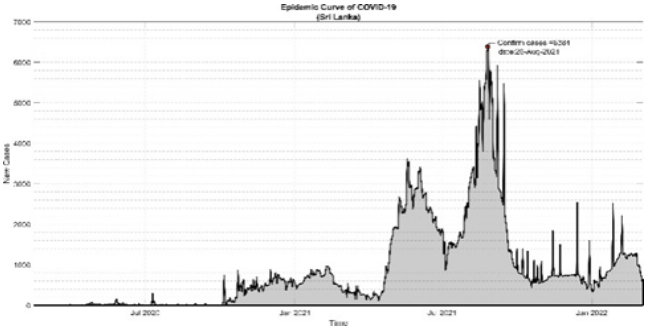
1.5. *Daily confirmed cases of Covid-19 of Maldives as of the 5th of March, 2022. Red point indicates the highest confirmed cases of 2838 in one day and it was 30-Jun-2022.*



1.6. *Daily confirmed cases of Covid-19 of Nepal as of the 5th of March, 2022. Red point indicates the highest confirmed cases of 10052 in one day and it was 20-Jan-2022.*

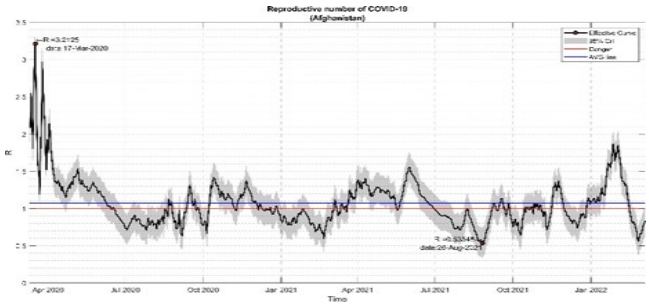


1.7. *Cases of Covid-19 in SAARC countries are confirmed daily in Pakistan as of the 5th of March, 2022. Red point indicates the highest confirmed cases 8183 in one day and it was 28-Jan-2022*

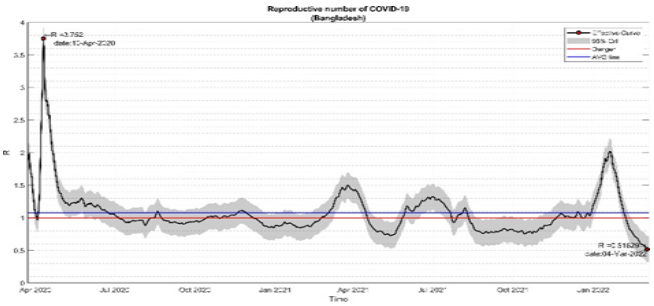


1.8. *Cases of Covid-19 in SAARC countries confirmed daily in Sri_Lanka as of the 5th of March, 2022. Red point indicates the highest confirmed cases 6384 in one day and it was 26-Aug-2021*

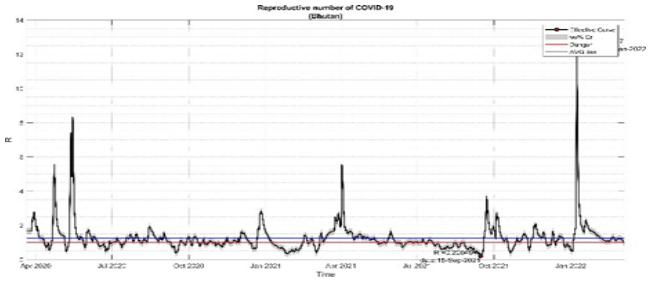
Fig. 1. *Cases of Covid-19 in SAARC countries confirmed on a daily basis. (https://ourworldindata.org/coronavirus-source-data)*



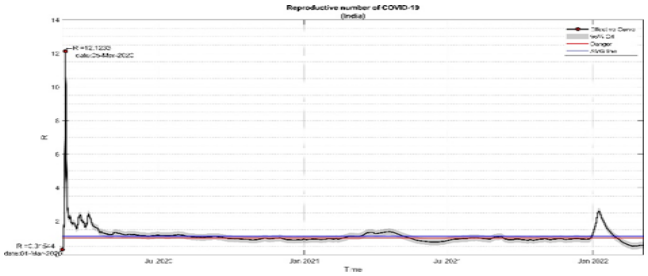
2.1. *Reproduction number of COVID-19 for Afghanistan from March 2020 to March 2022. The blue line represents the reproduction number's mean value, while the red line represents the measurement line where the reproduction number's value equals 1*



