

Research Article

COVID-19 Pandemic in India: Chronological Comparison of the Regional Heterogeneity in the Progression of the Pandemic and Gaps in Mitigation Strategies

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ABSTRACT

Background: The progressions of the first and second waves of the COVID-19 pandemic in India were heterogeneous in different regions and their respective states and union territories. Our work aims to understand the major differences between the two waves and the mitigation strategies implemented during these waves.

Methods: An extensive analysis of the temporal variations in new cases and fatalities in all the states of India was done for both the first wave (30th January 2020 to 31st January 2021) and second wave (1st February 2021 to 29th May 2021) of the pandemic. Variations in different epidemiological parameters, like case fatality ratio (CFR), cumulative case ratio (CCR), and cumulative death ratio (CDR) were quantified.

Results: The Southern and Western regions were the top contributors of cases and fatalities in both waves. The state of Punjab and Maharashtra reported the highest CFR (3.24 and 2.5 respectively) in the country during the first wave and Andaman and Nicobar Islands (2.6), and Punjab (2.25) reported the highest CFR during the second. Goa and Delhi respectively showed the highest CCR and CDR during the first wave, whereas Lakshadweep and Goa respectively reported the highest CCR and CDR in the second wave. In the majority of states and UTs, the test-to-case ratio has been found below than the WHO recommended mark.

Conclusion: The study comprehends the chronological heterogeneity in the patterns of pandemic progression and the severity of the second wave over all the states of the country, highlighting the major hotspot regions and some gaps in mitigation strategies.

Keywords: COVID-19; Pandemic; First wave; Second wave; Regional heterogeneity; Hotspot regions

Abbreviation: COVID-19: Coronavirus Disease 2019; NR: Northern Region; CR: Central Region; WR: Western Region; ER: Eastern Region; NER: North Eastern Region; SR: Southern Region; UT: Union Territory; CCR: Cumulative Case Rate; CDR: Cumulative Death Rate; CFR: Case Fatality Ratio; SARS CoV-2: Severe Acute Respiratory Syndrome Coronavirus-2; LAGE: Legislative Assembly General Election; WHO: World Health Organization

INTRODUCTION

India is currently the second-largest contributor to the total COVID-19 cases of the world, accounting for about 16% of the total cases and around 9% of the deaths worldwide [1]. The state of Kerala has reported the first case of COVID-19 in India on January 30th, 2020 [2]. Thereafter, from March 2020, the number of active cases started to rise at a rapid pace. Amid this crisis, the Government of India announced a nationwide lockdown with implementations

of measures for public health, nevertheless, the COVID-19 cases started rising once again after the first phase of unlocking, from May 31st, 2020 [3]. In most of the states, cases started to surge from June 2020, which reached their respective maxima in the middle of September 2020 [4]. The first wave however subsided towards the end of January 2021 which led to the withdrawal of several restrictions on social and political gatherings [5]. However, the consequence of this relaxation soon turned out to be catastrophic as the second wave of COVID-19 pandemic commenced from the

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The Indian subcontinent is characterized by diverse geographical and demographical regions, populated by heterogeneous cultural, political, linguistic, and ethnic groups of people covering an area of 3.28 million square kilometers with a total population of about 138 cores [10-14]. This huge diversity is likely to contribute to the visible heterogeneity in the progression patterns of the pandemic in each region of the country, which therefore demands the detailed analysis of chronological heterogeneity in the regional and state-specific infection rates, death rates, wave patterns, and testing capacities for a clear interpretation of the progression patterns of the two wave of the COVID-19 pandemic across the country. Previous publications on the effects of COVID-19 pandemic in India have either discussed the adverse impacts of the pandemic on the social structure, food security, mental and psychological health of the people, economic growth, and healthcare infrastructure or highlighted the gaps in communication between the health agencies and the Government of India, or demonstrated the containment measures, and the progression of the pandemic during the earlier part of the first wave [15-21]. However, no former study has reported the temporal dynamics of cases, deaths, and recoveries in the states and union territories of India and their respective contributions to the nation's COVID-19 situation throughout the first and second wave of the pandemic. In this study, for the first time, we did a comprehensive analysis of the chronological changes in the patterns of progression of the pandemic during the first and second wave in each region of the country and its respective states and union territories-India comprises 28 states and 8 unions territories, divided along 6 administrative subdivisions, the Northern Region (NR), Central Region (CR), Western Region (WR), Eastern Region (ER), North Eastern Region (NER) and the Southern Region (SR) (Table 1 and Table 2) [22,23]. The analyses, revealing the differential progression patterns of the two waves, contribute significantly to the evaluations of the real scenario of the COVID-19 pandemic across the nation as well as disclose the gaps in pandemic mitigation strategies.

