R_0 values, daily incidences, and daily Deaths

***$R_0 \leq 1 \Rightarrow$* Epidemic is under control. Numbers of susceptible population are less and the peak, in daily incidences, has already appeared in those cases**

India:

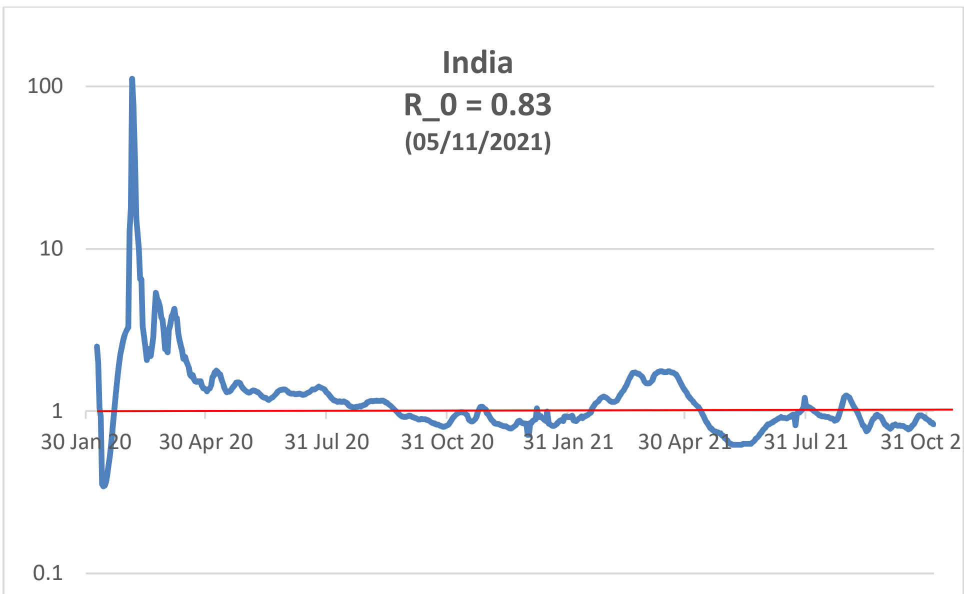

Fig. A: *Evolution of basic reproduction rate (R_0) with time. The red horizontal line indicates $R_0 = 1$.*

24th September 2021	28th September 2021	5th October 2021	11th October 2021	15th October 2021	20th October 2021	24th October 2021	28th October 2021	2nd November 2021	5th November 2021
0.93	0.86	0.82	0.81	0.79	0.82	0.92	0.93	0.87	0.83

Table 2: Past values of R_0 for India.

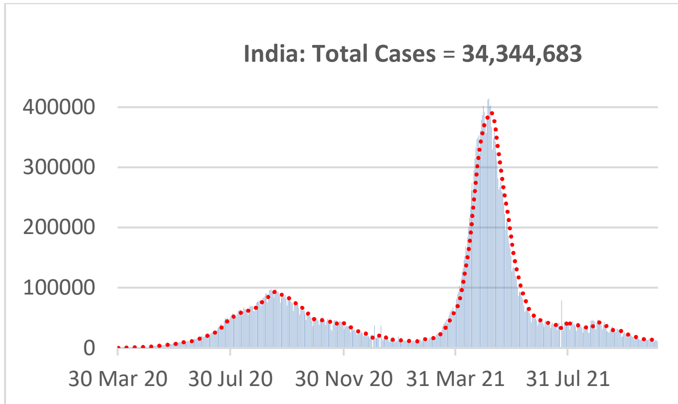

Fig. B: *Daily new cases (*last updated on 5th November, 2021). Red dotted line shows trend (5 days rolling average) of the curve.

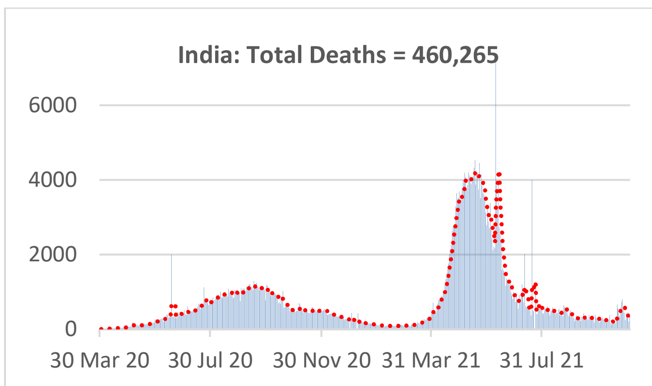

Fig. C: *Daily new deaths (*last updated on 5th November, 2021). Red dotted line shows trend (5 days rolling average) of the curve.

West Bengal:

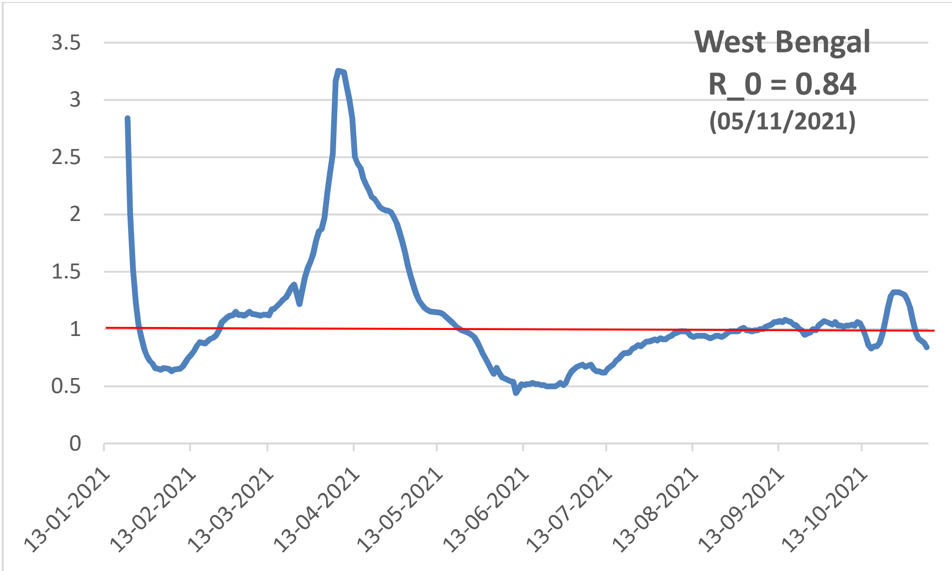

Fig. D: *Evolution of basic reproduction rate (R_0) with time. The red horizontal line indicates R_0 = 1.*

22nd August 2021	28th September 2021	4th October 2021	11th October 2021	14th October 2021	20th October 2021	23rd October 2021	27th October 2021	1st November 2021	5th November 2021
0.95	**0.91**	**1.03**	**1.06**	**0.93**	**0.96**	**1.29**	**1.31**	**0.97**	**0.84**

Table 3: Past values of R_0 for West Bengal.

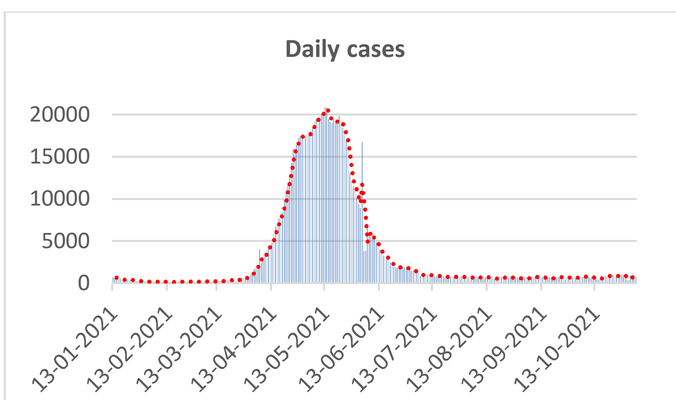

Fig. E: (For West Bengal) *Daily new cases*. Red dotted lines show trend (3 days rolling average) of the curve.

Supplementary Information: India

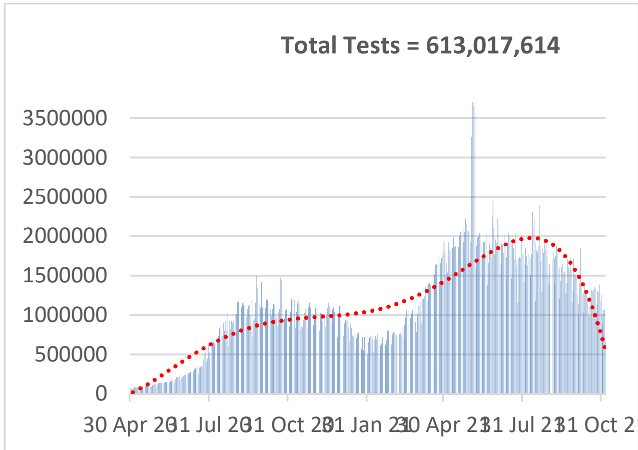

Fig.I: *Daily new clinical tests (*last updated on 5th November, 2021*)*. Red dotted line shows trends of the curve.

