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Regional Characteristics of COVID-19 Infection Trends 2021 in India

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Abstract This study examines the regional characteristics of COVID-19 infection trends in India from January to October 2021 through GIS mapping.

In January and February, the number of new infections throughout India decreased, while new infections tended to be concentrated in Kerala and Maharashtra. In March, the number of new infections in India began to increase, with Kerala experiencing a significant decrease in new infections, while Maharashtra experienced a marked increase therein. The number of new infections in India increased rapidly during April and May. The distribution of infections in the states with high numbers of new infections differed between April and May, with April showing high numbers of new infections in the northern and western states of India, and May showing high numbers in the western and southern states. In June, the number of new infections began to decline significantly nationwide, while the number of new cases was again highest in Kerala. Additionally, new infections tended to be concentrated in western and southern India, as in May. In July, as in June, total infection in India plateaued abruptly, although the number of new cases in Kerala increased exceptionally. This increase in the number of new infections in Kerala continued in August. The number of new infections in Kerala began to decline in September, although the concentration of new cases in Kerala did not change. The infection trend in October resembled that in September, but showed a further convergence of infections across India.

Key words COVID-19, spatial pattern, GIS, India

I. Introduction

This study examines the regional characteristics of COVID-19 infection trends in India through geographic information system (GIS) mapping for the year 2021 as the period of analysis. The study is a continuation of the analysis conducted on data for the year 2020, whose results have already been published (Katsumata and Tsukimori, 2020; Katsumata et al., 2021).

As of December 2021, the COVID-19 pandemic is not yet under control, while various effects have been observed globally. According to data compiled by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University,[1] the total number of COVID-19 infections worldwide, as of December 31, 2021, was 286,557,411, while the number of deaths was 5,431,779. Considering the total number of infections by country, the United States had the highest number of 54,277,214, followed by India (34,838,804), Brazil (22,281,649), the UK (12,820,685), and Russia (10,299,923). Thus, India, which is the focus of this study, has the second largest number of infections in the world.

Therefore, studies were conducted to analyze COVID-19 infections in India from a geographical perspective using GIS technology. These studies can be divided into three major categories.[2] The first category comprises studies about the distribution of infection, recovered cases, and deaths. Through GIS mapping, studies were accumulated that analyzed the distribution of infection by state (Machireddy, 2020; Murugesan et al., 2020) and within states and cities (Bhole and Sridhar, 2020; Meer and Mishra, 2021).[3] Some studies analyzed the distribution of infection in a time series (Kumar et al., 2020); similarly, we analyzed the trends of infection in 2020 in a time series (Katsumata and Tsukimori, 2020; Katsumata et al., 2021). Bag et al. (2020) used spatial statistical analysis to show the time and space patterns of the spread of infection.

In the second category, studies attempted to elucidate the regional factors that defined the distribution of infection cases. Gupta et al. (2020) analyzed natural conditions and population density as indicators, suggesting that infections tended to flourish in regions with relatively high temperatures but low humidity and low elevation.[4] Joshua et al. (2021) focused on socioeconomic factors and examined the factors that defined the distribution of infection by state using principal component analysis. This study showed that seven factors were highly correlated with the number of infections: illiteracy, mean number of persons per room, residential population, homeless population, elderly population aged 60 years or more, disability rate, and slum population.[5] Similarly, Khobragade and Kadam (2021) analyzed the socio-demographic factors

that defined mortality by state. Another study examined the usefulness of spatial statistical analysis for analyzing the factors that contributed to the occurrence of COVID-19 infection by district (Dutta et al., 2021).

The third category comprises studies that have assessed the risk areas for infection within cities. Case studies of Jaipur and Kolkata were conducted by Kanga et al. (2020, 2021) and Nath et al. (2021). The analysis in these studies is characterized by the use of remote sensing in addition to GIS, and by a focus on specific cities to provide a more detailed regional level of analysis.

As in our previous papers (Katsumata and Tsukimori, 2020; Katsumata et al., 2021), this study uses GIS to create epidemic maps and analyze the regional characteristics of COVID-19 infection trends in India. Although this is a simple analysis, it is considered to be meaningful in terms of providing basic data, as it enables us to grasp the COVID-19 infection trends in a time series, including the data in the previous papers. The period analyzed is from January 1, 2021 to October 31, 2021. As described below, due to the limitations of the data used in this study, it is not possible to include the months of November and December. In addition, the spatial analysis is conducted at the state level, while the number of infections per month is captured as a time series. In this study, the term "state" is used to include the union territories.

The paper is structured as follows: Section II explains the data used in this study. The COVID-19 infection trends in India are reviewed in a time series in Section III. In Section IV, the COVID-19 infection trends by state and month are analyzed. Finally, the results are summarized in Section V.

II. Data

As in the previous papers (Katsumata and Tsukimori, 2020; Katsumata et al., 2021), the study used the COVID-19 infection data collected by covid19india.org.[6] The data are published in the form of API documents and CSV files on its website,[7] and can be downloaded for use. However, the organization's activities of collecting and publishing the data ended on October 31, 2021,[8] with data from November 1 unavailable.

The data are published in several sheets. In this study, we use two sheets, "case time series" and "state wise daily," following Katsumata et al. (2021), who analyzed the data for 2020. The "case time series" shows the number of new infections, total infections, new recovered cases, total recovered cases, new deaths, and total deaths for each day throughout India. The "state wise daily" shows the number of new infections, new recovered cases, and new deaths per day by state. In this study, we limit our analysis to the number of new infections.

Arc GIS 10.6.1 was used to map these data. For mapping data for the state boundaries, we used boundary data based on the 2011 Census of India purchased from ML Infomap, Delhi. In using these map data, it is necessary to pay attention to the handling of states whose administrative divisions have changed since 2011. Specifically, Telangana was separated from Andhra Pradesh in 2014, and Jammu & Kashmir were divided into the union territory of Jammu & Kashmir and the union territory of Ladakh in 2019. In addition, the union territory of Dadra & Nagar Haveli and that of Daman & Diu were merged in 2020. Of these, the states of Telangana and Andhra Pradesh were considered as independent states, and their map data were reorganized. Jammu & Kashmir were left in their 2011 status because it was difficult to reorganize the map data. In the covid19india.org data, the union territory of Jammu & Kashmir and that of Ladakh are aggregated separately; thus, the figures for the two are combined for the analysis. In addition, the infection case data in the union territories of Dadra & Nagar Haveli and those of Daman & Diu are counted separately in covid19india.org; thus, the map data are treated as the boundaries as of 2011. Based on this, the state boundaries used in this study were assumed to result in the 36 states shown in Figure 1.

III. COVID-19 Infection in India

Figure 2 shows the number of new infections and total infections by week from January 30, 2020, to October 31, 2021. Although daily data on the number of infections are provided, the data are disaggregated by week for the time series characteristics to be seen more clearly.[9]

The infection trends from January 30, 2020, to January 2, 2021 were described in detail in a previous paper (Katsumata et al., 2021); thus, we will only outline them here. In India, the first case of infection was confirmed on January 30, 2020. In March, the number of cases began to increase gradually, reaching 10,000 new cases in the week of April 19, 50,000 in the week of May 24, and 100,000 in the week of June 21. The subsequent spread of the disease was remarkable, with the number of new cases reaching 200,000 in the week of July 12 and 496,276 in the week of August 23, nearly half a million. This increase continued until the week of September 13, when the number of new infections reached 646,425, marking the peak of weekly infections in 2020.

