Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Dialogues in Health 1 (2022) 100016

Contents lists available at ScienceDirect

Dialogues in Health

journal homepage: www.elsevier.com/locate/dialog

Statistical Model for COVID-19 in Different Waves of South Indian States

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ARTICLE INFO

Keyword:
COVID-19
Active Cases
Case Fatality Rate
Phases
South India

ABSTRACT

Background: COVID-19 has resurfaced in India, where it is rapidly spreading and wreaking havoc in rural areas. An effort has been undertaken to assess the levels and patterns of COVID-19 active cases in the southern states of India. To trace and reason out anomalous trends in the COVID-19 curve so that particular actions such as lockdown, de-lockdown, and healthcare improvisation can be implemented at the appropriate time.

Methods: The data has retrieved from the government websites through a platform called Kaggle. The entire duration of COVID – 19 were classified into three compartments: Phase one, Resting phase, and Phase two. The Case Fatality Rate in south Indian states was analysed corresponding to the phases, and a compartmental model for COVID-19 dynamics in the region was proposed.

Results: The quadratic regression model was fitted and found to be the best model for the phases except for the resting phase. Phase one was comparatively less fitted when compared to phase two. In most of the south Indian states, the active cases in phase one were almost more than four times that of phase two. The average CFR value in phase one was lower than the subsequent phase in all of the southern Indian states. In phase one, Telangana, Karnataka, and Tamil Nadu had the highest CFR (4.77,4.22, and 3.71, respectively), whereas Lakshadweep and Kerala had the lowest CFR (0.27 and 0.71, respectively). In the resting phase, the CFR stabilized in all states and reached a value between 0.2 to 2. The trend was similar in phase two also, CFR of Lakshadweep, Kerala, Telangana, and Andhra Pradesh (0.143, 0.416,0.553, 0.803) were very low, while the CFR of Andaman and Nicobar Islands, Karnataka, and Tamil Nadu (1.237, 1.306, 1.490) were very high.

Conclusion: The first and second phases of the COVID-19 virus in south Indian states had different characteristics. A District-level working group with the autonomy to respond to rapidly changing local situations must be empowered to tackle the next phase. The upcoming phases could be more peaked in less time and could be a hectic situation for the health care system.

Introduction

COVID-19, which began as a pneumonia-like outburst in late 2019 in the city of Wuhan, has spread globally to become a catastrophic event.[1] The first instance of COVID-19 in India, specifically in the southern states of Kerala, was reported on January 30, 2020[2], and it has since impacted over thirty million individuals in the country, resulting in about four hundred thousand deaths. The physical manifestation comprises respiratory illness with symptoms that range from a common cold to severe viral pneumonia, which causes acute respiratory distress, typically fatal in nature. The first wave peaked in September 2020, with daily cases reaching about 0.1 million. The morbidity was initially low, but it becomes noticeable towards the middle of June 2020. The decrease in the first wave was most likely due to several factors, including effective government actions, increased awareness, and, most crucially, medical professionals' expertise in treating the disease in the early months.

The second COVID-19 wave in India, which was different in different states roughly started on February 11, 2021, has been disastrous, with a number of cases reaching 0.2 million per day on April 14, 2021, which is already quadruple that of the first wave peak. The first and second waves are around five months apart. The rapid increase in the number of cases after such a long period of 'cooling' is baffling and wreaking havoc across the globe. This wave also spread to rural communities and villages of India as of May 2021.[3] States like Delhi, Karnataka, Tamil Nadu, Kerala, and Maharashtra are severely affected by the second wave.[4] The number of cases and deaths have risen drastically in India. Based on the cases discovered by the USA and Brazil on April 10, 2021, India has been in the third position.[5] According to an exponential fit on the current data, the infection rate is substantially more significant than the previous wave, but the case fatality rate is lower. Preliminary projections using the SIR model estimates that the second wave will peak in mid-May 2021, with daily counts topping 0.35 million.[6]

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http://dx.doi.org/10.1016/j.dialog.2022.100016
Received 5 August 2021; Received in revised form 22 May 2022; Accepted 22 May 2022
Available online 27 May 2022

The viral genome has acquired mutations over time as it goes throughout its host and results in the infamous double mutant COVID variant. India has almost 7,684 variations of COVID-19 virus.[7] The current increase in the number of infections in some Indian states may also be due to virus variants. South African, The UK, Brazilian, and Nigerian variants and variants that bear the lineage of such variants are among the critical spike mutation of worldwide concern that is a key for surveillance in the Indian landscape. N440K, a mutation with higher frequencies in Andhra Pradesh, is also included in the list. Despite the increased caseload, numerous national movements, such as the farmers' movement, have been active, and elections have been held in some states. These factors increase the risk of COVID-19 transmission.[8]

During the first wave, the Indian government imposed nationwide curfews, social distancing, and lockdown, which further implemented as a strict lockdown and other countermeasures so that infected individuals are identified and isolated.[9] However, because the second wave differed from the first, the government decided to speed up the vaccine campaign to combat COVID-19 with a state-wise strict lockdown. The government takes urgent steps along two paths of action: large-scale vaccination to reduce disease severity and break the transmission chain through safe behaviours.

The overall Case Fatality Ratio (CFR) has been estimated to be 1.3 percent since the pandemic began in March 2020, but the CFR among individuals who have infected the virus since 2021 is much lower at 0.87 percent. Provisionally, CFR looks to be lower in the second wave. Despite this, India reports 664 deaths a day (7-day moving average as of April 10, 2021). Fatality number lags the infection rate, and it is likely to increase as infectious rise.[10] The average time to recover from disease was ranging from 5 to 36 days in Indian states/union territories.[11]

Studies assessed lockdown extension by fitting an exponential model to the rise of COVID-19 using data from multiple states (Mondal and Ghosh, 2020).[12] Since no infection/ disease could ever follow the exponential distribution due to the virus's self-diminishing properties, modelling the growth and forecasting the number of affected persons and deaths is difficult; though there is a long tradition of research in the epidemiology of diseases in statistical modelling (Pastor-Satorras et al., 2015).[13] To ease the strain of Healthcare System and provide the best possible care for COVID-19 patients, appropriate models are expected to estimate the risk of Active Cases for proper planning, diagnosis, and cure of the disease.[14] Therefore, it is imperative to study the many phases of each wave, as the consequences of attempting to manage COVID-19, on the other hand, are being felt not only in the health sector, but also in the environment, the economy, and society. Every disease, more so communicable acute disease, is expected to follow a pattern, which usually includes, i) Acceleratory phase, ii) Optimum level, and ii) De-acceleratory phase. Usually, when data is available at the time of evaluation, the disease is expected to be in de-acceleratory phase. India's calculated case fatality rate has decreased to 1.59 percent as of September 21, 2020, from 3.38 percent in April.[15] From a public health point of view, it is critical to track case fatality rates and new cases over time in order to assess illness severity and reduce the degree of risk in disease pandemics. This study's motivation stems from a desire to add to the statistical investigation of COVID-19 pattern in South Indian states, where there is a paucity of literature. Hence, an attempt has been undertaken to study the levels and trends of the COVID-19 active cases, new cases, and CFR in southern states of India and to fit a quadratic regression model predict the upcoming phases of the pandemic so that appropriate actions as lockdown, de-lockdown and standardization of line of treatment could be taken at the appropriate time to optimize health and financial benefits.[16]

Materials and Methods

The COVID-19 data have been retrieved from the government website (https://www.mohfw.gov.in) through Kaggle (COVID-19 in India, 2020)[17], which provides a platform for extracting data on coronavirus infections to assist the worldwide community and health organizations in making better decisions. The website has hosted a number of tasks aimed at improving knowledge on COVID-19 infectious disease.

