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Spatial-temporal variations in community mobility during lockdown, unlock, and the second wave of COVID-19 in India: A data-based analysis using Google’s community mobility reports

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ABSTRACT

COVID-19 has been altering all aspects of societal life including community mobility since December 2019. This study analyzes the spatial-temporal variations in human mobility patterns as the influence of COVID-19 during different periods at the state and union territory (UT) levels in India. From the spatial and temporal perspective, we find that change of mobility patterns and variations within states and UTs. The residential mobility has been increased because the mobility towards the home increased during the lockdown and the second wave but during the unlocking period reduced to some extent. There have spatial variations in mobility towards different places within states and UTs during the lockdown and second wave (lockdown to partial lockdown) but overall mobility towards different places like retail, parks, workplace, and transit stations have been reduced in India. During unlocking, mobility has been reduced all over the states and UTs in India but there have spatial-temporal variations within.

1. Introduction

The novel Coronavirus disease 2019 (2019-nCoV) caused by the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), has become the worst serious global risk to humanity in the last century (Chang et al., 2020; Favre et al., 2020; Sharma et al., 2020; Saha and Chouhan, 2021a). The first confirmed case of COVID-19 was reported in Wuhan City, Hubei Province of China on December 8, 2019 (Baloch et al., 2020; Wu and McGoogan, 2020), and since that time SARS-CoV-2 has increased at a fast pace, resulting in more than 166.86 million confirmed cases and over 3.46 million deaths as of May 24, 2021 (05:50 am GMT-7) (WHO, 2021). Pointing to over 118,000 confirmed COVID-19 cases in over 110 countries and territories around the world and the continued threat of further global transmission, the World Health Organization (WHO) declared COVID-19 a pandemic on 11th March 2020 and asked all countries to get imperative and aggressive steps against this community health disaster. Globally, as of 21st December 2021, 222 countries and territories are affected. As of 25th May 2021, a total of 26,948,874 confirmed cases (with 2,586,782 active cases comprising 9.60% of the total cases) have been reported in India and 24,054,861 (89.26%) cases have recovered while the cases fatality is 1.14% (MoHFW, 2020).

Globally, up to March 23, 2020, 14,509 people have died with 1,727 new death cases and a total of 332,930 confirmed cases have been infected by Coronavirus with a total of 40,788 new confirmed cases (WHO, 2020). Also, in India, the first case of the COVID-19 illness was reported on January 30, 2020, which was originating from China, and confirmed cases of COVID-19 reaches 499 (MoHFW, 2020; India Today, 2020). For this very ground, various educational institutions and various business establishments have been close down in all of the countries. In response to the global COVID-19 pandemic, the Indian Prime Minister announced Janata (people’s) curfew on 22 March 2020 from 7 am until 9 pm, followed by enforcement of a series of regulations in the country’s COVID-19 affected regions (UN News, 2020). On the evening of 24 March 2020, the Government of India under Prime Minister Narendra Modi has declared lockdown for 21 days all over the country for reducing movement of the population of India as a preventive measure against the COVID-19 pandemic (Ministry of Home Affairs, 2020; Singh and Chauhan, 2020; Saha and Chouhan, 2021b).

On 14th April 2020, the Government of India extended the countrywide lockdown until 3 May 2020, again on 1st May 2020; lockdown was extended further by two weeks until 17th May 2020 (Livemint, 2020; Sharma et al., 2020). This essentially extended the lockdown from most states and Union Territories to the entire country and provided a...
more definite timeline. On 14th April 2020, the Government of India extended the nationwide lockdown until 3 May 2020, again on 1st May 2020; lockdown was extended further by two weeks until 17th May 2020 and on May 17, the lockdown was extended by the National Disaster Management Authority until May 31, 2020 (Livemint, 2020; Saha and Chouhan, 2021b). The Government of India extended lockdown as a social distancing measure which is the only way to flatten the curve and break the cycle of COVID-19 infection in India (The Economic Times, 2020; Golechha, 2020). The non-medical policies implemented by many countries reduce the curve of the confirmed cases during the COVID-19 outbreak by maintaining social and physical distancing interactions (Block et al., 2020; Courtemanche et al., 2020; Singh et al., 2020). By this nationwide lockdown in India, more or less all grocery stores, parks, workplaces, and places of transit, retail and recreational activities have been ordered to stop (Saha and Chouhan, 2021b). Therefore, the lockdown has been significant for dropping the community movement of the entire 1.3 billion human beings of India as a preventive measure combating the COVID-19 pandemic (Gentleman and Schultz, 2020; Ghosh et al., 2020).

After lockdown due to the slowdown of COVID-19 confirmed cases (except the containment zones), the Government of India announced unlock period including different phases up to December 2020 (Saha and Chouhan, 2021b). The rate of turn down of confirmed COVID-19 cases from the first wave was slow-active cases began declining only from late September last year (2020), a trend which continued till the beginning of the second wave in the middle of February (BBC NEWS, 2021), the second wave of COVID-19 is affecting most of the world. As the second wave of COVID-19 hit India which began around form 11th February 2021 (Ranjan et al., 2021; BBC NEWS, 2021), several states and union territories went in partial or complete lockdown again. In the absence of a nationwide lockdown and with Covid-19 cases on a steady rise, several states in India have imposed complete lockdowns to reduce the spread of the coronavirus virus amid a deadly second wave. Even the states that have not opted for statewide lockdowns have induced lockdown-like strict curbs on the movement of people (The Indian Express, 2021).