Figure 1. States of India
Source: Katsumata et al. (2021).

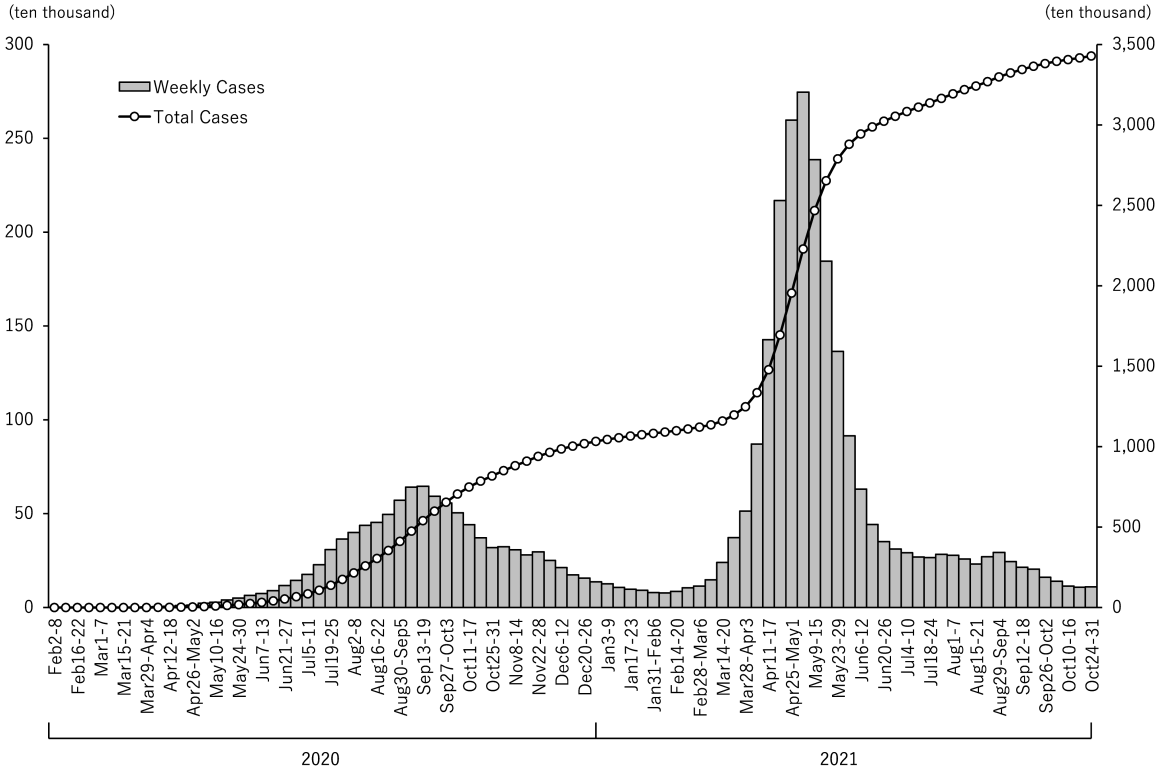

Figure 2. Trend in COVID-19 infection in India
Source: Based on data from covid19india.org.

After peaking in 2020 during the week of September 13, the infections began to converge, while the number of new infections declined almost consistently thereafter. By the week of October 11, the number of new infections had dropped below 500,000 to 441,217. The number of new infections then dropped to 400,000 the following week, 300,000 in the week of November 15, and below 200,000 in the week of December 13. In the week of December 27, the last week of 2020, the number of new infections was 136,221. The total number of new cases through the same week reached 10,324,537, exceeding 100 million in aggregate.

In the week of January 3, 2021, the number of new infections was 126,733, a decrease of approximately 10,000 from the figure in the week of December 27. Thereafter, the number of new infections continued to decrease, and in the week of January 17, the number of new cases fell below 100,000, at 96,729. In the week of February 7, the number of new infections was 77,459, the smallest number of new cases by week through October 31, 2021.

After this week, the number of new infections began to increase, and in the week of February 21, the number of new cases again exceeded 100,000, at 105,350. The pace of increase rose in March, from 148,024 new cases in the week of March 7 to 240,065 new cases in the week of March 14, showing an increase of nearly 100,000 cases in that period. Thereafter, the pace of increase gained momentum, with the number of new cases exceeding 500,000 in the week of March 28, 1 million in the week of April 11, and 2 million in the week of April 18. Then, the week of May 2 saw 2,746,319 new infections, the highest number of cases by week through October 31, 2021. Thus, given that the peak weekly number of infections in 2020 was 646,425 new cases in the week of September 13, 2020, the number of infections clearly increased rapidly in 2021.

Thereafter, the number of new infections began to decline rapidly. The number of new cases declined to 2 million in the week of May 16, 1 million in the week of May 30, and below 500,000 in the week of June 13. By the week of July 4, the number of new cases was 291,499, and it remained in the 200,000s until the week of September 19. In the week of September 26, the number of new infections dropped below 200,000 to 161,362, and continued to decline. In the week of September 24, the last week of the data used in this study, the number of new cases was 97,818.[10] Moreover, the total number of infections until October 31, 2021 reached 34,285,399.

IV. Trends in COVID-19 Infection by State

In this section, we examine the trends in the number of new cases of COVID-19 infection by state in a time series. The time series is classified by month. However, since covid19india.org ended its activities of collecting and publishing data about the number of COVID-19 infection cases on its website on October 31, as mentioned earlier, the period of analysis is from January to October 2021. To the best of our knowledge, there are no similar data for the number of new infections in November and December. In the analysis of the 2020 data, there were some months when the data about the number of new infections by state included figures for which the infected state was unknown, and the total number of new infections by state did not match the figures for the whole country that were used in Chapter II (Katsumata and Tsukimori, 2020; Katsumata et al., 2021); however, this was not the case in the 2021 data.

1. January

Figure 3 shows the number of new COVID-19 infections in January 2021 by state. The number of new infections in January 2021 was 472,317, compared to 823,056 in December 2020, indicating a decrease to less than 60% of the December 2020 figure.

Examined by state, Kerala had the highest number of new infections, at 168,245, accounting for 35.6% of the national total. Kerala was followed by Maharashtra, with 94,287 new infections (20.0%). Similarly, in December 2020, Kerala and Maharashtra were the top two states in terms of the number of new infections; however, the shares of these two states combined in the total number of infections increased significantly. That is, in December 2020, Kerala accounted for 19.2% (157,951) and Maharashtra 13.2% (108,216), bringing the shares of the two states combined from 32.3% to 55.6%. Notably, the number of new infections in Kerala continued to increase while the number of new infections in the whole of India decreased.

These two states were followed by Chhattisgarh, with 25,792 new cases (5.5%). However, except for these three states, no other state recorded a national ratio of more than 5%. Delhi, which experienced the fourth highest number of new infections in December 2020, at 54,995 (6.7%), also saw a drop in the number of new infections to 9,727 (2.1%), and its ranking dropped to 10th.