The state-wise trends of COVID-19Active Cases have been studied in South Indian states.

$$Active\ cases = Total\ Cases - (Cured + Death)$$

Case Fatality Rate of COVID-19 given as

$$\mathrm{CFR} = \frac{\mathrm{Deaths}}{\mathrm{Cured} + \mathrm{Deaths}} \times 100$$

The data on the number of confirmed cases, cured, and deaths available in the public domain from January 30, 2020 to May 19, 2021, were analysed using statistical software like SPSS-22 and Microsoft Excel 2016. The model was built using data from the day on which there were more than one death due to COVID-19. Since the active cases for some states/ union territory are not linearly related, transformations are used to make it easier to model and analysing data.

A quadratic regression model is a polynomial of degree 2 with all the terms present.

$$EY_t = \beta_0 + \beta_1 t + \beta_2 t^2$$

This equation has the linear effect parameter β1 and quadratic effect parameter β2, respectively as well as the constant parameter β0.[18]

The paper proposes a compartmental model for the dynamics of COVID-19 in south India. First of all, the data was normalised to the total population of individuals, and the compartments were created (Phase one, Resting Phase and Phase two) as per trends in Active Cases. The entire period of COVID in south Indian states has been divided into three groups. More specifically, the compartment collects all the individuals that are affected by the virus. Phase one is defined with the trend in active cases from the initial period, which has at least one extreme peak to the lowest value of the active cases. The resting phase is considered as the linear, less drastic period with an approximately constant magnitude in active cases. Phase two initiate from the sudden increase in the active cases from the restating phase.

Results

Table 1 reveals treatment performance of COVID-19 cases by states/ union territories. It shows that Karnataka and Lakshadweep have 25 percent active cases followed by Puducherry (19.92%), Kerala, Andhra Pradesh, and Tamil Nadu by 15%. In contrast, Telangana and Andaman and Nicobar Islands have only around 9 and 3 percentage of active cases respectively and could say the best in controlling the pandemic. Furthermore, the trends in the South Indian States' performance in controlling the COVID-19 have been analysed using a statistical model so that unusual trends in the cure of COVID-19 are traced and reasoned out.

Table 2 classifies the duration of COVID-19 disease in each state and has been classified into three phases. In each phase, there was a difference in the average Case Fatality Rate. The average Case Fatality Rate in most of the states are less than two. However, in phase one there was a change in

Table 1
COVID-19 Cured, Deaths and Confirmed cases and active cases in south Indian states of India, as of May 19, 2021

States	Cured	Deaths	Confirmed	Active Cases (%)
Andaman and Nicobar Islands	6359	92	6674	223 (3.34)
Andhra Pradesh	1254291	9580	1475372	211501 (14.34)
Karnataka	1674487	22838	2272374	575049 (25.31)
Kerala	1846105	6612	2200706	347989 (15.81)
Lakshadweep	3915	15	5212	1282 (24.6)
Puducherry	69060	1212	87749	17477 (19.92)
Tamil Nadu	1403052	18369	1664350	242929 (14.6)
Telangana	485644	3012	536766	48110 (8.96)

Table 2
Case Fatality Rate in south Indian states of India, as of May 19, 2021

State	Phase	Days	Minimum	Maximum	Mean	Std. Deviation
Andaman and Nicobar Islands	Phase1	183	0.508	4.313	1.568	0.578
	Resting phase	57	1.231	1.244	1.237	0.004
	Phase2	51	1.162	1.426	1.229	0.058
Andhra Pradesh	Phase1	178	0.813	2.879	1.493	0.721
	Resting phase	112	0.806	0.813	0.808	0.002
	Phase2	58	0.758	0.818	0.803	0.014
Karnataka	Phase1	307	1.310	37.500	4.228	5.364
	Resting phase	33	1.304	1.310	1.306	0.002
	Phase2	76	1.292	1.394	1.320	0.031
Kerala	Phase1	406	0.000	8.000	0.715	0.897
	Resting phase	13	0.414	0.419	0.416	0.002
	Phase2	52	0.357	0.432	0.414	0.020
Lakshadweep	Phase1	30	0.163	0.408	0.272	0.078
	Resting phase	18	0.134	0.160	0.143	0.007
	Phase2	35	0.075	0.394	0.238	0.114
Puducherry	Phase1	165	1.685	6.034	2.596	0.944
	Resting phase	112	1.664	1.691	1.676	0.007
	Phase2	65	1.616	1.730	1.668	0.028
Tamil Nadu	Phase1	265	0.000	50.000	3.713	7.174
	Resting phase	111	1.467	1.525	1.490	0.015
	Phase2	63	1.263	1.467	1.393	0.076
Telangana	Phase1	259	0.000	87.500	4.779	11.515
	Resting phase	97	0.547	0.578	0.553	0.007
	Phase2	68	0.549	0.634	0.568	0.021

the average Case Fatality Rate in almost all states thereafter the resting phase, and phase two had CFR less than 2.

Table 3, Quadratic Regression Models for COVID-19 by the States of India, reveals explanatory power of the Regression Models varying from 55% in phase 1 to 99% in phase two of Puducherry. The entire period of COVID 19 have been classified into three Phases, and their quadratic regression models were fitted. In the first Phase, the best-fitted state was Karnataka, followed by Andaman and Nicobar Islands. Whereas in the second phase, the best-fitted state/ union territory was Puducherry, followed by Tamil Nadu and Andaman and the Nicobar Islands. All the states had a linear trend with a slight slope towards the x-axis in the resting phase, and the R square values were found to be more than 90% in all the states.

In the first phase, the case fatality rate in every South Indian state/union tertiary fluctuated, then stabilized in the second and third phases. The CFR increased and gained prominence in the early stages of phase 1 before stabilizing in the range of 0.5 to 2. In Figure 1a, the patterns stabilized around the 160th day on the initial occurrence of the disease in Andaman and Nicobar Islands whereas in Andra Pradesh, it was around 180 days as per Figure 2a. In Karnataka and Kerala, CFR stabilized in 70 to 100 days, with the exception of a few heaps and dips as indicated in Figure 3a and Figure 4a . Figure 5a shows that the CFR rates in the union territory of Lakshadweep were relatively less as compare to other states or union territories, but to stabilize to a linear pattern was relatively less. In the phase 1 and resting phase, it showed a decreasing trend hitting below 0.1, and thereafter it increased and attained up to 0.4. Figure 6a of Puducherry shows a stability in CFR around 1.8 by the end of the first phase and continued the pattern throughout the resting phase and phase 2. Figure 7a depicts thatTamil Nadu was having a drastic increase in CFR in the initial stages of Phase 1, and thereafter by the 66th day, it also attained stability in the upcoming phases. In Figure 8a, Telangana also showed a similar trend to that of Karnataka and Kerala, which stabilized by the 75th day with minor fluctuations.