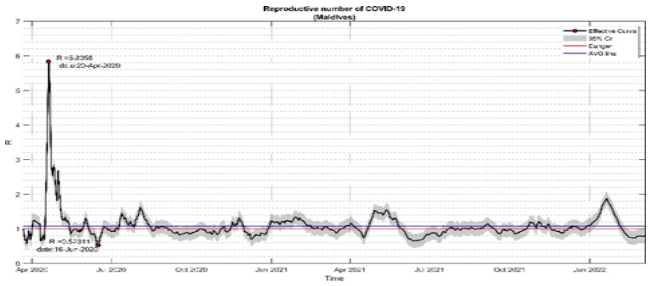
2.2. *Reproduction number of COVID-19 for Bangladesh from March 2020 to March 2022. The blue line represents the reproduction number's mean value, while the red line represents the measurement line where the reproduction number's value equals 1.*



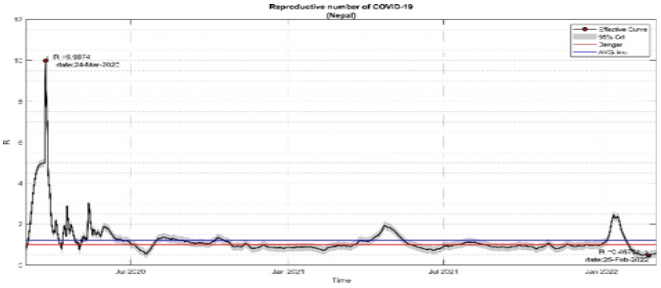
2.3. *Reproduction number of COVID-19 for Bhutan from March 2020 to March 2022. The blue line represents the reproduction number's mean value, while the red line represents the measurement line where the reproduction number's value equals 1.*



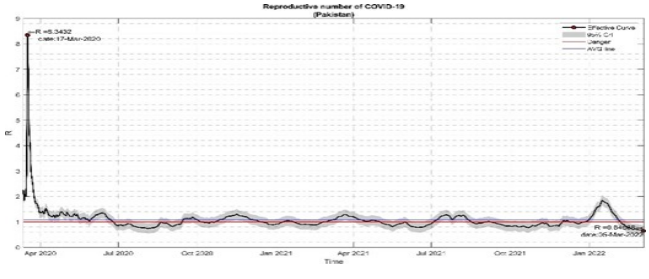
2.4. *Reproduction number of COVID-19 for India from March 2020 to March 2022. The blue line represents the reproduction number's mean value, while the red line represents the measurement line where the reproduction number's value equals 1.*



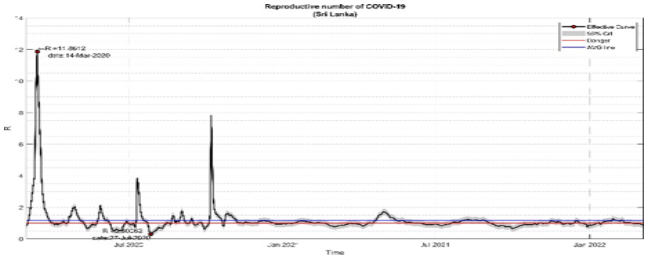
2.5. *Reproduction number of COVID-19 for the Maldives from March 2020 to March 2022. The blue line represents the reproduction number's mean value, while the red line represents the measurement line where the reproduction number's value equals 1.*



2.6. *Reproduction number of COVID-19 for Nepal from March 2020 to March 2022. The blue line represents the reproduction number's mean value, while the red line represents the measurement line where the reproduction number's value equals 1*



2.7. *Reproduction number of COVID-19 for Pakistan from March 2020 to March 2022. Here blue line indicates the mean value of the reproduction number and the red line specifies the measurement line where the value of the reproduction number is 1.*



2.8. *Reproduction number of COVID-19 for Sri_Lanka from March 2020 to March 2022. Here blue line indicates the mean value of the reproduction number and the red line specifies the measurement line where the value of the reproduction number is 1.*

Fig. 2. *Reproduction number of COVID-19 for SAARC countries*

Table 3. Statistical analysis of COVID-19 South Asian Association for Regional Cooperation (SAARC) countries as of March 2022

Country Name	Number of Observations	Degree of Freedom	RMSE	R^2	Adjusted R -Squared	F-Statistic vs Zero Model	p-value
Afghanistan	740	736	371.892	0.047	0.041	12.5651	5.10524e-08
Bangladesh	728	724	3326.13	-0.037	-0.043	61.226	2.76491e-35
Bhutan	730	726	71.0609	-0.085	-0.091	19.2687	4.96915e-12
India	767	763	3626.13	-0.029	-0.023	63.226	2.56491e-35
Maldives	729	725	535.619	-0.396	-0.403	60.2701	8.54153e-35
Nepal	713	709	1695.24	0.245	0.24	196.449	1.03306e-92
Pakistan	739	735	1952.93	-0.316	-0.323	155.132	6.91045e-78
Sri_Lanka	725	721	723.126	0.605	0.603	435.928	1.83455e-161

0.645879 0.881478, respectively.