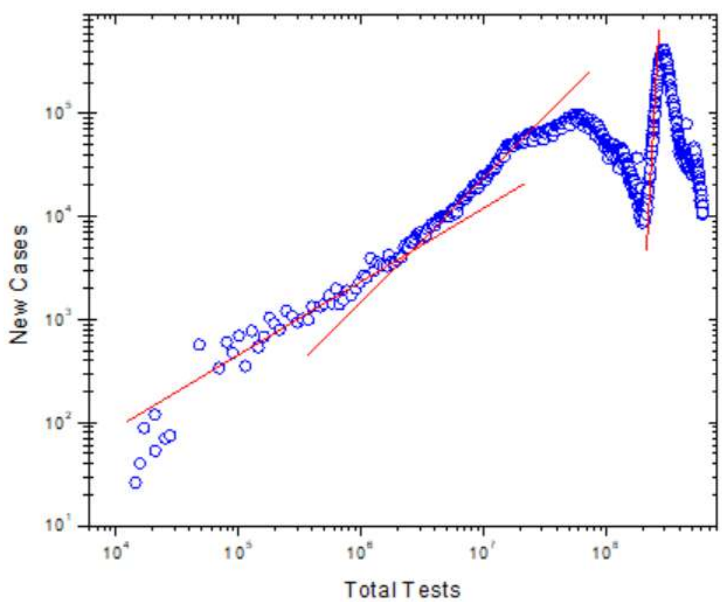

Fig.II: *Daily new cases vs. total tests*. Red continuous lines are guide to eyes (last updated on 5th November, 2021).

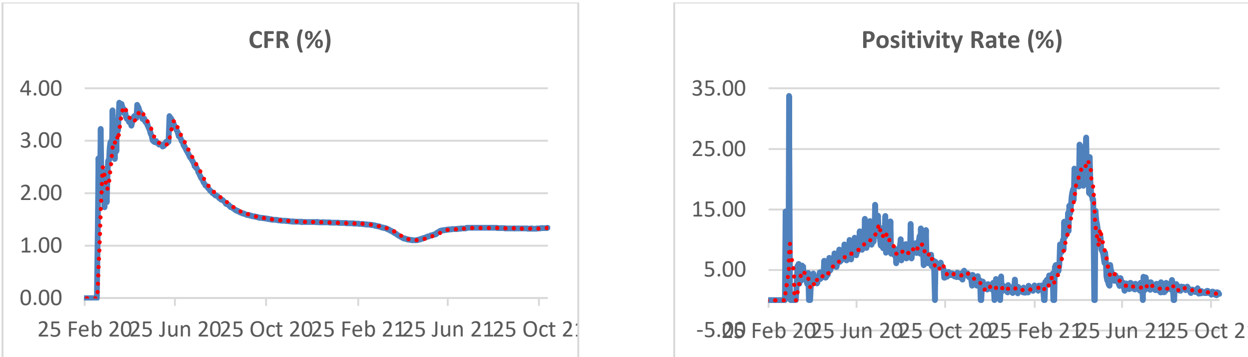

Fig.III: *Left: Case Fatality Ratio (CFR), defined as the ratio of total deaths to total cases (*last updated on 5th November, 2021); *Right: Positivity rate, defined as ratio of daily new cases to daily new tests (*last updated on 5th November, 2021*). Red dotted lines show trend (5 days rolling average) of the curve*.

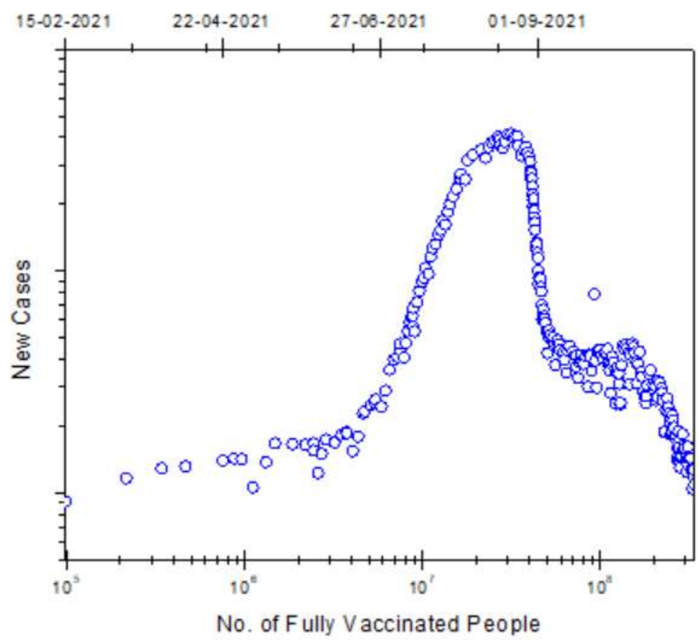

Fig.IV: Daily new cases with respect to number of fully vaccinated population (last updated on 5th November, 2021).

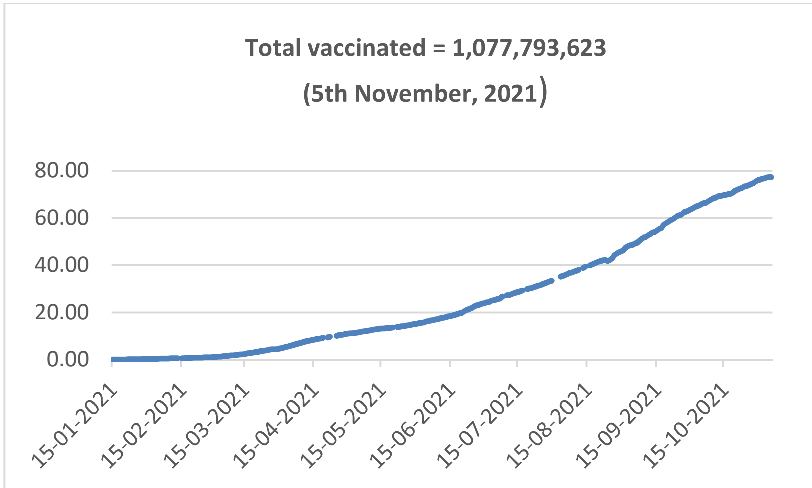

Fig.V: Total (includes both 1st and 2nd) v*accination per 100 person*.

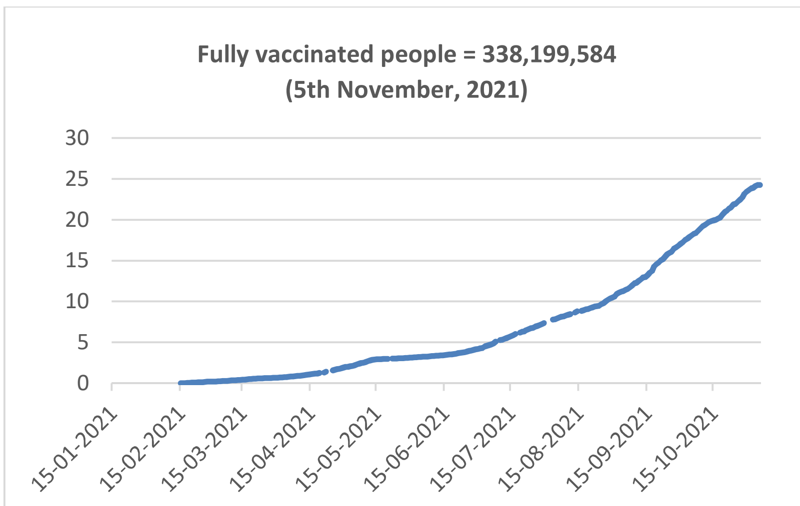

Fig.VI: Fully v*accination per 100 person*.

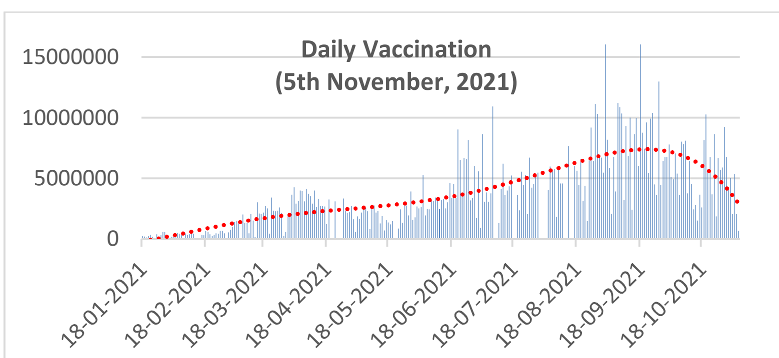

Fig.VII: Daily vaccination. Red dotted line shows trends of the curve.

Estimation of *R-zero* from Global Data: An Initial Case Study

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Abstract:

Based on the data available till 22nd April 2020, the basic reproduction rates, R_0, have been reported across the continents. R_0 is an epidemiological metric used to explain transmissibility of the disease from one person to others. It is a function of various socio-behavioral factors, and its estimation requires a complex mathematical modeling. Evaluation of R_0 is dependent on underlying structures and assumptions of the model used. Our results show a wide range of R_0 which, to some extent, reflects measures adopted by respective countries to curb it. An updated result of evolution of R_0 with time for different countries is depicted in table 1. Another table, table 2, contains R_0 data for India from 25th August onwards. Supplementary information has also been provided at the end.