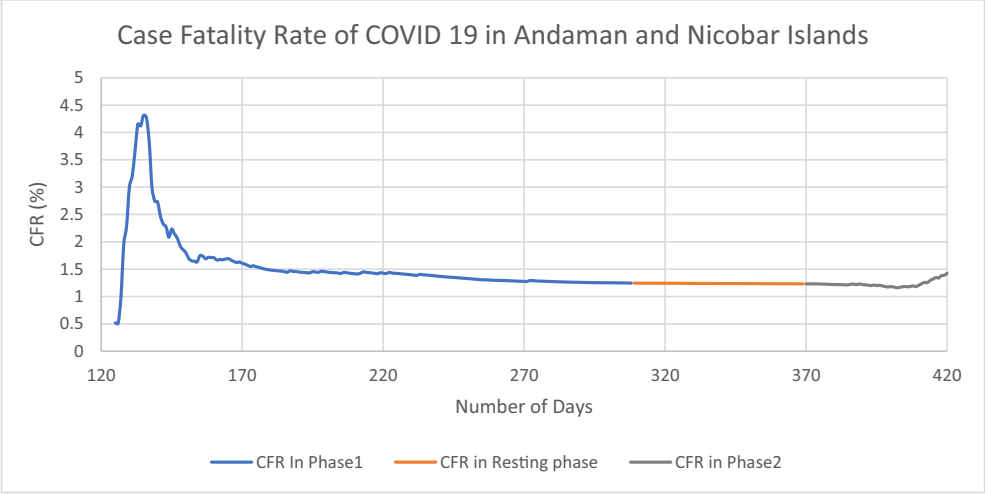
New cases and active cases had a nearly identical trend in every state, but the smoothness in active cases was much higher than in new cases. The first significant increase in the Andaman and Nicobar Islands occurred around the 110th day, but there was a minor trigger phase between 90 and 110 days. The first phase peaked around the 150th day (approximately 1180 Active Cases and 150 New Cases and abruptly declined during the next 25 days. The final quarter of phase one was slow and protracted, with a lot of fluctuations. The active and new cases stabilized with a small magnitude during the resting phase. Phase two began around the 309th day and increased until the 400th day, but it did not reach the same heights (approximately 210 Active Cases and 100 New Cases) as the previous phase (Figures 1b, 1c).

The peak of the Second phase (approximately 0.22 million Active Cases and 25thousand New Cases) in Andra Pradesh has clearly doubled that of Phase one(approximately 0.1 million Active Cases and 12 thousand New Cases). Phase one triggered around the 100th day and reached its maximum height by 180th day, and by 265, it was found to be slowly changing into a resting phase. The resting phase continued around 100 days, and thereafter a sudden trigger resulted in phase two by the 377th day of the initial COVID reporting (Figures 2b, 2c).

Karnataka had a drastic increase in the active and new cases when comparing phase one and two, it was around fivefold of the first phase. The resting phase found to be very less, around 33 days when compared to other states except for Kerala. Phase one increased drastically after the 100th day, and went up to the 250th day, then gradually decreased and went to a small resting period by the 328th day of initial infection. By 361thday the cases had increased and reached a maximum by 425th day (approximately 0.6 million Active Cases and 50 thousand New Cases)

Table 3
Quadratic Regression Models for COVID-19 instates of South India, as of May 19, 2021

State	Phase	Model Summary					Parameter Estimates		
		R Square	F	df1	df2	Sig.	Constant	b1	b2
Andaman and Nicobar Islands	Phase 1	0.787	345.620	2	187	.000	0.089	-0.001	2.688E-06
	Phase 2	0.939	370.808	2	48	.000	-7746.987	35.594	-0.040
Andhra Pradesh	Phase 1	0.777	304.471	2	175	.000	-321699.471	4476.447	-12.535
	Phase 2	0.976	1121.953	2	55	.000	10397781.149	-55346.070	73.627
Karnataka	Phase 1	0.968	4906.606	2	324	.000	1.544	0.095	0.000
	Phase 2	0.975	1404.113	2	73	.000	27591727.516	-146626.706	194.737
Kerala	Phase 1	0.670	409.900	2	403	.000	-19787.861	293.836	-0.156
	Phase 2	0.927	311.656	2	49	.000	12011107.750	-62708.623	80.921
Lakshadweep	Phase 1	0.677	68.022	2	65	.000	-124.037	4.364	-0.016
	Phase 2	0.837	81.939	2	32	.000	-49073.519	677.552	-2.280
Puducherry	Phase 1	0.553	153.626	2	248	.000	-1320.115	33.095	-0.053
	Phase 2	0.996	7233.410	2	62	.000	750201.624	-4059.235	5.493
Tamil Nadu	Phase 1	0.745	382.982	2	262	.000	-24086.239	804.052	-2.379
	Phase 2	0.984	1852.479	2	60	.000	7462955.926	-39728.715	52.911
Telangana	Phase 1	0.747	378.885	2	256	.000	-6647.846	165.609	-0.124
	Phase 2	0.969	1010.937	2	65	.000	4814860.731	-25517.422	33.789



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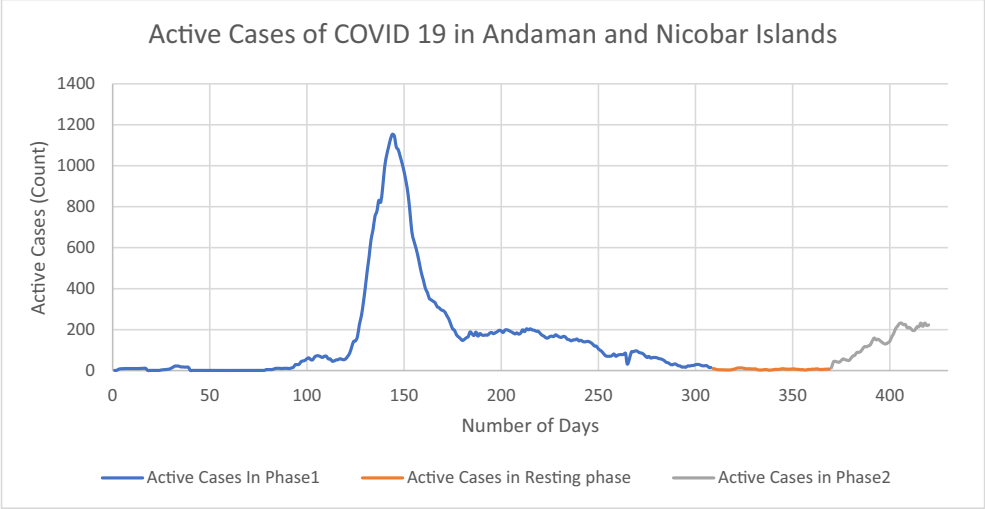

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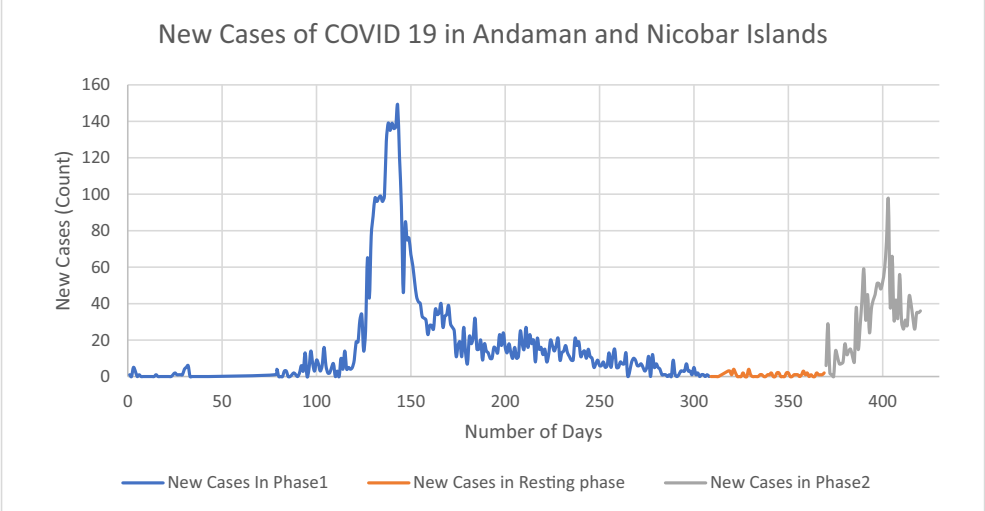