Table 3. lists the statistical parameters for each country, including coefficient of determination, corrected p-value, root mean square error (RMSE), and F-statistics VS Zero model. For most nations, the coefficient of determination and p-value of the model is near to 1 and 0, indicating that the finding is statistically significant.

DISCUSSION

The COVID-19 epidemic had caused a massive global outbreak, necessitating regional, national, and global responses. Because of their large populations, inadequate general and health-care facilities, and weak monitoring, South Asian countries are especially vulnerable to the pandemic. South Asian countries have all taken safeguards by establishing social distance. i.e., physical distance and travel restrictions or prohibitions for both forward and return travel by air, sea, or land. To address the COVID-19 pandemic public health calamity, the Indian government took the lead in establishing the SAARC nations' emergency fund (Sharma *et. al.,* 2020). India was the first SAARC country to record a case on January 30, 2020, and the virus has been rapidly spreading across the country since then (Malik *et. al.,* 2021). The first case of COVID-19 in Bangladesh was verified on March 8, 2020. Bangladesh has to deal with the collapse of its healthcare system and ordinary social life as a densely populated country (Rahman *et. al.,* 2020). While Pakistan's first two cases of the coronavirus were verified on February 26, 2020 (a student in Karachi who had recently give back from Iran and another one in the Islamabad Capital Territory), the disease has since spread throughout the country.

The significance of the reproduction number (R) is that it assists governments in estimating and strategizing fast in order to avoid any undesirable conditions. The reproductive number (R) is dependent on numerous factors including i) the infected population's contact rate; ii) the probability of contagion transmission during interaction; iii) the longevity of the infection (Greenland *et al.,* 2013) When control measures are implemented, the vary over time and typically decreases. Unless adequate control measures are put in place, the pandemic will be self-sustaining. suggest that the prevalence of new cases would decline over time, and the outbreak will finally end.

The initial reproduction number of COVID-19 was 3.212531088, 3.751980064, 12.12329919, 12.1232992, 5.835846008, 9.987429042, 8.343200126, 11.8612048 in Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka respectively.

The current situation of COVID-19 epidemic is improving day by day, especially in South Asian countries. In this paper. in this paper, we recorded the highest reproduction number of COVID-19 was 12.123 while the present reproduction number is 0.57 in India. At present the reproduction number of Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka is $0.77839\ (CI\ 0.752213\ -\ 0.804943)$, $0.521055\ (CI\ 0.514541\ -\ 0.527605$), $1.01686\ (CI\ 0.993111\ -\ 1.04084)$, $0.796477\ (CI\ 0.782209\ -\ 0.810853)$, $0.567612\ (CI\ 0.548069\ -\ 0.587442)$, $0.645879\ (CI\ 0.637507\ -\ 0.654297)$ and $0.881478\ (CI\ 0.869538\ -\ 0.893487)$. It was observed that all of reproduction number of these countries is below 1 that indicates the epidemic situation is going on better situation. Countries have now lifted all restrictions imposed to prevent the COVID-19 pandemic like as lockdown, stop social gathering, educational institution closed etc. and people are slowly returning to their normal lives. The biggest reason behind this improvement

is to vaccinate properly.

Conclusion

The SAARC region is one of the world's most densely inhabited areas. It is very vulnerable to any large-scale disease pandemic due to its low health structure and level of development. The SAARC countries used different tactics to limit the current COVID-19 pandemic's transmission and spread. Bhutan, Afghanistan, Bangladesh, and the Maldives all fared better under a country-wide shutdown, whereas Sri Lanka did not. According to the latest statistics, the present study concluded that the estimate R for COVID-19 in SAARC countries by MATLAB translation of parts of the R package EpiEstim indicated that in the present image, the reproduction number of COVID-19 in the SAARC area has been steadily declining and it is less than one indicating that the Covid-19 situation of SAARC countries going on better. Proper vaccination and public education against COVID-19 might assist in putting a stop to the COVID-19 epidemic. Finally, for proper planning and care in the coming days, a better knowledge of the worldwide epidemiology of COVID-19, ongoing monitoring, and greater population screening and testing with transparent and accurate reporting of patient features are necessary.

Conflict of interest

The authors declare that they have no conflict of interest.

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