MATERIALS AND METHODS

Study design and data sources

A detailed study of the COVID-19 infections and their related statistics in India was done for the periods, from January 30th, 2020 to January 31st, 2021 for the first wave, and from February 1st, 2021 to May 29th, 2021 for the second wave. The day, reporting the highest number of active cases was defined as the peak of the wave. The pandemic wave was defined by a phase of a rising number of COVID-19 cases with a definite peak, followed by a phase of the declining number of cases, or the trough period (in which the rates of new infections and active cases have declined significantly). The days of first reported infection, rising (a 10% consistent increase in the number of active cases) and declining phases of the two waves, peaks of the waves, numbers of new infections, death, recoveries along with the testing and demographical data for all the 6 administrative regions, comprising of 28 states and 8 union territories (UTs) of the country, were obtained from the online monitoring official website of the Government of India [4] and other national and international websites [24]. The numbers of monthly new cases, deaths, and recoveries for each state were

calculated and the chronological (monthly) contributions of each administrative region of the subcontinent (contributions from all the states and union territories of the concerned region were summed up) to the nation's total number of new cases, deaths, and recoveries were calculated.

Statistical analysis

Extensive analysis was performed to establish the epidemiological parameters, such as CCR or cumulative case rate (cases per 1 lakh or 100000 populations), CDR or cumulative death rate (deaths per 1 lakh), CFR or case fatality ratio (number of deaths reported per number of cases reported × 100), and TPC or test per case (total number of tests/total number of cases) for both the first and second waves. These values were plotted on the Indian political map using https://mapchart.net/india.html to depict the heterogeneous progression of the pandemic in the states and UTs during the two waves. The weekly average numbers of new confirmed cases, active cases, and deaths were quantified by averaging the changes in numbers between the successive days over a week. The fold changes in average daily new cases for each month (before, during, and after LAGE) for the 5 states, which underwent elections, were calculated and compared with 5-other states that didn't experience any major public gathering.

RESULTS

A chronological overview of the contributions of different regions of India towards the cases and fatalities in the two waves of the COVID-19 pandemic

The chronological variations in the number of new cases and new deaths in India (Figures 1A and 1B) and the contributions of different regions towards the total cases and fatalities of the nation are noteworthy. At the beginning of the first wave, the SR accounted for nearly 40% of the nations' total cases in March 2020. From April 2020 till June 2020, the WR remained the major contributor of COVID-19 cases of the nation (43%, 46%, and 31% of the total cases respective in these months). Subsequently from June 2020, when the first phase of unlocking (unlock-1) started in the country (Figure 1A), till the end of October 2020, the SR contributed 41%, 40%, 34%, and 41% of the total COVID-19 cases of India in the respective months. In November 2020, the NR was the major contributor (31%), whereas from December 2020, till February 2021, SR again contributed respectively 31%, 47%, and 43% of the total cases of the nation. At the beginning of the rising phase of the second wave, from March 2021 till April 2021, the WR contributed about 63%, and 30% of the nations' total cases respectively, and in May 2021, the SR became the major contributor of new cases (42%) in the country (Figure 1C).

In terms of fatality, the WR accounted for the highest monthly fatality from March 2020 till October 2020 (contributed nearly 35%, 59%, 62%, 51%, 41%, 37%, 39%, and 31% of the total monthly deaths of the nation respectively) (Figure 1D). The NR contributed over 33% and 31% of total fatality in November and December 2020, and the WR was the highest monthly contributor of COVID-19 related fatality from January 2021 till April 2021 (30%, 40%, 39%, and 33% of the total fatality in the respective months). However, in May 2021, the SR accounted for the maximum proportion of fatality of the country (28%) (Figure 1D). Thus, it can be inferred from these results that both the Western and Southern Indian states have been the major hotspots of the COVID-19 pandemic in the Indian subcontinent (Figures 1E and 1F)



The first wave of COVID-19 in India-A detailed analysis

Apart from Kerala, most of the Indian states reported their first COVID-19 infection in March or April 2020. The Government of India has implemented a nationwide complete lockdown and strict containment protocols from March 25th, 2020 to combat the dissemination of the viral infection. The unlock process, implemented in six phases, commenced from June first, 2020 to November 30th, 2020, although the daily cases began to surge steadily, especially from the end of May 2020 to September 2020 in the majority of Indian states (Table 1) [25]. The adverse effects of unlocking can be understood from the following statistics - from the week, before the last week of lockdown (May 18th, 2020 to May 24th, 2020) to the week, after one continuous week of unlock-1 (June 8th, 2020 to June 14th, 2020), the change in weekly-average numbers of new confirmed cases, active cases, and deaths respectively showed an increase from 6369 to 11170 (1.75-fold), from 3153 to 4048 (1.28-fold), and from 144 to 340 (2.35-fold) (analysis not shown). India reported the maximum number of daily new cases on September 16th, 2020 (around 98,000) and the maximum active cases on September 17th, 2020 (1018454), which was marked as the peak of the first wave. Subsequently, the figures of daily cases started to drop steadily in the following weeks, till the end of January 2021, when the number reduced around 10,000 cases/day; marking the trough of the wave. Among the 10758629 cases reported during the first wave, the highest number of cases was reported from SR (3933360), contributing 36.5% of the total cases where the state of Karnataka was the top contributor (~8.7%) (Table 1). The WR contributed 21.6% of the nation's total cases, where the top contributor was Maharashtra (2026399 cases, ~18.8%). The NR accounted for about 16.4% of total cases, where the highest contributor was Delhi

(5.9%). The ER shared 11.8% of the total cases, where West Bengal contributed maximally (5 5.3%). The CR reported 10.7% of the total cases in which Uttar Pradesh contributed the majority of cases (5.5%). The NER was the lowest contributor of cases (3%) in the first wave where Assam contributed the major number of cases (2%) (Table 1). The CCR was found to be highest in Ladakh (3352 cases/1 lakh of the population), followed by Delhi (3175) and Chandigarh (1773).