Introduction:

Outbreak of COVID-19 poses a great threat to the present world. Hundreds of thousands of cases are being reported globally and nations are working round-the-clock in a war-like situation to tackle it. Lockdown has been imposed in several countries and organizations like National Health System (NHS, UK), Johns Hopkins University (JHU, USA), World Health Organization (WHO), etc. are constantly updating current situation. Scholars around the world are trying to model the pandemic- mainly to predict growth rates and to assess probable duration of the pandemic. Modeling infections are important not only for academicians but also for taking effective measures for authorities concerned.

Modeling is also an important tool to track situations. Through modeling one can look for different parameters and study their trends. One of the important parameters is the basic reproduction ratio, denoted by R_0 (R-zero). It is not a biological constant for a pathogen. The formal definition of R_0 is the average number of secondary cases produced by a single infected case in otherwise susceptible population. For example, if the R_0 for measles in a population is 15, then one can expect that each new case of measles would generate, on an average, 15 new secondary cases (assuming everyone around the case was susceptible).

R_0 is an important yardstick to study the progression of an infectious disease; to know how it varies with time in different geographies and what containment measures one should take into account are. In general, for an epidemic to occur in a susceptible population R_0 must be >1, implying that the number of cases will be increasing. When R_0 is equal or less than 1, then it implies the epidemic is under control. The value of R_0 is quite important for organizations like drug-makers, public health officials as it informs them about the urgency they need to employ to avoid the worst case scenario.

Methodology:

R_0 cannot be measured directly. Values of R_0 are usually estimated from mathematical models, and the estimated values are dependent on models and values of the parameters used. R_0 is affected by several factors including the duration of infectivity of affected patients, the infectiousness of the organism, and the number of susceptible people in the population that the affected patients are in contact with.

The mathematical model used here is based on what is described in the article of Wallinga & Teunis [1]. Methodology includes Bayesian framework for analytical estimation of instantaneous reproduction numbers over different time period. It is quite generic and requires only case incidence data (number of cases/ day), I_t, and the distribution of the serial incidence/ interval, w_s (also known as probability distribution of infectivity function). The serial interval is defined as the time between the onset of symptoms in a primary case and the onset of symptoms of secondary cases.

The R_0 at time t is defined as: $R_0(t) = R_t$, can be estimated from the following equation:

$$E[I_t] = R_t \sum_{s=1}^{t} I_{t-s} w_s \qquad (1)$$

Where $E[X]$ denotes the expectation value of a random variable X. We obtained the mean R_t by averaging transmissibility over a time window [t-τ+ 1; t]. In our case τ = 7, i.e. averaging is over one week window.

The estimation of infectivity distribution is the following. w_s can be obtained after evaluating the shifted gamma function.

$$\begin{aligned} w_k &= k * F_{\Gamma,a,b}(k) + (k-2) * F_{\Gamma,a,b}(k-2) - 2 * (k-1) * F_{\Gamma,a,b}(k-1) \\ &\quad + ab\left(2F_{\Gamma,a+1,b}(k-1) - F_{\Gamma,a+1,b}(k-2) - F_{\Gamma,a+1,b}(k)\right) \end{aligned} \qquad (2)$$

Where $F_{\Gamma,a,b}$ is the cumulative density function of a Gamma distribution with parameters (a, b). One can estimate the value of R after putting these values in equation (1). From now on we will use R_0 and R interchangeably.

Calculations have been carried out in Microsoft Excel (Microsoft Corporation, Redmond, Washington) spreadsheet using the prescription given by Cori et al., in the reference [2, 3, 4]. The values of R_0 mentioned everywhere are *posterior median obtained within 95% credible interval and is averaged over a window of time (7 days)*.

Observations:

We have chosen selected countries across geographies. Main emphasis was on the countries of Europe and Asia. Data was collected from "Our World in Data" (https://ourworldindata.org/coronavirus-data). The original data belong to "European Centre for Disease Prevention and Control" (https://www.ecdc.europa.eu/en). The lists of countries selected are the following:

AFRICA:

Consolidated data of different African countries have been selected.

ASIA:

List of countries:

1. India
2. Singapore
3. South Korea
4. Israel
5. China

EUROPE:

List of countries:

1. France
2. Germany
3. UK
4. Italy
5. Iceland
6. Russia
7. Sweden

OCEANIA & AUSTRALIA:

1. Australia
2. New Zealand

NORTH & SOUTH AMERICA:

1. Brazil
2. Canada
3. Mexico

ASIA:

INDIA:

India is one of the most densely populated countries in South-East Asia. Considering its infrastructure and inadequate medical support system, apprehensions are there that the outbreak will be quite disastrous. Almost all states across India have been suffered by coronavirus. So far, the situation is well under control. In a silver lining, Goa and Manipur have declared themselves as Coronavirus-free states. India is under lockdown till May 3. The value of R_0, in figure 3, as on 22nd April is 1.53. Efforts are being made to reduce the R_0 value below 1. The black arrow indicates the starting of the lock down from 84th day (24th March, 2020).

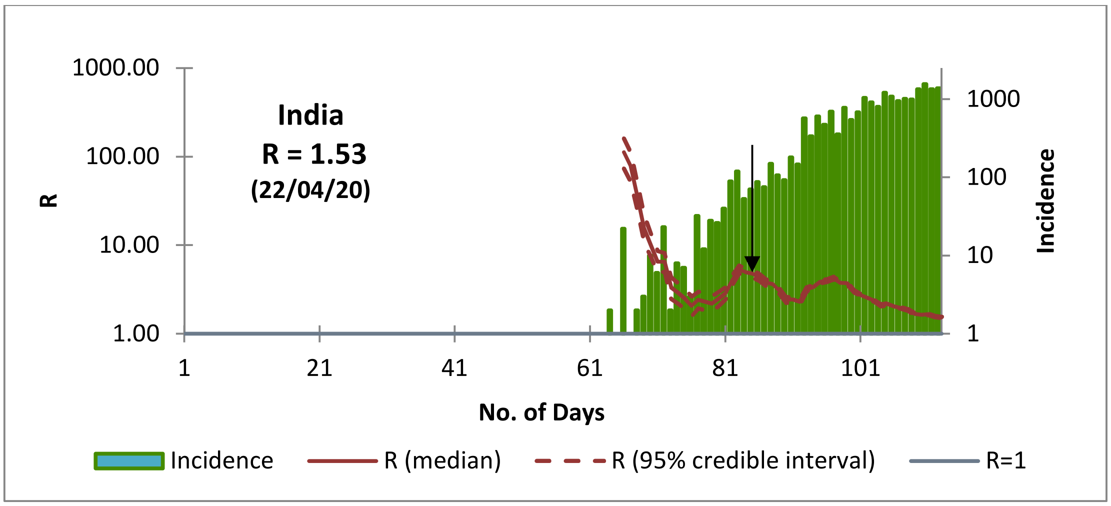

Fig.1: *Incidence number per day and corresponding basic reproduction number for India. The arrow indicates the onset of lockdown (24th March, 2020).*

SINGAPORE:

Authorities have managed to contain the spread of the virus by rigorous contact tracing and surveillance. The initial R_0values, as is shown in figure 4, indicates that they could managed to bring it below 1, but presently it is showing an increasing trend. The present value of R_0 is 3.46. This could be attributed to more reporting of new cases and relaxation of restriction norms.

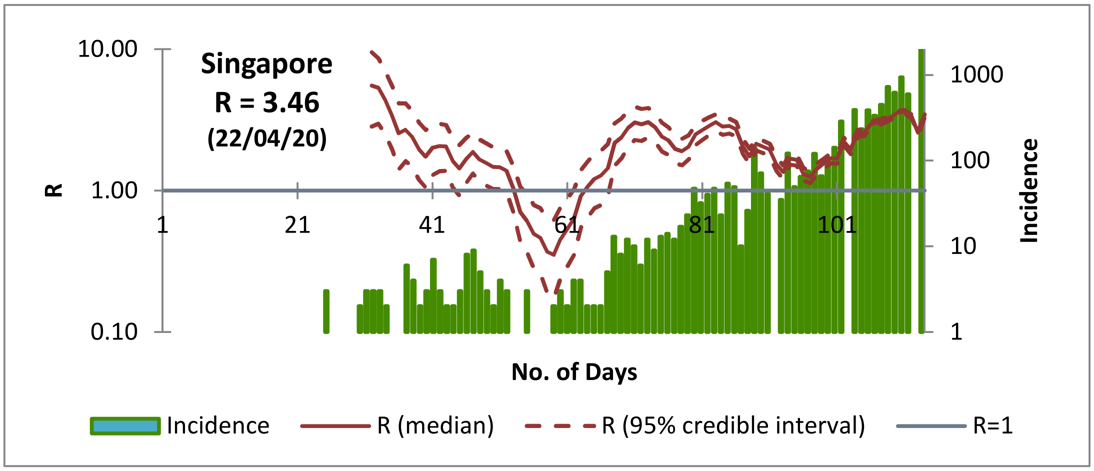

Fig.2: *Incidence number per day and corresponding basic reproduction number for Singapore.*

ISRAEL:

It is evident from the figure 5 that the peak has already appeared in incidence curve. This is also reflecting in the low R_0 value. The Israeli government approved a series of steps to ease the lockdown restrictions, including allowing group prayer, partial reopening of the economy and certain stores.