2. February

Figure 4 shows the number of new infections by state

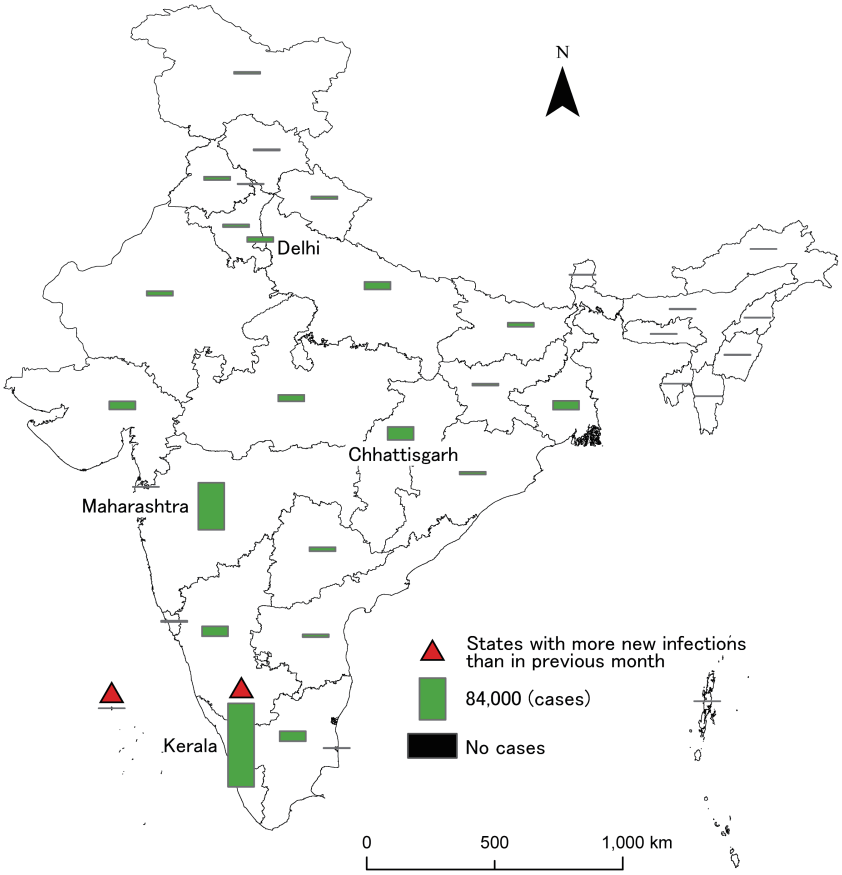

Figure 3. Number of new infections by state in January 2021
Source: Based on data from covid19india.org.

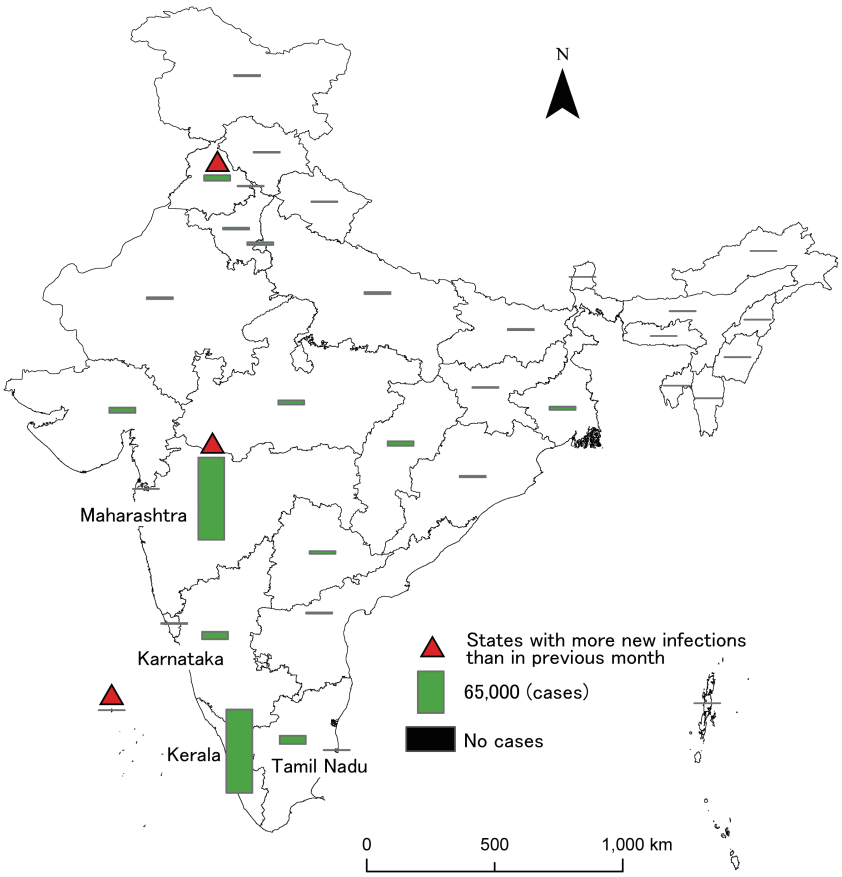

Figure 4. Number of new infections by state in February 2021
Source: Based on data from covid19india.org.

in February. The number of new infections in this month was 353,427, which was lower than that in January.

Considering the number of new infections by state, the highest number was in Kerala (130,225), as in January, and the national ratio was 36.9%, a further increase from the January figure. However, the number of new infections decreased from 168,245 in January. There was no change in Maharashtra, which registered the second highest number of new cases after Kerala. The number of new infections in this state was 128,671, up from 94,287 in January. Maharashtra's share of total new infections increased from 20.0% to 36.4%. Consequently, the shares of these two states combined also increased significantly from 55.6% to 73.3%.

After Maharashtra, Tamil Nadu and Karnataka were the next most affected states; however, the numbers of new infections were only one-tenth that of Maharashtra, at 13,202 (3.7%) and 11,864 (3.4%), respectively. Thus, the COVID-19 infections in February continued to be concentrated in Kerala and Maharashtra, as in January, and this trend was further strengthened.

3. March

Figure 5 shows the number of new infections by state in March. The total number of new infections in March was 1,108,656, which was more than three times the number in February.

Focusing on the number of new infections by state, Maharashtra registered the highest number (657,910). Compared to 128,671 in February, the number of new infections increased more than five-fold and accounted for 59.3% of total new infections. Kerala, which experienced the highest number of new infections in the previous month, recorded 65,181 new infections, second only to Maharashtra. However, the national ratio dropped significantly to 5.9% from 36.9% in February, while the number of new infections decreased by approximately half to 65,181, from 130,225 in February. Meanwhile, for the other states, except Manipur, Meghalaya, and Mizoram,[11] the numbers of new infections increased compared to those in February.

Thus, the number of new COVID-19 cases in India began to increase in March, with Maharashtra the most significant. The number of new infections in Kerala, which registered the highest number of new infections until February, decreased in March; however, the number of new infections increased in many other states.