In addition to contributing to the second-highest number of COVID-19 cases, states of the WR also contributed the maximum number of deaths during the first wave (accounted for 36.4% of the nation's total deaths of 154428). The state of Maharashtra accounted for the most number of deaths in the region (33%). The trend also remained similar for the SR, which accounted for 24.4% of the nation's total deaths (Table 1). Contributions from the Northern states were about 17.7% to the total fatalities of the nation (Table 1), whereas, the CR and ER respectively accounted for 10.5% and $^{\sim}9.5\%$ of the total deaths (Table 1). The NER states reported the least mortality and contributed only \sim 1.51% of the total deaths of the nation (Table 1). The highest CDR was however reported by the national capital, Delhi (54/1 lakh of the population), followed by Goa (50), Ladakh (45), and Maharashtra (42) (Table 1). The CFR was found to be highest in the state of Punjab (3.24) in the NR, followed by Maharashtra (2.5) in the WR with Sikkim (2.18) stands next from the NER. The state of West Bengal (1.785) accounted for the highest CFR from the ER, followed by Uttarakhand (1.71), Delhi (1.71), and Himachal Pradesh (1.69) from the NR. Among the states of Southern India, Puducherry recorded the highest CFR (1.66) (Figures 2A and 2C and Figures 3A and 3C) (Table 1).

Table 1: First wave of CC ratios.	VID-19 in India	a: An account of t.	he impact of the :	first wave of	COVID-19,	as of January	7 31st, 2021, i	in the differ	ent regions a	nd their res _l	pective states	and UT's c	of the country	and testing
States and Union Territories (UTs)	Population	First Report	Peak	TC	PCC	DT	PDC	CFR	CCR	CDR	TR	RPC	TT	TPC
Northern India														
Haryana	2900000	4/3/2020	19-09-2020	267897	2.49	3019	1.955	1.127	923.783	10.41	263874	0.985	5170000	19.298
Himachal Pradesh	7300000	14-03-2020	28-11-2020	57536	0.535	026	0.628	1.686	788.164	13.288	56195	0.977	930000	16.164
Uttarakhand	11000000	15-03-2020	19-09-2020	96129	0.894	1644	1.065	1.71	873.9	14.945	91966	0.957	2130000	22.158
Punjab	3000000	9/3/2020	19-09-2020	173276	1.611	5621	3.64	3.244	577.587	18.737	121822	0.703	4480000	25.855
Rajasthan	7700000	3/3/2020	5/7/2020	397491	3.695	2766	1.791	0.696	516.222	3.592	312564	0.786	5850000	14.717
Chandigarh (UT)	1180000	19-03-2020	16-09-2020	20925	0.194	334	0.216	1.596	1,773.31	28.305	20426	0.976	200000	9.558
Delhi (UT)	2000000	2/3/2020	14-11-2020	635096	5.903	10853	7.028	1.709	3,175.48	54.265	622882	0.981	11000000	17.32
Jammu and Kashmir (UT)	1300000	9/3/2020	20-09-2020	124506	1.157	1936	1.254	1.555	957.738	14.892	121822	0.978	4540000	36.464
Ladakh (UT)	290000	7/3/2020	8/10/2020	9720	0.09	130	0.084	1.337	3,351.72	44.828	9523	0.98	NA	NA
Central India														
Chattisgarh	2900000	19-03-2020	21-09-2020	305367	2.838	3701	2.397	1.212	1,052.99	12.762	297339	0.974	4220000	13.819
Madhya Pradesh	82000000	20-03-2020	23-09-2020	255112	2.371	3810	2.467	1.493	311.112	4.646	248367	0.974	5360000	21.01
Uttar Pradesh	22500000	4/3/2020	17-09-2020	600299	5.58	8658	5.606	1.442	2,668.00	38.48	586116	0.976	2800000	46.643
Western India														
Goa	1540000	25-03-2020	24-09-2020	53409	0.496	768	0.497	1.438	3,468.12	49.87	59891	1.121	450000	8.426
Gujarat	6800000	19-03-2020	3/10/2020	261540	2.431	4387	2.841	1.677	384.618	6.451	253803	0.97	11000000	42.059
Maharashtra	122000000	9/3/2020	17-09-2020	2026399	18.835	51082	33.078	2.521	1,660.98	41.87	1929005	0.952	1500000	7.402
Dadra and Nagar Haveli and Daman and Diu (UT)	960000	9/4/2020	14-08-2020	3380	0.031	2	0.001	0.059	352.083	0.208	3342	0.989	1100	0.325
Eastern India														
Bihar	120000000	22-03-2020	15-08-2020	260719	2.423	1501	0.972	0.576	217.266	1.251	258018	0.99	21000000	80.546
Jharkhand	3700000	31-03-2020	9/9/2020	118692	1.103	1072	0.694	0.903	320.789	2.897	117067	0.986	5220000	43.979
Odhisa	4400000	16-03-2020	24.09-2020	335072	3.114	1959	1.269	0.585	761.527	4.452	332103	0.991	7710000	23.01
West Bengal	00000026	17-03-2020	22-10-2020	569998	5.298	10173	6.588	1.785	587.627	10.488	554272	0.972	800000	14.035
North Eastern India														
Arunachal Pradesh	5200000	2/4/2020	16-10-2020	16828	0.156	56	0.036	0.333	32.362	0.108	16759	0.996	390000	23.176
Assam	3400000	31-03-2020	30-09-2020	217141	2.018	1082	0.701	0.498	638.65	3.182	214178	0.986	6470000	29.796