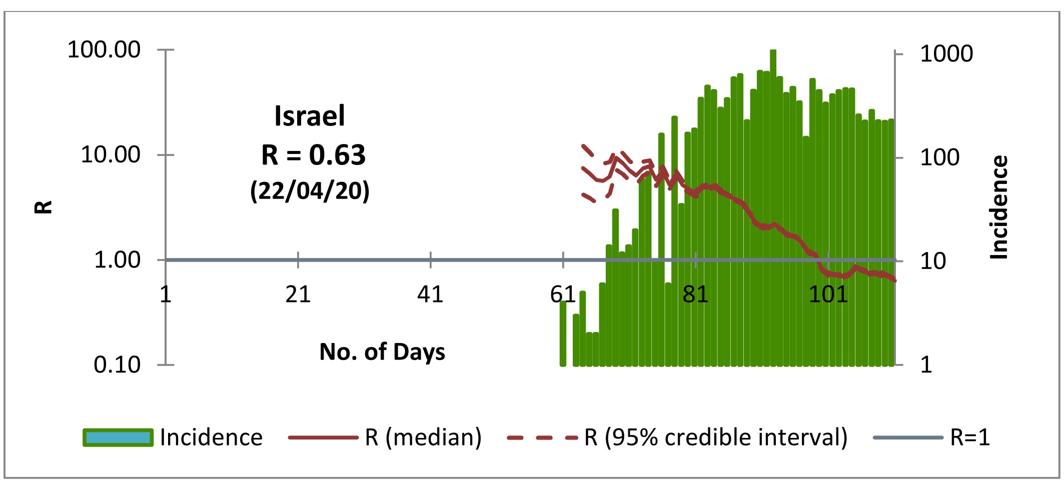

Fig.3: *Incidence number per day and corresponding basic reproduction number for Israel*.

SOUTH KOREA:

South Korea is one of the few countries that tackle the situation very efficiently. Although the rapidity with which COVID-19 took hold in South Korea initially surprised people, well-established strategies were soon put into place. The present R_0 value is substantially low (see figure 6). One may notice the appearance of a weak second hump in the incidence plot.

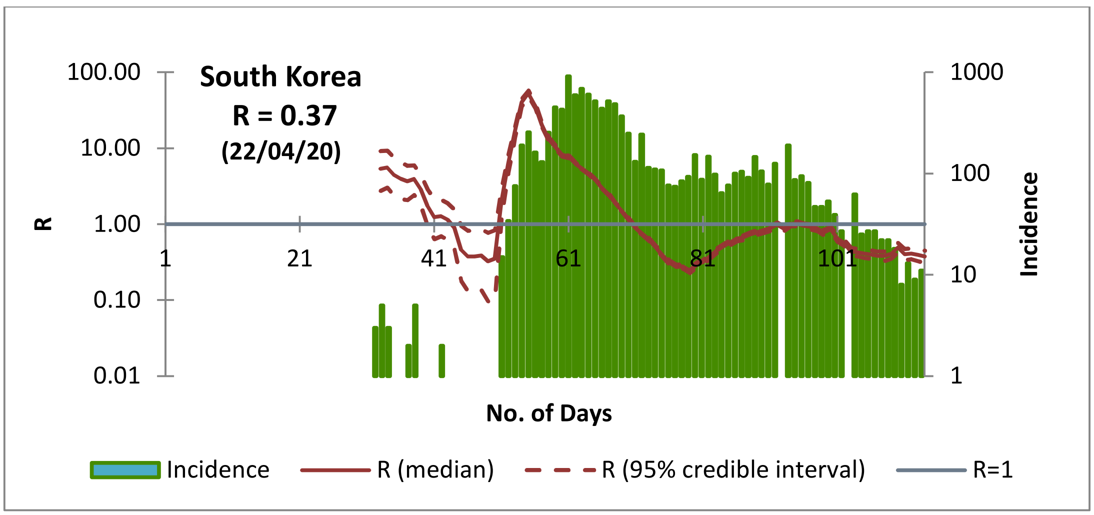

Fig.4: *Incidence number per day and corresponding basic reproduction number for South Korea*.

CHINA:

China was the first country to report COVID-19 outbreak. Initially, it tried to hide the outbreak. Later it managed to contain the situation by imposing stringent lockdown. The success of those measure was reflected in substantially lower R_0 (~ 0.1) around 75th days in the graph 7. However, R_0 again increased to around 0.86 once lockdown condition was relaxed. A more prominent second peak is observed in incidence data.

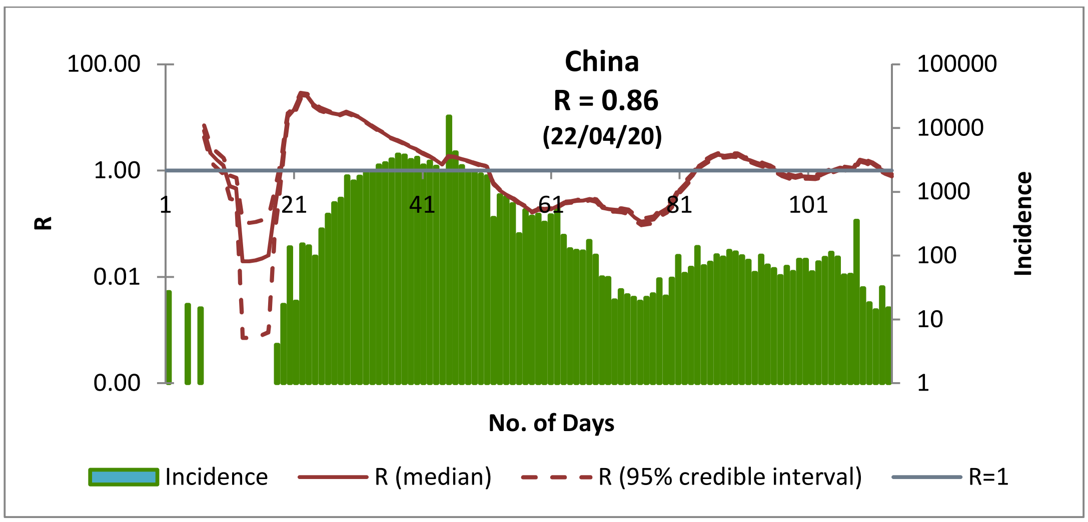

Fig.5: *Incidence number per day and corresponding basic reproduction number for China*.

AFRICA:

In Africa, the virus has spread to dozens of countries within weeks. Governments and health authorities are striving to limit widespread infections. Many African countries are in shut down in efforts to contain the spread of this disease. The aggregated values are shown in figure 1. The green bars indicate number of incidence per day and the red solid line is the posterior median value of R_0. The dashed lines indicate the 95% confidence interval. The present R_0 value estimated is 1.47.

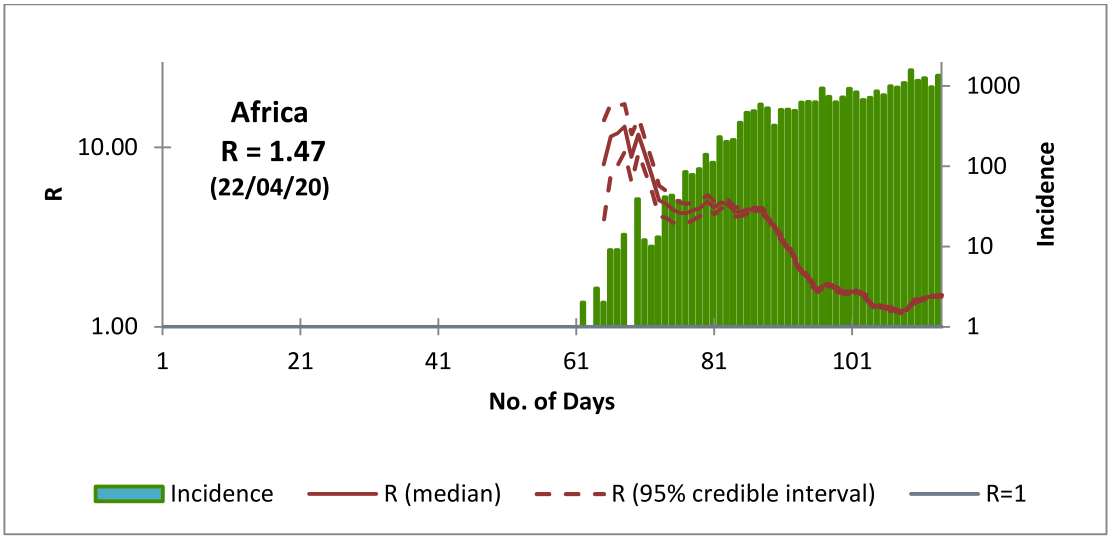

Fig.6: *Incidence number per day and corresponding basic reproduction number for Africa*.

The solid continuous line in figure 2 indicates the serial interval distribution obtained from equation 2.