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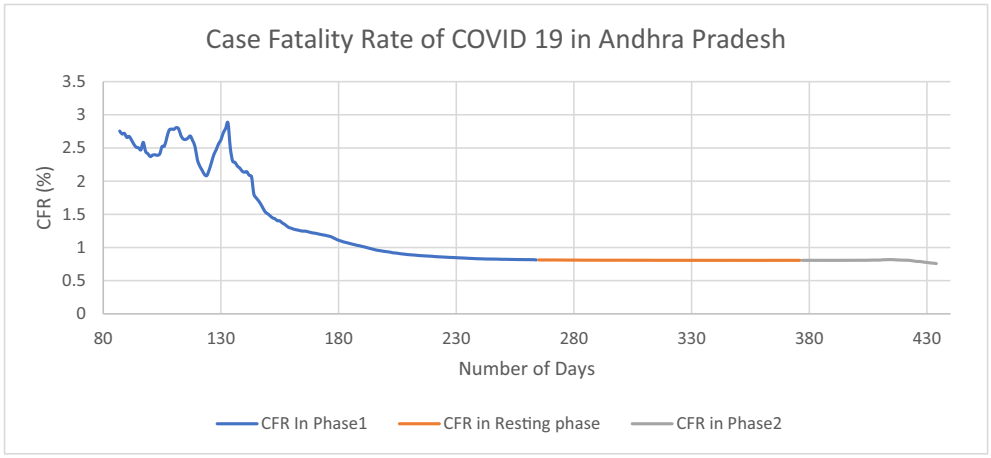
Figure 1. Andaman and Nicobar Islands



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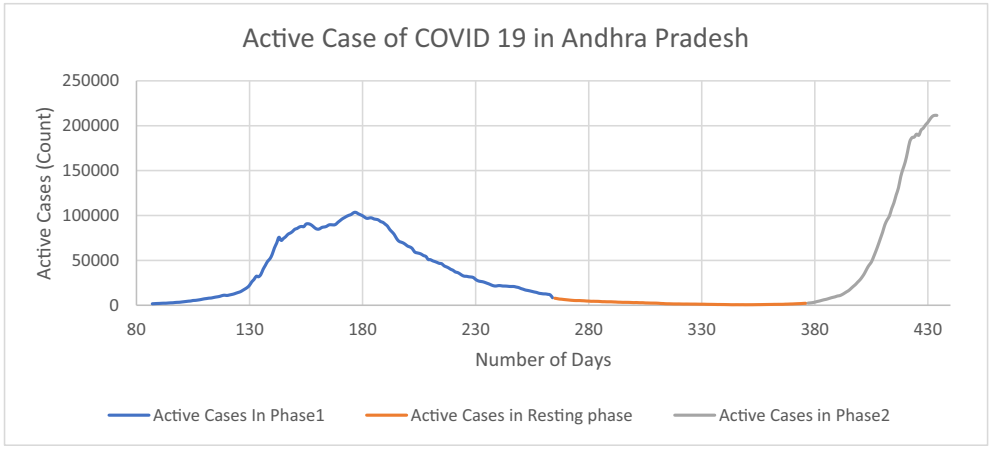

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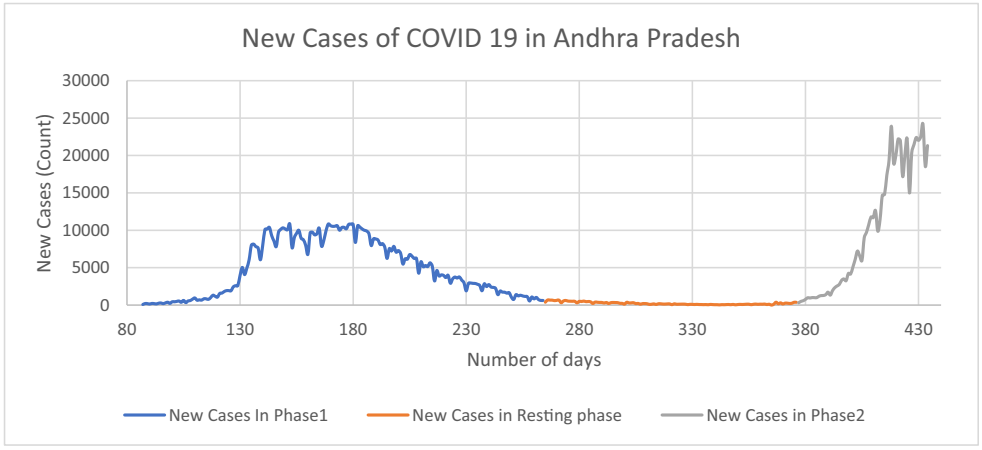

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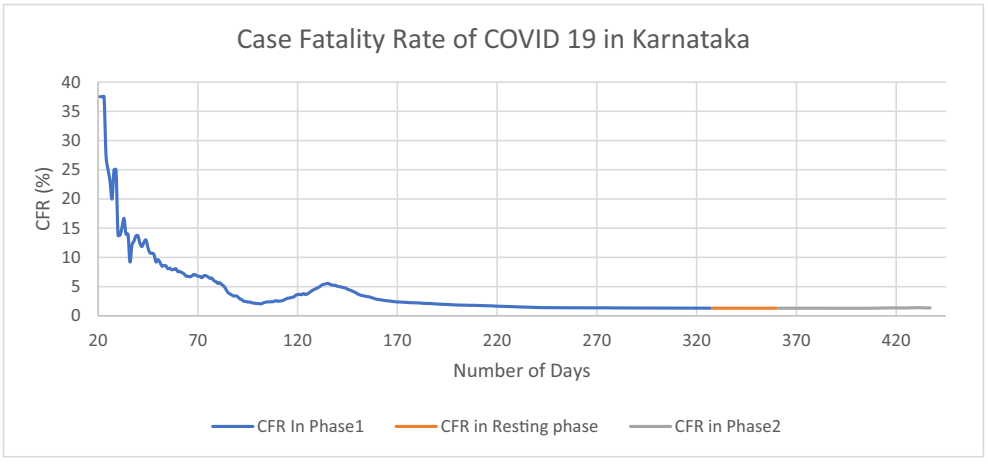
Figure 2. Andhra Pradesh

Similar to Karnataka (Figures 3b, 3c), Kerala (Figures 4b, 4c), Puducherry (Figures 6b, 6c), Tamil Nadu (Figures 7b, 7c), Telangana (Figures 8b, 8c) also had a 4.5 to 5 fold increase in the active and new cases when comparing phase one and two. The first state to report COVID cases in India was Kerala. However, the initial phase of Kerala had a long and stable initial quarter, and the increase has been triggered from the 200th day and continued towards 200 days. Whereas, Puducherry, Tamil Nadu, and Telangana initiated the trigger around the 100th day of the initial case reported. There were only 13 days in the resting phase in Kerala and 112, 63, and 97 respectively for Puducherry, Tamil Nadu, and Telangana. Thereafter the second phase had a very drastic and went up to 4.5 to 5 times for both Active Cases and New Cases.