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Meghalaya	3220000	13-04-2020	16-10-2020	13764	0.128	146	0.095	1.061	427.453	4.534	13550	0.984	330000	23.976
Mizoram	1190000	26-03-2020	22-09-2020	4372	0.041	6	0.006	0.206	367.395	0.756	4330	0.99	210000	48.033
Tripura	3990000	7/4/2020	13-09-2020	33347	0.31	388	0.251	1.164	835.764	9.724	32915	0.987	610000	18.293
Nagaland	2150000	6/4/2020	14-08-2020	12094	0.112	144	0.093	1.191	562.512	6.698	11806	0.976	120000	9.922
Sikkim	660000	4/5/2020	26-09-2020	0609	0.057	133	0.086	2.184	922.727	20.152	5775	0.948	74700	12.266
ern India														
ndhra Pradesh	5200000	12/3/2020	2/9/2020	887836	8.252	7153	4.632	0.806	1,707.38	13.756	879405	0.991	1800000	20.274
Karnataka	66000000	9/3/2020	10/10/2020	939387	8.731	12217	7.911	1.301	1,423.31	18.511	921112	0.981	17000000	18.097
Kerala	3500000	30-01-2020	9/10/2020	929179	8.637	3744	2.424	0.403	2,654.80	10.697	854206	0.919	9630000	10.364
Tamil Nadu	7600000	7/4/2020	3/7/2020	838340	7.792	12356	8.001	1.474	1,103.08	16.258	821430	0.98	16000000	19.085
Telangana	3700000	2/3/2020	4/9/2020	294469	2.737	1599	1.035	0.543	795.862	4.322	290630	0.987	7860000	26.692
uman and Nicobar Islands (UT)	400000	26-03-2020	15-08-2020	4994	0.046	62	0.04	1.241	1,248.50	15.5	4928	0.987	220000	44.053
iducherry (UT)	1500000	17-03-2020	26-09-2020	39068	0.363	648	0.42	1.659	2,604.53	43.2	38135	0.976	580000	14.846
cshadweep (UT)	68000	16-01-2020	13-03-2021	87	0.001	0	0	0	127.941	0	49	0.563	2300	26.437

Regarding the testing of cases, until the end of January 2021, we found that more than 228.4 million COVID-19 tests were performed all over India. The WHO has recommended an optimum of 30 test-to-case ratios (T: C) as standard; however apart from the states and UT, like Jammu and Kashmir (36.5), Uttar Pradesh (46.6), Gujarat (42), Bihar (80.5), Jharkhand (44), Assam (29.7), Mizoram (48), and Andaman and Nicobar Islands (44), all other states and union territories had a T: C ratio less than the WHO recommended mark [26] (Table 1).

The second wave of COVID-19 in India: A detailed analysis

The period between the end of February 2021 and early March 2021, marked the rising phase of the catastrophic second wave of the COVID-19 pandemic in India. During this period, the country reported more than 3 lakhs new cases/day in April that soared to over 4 lakhs cases/day and over 4000 daily deaths in the first week of May 2021, which abruptly overburdened the healthcare system of the country. On May 6th, 2021, India reported its highest number of over 414280 new cases in a day, which marked the peak of the second wave until now. Thereafter, the daily cases started to decrease gradually, however the fatality rate remained high.

Starting from February first till May 29th, 2021, India reported a total number of 17134975 cases and over 1.7 lakh deaths. Until May 29th, 2021, the SR remained the top contributor of cases (32%) and also accounted for 22% of the country's fatality, where the state of Karnataka (9.5%) and Kerala (9.1%) together accounted for more than half of the total cases of the region, and Karnataka (9.3%) and Tamil Nadu (6.3%), like in the first wave, were also the major contributors to the nation's fatalities (Table 2). The WR contributed over 25% and 29% of the cases and fatalities respectively during this period. The NR, CR, and ER contributed 16%, $^{\sim}$ 13%, and $^{\sim}$ 10.8% respectively to the total cases, and 27%, 14.5%, and 7.7% to the nation's total deaths respectively. The NER reported the least number of cases (1.63%) and fatalities (2%) in the country (Table 2).