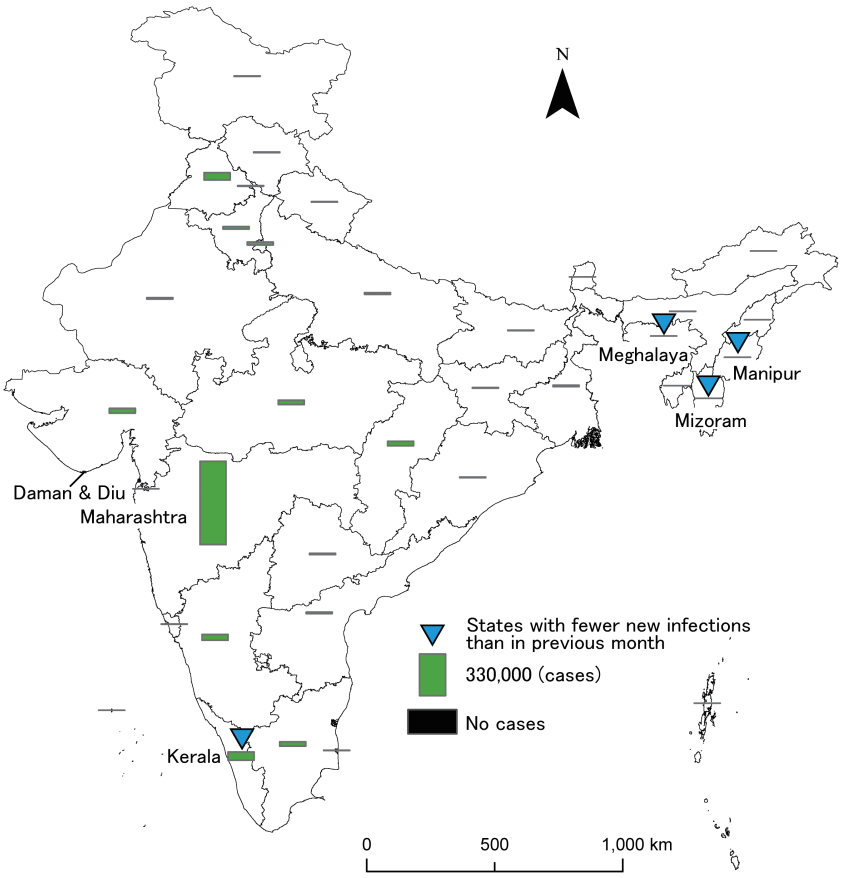

Figure 5. Number of new infections by state in March 2021
Source: Based on data from covid19india.org.

4. April

Figure 6 shows the number of new infections by state in April. Noteworthily, the number of new infections increased more than six-fold compared to that in March, with 6,936,345 new cases in this month.

The number of new infections by state remained the highest in Maharashtra, with 1,789,492 new infections. It increased by more than a million from March, although the national ratio declined from 59.3% to 25.8%. The states with the next highest numbers of new infections were Uttar Pradesh (635,130, 9.2%), Karnataka (526,138, 7.6%), Delhi (486,903, 7.0%), Kerala (446,599, 6.4%), and Chhattisgarh (379,513, 5.5%), with the national ratios for these states each exceeding 5%. In particular, the numbers of new infections in the three states of Uttar Pradesh, Karnataka, and Delhi increased by more than 450,000 cases from March. Considering the distribution of new infections in these top states, except for Chhattisgarh, new infections occurred mostly in northern and western India.

The number of new infections in Kerala almost halved in March, but increased by over 380,000 in April. The number increased in all other states except Daman & Diu, where there were no data on new cases, indicating that the COVID-19 infection had spread throughout India.

5. May

The number of new infections in May was 9,016,687, an increase of 2,080,342 compared to that in April. Although the pace of increase slowed down compared to the increase in the number of new infections to 5,827,689 in April, there was a large spread of infection of over 2 million cases.

By state, Maharashtra recorded the highest number of new infections, as in the previous month, with 1,144,420 cases (Figure 7). However, the number of new infections in Maharashtra decreased by approximately 650,000 compared to the April figure, while the national ratio dropped to 12.7%. This was followed by Karnataka (1,081,289, 12.0%), Kerala (955,396, 10.6%), and Tamil Nadu (929,760, 10.3%), all of which recorded a national ratio above 10%. Unlike in Maharashtra, the number of new infections increased in all three states compared to the April figures, including 555,151 in Karnataka, 508,797 in Kerala, and 649,677 in Tamil Nadu, an increase of more than 500,000 cases.

Considering Uttar Pradesh, Delhi, and Chhattisgarh, which recorded high numbers of new infections in April, the numbers of new infections in May were 439,164 (4.9%), 276,907 (3.1%), and 242,763 (2.7%), respectively.

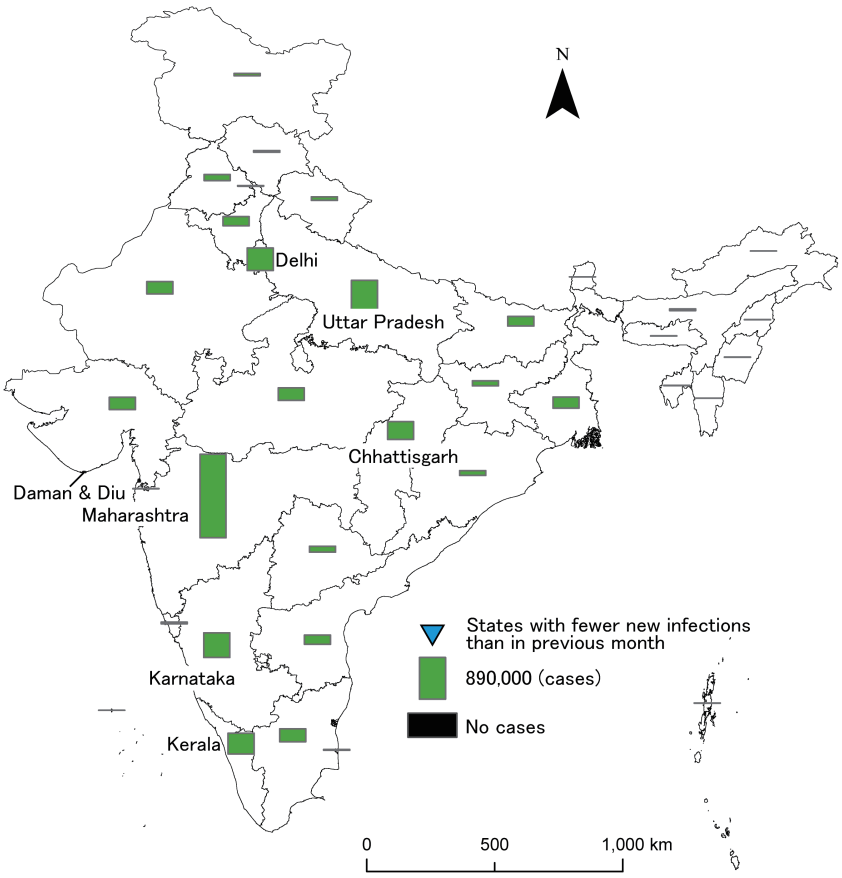

Figure 6. Number of new infections by state in April 2021
Source: Based on data from covid19india.org.