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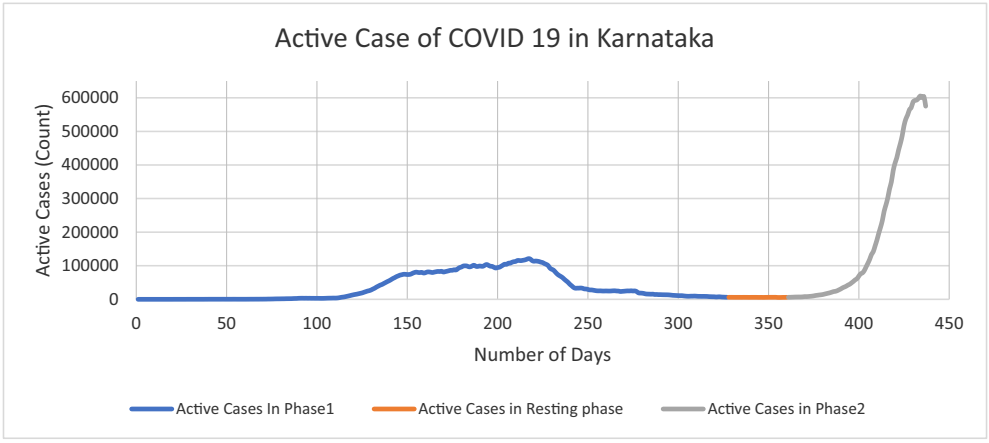

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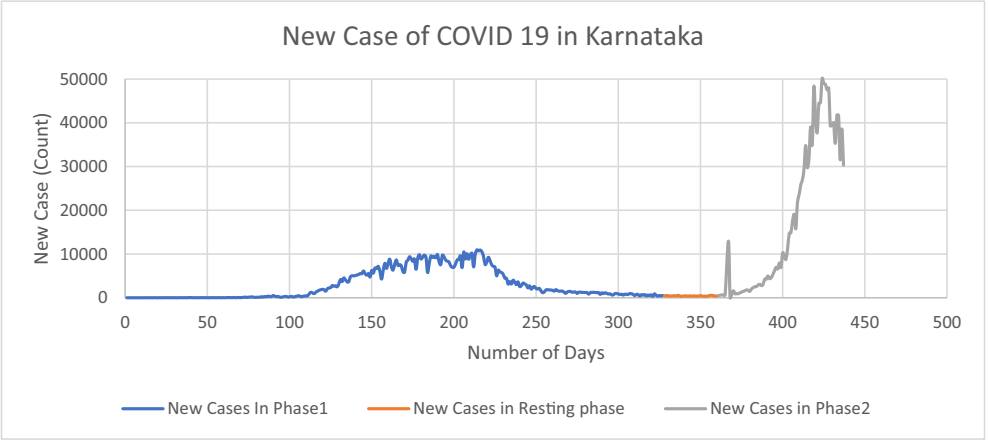

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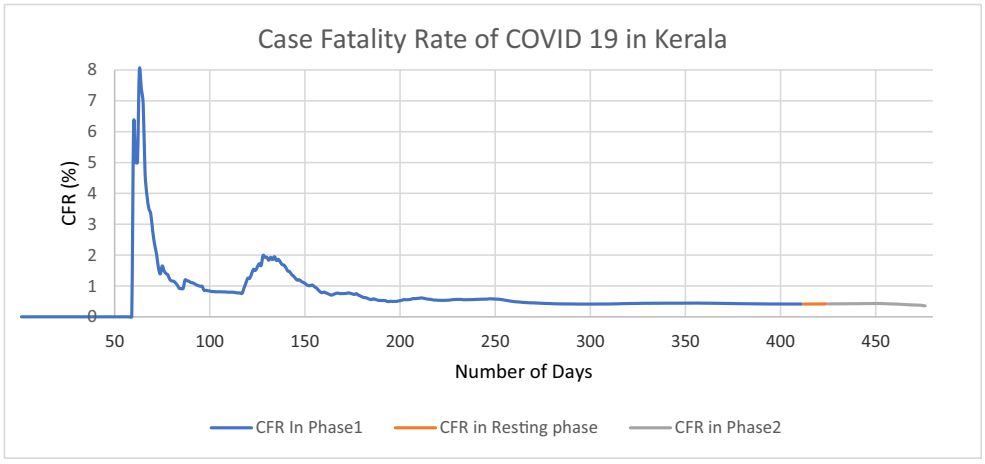
Figure 3. Karnataka

Discussion

COVID 19 is transmitted from the reservoir/source of infection to the susceptible host. The COVID 19 infection model is depicted in Figure 9. The reservoir, modalities of transmission, and susceptible host are the three main components of the transmission chain.[19]

In phase one, the source or the reservoir was only the individuals who were infected and was travelling, whereas during the phase on, the transmission rate was very high, and the disease became community-based thereafter, the infection came to a resting phase. In the second phase, the source or the reservoir was almost many from the community itself therefore, a four to fivefold increase in the transmission within a very small



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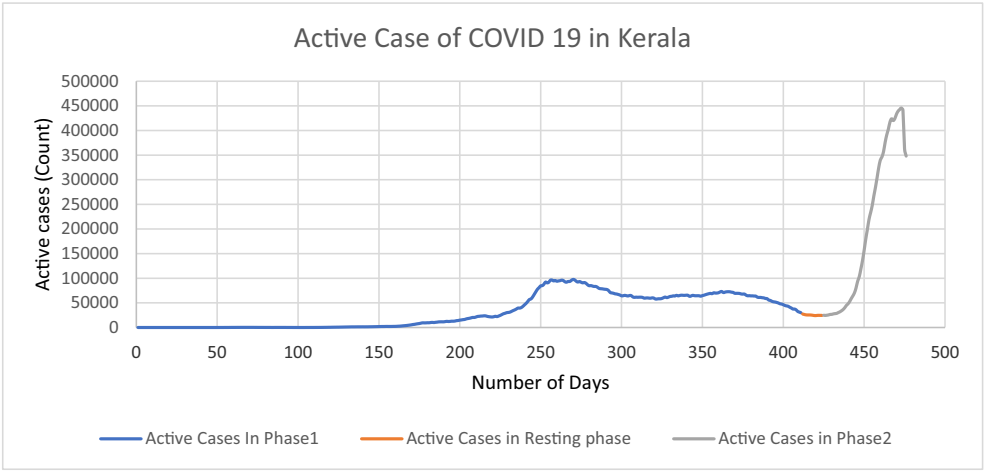

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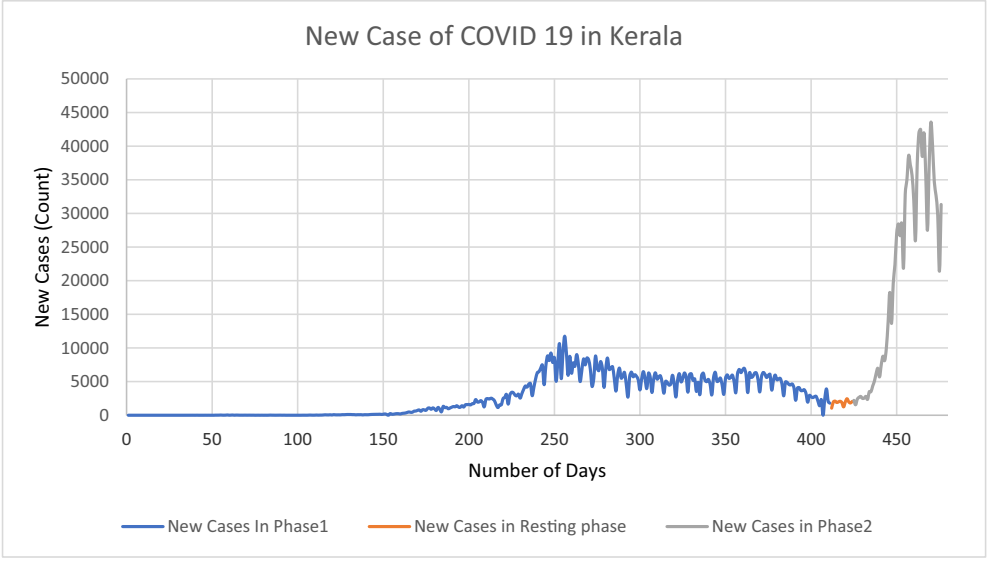