Until May 29th, 2021, the highest CFR was reported by Andaman and Nicobar Islands (2.59), followed by Punjab (2.23) from the NR and Nagaland (2.22) from the NER. The highest CDR was found for Goa (118 deaths/1 lakh), followed by Uttar Pradesh (51), and Lakshadweep (45). Lakshadweep was also found to contribute highest to the CCR (11084 cases/1lakh), followed by Uttar Pradesh (4835) and Chandigarh (3289). It is noteworthy that regarding test per case, apart from Andaman and Nicobar Islands (86.2), Haryana (49), and Ladakh (29.1), all other states and union territories were lagging behind the recommended WHO level26 (Figures 2B and 2D and Figures 3B and 3D).

One of the other major contrasts between the first and second waves is the evolution of new variants of the novel SARS-CoV-2 virus during the second wave. The three imported viral variants of concern that have been identified in India are the UK (B.1.1.7) variant, the South African (B.1.351) variant, and the Brazilian (P1) variant, among which the B.1.1.7 variant was predominantly present in Delhi and Punjab in April 2021. Among the two novel variants of India, the highly contagious B.1.617.2 (Delta) variant from Maharashtra has started evolving rapidly and overtook the B.1.618 variant in West Bengal, and eventually became the major variant in most of the states. The WHO has already designated the delta variant as a 'variant of concern' in May 2021. This variant has spread in all states across the nation and is identified as one of the major causes of the calamity associated with the second wave of COVID-19 in India, as per the study conducted by the Indian

SARS-CoV-2 Genomics Consortium (INSACOG), which was launched by the Ministry of Health and Family Welfare, Govt. of India, on December 30th, 2020 [27,28].

Roles of some major mass-scale public events, during the second wave, on COVID-19-related outcomes

Mass-scale public gatherings, like Kumbh Mela 2021 (9 million participants) and the state elections (covering 243 million residents) have contributed to the escalated spreading of the second wave in the nation [29,30]. A 117-fold increase in the number of weeklyaverage new cases and a 266-fold increase in the weekly-average new deaths were found for the state of Uttarakhand when we compared the data between before and after the festival of Kumbh Mela 2021. Uttar Pradesh, like Uttarakhand, also showed a sharp jump in the weekly average new cases and deaths - respectively a 240-fold and 201-fold increase in the numbers of new cases and deaths after this religious festival (Table S1 and Figure S1). These numbers are much higher than the fold-increase found for the new cases (20.9-fold) and new deaths (35.4-fold) for the entire nation between the mentioned periods. Four Indian states, Assam, Kerala, Tamil Nadu, West Bengal, and one UT, Puducherry, that witnessed their 'legislative assembly general elections' (LAGEs) from the end of March to the end of April 2021, also reported a substantial increase in the average daily cases after the elections compared to some of the other states with no LAGE or major public gatherings during the same period (Table S2 and Figure S2). These increases in numbers are mainly attributed to the electionrelated rallies and mass-scale public meetings which were organized by the local political parties [31]. However, it is noteworthy that we could not dissect out the exact contributions of such gatherings from the general increase in the numbers of cases and deaths due to aggravation of the pandemic itself using the available data.

DISCUSSION

The second wave of COVID-19 pandemic resulted in total unexpected disarrays in all states of the country. While the first wave caused a little over 1.08 crore infections and over 1.5 lakhs fatality in the whole country within 11 months, the ongoing second wave resulted in over 1.7 crore infections and nearly 2 lakhs fatalities in a span of merely 4 months. The daily average number of new cases during April 2021 was around 2.31 lakhs which soared to about 3.01 lakhs cases/day in May 2021, which are nearly 2.7 and 3.5 times the average daily cases (87,000 cases/day) of September 2020, when India reported its peak of the first wave. The CCR and CDR for the second wave were also found to elevate substantially in comparison to the first wave (Table 1), however, the CFR for both the waves did not show much variation for the majority of states (except for Maharashtra and Punjab) until May 29th, 2021 (Table 2). The advent of new and more infectious variants of the virus, inaccuracy in diagnosis, lack of testing, non-transparency in data sharing, low rate of vaccination, decreased rate of genome sequencing of the positive samples along with unchecked social, religious, and political gatherings, the inflexible attitude of the citizens (violating the containment protocols), and importantly, the serious lack of persistent measures to mitigate COVID-19, despite previous warnings, were held responsible for this unprecedented escalation of the pandemic in the country by many reports [15,32-34]. Despite an increase in the daily test numbers, the test-to-case ratio has dropped in the majority of states during the second wave (Figure 3D and Table 2). Thus, the need of the hour is to accelerate the testing rates both in the rural and urban regions of the nation to get a clear picture of the infection scenario, which will aid to avert the nucleation of another catastrophic wave of the pandemic [35,36].