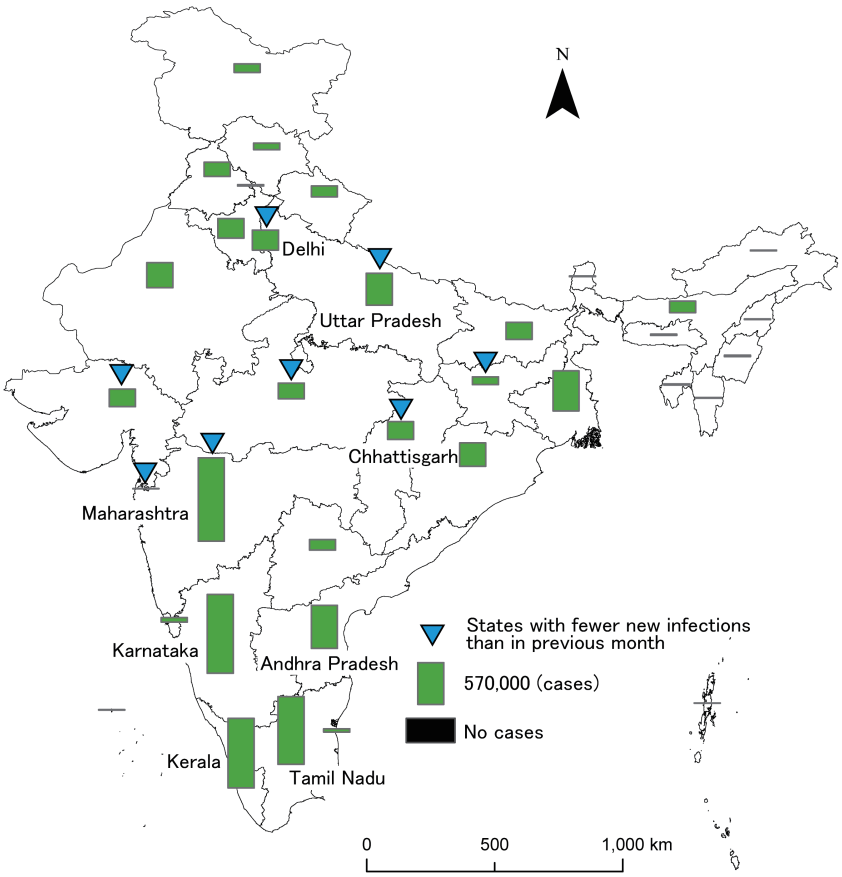

Figure 7. Number of new infections by state in May 2021
Source: Based on data from covid19india.org.

Compared to the April figures, these three states saw a decline of over 100,000 cases each, with 195,966, 209,996, and 136,750, respectively. Including Andhra Pradesh (591,395, 6.6%), which recorded the second highest number of new infections after Tamil Nadu, the top five states in terms of new cases accounted for 52.2% of the national total. Thus, the concentrations of new infections in the western and southern states of India increased in May.

6. June

The total number of new infections in India was 2,236,883 in June. Compared to the May figure, the number of new infections in June was significantly lower (6,779,804), which was less than a quarter of the number in May.

The highest number of new infections by state was in Kerala, with 397,586 new cases (17.8%) (Figure 8). Maharashtra registered the highest number of new infections from March to May; however, the ranking changed in June, with Kerala again registering the highest number of new cases.

After Kerala, the states with the highest numbers of new infections were Tamil Nadu (383,180, 17.1%), Maharashtra (314,512, 14.1%), Karnataka (239,379, 10.7%), Andhra Pradesh (196,428, 8.8%), Odisha (144,803, 6.5%), West Bengal (123,406, 5.5%), and Assam (97,268, 4.4%). The composition of new infections in the top five states remained unchanged from May, although there was a change in the rankings. Thus, new infections continued to be concentrated in the western and southern states of India, with the top five states accounting for 68.4% of the national ratio, up from 52.2% in May. Outside of these five states, the eastern Indian states of Odisha, West Bengal, and Assam were also slightly more conspicuous in terms of infections.

The number of new infections in each state decreased in June from the May figure in all the states except Mizoram.[12] The states that showed significant decreases in the numbers of new cases from May to June were Karnataka (-841,910), Maharashtra (-829,908), Kerala (-557,810), Tamil Nadu (-546,580), West Bengal (-424,605), Uttar Pradesh (-424,545), Andhra Pradesh (-394,967), and Rajasthan (-329,493), with the numbers of new infections in these states each falling by more than 300,000. The number of new infections in Delhi was 7,948 (0.4%) in June, also a significant decrease from 276,907 (3.1%) in May.

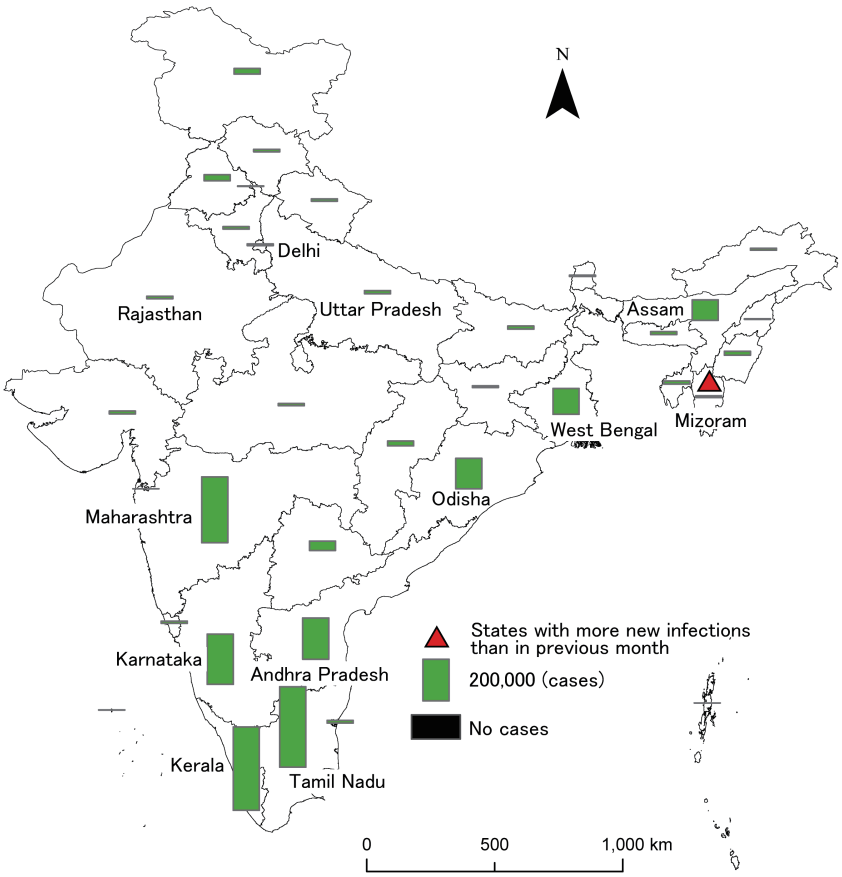

Figure 8. Number of new infections by state in June 2021
Source: Based on data from covid19india.org.