The COVID-19 Community Mobility report uses aggregated and anonymized data to chart movement trends over time by geography, across different categories of places such as retail and recreation, groceries and pharmacies, parks, transit stations, workplaces, and residential and compares it to a baseline activity established as per pre-lockdown (Google, 2020; Sulyok and Walker, 2020; Erim et al., 2021; Porcher and Renault, 2021; Askitas et al., 2021). Given the extremely contagious character of COVID-19, falling levels of social contact and population movement have been seen as key in dropping the rates of COVID-19 spread. As a social distancing measure, the residential mobility has been increased by approximately 31.5%, 30.8%, 26.2%, 23%, 17.6%, and 18.2% from the baseline period were observed during lockdown phase 1, phase 2, phase 3, phase 4, unlock 1.0, and unlock 2.0, respectively, in India (Saha and Chouhan, 2021b). The states and union territories that have the highest drop in overall mobility to non-residential mobility are Chandigarh (-85%), Delhi (-82%), Andaman and Nicobar Islands (-71%) and Maharashtra (-71%) and the lowest drop showed in Mizoram (-34%), Arunachal Pradesh (-39%), Bihar (-41%) and Manipur (-41%) from the baseline during lockdown (Mullick, 2020; Saha et al., 2020c).

This study finds out periodic temporal mobility changes and spatial variations of population mobility during the lockdown, unlock, and the second wave of COVID-19 as a measure of social distancing which is the way to reduce the confirmed rate curve of COVID-19 in India. From the spatial and temporal perspective, we find that change of mobility patterns during different periods of COVID-19 and variations in mobility during the lockdown, unlock, and the second wave of COVID-19 within states and UTs of India. This study helps to give supports to the control of the pandemic in other regions and countries which is a non-medical measure to flatten the curve of COVID-19.

2. Different types of community mobility

Google Community Mobility Reports (CMRs) use aggregated and anonymized sets of data from users who have turned on the location history setting, which is off by default (Saha et al., 2020c), and to graph changes in mobility concerning different classes of places like retail and recreational, grocery and pharmacy, parks, transit stations, workplaces, and residential areas (Table 1). Mobility indicators are calculated based on the frequency and length of visits to places. The baseline is the median value, for the corresponding day of the week, during the 5 weeks Jan 3–Feb 6, 2020 (Saha et al., 2020c; Rice and Pan, 2020). The summary of descriptive statistics like mean, median, minimum, maximum, standard deviation of mobility data are given in Table 1 during the pre-lockdown, lockdown, unlock, and second wave of COVID-19 in India.

3. Materials and methods

3.1. Sources of data and coverage

The data on community mobility in India are drawn from the Google COVID-19 Community Mobility Reports (CMRs) released by Google in 2020. These CMRs are created with aggregated, anonymized sets of data from users mobile devices who have turned on the location history setting, which is off by default, and the CMRs chart movement trends over time, across different categories of places such as retail and recreation, groceries and pharmacies, parks, transit stations, workplaces, and residential (Mendolia et al., 2021; Saha et al., 2020c). For this study, daily data were collected from 15th February 2020 to 9 May 2021 during the COVID-19 the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India. The data used in this study is available in the public domain (https://www.google.com/covid19/mobility/).

The data on the stringency index were collected from Our World in Data (https://ourworldindata.org/grapher/covid-stringency-index). The daily confirmed cases of COVID-19 data were collected from the Our World in Data COVID-19 dataset (https://github.com/owid/covid-19-data/tree/master/public/data). For this study, data (stringency index and daily confirmed new COVID-19 cases) from January 30, 2020, to May 31 2021 were used during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India.

3.2. Methods

For this study, we have used data-based analysis of Google’s Community Mobility Reports (CMRs) to represent the spatiotemporal variations in how the population move during the pre-lockdown, lockdown, unlock, and second wave of COVID-19 in India. To show, daily change in stringency index and new confirmed cases during different periods of COVID-19, daily time-series data has been divided into four-time frames i.e. pre-lockdown (30 January to 24 March 2020), lockdown (25 March to 31 May 2020), unlock (1 June 2020 to 10 February 2021), second-wave (11 February to 31 May 2021). The stringency index is a composite measure based on nine response indicators including school closures, workplace closures, and travel bans, rescaled to a value from 0 to 100 (100 = strictest) (Kuyral and Buzurl, 2020; Royo, 2020). It provides an image of the phase at which any country imposed its strongest measures (Sulyok and Walker, 2021).

To calculate summary of descriptive statistics like mean, median, minimum, maximum, standard deviation of different types of mobility data during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India, the Microsoft Excel Workbook Data Analysis tool has been used using.