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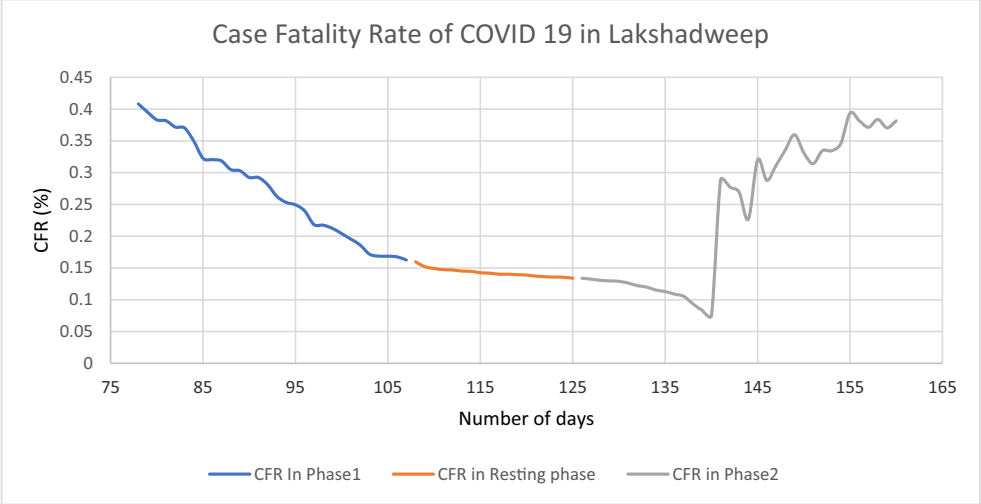
Figure 4. Kerala



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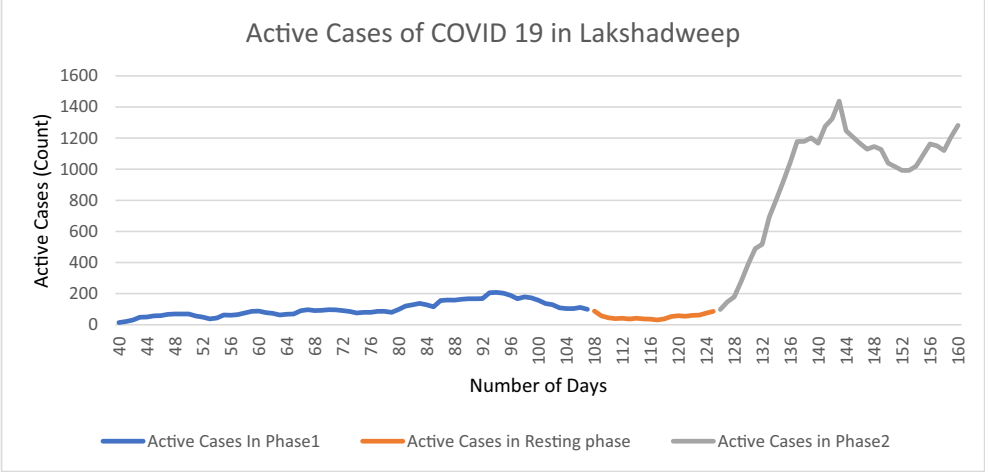

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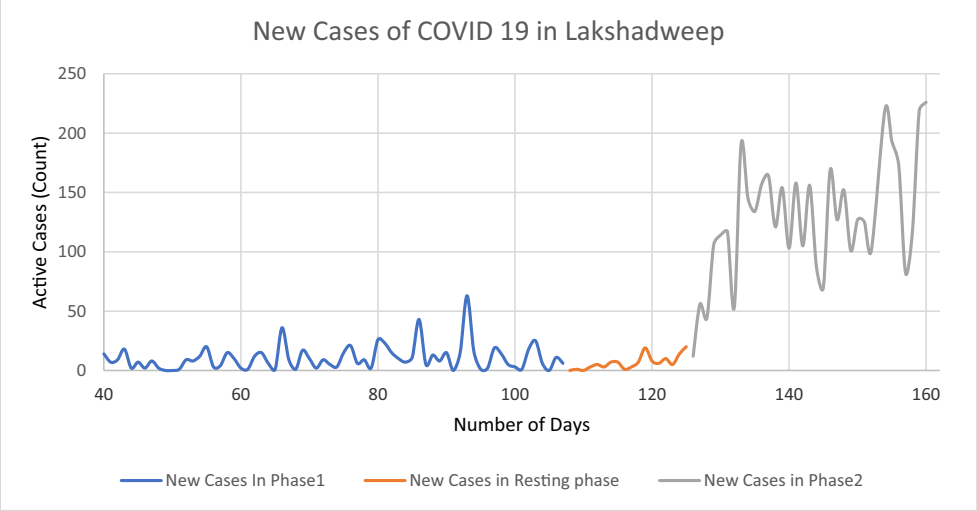

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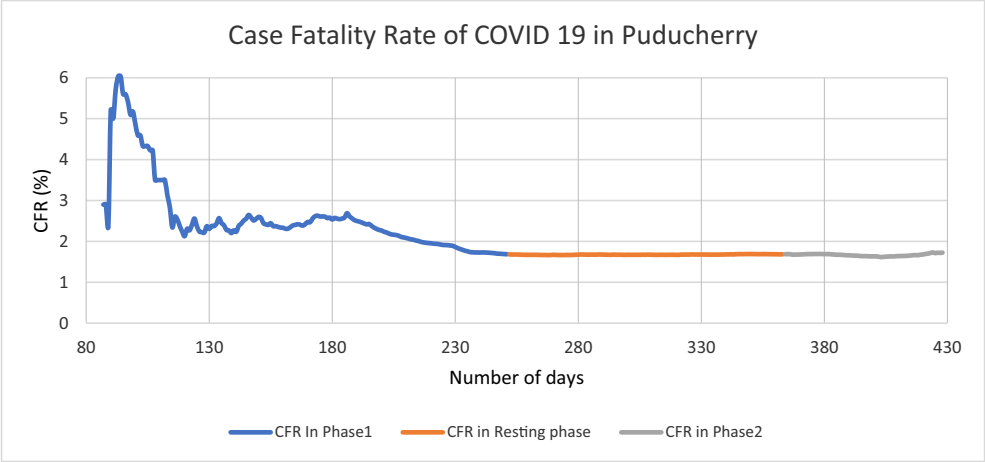
Figure 5. Lakshadweep



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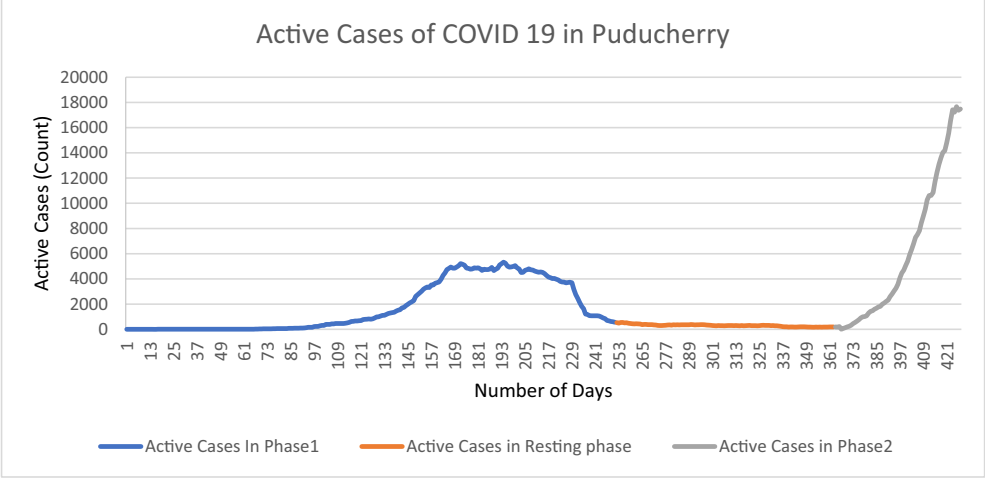