7. July

In July, the number of new infection cases was 1,243,973. Compared to the number of new infections in June (2,236,883), the number in July decreased by 992,910, which was almost half of the number in June, indicating that the infection had rapidly subsided.

The highest number of new infections occurred in Kerala, as in June, with 466,595 new cases (37.5%) in July (Figure 9). Noteworthily, while the number of new infections in the whole of India had declined significantly, it started to increase in Kerala. Consequently, Kerala's share of the total number of new infections in India rose from 17.8% in June to 37.5%.

After Kerala, Maharashtra recorded the second highest number of new infections in July. The number of new cases was 242,311 (19.5%), a decrease of 72,201 from the previous month's figure. Considering Tamil Nadu, Karnataka, and Andhra Pradesh, which are located in western and southern India, where the number of new infections in June was high, as in Maharashtra, the numbers of new infections were 79,901 (6.4%), 61,314 (4.9%), and 76,662 (6.2%), respectively. Compared to the number of new infections in June, the numbers decreased by more than 100,000 to 303,279, 178,065, and 119,766, respectively. The ratio to total cases in these five states, including Kerala, increased to 74.5% in July compared to 68.4% in June. However, the national ratio increased only in Kerala (from 17.8% to 37.5%) and Maharashtra (from 14.1% to 19.5%); considering the number of new infections in both states in July, new cases were clearly concentrated in these two states.

The numbers of new infections in Odisha, West Bengal, and Assam in eastern India, where infections were somewhat conspicuous in June, also decreased significantly in July to 77,335, 95,170, and 39,554, respectively, compared to those in June. In contrast, some northeastern states recorded increases in the numbers of new cases, such as Mizoram (10,001 up), Manipur (9,670 up), Arunachal Pradesh (3,680 up), Meghalaya (1,572 up), and Sikkim (777 up).[13] The number of new infections in Delhi was only 2,077 (0.2%) in July.

8. August

The number of new infections in August was 1,156,001, a decrease of 87,972 compared to the July figure. Infections continued to subside in July, although the decrease was small compared to that from June to July.

In terms of the number of new infections by state,

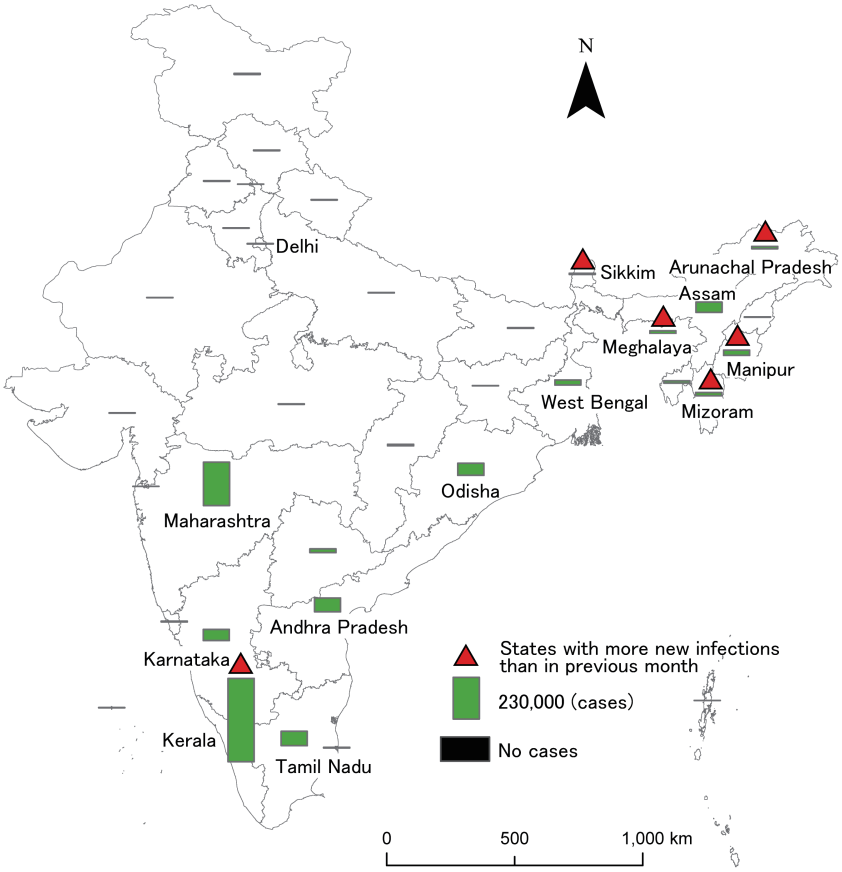

Figure 9. Number of new infections by state in July 2021
Source: Based on data from covid19india.org.

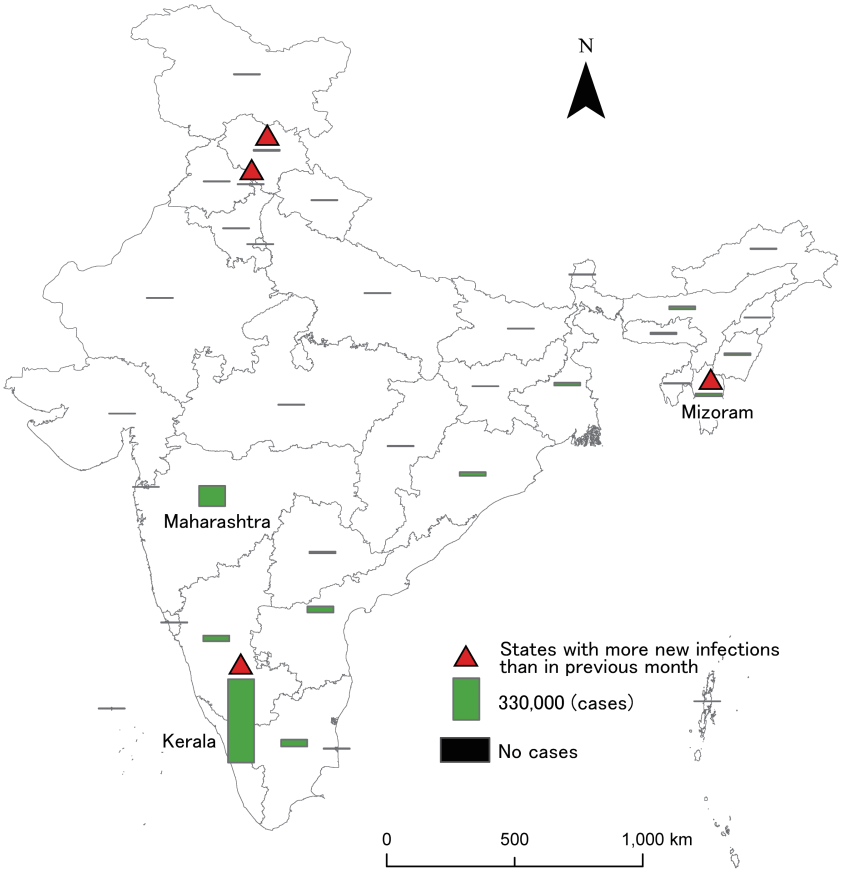

Figure 10. Number of new infections by state in August 2021
Source: Based on data from covid19india.org.