To represent state and union territory wise spatial-periodic change of different community mobility, we have prepared choropleth maps to represent the mobility data for each state and territory as they are and also prepared different period wise proportional circle maps to represent
| Mobility type       | Definition                                                                 | Descriptive statistics | Mobility (% change from baseline) during different period                                                                 |
|--------------------|----------------------------------------------------------------------------|------------------------|------------------------------------------------------------------------------------------------------------------------|
|                    |                                                                            | Pre-lockdown period    | Lockdown period (25th March to 31st May 2020)                                                                           | Unlock period (1st June 2020 to 10th February 2021) | During second wave 11th to 28th February 2021 | March 2021 | April 2021 | 1st to 9th May 2021 |
| Retail and         | This includes mobility towards places like restaurants, cafes, shopping     | Mean -7.5              | -75.5                                                                   | -39.7                                         | -20.4                                         | -19.2     | -31.7     | -59.3             |
| recreational       | centers, theme parks, museums, libraries, movie theaters (Saha et al., 2020c). | Min -16.0              | -86.0                                                                   | -57.1                                         | -40.3                                         | -39.3     | -61.9     | -77.0             |
|                    |                                                                            | Max -5.9               | -65.6                                                                   | -25.4                                         | 18.8                                         | 27.4      | 22.9      | -32.2             |
|                    |                                                                            | Median -8.1            | -75.4                                                                   | -40.5                                         | -19.5                                         | -20.3     | -27.6     | -61.4             |
|                    |                                                                            | SD 4.7                 | 5.4                                                                     | 7.0                                           | 10.3                                         | 11.6      | 16.0      | 11.7              |
| Grocery and        | This includes mobility towards places like grocery markets, food warehouses,| Mean -5.4              | -41.4                                                                   | -3.3                                          | 11.4                                         | 14.7      | 3.6       | -27.6             |
| pharmacy           | farmer’s markets, specialty food shops, drug stores, and pharmacies        | Min -24.5              | -72.2                                                                   | -39.4                                         | -35.1                                         | -30.8     | -32.6     | -66.0             |
|                    | (Saha et al., 2020c).                                                      | Max 3.2                | -17.0                                                                   | 35.9                                          | 58.9                                         | 74.0      | 37.9      | 10.8              |
|                    |                                                                            | Median -4.9            | -41.1                                                                   | -1.1                                          | 10.9                                         | 14.0      | 8.5       | -29.1             |
| Parks              | This includes mobility towards local parks, national parks, public          | Mean -1.6              | -51.8                                                                   | -33.1                                         | -10.6                                         | -9.2      | -23.2     | -43.3             |
|                    | beaches, marinas, dog parks, plazas, and public gardens (Google, 2020).     | Min -14.2              | -91.9                                                                   | -62.8                                         | -30.8                                         | -30.8     | -50.1     | -75.4             |
| Transit stations   | This includes mobility towards public transport hubs such as subway, bus,  | Mean -5.5              | -58.0                                                                   | -22.5                                         | -2.1                                         | -0.7      | -16.6     | -45.9             |
|                    | and train stations (Saha et al., 2020c).                                   | Min -14.4              | -78.4                                                                   | -39.1                                         | -21.4                                         | -20.7     | -49.6     | -69.1             |
|                    |                                                                            | Max 4.9                | -30.3                                                                   | 19.3                                          | 64.2                                         | 68.2      | 48.8      | -18.1             |
|                    |                                                                            | Median -5.8            | -59.4                                                                   | -23.4                                         | -3.7                                         | 4.0       | -16.7     | -48.5             |
| Residential        | This includes mobility towards places of residence where a person or        | Mean -3.7              | -43.8                                                                   | -19.7                                         | -12.1                                         | -10.6     | -21.9     | -41.6             |
| workplaces         | community lived (Saha et al., 2020c).                                      | Min -10.1              | -72.3                                                                   | -35.4                                         | -30.6                                         | -25.8     | -46.5     | -68.3             |
|                    |                                                                            | Max 8.8                | -17.2                                                                   | -1.4                                          | 21.5                                         | 22.6      | 19.9      | -15.9             |
|                    |                                                                            | Median -5.0            | -42.7                                                                   | -18.3                                         | -12.3                                         | -10.8     | -19.8     | -42.1             |
|                    |                                                                            | SD 4.6                 | 12.9                                                                    | 7.9                                           | 9.0                                          | 8.9       | 12.5      | 12.5              |
| Residential        | This includes mobility towards places of residence where a person or        | Mean 2.7               | 21.9                                                                    | 11.3                                          | 6.2                                          | 7.3       | 13.5      | 22.8              |
| workplaces         | community lived (Saha et al., 2020c).                                      | Min 0.4                | 10.5                                                                    | 6.7                                           | 2.1                                          | 2.4       | 5.3       | 10.8              |
|                    |                                                                            | Max 5.3                | 32.2                                                                    | 16.5                                          | 9.6                                          | 12.9      | 28.0      | 32.0              |
|                    |                                                                            | Median 2.5             | 21.3                                                                    | 11.2                                          | 6.2                                          | 7.4       | 12.5      | 22.4              |
|                    |                                                                            | SD 1.3                 | 6.0                                                                     | 2.4                                           | 1.8                                          | 2.1       | 4.6       | 4.8               |

Note: Min = Minimum; Max = Maximum; SD = Standard deviation.
the COVID-19 active cases data during the pre-lockdown, lockdown, unlock, and second-wave (11-19 February, March, April, and 1-9 May 2021) of COVID-19 pandemic. To present mean changes of different community mobility during different periods of COVID-19, suitable line graphs have been plotted for each state and UT in India to represent retail and recreational, grocery and pharmacy, park, transit station, and workplaces mobility. To depict the residential mobility, bar graphs have also been plotted for each state and union territory, and also 2 period moving average line graphs have been plotted to represent the two periodic changes over different periods of COVID-19 in India.