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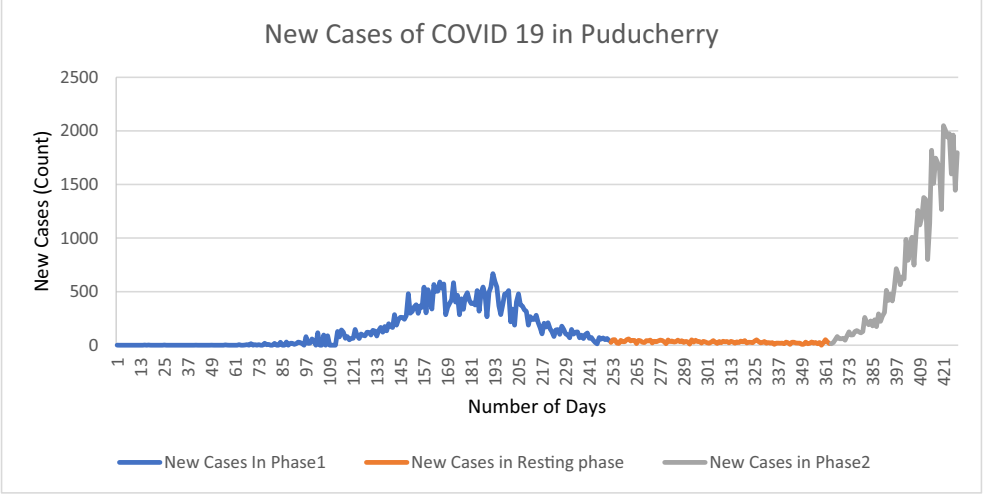

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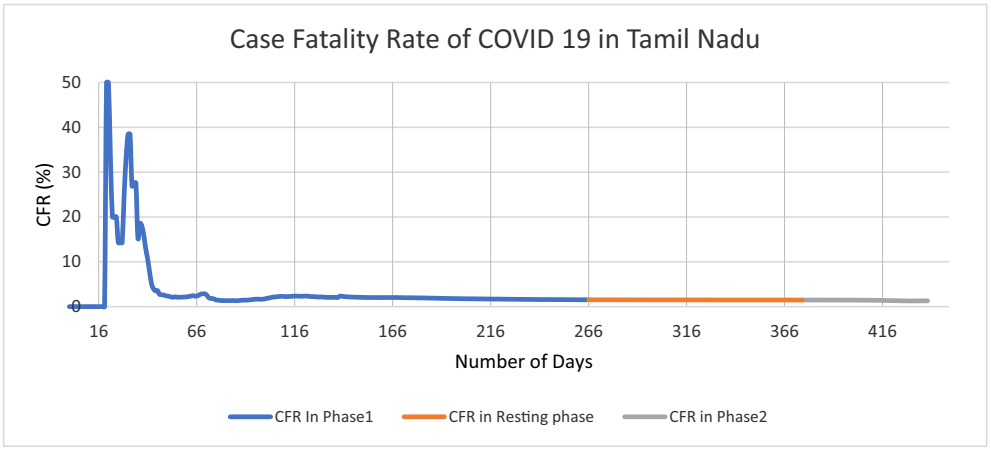
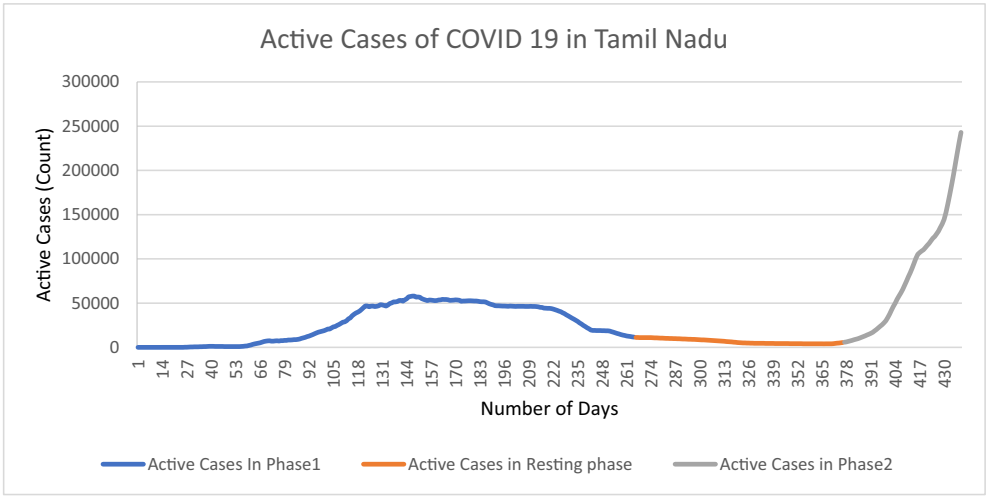
Figure 6. Puducherry

period of time. It was very clear that the second phase was very short but had very high intensity.

Kerala and Karnataka were having the highest days in phase one with 406 and 307 days, followed by Tamil Nadu and Telangana. Whereas the resting phase was more in Andra Pradesh, Tamil Nadu, and Telangana with 112, 111, and 97 days respectively, the state of Kerala and Karnataka was having the least with 13 and 33 days, respectively. When comparing the average CFR value in phase one was a



(a)



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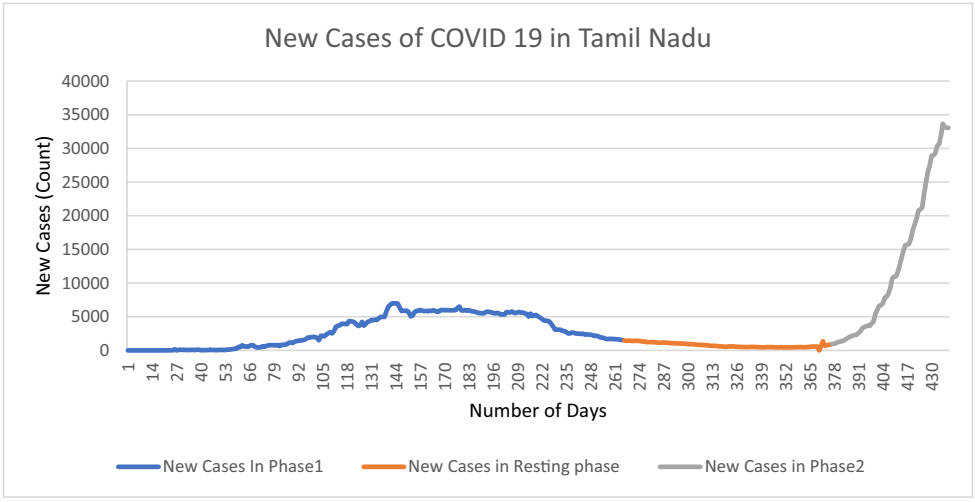
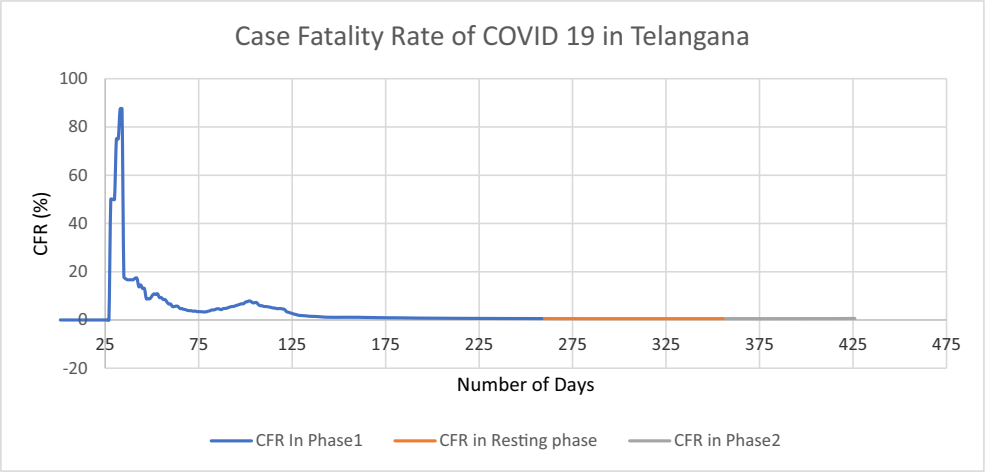