Kerala remained the state with the highest number of new cases (Figure 10). The number of new cases in Kerala was 666,472 in August, an increase of 199,877 from the July figure. The increase in the number of new infections was confirmed after July, and it is important to note that this was almost three times higher than the increase from June to July (69,009). Kerala's share of the total number of new infections also increased significantly to 57.7%, from 37.5% in July. In August, although infections declined nationwide, Kerala was the exception to the rule as its infections continued to spread.[14]

After Kerala, Maharashtra registered the second highest number of new cases, as in the previous month, and the number of new infections was 161,161 in August. The number of new cases decreased by 81,150 from the July figure, and the ratio to total infections decreased from 19.5% to 13.9%. Thus, COVID-19 infections appeared to be concentrated in Kerala in August.

After an increase in the number of new infections in the northeastern states of India in July, only Mizoram showed an increase in August. The number of new infections in this state was 21,055 (1.8%) in August, an increase of 3,066 from 17,989 in July.

9. September

In September, the number of new infections was confirmed at 954,756. The number of new cases continued its downward trend with a decrease of 201,245 from August.

Kerala continued to be the state with the highest number of new infections, as in the previous months (Figure 11). The number of new infections was 623,625 in September. This was a decrease of 42,847 compared to the August figure, and in line with the national trend, the number of new infections started to decrease, although the ratio to the total number of infections increased to 65.3% from 57.7% in July.

Maharashtra registered the second highest number of new infections after Kerala, as in the previous months. The number of new infections was 85,980, which was 9.0% of the national total. It decreased by a further 75,181 from August, almost halving the number of new cases. Therefore, COVID-19 infections tended to be concentrated in Kerala in September.

In Mizoram, where an increase in the number of infections had been observed since July, contrary to the national trend, 34,541 new cases were reported in September. Compared to the number of new infections in August (21,055), the number continued to increase by

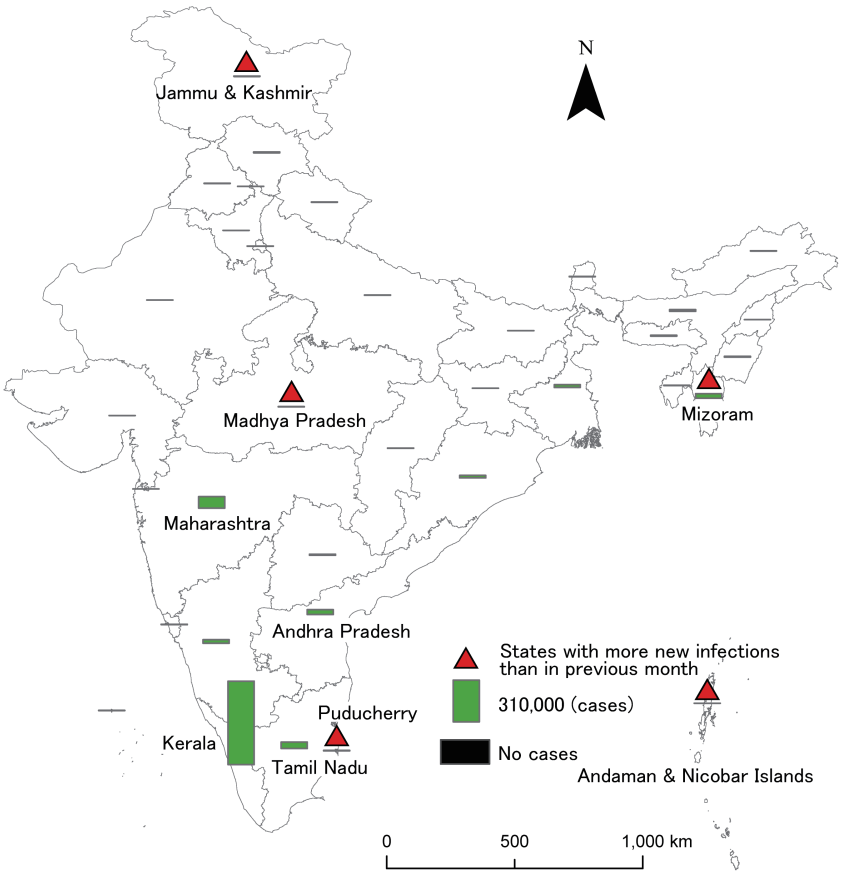

Figure 11. Number of new infections by state in September 2021
Source: Based on data from covid19india.org.

13,486. In addition to Mizoram, other states that experienced an increase in the number of new infections from August to September were Puducherry (138 up), Jammu & Kashmir (79 up), Andaman & Nicobar Islands (26 up), and Madhya Pradesh (9 up); however, Mizoram's increase was outstanding. Mizoram's ratio to the national total also rose to 3.6% from 1.8% in August, making it the state with the fifth most new infections in India after Kerala, Maharashtra, Tamil Nadu (48,917, 5.1%), and Andhra Pradesh (36,208, 3.8%).

10. October

Finally, the number of new infections in October was confirmed at 520,120, showing a decrease of 434,636 from the September figure. Compared to the decrease from August to September (201,245), the decrease was more than 2 times, indicating a further convergence of the infection rate.

Kerala experienced the highest number of new infections, a position that has remained unchanged (Figure 12). The number of new infections was 287,799 in October, a significant decrease of 335,826 cases compared to the September figure. The decline in the number of new infections in this state accounted for 77.3% of the national total. Consequently, Kerala's ratio to the total number of new infections in India dropped to 55.3% in October, from 65.3% in September.

After Kerala, Maharashtra registered the highest number of new infections, with no change. The number of new infections was 60,222 in October, which was a decrease of 25,758 compared to the September figure. Although the number of new infections continued to decrease, the ratio of new infections to the national total changed from 9.0% to 11.6%. As mentioned earlier, Kerala's ratio to all new infections remained overwhelmingly high at 55.3%; however, the concentration of new infections in this state weakened relatively, due to the significant decrease in the number of cases in October.

Furthermore, Mizoram, which had experienced an increase in the number of cases until the previous month, registered a decrease of 6,842 new cases in October from September's 27,699. The number of new infections increased from September to October in only four states: West Bengal (3,372 up), Jharkhand (179 up), Gujarat (127 up), and Dadra & Nagar Haveli (1 up). Additionally, no state was found to have an increase of more than 10,000 cases. Thus, even in the states where the number of new cases increased, the increase was limited compared to the