4. Results and discussion

4.1. Mean changes in retail and recreational mobility during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India

Table 2 shows the changes of mean retail and recreational mobility from the baseline percentage during the period of pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India. In India, before the lockdown, the mean changes of retail and recreational mobility was slightly decreased from the baseline percentage. The states and UTs where the maximum fall of mean retail and recreational mobility from the baseline recorded in Andaman and Nicobar Islands (-16%), Andhra Pradesh (-7.7%), Assam (-10.0), and Haryana (-1.2%), and lowest drop of mean retail and recreational mobility from the baseline were Sikkim (3.9%), Dadra and Nagar Haveli (1.0%), Meghalaya (-0.8%), and Mizoram (0%) during the pre-lockdown period. When the lockdown was imposed due to the COVID-19 pandemic the mean retail and recreational mobility has been dropped largely from the baseline, the states, and UTs which reported the highest drop of mean retail and recreational mobility from the baseline were Chandigarh (-88%), Delhi (-84%), Maharashtra (-83.2%), Telangana (-83.2%), Andaman and Nicobar Islands (-82.4%) and Gujarat (-82.4%). The minimum mean retail and recreational mobility drop from the baseline during the lockdown period in Arunachal Pradesh (-65.6%), Tamil Nadu (66.1%), Himachal Pradesh (-67.1%), Dadra and Nagar Haveli (-67.5%), and Bihar (-69.2%). The pattern of mobility during the lockdown period is the same as the previous study which was based on the national level in India, and other findings are also similar in the context of the present analysis (Saha et al., 2020c). But when unlock started all the states reported a slight increase in mean retail and recreational mobility as compared to the lockdown period. In this period Mizoram (-57.1%), Manipur (-50.4%), Maharashtra (-49.2%), Goa (-47.1%), and Arunachal Pradesh (-46.8%) had the maximum drop of mean retail and recreational mobility from the baseline but slightly increased from lockdown period. The states and UTs that recorded the lowest drop of mean retail and recreational mobility from the baseline were Bihar (-25.4%), Uttarakhand (-26.5%) Andaman, and Nicobar Islands (-27.2%), Himachal Pradesh (-31.4%), and Uttar Pradesh (-32%).

During the second wave of the COVID-19 pandemic, the mean changes of retail and recreational mobility from the baseline improved compared to unlock period. In this period February (11th to 28th) highest

| States and union territories | Retail and recreational mobility (% change from baseline) | Unlock period (1st June, 2020 to 10th February 2021) | During second wave (11th to 28th February 2021) |
|-----------------------------|--------------------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| Andaman and Nicobar Islands | -16.0                                                  | -82.4                                          | -27.2                                         |
| Andhra Pradesh              | -6.8                                                   | -77.6                                          | -37.3                                         |
| Arunachal Pradesh           | -9.0                                                   | -65.6                                          | -46.8                                         |
| Assam                       | -5.6                                                   | -75.3                                          | -36.9                                         |
| Bihar                       | -4.1                                                   | -69.2                                          | -25.4                                         |
| Chandigarh                  | -12.0                                                  | -88.0                                          | -45.5                                         |
| Chhattisgarh                | -10.7                                                  | -72.5                                          | -38.2                                         |
| Dadra and Nagar Haveli      | 1.0                                                     | -67.5                                          | -38.9                                         |
| Daman and Diu               | -1.4                                                   | -78.7                                          | -42.1                                         |
| Delhi                       | -14.8                                                  | -84.0                                          | -44.5                                         |
| Goa                         | -11.4                                                  | -74.8                                          | -47.1                                         |
| Gujarat                     | -10.0                                                  | -82.4                                          | -42.1                                         |
| Haryana                     | -7.6                                                   | -75.2                                          | -34.1                                         |
| Himachal Pradesh            | -1.2                                                   | -67.1                                          | -31.4                                         |
| Jharkhand                   | -7.0                                                   | -74.0                                          | -34.5                                         |
| Karnataka                   | -9.4                                                   | -77.5                                          | -42.9                                         |
| Kerala                      | -14.9                                                  | -77.7                                          | -43.7                                         |
| Madhya Pradesh              | -8.6                                                   | -78.1                                          | -36.4                                         |
| Maharashtra                 | -13.6                                                  | -83.2                                          | -49.2                                         |
| Manipur                     | -5.8                                                   | -72.0                                          | -50.4                                         |
| Meghalaya                   | -0.8                                                   | -69.6                                          | -43.2                                         |
| Mizoram                     | 0.0                                                    | -75.5                                          | -57.1                                         |
| Nagaland                    | -3.5                                                   | -69.7                                          | -46.3                                         |
| Odisha                      | -10.4                                                  | -75.2                                          | -41.1                                         |
| Puducherry                  | -11.4                                                  | -78.6                                          | -40.3                                         |
| Punjab                      | -9.5                                                   | -76.3                                          | -34.7                                         |
| Rajasthan                   | -8.9                                                   | -75.7                                          | -35.3                                         |
| Sikkim                      | 3.9                                                    | -75.7                                          | -33.3                                         |
| Tamil Nadu                  | -6.0                                                   | -66.1                                          | -40.8                                         |
| Telangana                   | -8.6                                                   | -83.2                                          | -44.9                                         |
| Tripura                     | -6.3                                                   | -73.2                                          | -37.5                                         |
| Uttar Pradesh               | -6.2                                                   | -74.6                                          | -32.0                                         |
| Uttarakhand                 | -7.3                                                   | -70.4                                          | -26.5                                         |
| West Bengal                 | -9.9                                                   | -78.7                                          | -41.9                                         |

Source: Own calculation based on data from Google COVID-19 Community Mobility Reports (Saha et al., 2020c).
mean drop of retail and recreational mobility was found in Mizoram, Arunachal Pradesh, Nagaland, and Manipur. From March to April 2021 the decrease rate of mean retail and recreational mobility was almost the same as the baseline but in May (1st to 9th), there was a high drop in mean retail and recreational mobility from the average baseline of the country (Table 2).