Table 2: Jecolia Wave Ol		יווחומ / ז זוו זאומא ב/ר	11, 2021). MIL au		uupact of the				nucii icabe	CULINE STATES AL		d1100109, d10	
States and Union Territories (UTs)	Population	Peak (Till Date)	TC	PCC	TD	PDC	CFR	CCR	CDR	TR	RPC	ΤT	TPC
Northern India													
Haryana	2900000	9/5/2021	486040	2.83	5113	2.98	1.052	1676	17.631	458837	0.944	23830000	49.029
Himachal Pradesh	7300000	13-05-2021	131068	0.76	2100	1.224	1.602	1795.452	28.767	112329	0.857	000026	7.401
Uttarakhand	1100000	15-05-2021	230983	1.34	4716	2.749	2.042	2099.845	42.873	191996	0.831	2600000	11.256
Punjab	3000000	12/5/2021	389555	2.27	8684	5.061	2.229	1298.517	28.947	384527	0.987	460000	1.181
Rajasthan	7700000	15-05-2021	538671	3.14	10213	5.953	1.896	699.573	13.264	599188	1.112	11150000	20.699
Chandigarh (UT)	1180000	10/5/2021	38815	0.22	406	0.237	1.046	3289.407	34.407	36108	0.93	300000	7.729
Delhi (UT)	2000000	28-04-2021	789550	4.6	13220	7.705	1.674	3947.75	66.1	764656	0.968	800000	10.132
Jammu and Kashmir (UT)	1300000	13-05-2021	162178	0.94	1905	1.11	1.175	1247.523	14.654	121766	0.751	3950000	24.356
Ladakh (UT)	290000	22-04-2021	8590	0.05	57	0.033	0.664	2962.069	19.655	6994	0.814	250000	29.104
Central India													
Chattisgarh	2900000	16-05-2021	662278	3.86	9278	5.408	1.401	2283.717	31.993	614413	0.928	4800000	7.248
Madhya Pradesh	8200000	11/5/2021	522237	3.04	4149	2.418	0.794	636.874	5.06	490124	0.939	5640000	10.8
Uttar Pradesh	22500000	30-04-2021	1087833	6.34	11550	6.732	1.062	4834.813	51.333	1035607	0.952	21000000	19.304
Western India													
Goa	1540000	13-05-2021	101010	0.58	1829	1.066	1.811	6559.091	118.766	76875	0.761	370000	3.663
Gujarat	6800000	2/5/2021	544077	3.17	5403	3.149	0.993	800.113	7.946	503321	0.925	600000	11.028
Maharashtra	122000000	22-04-2021	3686816	21.51	42948	25.032	1.165	3021.98	35.203	3410833	0.925	20000000	5.425
Dadra and Nagar Haveli and Daman and Diu (UT)	960000	29-04-2021	6823	0.03	2	0.001	0.029	710.729	0.208	6507	0.954	1100	0.161
Eastern India													
Bihar	120000000	6/5/2021	443454	2.58	3551	2.07	0.801	369.545	2.959	420018	0.947	0000006	20.295
Jharkhand	3700000	8/5/2021	217548	1.26	3887	2.266	1.787	587.968	10.505	203269	0.934	3170000	14.571
Odhisa	4400000	23-05-2021	412071	2.4	780	0.455	0.189	936.525	1.773	326545	0.792	4290000	10.411
West Bengal	00000026	15-05-2021	784958	4.58	5095	2.97	0.649	809.235	5.253	683018	0.87	400000	5.096
North-Eastern India													
Arunachal Pradesh	5200000	24-05-2021	9950	0.05	58	0.034	0.583	19.135	0.112	5987	0.602	190000	19.095
Assam	3400000	20-05-2021	186482	1.08	2163	1.261	1.16	548.476	6.362	129905	0.697	4530000	24.292

ective states and union territories, and the testing ratio. and their wave in diffe puo ct of the int of the in (Till May 79th 7071). An act of COVID.19 in India A W/a Table 2: Se