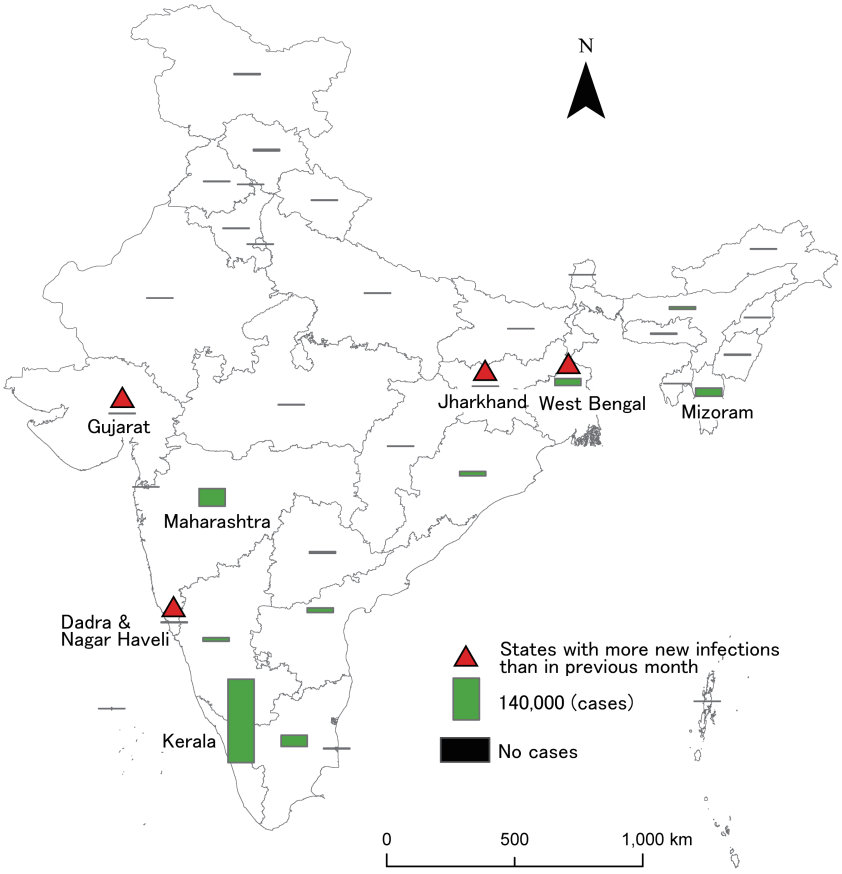

Figure 12. Number of new infections by state in October 2021
Source: Based on data from covid19india.org.

previous month's figure, and no large-scale spread of the disease occurred. Consequently, October was a period of great convergence of infection throughout India.

V. Conclusion

In this study, the regional characteristics of COVID-19 infection trends in India were revealed through GIS mapping during the period of analysis from January to October 2021.

In January and February, the number of new infections throughout India decreased, while new infections tended to be concentrated in Kerala and Maharashtra. In March, the number of new infections began to increase in India. The number of new infections in Kerala decreased significantly in this month; however, the number of new cases in Maharashtra increased significantly, accounting for approximately 60% of the total number of new infections nationwide. The number of new infections in India increased rapidly during April and May. In both months, Maharashtra registered the highest number of new infections; however, the distribution of infection in the states with high numbers of new cases outside of Maharashtra exhibited different characteristics. In April, Maharashtra was followed by Uttar Pradesh, Karnataka, Delhi, and Kerala, while the northern and western states of India experienced high numbers of new cases. In May, Maharashtra was followed by Karnataka, Kerala, Tamil Nadu, and Andhra Pradesh in terms of the highest number of new infections, which tended to be concentrated in the western and southern states of India. In June, the number of new infections began to decline significantly nationwide, and Kerala again registered the highest number of new cases. After Kerala, Tamil Nadu, Maharashtra, Karnataka, and Andhra Pradesh recorded the highest numbers of new infections, indicating that new infections tended to be concentrated in western and southern India, as in May. In July, the total infection in India plateaued abruptly, as in June. One of the characteristics of infection by state in July is that the number of new infections in Kerala increased exceptionally. This increase continued in August and accounted for nearly 60% of the total number of new infections in India. The number of new infections in Kerala began to decline in September, although the concentration of new cases in Kerala did not change. The infection trend in October resembled that in September, but showed a further convergence of infections across India compared to September.

As described above, the COVID-19 infection trends in India from January to October 2021 were examined by state and by month. As revealed by the results of the data analysis of the COVID-19 infections in 2020, the regional characteristics of the infection trends in a time series were also related to the infection trends throughout India (Katsumata et al., 2021). That is, from April to June 2020, when the infection began to spread, Maharashtra, Gujarat, and Delhi experienced the most infections. In addition to Maharashtra, there was a marked increase in the number of infections in Karnataka and Andhra Pradesh in southern India during the period from July to September, when infections increased rapidly. After peaking in September, the total number of new infections in India began to decline, although infections in Kerala became more prominent during this period.

Similarly, the regional characteristics of the infection trends in 2021 were found to be related to the infection trends throughout India. In January and February, when the total number of new infections in India continued to decline, new cases tended to be concentrated in Kerala and Maharashtra. In March, when new infections in India began to increase, Maharashtra experienced by far the largest number of new cases. Then, as the infection spread rapidly throughout India, the number of new cases increased in the northern and western states of India in April, such as Uttar Pradesh, Karnataka, Delhi, and Kerala, in addition to Maharashtra. Meanwhile, new cases were concentrated in the western and southern states of India, including Maharashtra, Tamil Nadu, Maharashtra, Karnataka, and Andhra Pradesh in May. The number of new infections appeared to be concentrated in Kerala, while the number of new cases throughout India decreased from June.

Thus, while the number of new infections in India declined, new cases in Kerala became more prominent, which resembled the trend in 2020. However, when the number of new infections in India rose, infections in Kerala were not as prominent in 2020. By contrast, in 2021, infections in Kerala tended to be more prominent during periods of both expansion and contraction. This trend in Kerala was different from that in 2020. In future, a more detailed analysis is intended to focus on the states that have shown these characteristic infection trends.

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Notes

1. https://gisanddata.maps.arcgis.com/apps/dashboards/bda7594740fd40299423467b48e9ecf6 (accessed December 31, 2021).
2. The results of a study using countries other than India as a case study are reviewed in Ahasan et al. (2020), Franch-Pardo et al. (2020), and Fatima et al. (2021). Also available is Mishra and Singh (2021), which is not necessarily a study based on GIS analysis, but examines changes and challenges under the COVID-19 pandemic in India and other developing countries from multiple perspectives.
3. Bhole and Sridhar (2020) is a case study of Hyderabad, while Meer and Mishra (2021) is a case study of Jammu & Kashmir.
4. This is a study based on the distribution of total infection as of April 27, 2020.
5. This is a study based on the distribution of total infection as of October 12, 2020.
6. See Katsumata and Tsukimori (2020) and Katsumata et al. (2021) for further details on these data.
7. https://www.covid19india.org/ (accessed November 8th, 2021).
8. https://blog.covid19india.org/2021/08/07/end/ (accessed November 8th, 2021).
9. As there was only one case on January 30, we included it in the number of cases for the week of February 2 in Figure 2. Additionally, the number of cases on October 31, 2021 (12,907) is included in the week of October 24, 2021 in Figure 2. Incidentally, the total number of new cases between October 24 and 30 was 97,818.
10. In Figure 2, the number of new infections on October 31 is included in the week of October 24 for convenience; however, the description here excludes the number of new cases on October 31.
11. Daman & Diu recorded 0 new cases in both months.
12. The number of new cases in Mizoram was 6068 in May and 7988 in June.
13. Kerala and these five states were the only states with more new cases in July than in June.
14. Kerala (199,877 up), Himachal Pradesh (3,617 up), Mizoram (3,066 up), and Chandigarh (2,869 up) were the only four states in which the number of new infections increased between July and August. This shows that Kerala's increase was outstanding.

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