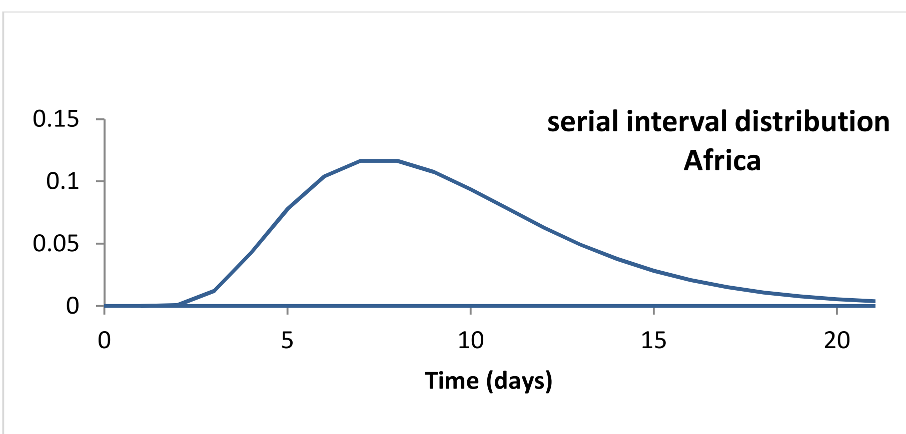

Fig.7: *Serial interval distribution of Africa*.

EUROPE:

The cases of selected countries in Europe are the following:

FRANCE:

The incidence curve seems to pass its peak and R_0 value is below unity (figure 8). President Emmanuel Macron announced that the total lockdown measures enforced since 17 March will be gradually lifted on 11 May. Restaurants, cafés, museums and other cultural venues will, however, remain closed.

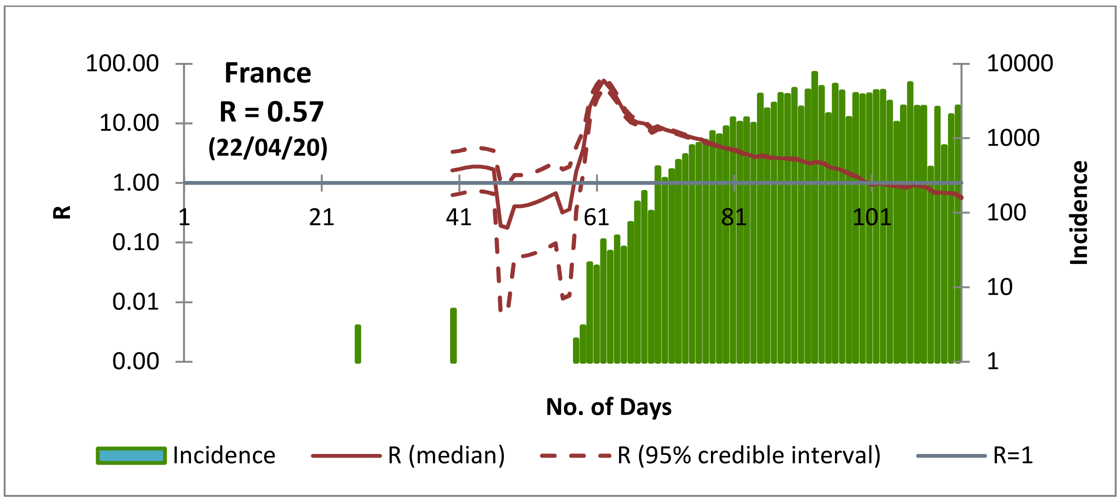

Fig.8: *Incidence number per day and corresponding basic reproduction number for France*.

GERMANY:

Germany has the fourth-highest number of cases in Europe behind Spain, Italy and France. R_0 value is 0.68 (figure 9) and number of case is decreasing. Apparently, peak has already appeared in figure 9.

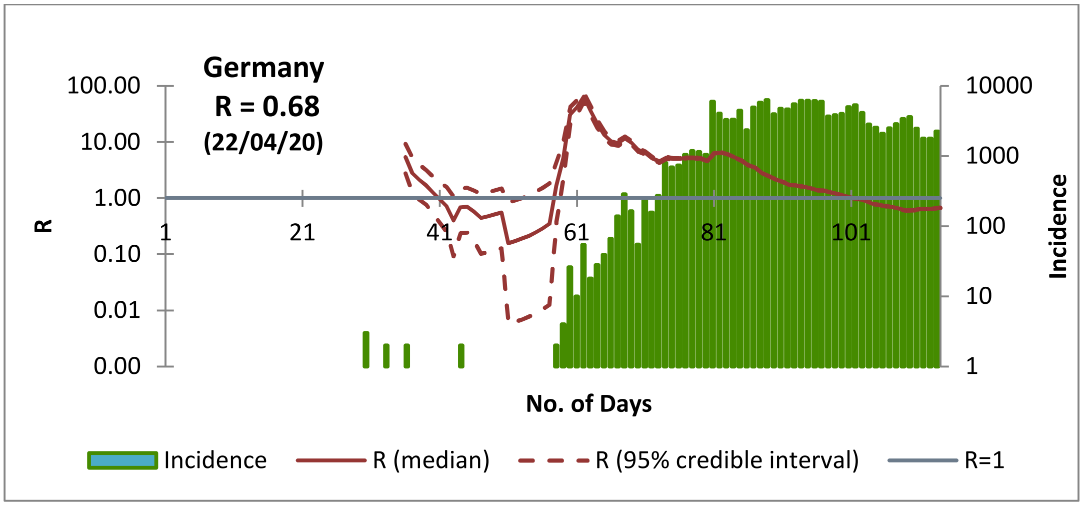

Fig.9: *Incidence number per day and corresponding basic reproduction number for Germany*.

SWEDEN:

Sweden has left its schools, gyms, cafes, bars and restaurants open throughout the spread of the pandemic. Instead, the government has urged its citizens to act responsibly and follow social distancing guidelines. The R_0 value shows steady decreasing trends and reaches quite close to 1 (figure 10).

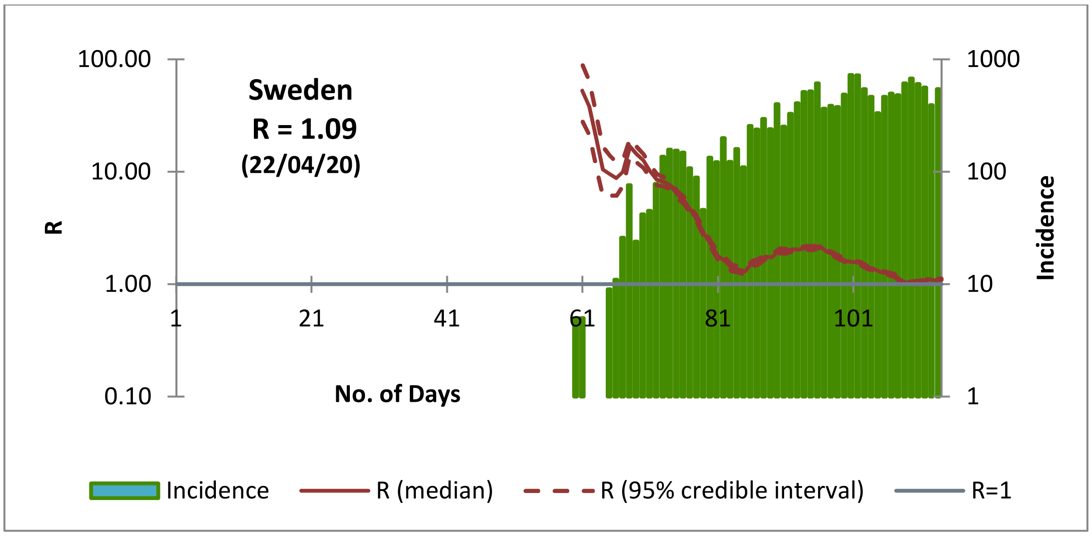

Fig.10: *Incidence number per day and corresponding basic reproduction number for Sweden*.

ITALY:

Italy is the one of the most affected countries and became the second hotspot after China. Initially, they showed a very casual approach. Later, however, they have enforced stringent restriction norms. The curve (figure 11) has started its descent and the number of deaths has started to drop. They somehow succeeded to bring R_0 value below unity.