Manipur	3100000	26-05-2021	19780	0.11	405	0.236	2.048	638.065	13.065	11491	0.581	190000	9.606
Meghalaya	3220000	20-05-2021	20684	0.12	405	0.236	1.958	642.36	12.578	12606	0.609	240000	11.603
Mizoram	1190000	25-05-2021	7287	0.04	26	0.015	0.357	612.353	2.185	4533	0.622	170000	23.329
Tripura	3990000	23-05-2021	16535	0.09	107	0.062	0.647	414.411	2.682	9493	0.574	310000	18.748
Nagaland	2150000	13-05-2021	9277	0.05	206	0.12	2.221	431.488	9.581	3608	0.389	20000	7.546
Sikkim	660000	2/5/2021	8823	0.05	114	0.066	1.292	1336.818	17.273	4841	0.549	45300	5.134
Southern India													
Andhra Pradesh	5200000	30-04-2021	783906	4.57	3585	2.09	0.457	1507.512	6.894	226709	0.776	1000000	1.276
Karnataka	66000000	4/5/2021	1628062	9.5	16081	9.373	0.988	2466.761	24.365	1267952	0.779	12000000	7.371
Kerala	3500000	15-05-2021	1565207	9.13	4712	2.746	0.301	4472.02	13.463	1398299	0.893	10370000	6.625
Tamil Nadu	7600000	27-04-2021	1201376	7.01	10905	6.356	0.908	1580.758	14.349	884868	0.737	11000000	9.156
Telangana	3700000	2/5/2021	279557	1.63	1648	0.961	0.59	755.559	4.454	243232	0.87	7140000	25.54
Andaman and Nicobar Islands (UT)	400000	1/5/2021	1970	0.01	51	0.03	2.589	492.5	12.75	1732	0.879	170000	86.294
Puducherry (UT)	1500000	11/5/2021	63828	0.37	849	0.495	1.33	4255.2	56.6	50111	0.785	460000	7.207
Lakshadweep (UT)	68000	1/5/2021	7544	0.04	31	0.018	0.411	11094.11	45.588	5547	0.735	127700	16.927
Note: Abbreviations: UT PDC: Proportion of Deat Ratio; CDR: Cumulative	: Union territor A Contribution Death Ratio; T	y; TC: Total Cases n (total no. of deat 'R: Total Recovere	;; PCC: Proporti ths in the respec d; RPC: Recover	on of Case C tive state or l ry Per Case (1	Contribution JT/total no. cotal no. recc	(total no. of . of deaths ir overed/total	cases in the the nation no. of cases)	respective sta); CFR: Case ;; TT: Total Te	te or UT/to Fatality Rati ests; TPC: T	otal no. of cas io (given in p est Per Case (es in the na ercentage); total no. of	tion); TD: Tot CCR: Cumul tests/total no	al Deaths; ative Case . of cases).

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Figure 3: Maps of case fatality ratio and test per case for the Indian states and UTs during the two waves: Different states and union territories (UTs) of India are color-coded to represent their different case fatality ratios during the first (A) and second wave (B) of the pandemic. Similarly, the differences in test per case (test-to-case ratio) for the states and UTs are represented for the first (C) and second wave (D).

Our study comprehends that the Southern and Western regions were the major hotspots of the pandemic in both waves. The state of Karnataka and Tamil Nadu from the SR and Maharashtra from the WR showed consistently high numbers of infections and fatalities throughout the two waves. These results indicate that irrespective of the presence of the highly infectious B.1.617 Indian variant of the SARS-CoV-2 in these states during the second wave, shortfalls in the health systems and deficits in the implementations of COVID-19 restriction protocols may be responsible for the upsurge of the pandemic in these territories.

Although the data on demographical differences in infection are not made available to the public by the Ministry of Health and Family Welfare, Govt. of India, however, many recent reports have suggested that a notable difference between the first and second wave in the country is that the second wave affected a large portion of the pediatric group, which remained largely asymptomatic in the first wave [37]. As of the first week of April 2021 (between March 1st to April 4th, 2021), it was reported that over 79,000 children were affected by the disease from the five states which include Maharashtra, Chattisgarh, Karnataka, Uttar Pradesh, and Delhi, of which over 60,000 cases were from Maharashtra [38], although the number of hospitalization among the children was only a handful. In India, the gap between the peaks of the two waves was about 7.5 months, which was a bit larger than the average gap of around 5 months reported for the majority of countries; however, the escalation of the second wave was far higher in this country than others [37]. At present, the second wave is in its declining phase for the majority of Indian states, albeit experts have suggested that unless the vaccination rate is accelerated, the country is set to face the 3rd wave by the end of this year, which may affect the unvaccinated population in large numbers [39-42]. Thus, ramping up of the clinical trials of vaccines both for the pediatric and adult groups, strengthening of the health infrastructure of the nation, wide-scale genomic sequencing of the positive samples, monitoring of the progression of new cases, and strict implementation of COVID-19 appropriate restrictions for the public are the urgent needs of the hour to protect the future of the country and its people from another COVID-19 tsunami [43].

CONCLUSION

The study comprehends the chronological heterogeneity in the patterns of pandemic progression and the severity of the second wave over all the states of the country, highlighting the major hotspot regions and some gaps in mitigation strategies.

FUNDING CONCLUSION

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CONFLICT OF INTERESTS

The authors declare no conflict of interests.