4.2. Mean changes in grocery & pharmacy mobility during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India

Table 3 represents the mean changes of grocery and pharmacy mobility from the baseline percentage during the period of pre-lockdown, lockdown, unlock, and the second wave of COVID-19 pandemic in India. During the pre-lockdown period, the mean changes of grocery and pharmacy mobility slightly declined from the baseline percentage. The states and UTs which had the highest drop of mean grocery and pharmacy mobility at the time of pre-lockdown were Dadra and Nagar Haveli (-17%), Andaman and Nicobar Islands (-18.9%), Goa (-11.8%), Arunachal Pradesh (-11.8%), Meghalaya (-10.4%) and Chandigarh (-10.2%). The states which had the lowest drop of mean change of grocery and pharmacy mobility from the baseline were Sikkim (3.2%), Mizoram (1.7%), Tamil Nadu (1.5%), Bihar (1%), and Telangana (-0.1%). In India grocery and pharmacy mobility highly drop during the lockdown due to the pandemic situation, the states, and UT’s grocery and pharmacy mobility largely decrease from the average baseline. The states and UTs such as Chandigarh (-72.2%), Andaman and Nicobar Islands (-70.8%), Delhi (-60.4%), Meghalaya (-55.5%), Gujarat (-52%), Tamil Nadu (-50.8%), and Nagaland (-50.1%) recorded the highest decrease of mean grocery and pharmacy mobility from the average baseline. The lowest minimum decrease of mean grocery and pharmacy mobility sites and UTs were Dadra and Nagar Haveli (-17%), Bihar (-18.6%), Chhattisgarh (-27.4%), and Kerala (-28.5%).

The finding is similar to the previous work on mobility in India and also the same as the finding in the USA (Paez, 2020). When the unlock period started the declining rate of mean grocery and pharmacy from the baseline quite improved. During the unlock period the maximum drop of mean grocery and pharmacy mobility was found in Nagaland (-39.4%), Meghalaya (-31.1%), Sikkim (-29.6%), and Chandigarh (-24.3%). The minimum variation of mean grocery and pharmacy mobility from the baseline average during the unlock period found in Dadra and Nagar Haveli (35.9%), Bihar (22.8%), Uttar Pradesh (15.5%), Uttarakhand (10.4%), and Himachal Pradesh (9.2%).

In India, during the second wave from February 11th to April 2021 the mean grocery and pharmacy mobility quite increased almost every state from the baseline. But in May (1st to 9th) the decreasing rate increased in some states such as Mizoram (-66.0%), Meghalaya (-57.2%), Chandigarh (-55.1%), Delhi (-50.6%), and Chhattisgarh (-49.7%) (Table 3).

4.3. Mean changes in parks mobility during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India

Table 4 represents the mean changes of park mobility for the period of pre-lockdown, lockdown, unlock, and the second wave of COVID-19

Table 3
Change in grocery and pharmacy mobility during pre-lockdown, lockdown, and second wave of COVID-19 in India.

| States and union territories | Grocery and pharmacy mobility (% change from baseline) | Unlock period (1st June to 10th February 2021) | During second wave |
|------------------------------|------------------------------------------------------|---------------------------------------------|-------------------|
|                              | Pre-lockdown period (15th February to 24th March 2020) | March 31st May 2020) | 11th to 28th February 2021 | March 2021 | April 2021 | 1st to 9th May 2021 |
| Andaman and Nicobar Islands | 1.8 | -38.0 | 8.9 | 28.1 | 29.7 | 27.0 | 2.2 |
| Andhra Pradesh               | -11.8 | -32.4 | 8.6 | 34.4 | 36.2 | 29.3 | 3.2 |
| Assam                        | 2.4 | -43.0 | 5.6 | 9.7 | 11.7 | 11.2 | 15.1 |
| Bihar                        | 1.0 | -18.6 | 22.8 | 34.4 | 36.2 | 29.3 | 3.2 |
| Chandigarh                   | -10.2 | -72.2 | -24.3 | -6.7 | -5.6 | -17.5 | -55.1 |
| Chhattisgarh                 | -5.9 | -27.4 | 6.4 | 19.5 | 20.5 | -28.7 | -49.7 |
| Dadra and Nagar Haveli       | -24.5 | -17.0 | 35.9 | 58.9 | 74.0 | 37.9 | -8.6 |
| Daman and Diu                | -3.1 | -50.1 | -11.8 | 4.2 | 5.0 | -14.0 | -36.6 |
| Delhi                        | -9.8 | -60.4 | -16.4 | -0.8 | 1.0 | -21.2 | -50.6 |
| Goa                          | -11.9 | -48.2 | -20.4 | 8.5 | 9.8 | 3.1 | -38.6 |
| Gujarat                      | -4.8 | -52.0 | -4.1 | 8.9 | 9.8 | 5.5 | -26.4 |
| Haryana                      | -4.6 | -41.0 | 0.1 | 10.9 | 15.8 | 12.5 | -36.0 |
| Himachal Pradesh             | -2.3 | -35.4 | 9.2 | 12.3 | 19.8 | 11.4 | -20.7 |
| Jharkhand                    | -3.6 | -41.4 | 7.4 | 23.3 | 28.3 | 13.6 | -22.9 |
| Karnataka                    | -1.4 | -37.5 | -2.5 | 10.7 | 14.0 | 2.2 | -35.7 |
| Kerala                       | -6.4 | -28.5 | 7.3 | 26.8 | 32.1 | 28.7 | -16.9 |
| Madhya Pradesh               | -5.9 | -45.5 | 7.4 | 19.7 | 17.5 | -20.4 | -47.6 |
| Maharashtra                  | -6.0 | -49.1 | -6.8 | 13.1 | 10.9 | -15.9 | -29.1 |
| Manipur                      | -6.3 | -36.2 | -21.4 | -6.1 | 1.5 | -6.2 | -48.3 |
| Meghalaya                    | -10.4 | -55.5 | -31.1 | -15.7 | -8.9 | -11.4 | -57.2 |
| Mizoram                      | 1.7 | -31.8 | -23.4 | -15.8 | -12.2 | -32.6 | -66.0 |
| Nagaland                     | -7.7 | -50.1 | -39.4 | -35.1 | -30.8 | -27.6 | -49.4 |
| Odisha                       | -5.1 | -39.6 | -5.0 | 16.6 | 19.4 | 11.7 | -32.1 |
| Puducherry                   | -6.9 | -42.6 | -7.4 | 9.9 | 12.8 | 8.5 | -11.0 |
| Punjab                       | -5.5 | -42.3 | 2.4 | 9.6 | 12.0 | 8.1 | -29.2 |
| Rajasthan                    | -4.2 | -34.0 | 10.4 | 18.6 | 20.5 | 2.1 | -34.3 |
| Sikkim                       | 3.2 | -34.0 | -29.6 | -11.8 | -6.2 | -17.5 | -54.4 |
| Tamil Nadu                   | 1.5 | -50.8 | 0.6 | 21.2 | 25.4 | 22.1 | 10.8 |
| Telangana                    | -0.1 | -42.8 | -1.0 | 15.0 | 18.2 | 12.0 | 0.3 |
| Tripura                      | -1.8 | -31.8 | 2.2 | 17.3 | 17.9 | 21.5 | 8.8 |
| Uttar Pradesh                | -0.4 | -32.9 | 15.5 | 26.1 | 32.4 | 23.9 | -25.6 |
| Uttarakhand                  | -5.1 | -35.3 | 10.4 | 26.3 | 32.0 | 21.0 | -27.7 |
| West Bengal                  | -3.7 | -41.2 | -1.1 | 10.7 | 11.6 | 11.5 | -13.3 |