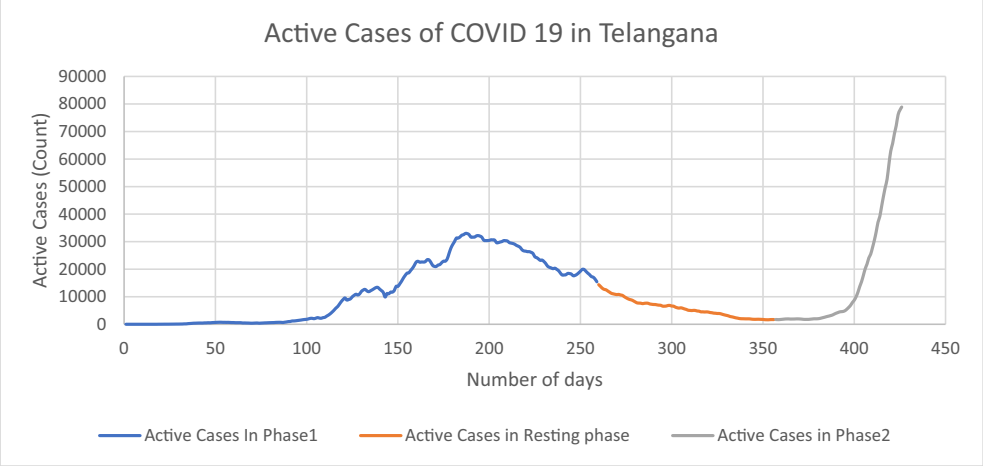
(c)

Figure 7. Tamil Nadu

little higher as compared to the other phases in all of the south Indian states, Telangana Karnataka and Tamil Nadu was having higher CFR in phase one with 4.77, 4.22, and 3.71 respectively. At the same time, Lakshadweep and Kerala had the lowest with CFR of 0.27 and 0.71. When it comes to the resting phase the CFR stabilized in almost all the states and attained value between 0.2 and 2. Lakshadweep (0.143), Kerala (0.416), Telangana (0.553) and Andra Pradesh (0.803) had a very less CFR and Andaman and Nicobar Islands (1.237), Karnataka (1.306) and Tamil Nadu (1.490) had a comparatively high CFR. The trend was found in Phase Two also.



(a)



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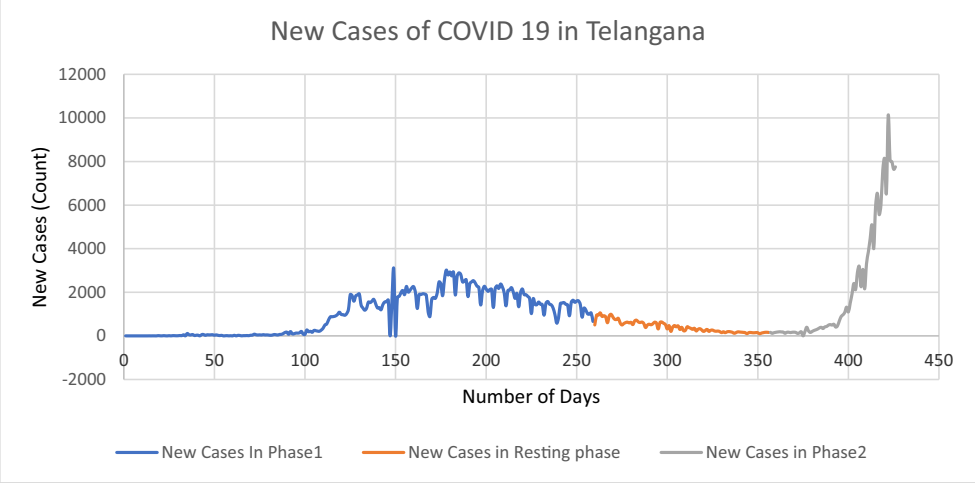

(c)

Figure 8. Telangana

When looking at the entire India, Rajesh and et.al. discovered that the CFR curve indicates a declining tendency, from 3.5 percent in mid-April 2020 to 1.2 percent in mid-April 2021.[20] Interestingly, while the virus appears to be more infectious in the second phase, the fall in the CFR curve suggests a silver lining in the form of a mutant that is less lethal. However, given the rapid increase in cases, it is projected that healthcare facilities will soon be fully throttled.

The paper also evaluated the optimal change points at which the COVID-19 cases turned their growth from linear to quadratic and then

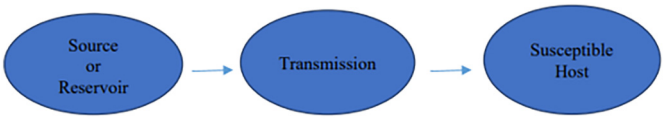

Figure 9. Model of COVID 19 Infection

back to linear. Those periods initial to the optimal change was mentioned as the Phase one and the linear phase was known as Resting phase, and the period after the second cut off was identified as Phase two. The quadratic Regression Model was fitted and found to be the best model in each of the phases except the resting phase. The initial phase (phase one) was comparatively less fitted when compared to the later phase (phase two). The Quadratic regression model could also be used to predict the upcoming phases of the pandemic, which will have both the resting and non-resting periods. The Global maxima of the model were found to be around five times more in phase two when compared with phase one. The findings could be beneficial in influencing health policy decisions or government initiatives, especially developing initiatives aimed at reducing case fatality rates in their region over time, hence improving the overall health care facilities. These findings should, however, be seen to pave ways to more advanced mathematical and epidemiological models in research.

Conclusion

The first and second COVID-19 wave in India had different characteristics, the second which have been roughly said to be initialized on February 11, 2021 and was different in different states. The second phase had almost five time more when compared with the first and has been disastrous, with a number of cases exceeding 0.2 million per day on April 14, 2021. COVID-19 virus has over 7,684 varieties in India. As of May, 2021, the resurgent wave of COVID-19 in India has been spreading to rural population. The pandemic has brought attention to India's long-standing need for universal health coverage (UHC). Yet in the present moment, India confronts an urgent need to save lives and alleviate suffering.

The characteristics of the phases identified can be used for handling the upcoming waves. A one-size-fits-all approach is untenable since the numbers of COVID-19 cases and health services differ substantially from district to district in the upcoming waves. Working groups at the district level that have the autonomy to respond to quickly changing local situations must be empowered to receive resources and funds to coordinate efforts across the multifarious sectors of the health care system, i.e. from the front-line workers to tertiary care. Relevant technologies along with the statistical modelling could have a role in streamlining the management of resources and commodities, such as oxygen, ambulances, hospital beds, and funeral services.

Ethical Approval and Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of supporting data

From
https://www.mohfw.gov.in/ through Kaggle.

Competing interests

The authors declare that they have no conflict of interest.

Funding

Not received any funding.

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