REFERENCES

- 1. COVID Live Update: 172,963,233 Cases and 3,718,849 Deaths from the Coronavirus. Worldometer n.d. 2021.
- Andrews MA, Areekal B, Rajesh K, Krishnan J, Suryakala R, Krishnan B, et al. First confirmed case of COVID-19 infection in India: A case report. Indian J Med Res. 2020;151:490-492.
- 3. PM Modi announces 21-day lockdown as COVID-19 toll touches 12. The Hindu n.d. 2021.
- 4. Coronavirus Outbreak in India. covid19india.org n.d. 2021.
- 5. Coronavirus live. Consistent fall in India's active caseload due to decline in daily infections: Health ministry. The Hindu n.d. 2021.
- 6. Coronavirus: WHO says religious, political gatherings contributed to India's surge in cases n.d. 2021.
- 7. Covid-19 surge in India: These states impose complete lockdown to curb spread. 2021.
- 8. The novel coronavirus variants and India's uncertain future. The Wire Science n.d. 2021.
- 9. Two variants responsible for second wave. The Sunday Guardian Live n.d. 2021.
- Mastana SS. Unity in diversity: An overview of the genomic anthropology of India. Ann Hum Biol. 2014;41:287-299.
- 11. Majumder PP, Basu A. A genomic view of the peopling and population structure of India. Cold Spring Harb Perspect Biol. 2015;7.
- 12. Geography of India n.d. 2021.
- 13. Statistical Year Book India 2016. In: Ministry of Statistics and Program Implementation, Government of India n.d. 2021.
- 14. Administrative divisions of India. Wikipedia n.d. 2021.
- Pal R, Yadav U. COVID-19 Pandemic in India: Present Scenario and a Steep Climb Ahead. J Prim Care Community Heal. 2020;11.
- Siddiqui AF, Wiederkehr M, Rozanova L, Flahault A. Situation of India in the COVID-19 pandemic: India's initial pandemic experience. Int J Environ Res Public Health. 2020;17:1-18.
- Ghosh A, Nundy S, Mallick TK. How India is dealing with COVID-19 pandemic. Sensors Int. 2020;1:100021.
- Kumar R, Bharti N, Kumar S, Prakash G. Multidimensional impact of COVID-19 pandemic in India-Challenges and future direction. J Fam Med Prim Care. 2020;9:5892.
- Kar SK, Ransing R, Arafat SMY, Menon V. Second wave of COVID-19 pandemic in India: Barriers to effective governmental response. E Clinical Medicine. 2021;36:100915.
- Laxminarayan R, Jameel S, Sarkar S. India's battle against COVID-19: Progress and challenges. Am J Trop Med Hyg. 2020;103:1343-1347.
- 21. Kumar SU, Kumar DT, Christopher BP, Doss CGP. The Rise and Impact of COVID-19 in India. Front Med. 2020;7:250.
- 22. States Uts. Know India: National Portal of India n.d. 2021.
- 23. India COVID: 28,574,350 Cases and 340,719 Deaths. Worldometer n.d. 2021.
- Lockdown Unlock in India COVID19 pandemic guidelines restrictions 2020 coronavirus lockdown series. India News. India TV n.d. 2021.
- 25. Who audio emergencies coronavirus press conference n.d. 2021.
- 26. Indian SARS-CoV-2 Genomics Consortium (INSACOG) launched. DD News n.d. 2021.
- 27. Coronavirus variants are spreading in India-what scientists know so far. News in focus n.d. 2021.

OPEN OACCESS Freely available online

- 28. Kumbh Mela and election rallies: How two super spreader events have contributed to India's massive second wave of COVID-19 cases-India News , Firstpost n.d. 2021.
- 29. 9.1 million thronged Mahakumbh despite Covid-19 surge: Govt data. Hindustan Times n.d. 2021.
- 30. India Covid crisis: Did election rallies help spread virus? BBC News n.d. 2021.
- 31. The Oxygen Crisis in Second Wave Covid-19 Pandemic in India and "We the People". Vivekananda International Foundation n.d. 2021.
- 32. India wasted its early successes in managing Covid-19, PM Modi's actions "inexcusable". Lancet-Coronavirus Outbreak News n.d. 2021.
- India Covid: Kumbh Mela pilgrims turn into super-spreaders. BBC News n.d. 2021.
- 34. Fewer Tests Could Be Why India's COVID-19 Numbers Have Declined Since May 1. The Wire Science n.d. 2021.
- 35. India's COVID-19 Testing Capacity Must Grow by a Factor of 10: Here's How That Can Happen. Center For Global Development n.d. 2021.

- 36. COVID Live Update: 177,419,908 Cases and 3,838,675 Deaths from the Coronavirus. Worldometer n.d. 2021.
- 37. More children infected in second wave, but no need for panic: Experts. Business Standard News n.d. 2021.
- 38. Coronavirus second wave affecting children more; over 79,000 tested positive since March n.d. 2021.
- 39. Coronavirus in India: Is Coronavirus 3rd wave 100% inevitable? The Financial Express n.d. 2021.
- 40. Explained: Will India witness a "dreaded" third wave after its Covid tsunami? India News. Times of India n.d. 2021.
- Maharashtra Preps For 3rd Wave As Covid Hits 8,000 Children. In: 1 District n.d. 2021.
- 42. Covid-19: Covid-19 crisis far from over; 3rd wave to be more dangerous: CSIR official, Health News, ET HealthWorld n.d. 2021.
- 43. More severe third wave of COVID on its way to India, vaccination may ensure lower mortality, claims SBI report. India News, Firstpost n.d. 2021.