Source: Own calculation based on data from Google COVID-19 Community Mobility Reports (Saha et al., 2020c).
in India. During the pre-lockdown phase, the mean mobility of parks drops a minimum from the baseline percentage. Parks mobility in north-eastern states depicted the lowest drop from the baseline. The states and UTs that recorded the highest drop during pre-lock down were Goa (-14.2%), Andaman and Nicobar Islands (-13%), Kerala (-10.8%), Dadra and Nagar Haveli (-7.6%), and West Bengal (-7.4%). The states that had the minimum mean park mobility were Chandigarh (-30.8%), Sikkim (-29.6%) Delhi (26.5%), and Gujarat (-24.9%). The states that had the minimum mean park mobility were Odisha (9.6%) Arunachal Pradesh (6.7%) Tripura (6.2%), Bihar (4.7%) Kerala (0.2%), and Uttar Pradesh (0.2%). The mobility during March, April and May (1st to 9th) of the second wave of COVID-19, the drop of mean parks mobility from the baseline was almost the same as the previous month. The highest drop of park mobility was found in April and May (1st to 9th) (Table 4).

### Table 4

| States and union territories | Parks mobility (% change from baseline) |
|-----------------------------|-----------------------------------------|
|                            | Pre-lockdown period (15th February to 24th March 2020) | Lockdown period (25th March to 31st May 2020) | Unlock period (1st June 2020 to 10th February 2021) | During second wave 11th to 28th February 2021 | March 2021 | April 2021 |
|------------------------------|-------------------------------------------------|------------------------------------------------|-------------------------------------------------|-----------------------------------|------------|------------|
| Andaman and Nicobar Islands  | -13.0                                          | -70.0                                          | -44.4                                          | -1.4                               | 4.8        | -14.3      |
| Andhra Pradesh               | 0.9                                            | -54.1                                          | -35.8                                          | -11.4                              | -11.9      | -20.4      |
| Arunachal Pradesh            | 5.8                                            | -11.7                                          | 4.7                                            | 6.7                                | 9.8        | 12.5       |
| Assam                        | -0.8                                           | -26.8                                          | -10.1                                          | -0.3                                | 0.8        | -5.1       |
| Bihar                        | 3.5                                            | -14.0                                          | 2.3                                            | 4.7                                | 5.7        | 1.3        |
| Chandigarh                   | -1.2                                           | -91.9                                          | -60.4                                          | -30.8                              | -30.8      | -42.9      |
| Chhattisgarh                 | -1.3                                           | -54.2                                          | -34.9                                          | -1.3                               | 0.7        | -43.2      |
| Dadra and Nagar Haveli       | -7.6                                           | -59.6                                          | -38.2                                          | -19.2                              | -22.5      | -42.2      |
| Goa                          | -7.3                                           | -89.0                                          | -62.8                                          | -26.5                              | -24.1      | -46.7      |
| Gujarat                      | -14.2                                          | -74.1                                          | -56.7                                          | -20.6                              | -29.0      | -50.0      |
| Haryana                      | -3.4                                           | -65.9                                          | -47.7                                          | -24.9                              | -28.0      | -46.8      |
| Himachal Pradesh             | -1.6                                           | -77.5                                          | -57.4                                          | -22.7                              | -20.1      | -26.5      |
| Jharkhand                    | 6.7                                            | -33.8                                          | -18.3                                          | -4.4                               | 0.3        | -7.4       |
| Madhya Pradesh               | 5.5                                            | -63.2                                          | -23.7                                          | -7.9                               | -2.2       | -16.7      |
| Maharashtra                  | -5.2                                           | -65.3                                          | -48.3                                          | -21.0                              | -19.2      | -31.8      |
| Manipur                      | -10.8                                          | -19.1                                          | -8.2                                           | 0.2                                | 1.8        | -5.4       |
| Meghalaya                    | -3.5                                           | -63.7                                          | -42.5                                          | -9.9                               | -13.1      | -37.6      |
| Mizoram                      | -8.9                                           | -70.8                                          | -49.2                                          | -21.7                              | -26.5      | -49.2      |
| Nagaland                     | -2.1                                           | -18.5                                          | -10.5                                          | -5.7                               | -2.7       | -8.5       |