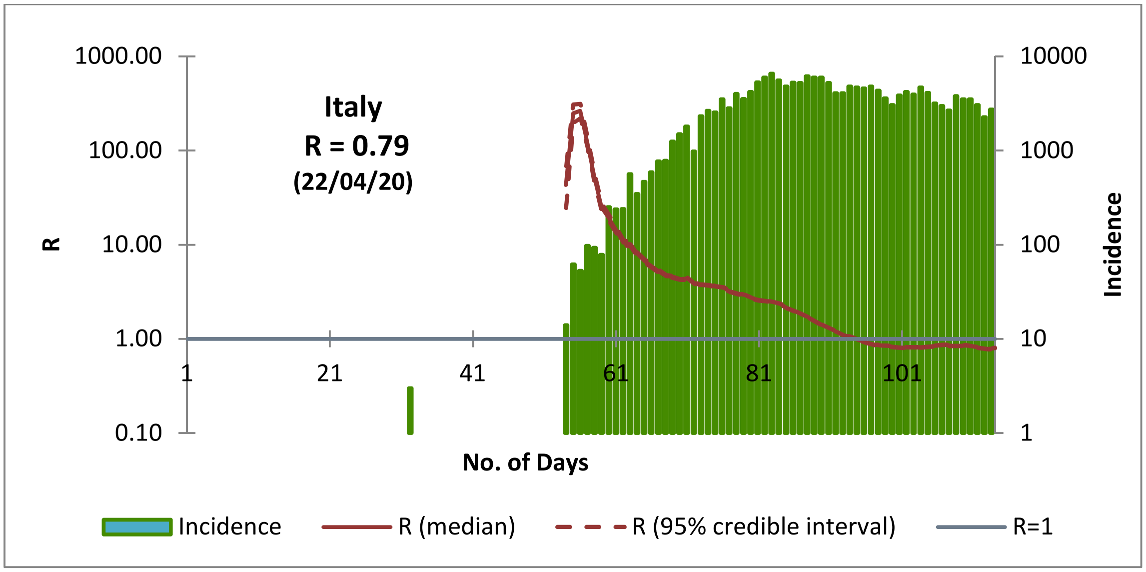

Fig.11: *Incidence number per day and corresponding basic reproduction number for Italy*.

UNITED KINGDOM:

The UK has been in lockdown, with restrictions on leaving the house except for essential reasons in force since March 23.As the numbers of new cases start to plateau, the government is now turning to the next part of its strategy to combat the virus through test, track and trace. The value of R_0 is found to decrease steadily and has reached a value around 0.99 (figure 12).

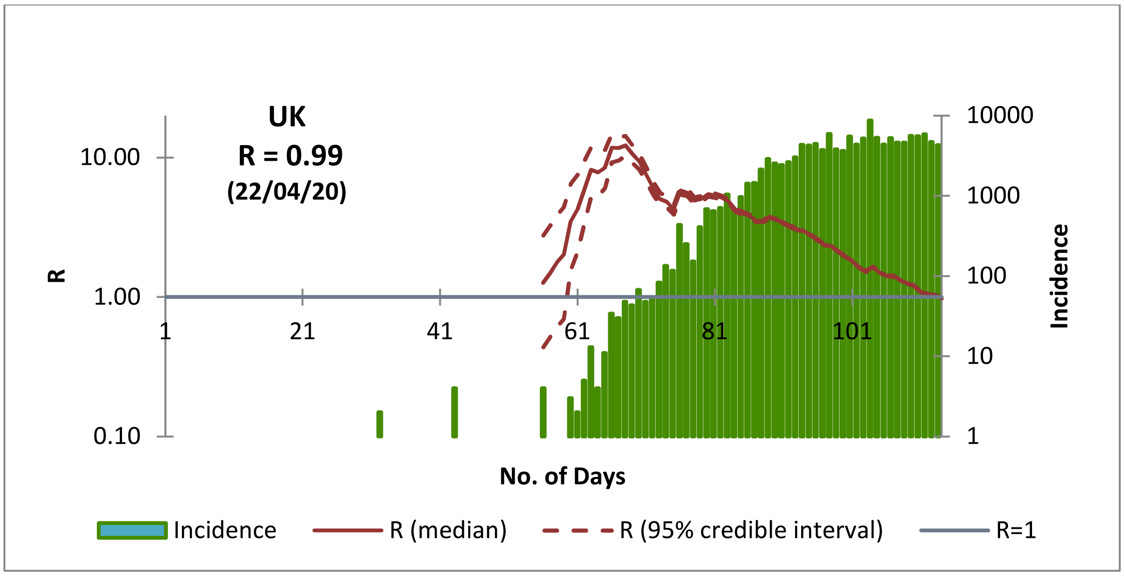

Fig.12: *Incidence number per day and corresponding basic reproduction number for UK*.

RUSSIA:

The continued rise in figures comes despite Russia's aggressive moves to respond to the spreading virus and impose tight restrictions. Even before many European nations started imposing restrictions, Moscow moved to shut down country's vast border with China. Present R_0 value is 2.52 (figure 13) but remains unchanged for some time window.

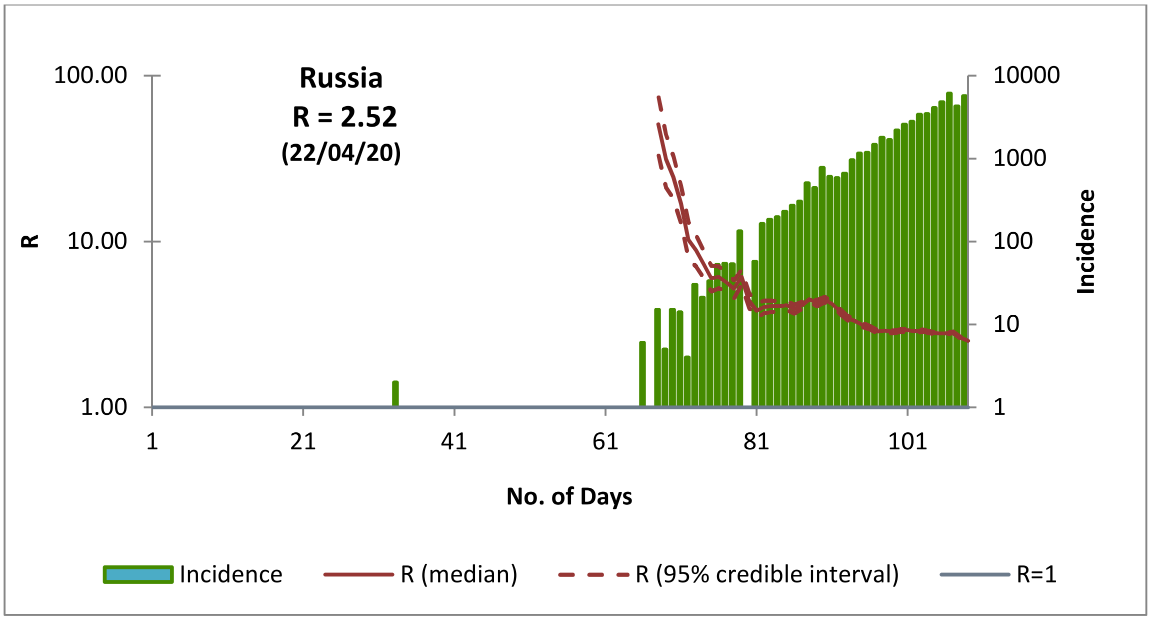

Fig.13: *Incidence number per day and corresponding basic reproduction number for Russia*.

ICELAND:

The peak is already visible in the incidence curve. Icelandic authorities have taken preventive steps to contain the potential spread of the COVID-19 virus. Iceland has few entry points and the lowest population density in Europe. The country has been able to move swiftly to identify, communicate with and quarantine its residents. The present R_0 value is well below 1 (figure 14) and is decreasing steadily.

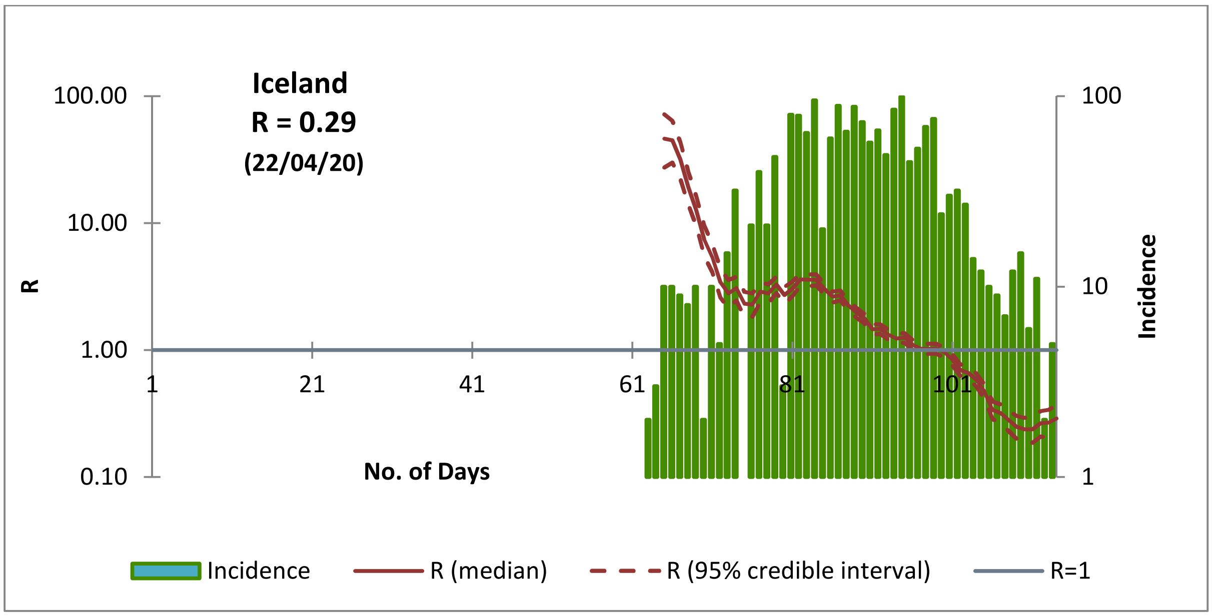

Fig.14: *Incidence number per day and corresponding basic reproduction number for Iceland*.