| Odisha                       | -2.3                                           | -33.8                                          | -14.2                                          | 9.6                                | 10.2       | -1.9       |
| Puducherry                   | 15.2                                           | -71.8                                          | -48.8                                          | -12.6                              | -5.5       | -18.8      |
| Punjab                       | -2.6                                           | -67.7                                          | -47.2                                          | -17.7                              | -15.4      | -22.4      |
| Rajasthan                    | -1.9                                           | -68.9                                          | -44.9                                          | -12.4                              | -14.0      | -29.9      |
| Sikkim                       | -3.4                                           | -68.9                                          | -35.7                                          | -29.6                              | -22.9      | -33.5      |
| Tamil Nadu                   | -1.8                                           | -43.4                                          | -29.7                                          | -5.4                               | -4.4       | -14.1      |
| Telangana                    | -1.3                                           | -63.2                                          | -45.3                                          | -15.5                              | -15.5      | -26.6      |
| Tripura                      | -3.6                                           | -16.2                                          | 1.3                                            | 6.2                                | 3.2        | -2.6       |
| Uttar Pradesh                | 0.6                                            | -49.1                                          | -28.5                                          | 0.2                                | 2.3        | -12.0      |
| Uttarakhand                  | -0.3                                           | -54.3                                          | -24.4                                          | -5.8                               | 2.5        | -15.6      |
| West Bengal                  | -7.4                                           | -52.8                                          | -29.3                                          | -6.2                               | -8.5       | -15.0      |

Source: Own calculation based on data from Google COVID-19 Community Mobility Reports (Google 2020).

4.4. Mean changes in transit stations mobility during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India

Table 5 shows the mean changes of transit station mobility from the average baseline during the period of pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India. The states and UTs which recorded the highest decline percentage rate in mean transit mobility during the pre-lockdown period were Delhi (-14.4%), Kerala (-13%), Maharashtra (-11.4%), Goa (-10.7%), Meghalaya (-10.6%), Andaman and Nicobar Islands and Daman Diu (-8.8%). At the same period, the states which recorded the lowest change of mean transit mobility from the average baseline were Manipur (0%), Bihar (0.8%), Jharkhand (1%), Sikkim (-3%), and Uttar Pradesh (-3.1%). But when the lockdown period started the changes of mobility from the average baseline increased, the states & UTs where the maximum drop from the average baseline happened were Delhi (-78.4%), Chandigarh (-78.3%), Maharashtra (-71.9%) Andaman, and Nicobar Islands (-69.2%), West Bengal (-67.8%) and Haryana (-67.7%). In this period Mizoram (-30.3%) Himachal Pradesh (-34.5%), Manipur (-38.1%), and Kerala (-47.3%) reported the
minimum mean changes of transit stations mobility from the average baseline of the country. This finding was in line with the findings in Italy (Beria and Lunkar, 2021). After the lockdown when the unlock period started the mean change of transit stations’ mobility was little minimized compared to the previous lockdown period. During the period of the second wave of COVID-19 the fall of mean transit stations mobility from the baseline were Himachal Pradesh (-2.6%), Chandigarh (-1.5%), Assam (-2.5%) and Andhra Pradesh (-2.6%) these states had the lowest percentage of decline rate.

4.5. Changes in workplaces mobility during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India

Table 5 represents the mean changes of workplace mobility from the average baseline percentage during the period of pre-lockdown, lockdown, unlock, and the second wave COVID-19 in India. Workplace mobility during the pre-lockdown period all the states record the lowest percentage of decline from the average baseline. In this period the highest fall of mean workplace mobility recorded in Maharashtra (-10.1%), Delhi (10%), Chandigarh (-9.1%), Nagaland (-8.8%), Uttar Pradesh (-8.1%), Haryana (-7.6%) and Telangana (-7.2%), at the same time Tripura (-0.5%), Tamil Nadu (0.6%), Meghalaya (1.4%), Puducherry (1.5%), Himachal Pradesh (1.7%), Assam (2.5%) and Andhra Pradesh (2.6%) these states had the lowest percentage of decline rate in workplace mobility from the baseline. When the lockdown started from the 25th March to 31st May 2020 the declining rate of workplace mobility increased, the states of Delhi (-72.3%), Chandigarh (-66.9%), Maharashtra (-66.1%), Gujarat (-59.9%), Telangana (-59.4%), Karnataka (-57.4%) and Haryana (-56.6%) were reported highest fall of mean percentages of workplace mobility from the baseline. On the other hand, the states that had the lowest fall of the mean workplace were Arunachal Pradesh (-17.2%), Tamil Nadu (-21.9%), Nagaland (-26.3%), Tripura (28.8%), Meghalaya (29.3%), and Bihar (-31.4%). A similar finding is also found in earlier studies conducted in the USA (Paez, 2020) where the mobility of the workplace tends to decrease with increasing COVID-19 cases. This finding is in agreement with another study conducted in Poland (Wielechowski et al., 2020). But when the unlock period started the falling rate of workplace mobility decreased from the average baseline of the country. In the period of unlocking the states which had displayed the highest decrease in workplace mobility were Maharashtra (-35.4%), Delhi (-35%), Karnataka (-32.6%), Telangana