OCEANIA AND AUSTRALIA:

AUSTRALIA:

Australia's response to the pandemic has largely centred on shutting its borders, limiting public gatherings, travel ban and conducting large-scale testing and contact tracing. They have succeeded in reducing R_0 to a substantially low and stable value for some period, around 0.37 (figure 15). The incidence curve has already past its peak.

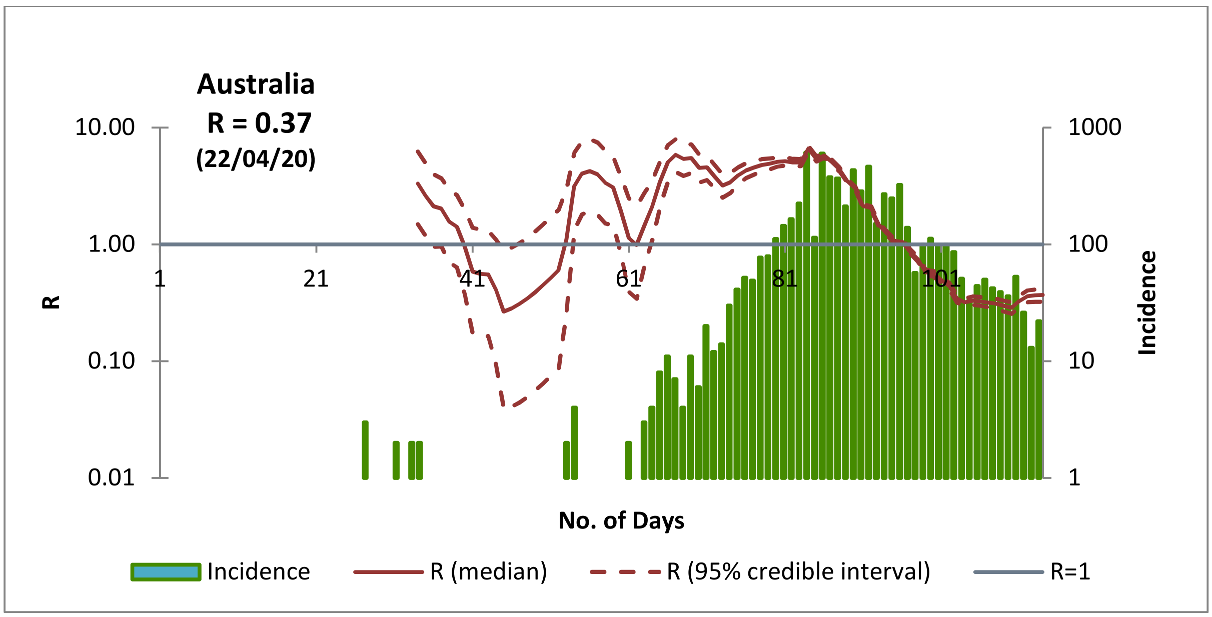

Fig.15: *Incidence number per day and corresponding basic reproduction number for Australia*.

NEW ZEALAND:

Most of the reported cases in New Zealand virus cases have links to overseas travel and arrivals, and the island country is now attempting to eliminate the virus with stringent lockdown rules. New Zealand is one of the few countries which tackle the COVID-19 situation quite wonderfully. The R_0 value is well below 1 and incidence curve has peaked around 81st day (figure 16).

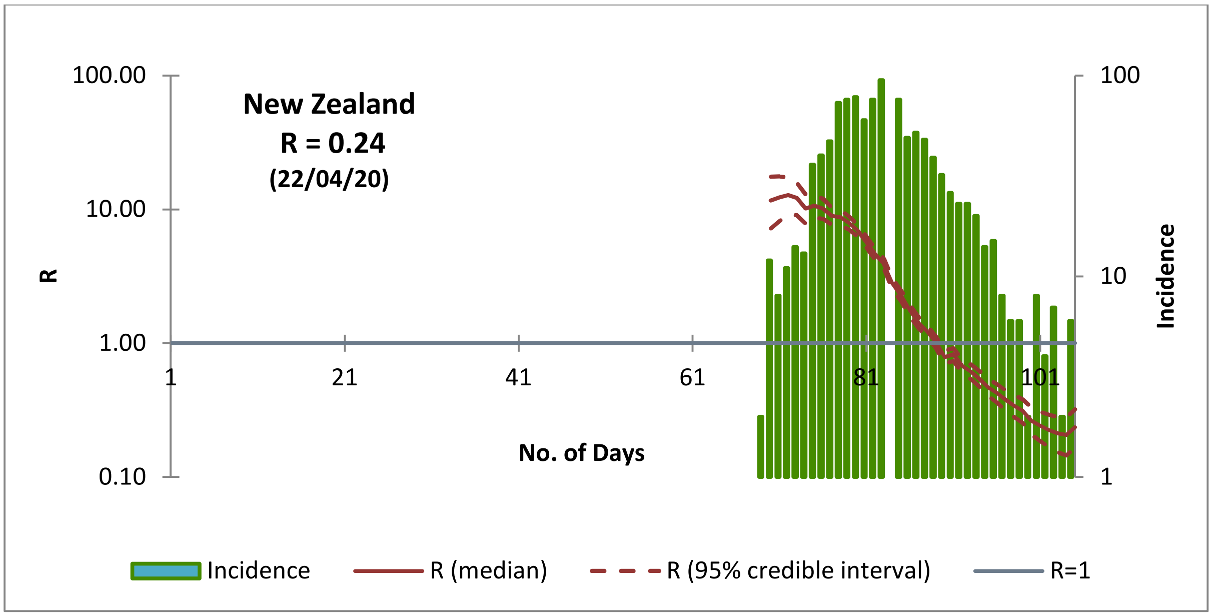

Fig.16: *Incidence number per day and corresponding basic reproduction number for New Zealand*.

SOUTH AND NORTH AMERICA:

BRAZIL:

The COVID-19 pandemic arrived in Brazil around early March. In contrast with China and other countries, where the outbreak began slowly with a small number of cases, it was started in Brazil by more than 300 people, and most of them came from Italy. The incidence number per day is increasing steadily, but R_0 has a decreasing trend and its value is 1.57 (figure 17).

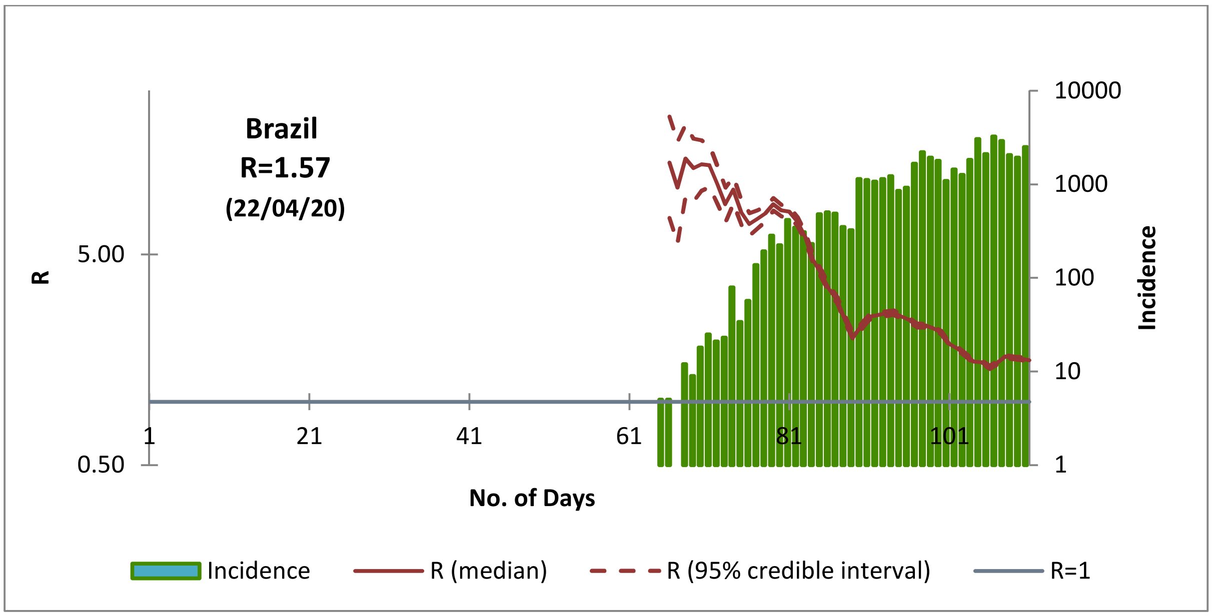

Fig.17: *Incidence number per day and corresponding basic reproduction number for Brazil*.

CANADA:

Canada has not seen the predicted surge of COVID-19 cases in hospitals that many feared would overwhelm the health-care system and lead to a surge in deaths. However, experts say relaxing physical distancing measures anytime could put that in jeopardy. The graph in figure 18 appears to have a plateau in the incidence data. R_0 was decreasing linearly over a period of time and has reached a value of 1.23 implies that the community spreading is on the wane. An upward trend is observed in R_0. On the whole, there is evidence that Canada is making progress in flattening the curve.

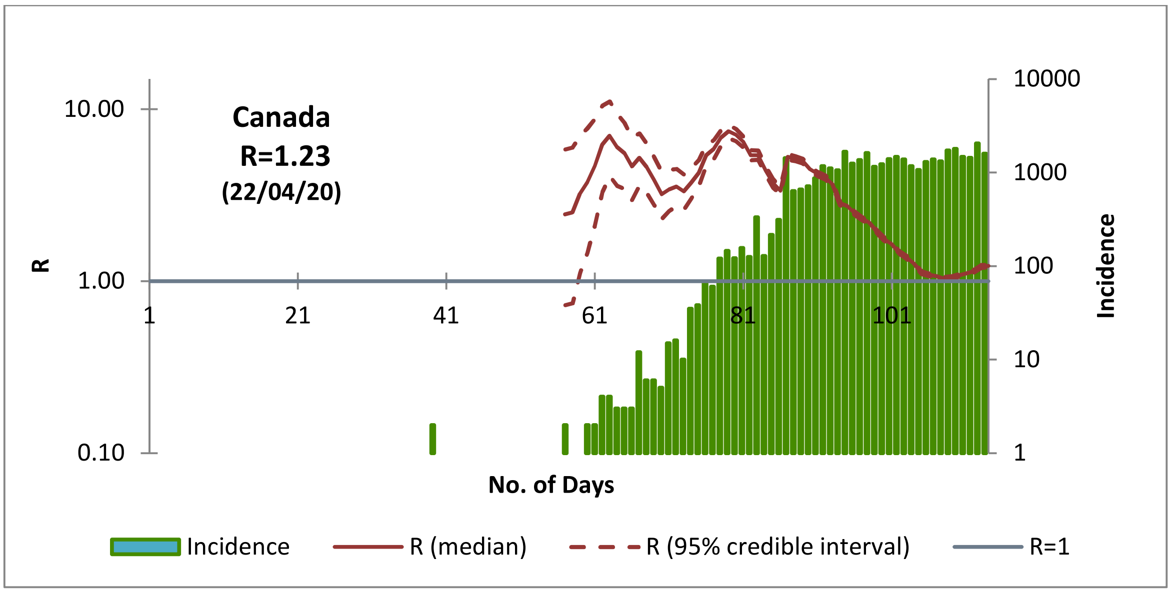

Fig.18: *Incidence number per day and corresponding basic reproduction number for Canada*.

MEXICO:

Health officials in Mexico have declared a public health emergency as the number of confirmed COVID-19 cases surges past 1,000. Total number of cases increases and peak is yet to come in the incidence curve (figure 19). But the good thing is that R_0 value is decreasing steadily and has reached at 1.67.

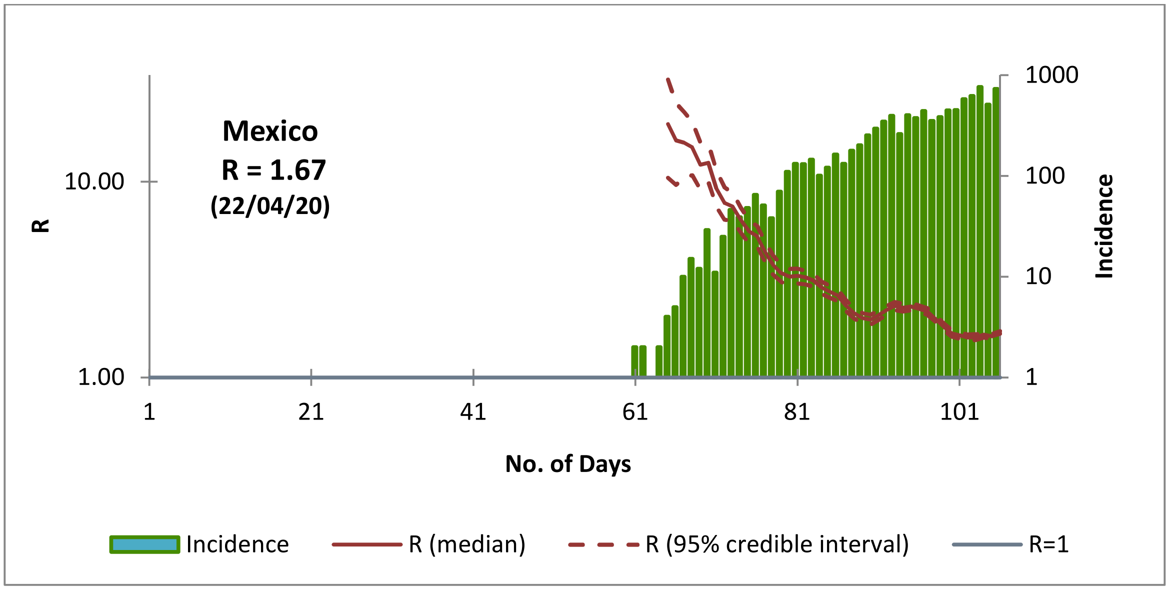

Fig.19: *Incidence number per day and corresponding basic reproduction number for Mexico*.

Summary:

Our present report gives a glimpse of degree of transmissibility of SARS-COV-2 across nations. In most of the cases, estimated values of R_0 are below 2. For many European countries and for Australia and Oceania, R_0 is well below 1. The scenario $R_0 < 1$ implies that numbers of susceptible population are less and the peak, in daily incidences, has already appeared in those cases. Values of R_0 for Russia and Singapore are comparatively high which possibly indicates that herd immunity has yet to achieve for people of those countries. The daily incidence shows a double peak for China and South Korea. The appearance of double-peak could be attributed to relaxation of restriction norms.

The present analysis is based on a particular mathematical model and on the available data set. It is also relied on the present socio-behavioral factors, e.g, lockdown condition, etc. One could obtain different results if those conditions are altered.

We would like to thank Dr. Bimal K. Roy for his encouragement, helpful advice on various technical issues, and comments. Authors, however, bear full responsibility for the article.

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Updated results:

Estimations have been done only for cases where $R_0 \geq 1$

Name of Country	22nd April	30th April	8th May	18th May	28th May	7th June	17th June	23rd June	8th July	14th July	23rd July	16th August	22nd Aug
Africa	**1.47**	**1.37**	**1.40**	**1.23**	**1.30**	**1.32**	**1.26**	---	---	---	---	---	---
India	**1.53**	**1.35**	**1.78**	**1.32**	**1.40**	**1.33**	**1.17**	**1.29**	**1.27**	**1.27**	**1.38**	**1.11**	**1.06**
Bangladesh	**3.14**	**1.53**	**1.44**	**1.50**	**1.35**	**1.45**	**1.22**	**1.16**	**0.90**	---	---	---	---
Pakistan	---	---	---	---	---	---	**1.32**	---	---	---	---	---	---
Singapore	**3.46**	**1.09**	---	**0.95**	**0.82**	**0.91**	**0.83**	---	---	---	---	---	---
Israel	**0.63**	**0.55**	---	---	---	---	---	---	---	---	---	---	---
South Korea	**0.37**	**0.53**	---	**1.55**	**1.54**	**1.24**	**0.96**	---	---	---	---	---	---
China	**0.86**	**0.16**	---	---	---	---	---	---	---	---	---	---	---
France	**0.57**	**0.59**	**0.85**	**0.47**	---	---	---	---	---	---	---	---	---
Germany	**0.68**	**0.61**	---	---	---	---	---	---	---	---	---	---	---
Sweden	**1.09**	**1.08**	**0.86**	**0.99**	**0.97**	**1.74**	**1.15**	---	---	---	---	---	---
Italy	**0.79**	**0.73**	---	---	---	---	**0.89**	---	---	---	---	---	---
UK	**0.99**	**0.90**	**1.06**	**0.75**	**0.82**	**0.72**	**0.79**	---	---	---	---	---	---
Russia	**2.52**	**1.41**	**1.64**	**1.03**	**0.91**	**1.0**	**0.98**	---	---	---	---	---	---
Iceland	**0.29**	**0.21**	---	---	---	---	---	---	---	---	---	---	---
Australia	**0.37**	**0.37**	---	---	---	---	---	---	---	---	---	---	---
New Zealand	**0.24**	**0.39**	---	---	---	---	---	---	---	---	---	---	---
Brazil	**1.57**	**1.86**	**1.59**	**1.42**	**1.29**	**1.07**	**1.03**	**1.2**	**1.06**	**1.0**	---	**0.99**	**0.84**
Canada	**1.23**	**1.03**	**1.01**	**0.78**	**0.91**	**1.0**	**0.62**	---	---	---	---	---	---
Mexico	**1.67**	**1.64**	**1.44**	**1.30**	**1.37**	**1.23**	**1.15**	**1.19**	**1.16**	**1.07**	**1.04**	---	---
USA	**1.03**	**0.97**	**0.94**	**0.89**	**0.93**	**1.0**	**1.05**	**1.27**	**1.32**	**1.26**	**1.10**	---	---

Table 1: Numerical values of evolution of R_0 for different countries with time.