**Table 6** Change in transit station mobility during pre-lockdown, lockdown, and second wave of COVID-19 in India.

| States and union territories | Transit stations mobility (% change from baseline) | Pre-lockdown period (15th February to 24th March 2020) | Lockdown period (25th March to 31st May 2020) | Unlock period (1st June 2020 to 10th February 2021) | During second wave (11th to 28th March 2021) | April 2021 | 1st to 9th May 2021 |
|-------------------------------|--------------------------------------------------|----------------------------------------------------|-------------------------------------------------|-------------------------------------------------|---------------------------------|-----------------|-----------------|
| Andaman and Nicobar Islands   | -8.8                                             | -69.2                                              | 19.3                                            | 64.2                                            | 68.2                            | 48.8            | -18.1           |
| Arunachal Pradesh             | -4.0                                             | -54.2                                              | -21.5                                           | -2.8                                            | -4.7                            | -12.6           | -36.9           |
| Assam                         | -5.5                                             | -59.4                                              | -22.8                                           | -1.0                                            | -2.1                            | -9.1             | -36.3           |
| Bihar                         | 0.8                                              | -54.3                                              | -13.3                                           | 7.3                                             | 7.3                             | -2.4             | -31.2           |
| Chandigarh                    | -9.1                                             | -78.3                                              | -38.4                                           | -2.3                                            | 0.8                             | -16.2            | -52.6           |
| Chhattisgarh                  | -6.5                                             | -63.1                                              | -30.7                                           | -5.8                                            | -6.5                            | -49.6           | -66.1           |
| Dadra and Nagar Haveli        | -9.3                                             | -64.9                                              | -21.1                                           | -3.2                                            | 13.3                            | 0.9              | -24.4           |
| Daman and Diu                 | -8.8                                             | -56.6                                              | -16.4                                           | 1.2                                             | -4.4                            | -38.3            | -56.7           |
| Goa                           | -10.7                                            | -53.5                                              | -33.4                                           | -5.8                                            | -8.7                            | -23.6            | -57.0           |
| Gujarat                       | -7.7                                             | -59.9                                              | -21.2                                           | -4.8                                            | -8.0                            | -29.1            | -43.3           |
| Haryana                       | -7.5                                             | -67.7                                              | -33.2                                           | -14.7                                           | -15.5                           | -25.1            | -60.7           |
| Himachal Pradesh              | -3.7                                             | -34.5                                              | 1.7                                             | 5.7                                             | 13.0                            | 4.0              | 26.3            |
| Jharkhand                     | -1.9                                             | -59.5                                              | -23.6                                           | 0.3                                             | 2.5                             | -15.3            | -42.7           |
| Karnataka                     | -7.1                                             | -54.6                                              | -23.2                                           | -5.4                                            | -6.7                            | -23.7            | -54.3           |
| Kerala                        | -13.0                                            | -47.3                                              | -23.8                                           | -13.7                                           | -10.3                           | -18.5            | -54.7           |
| Madhya Pradesh                | -5.2                                             | -62.0                                              | -19.0                                           | -0.7                                            | -4.3                            | -38.3            | -60.0           |
| Maharashtra                   | -11.4                                            | -71.9                                              | -36.4                                           | -10.4                                           | -16.1                           | -43.6            | -53.3           |
| Manipur                       | 0.0                                              | -38.1                                              | -4.9                                            | 6.6                                             | 7.5                             | -4.1             | -51.9           |
| Meghalaya                     | -10.6                                            | -39.7                                              | -4.8                                            | 15.2                                           | 14.9                            | 4.7              | -47.4           |
| Mizoram                       | 4.9                                              | -30.3                                              | -23.3                                           | -16.1                                           | -7.6                            | -30.1            | -66.0           |
| Nagaland                      | -3.7                                             | -58.8                                              | -29.8                                           | -11.7                                           | -5.1                            | -11.1            | -38.3           |
| Odisha                        | -4.7                                             | -58.3                                              | -29.5                                           | -15.0                                           | -15.2                           | -25.7            | -55.9           |
| Puducherry                    | -6.0                                             | -49.9                                              | -22.4                                           | -5.5                                            | -1.7                            | -16.7            | -41.1           |
| Punjab                        | -6.9                                             | -64.9                                              | -32.8                                           | -21.4                                           | -20.7                           | -27.3            | -55.0           |
| Rajasthan                     | -3.9                                             | -60.3                                              | -16.1                                           | 4.7                                             | 3.0                             | -16.8            | -49.6           |
| Sikkim                        | -3.0                                             | -60.3                                              | -32.7                                           | 3.5                                             | 12.7                            | -9.6             | -56.2           |
| Tamil Nadu                    | -3.8                                             | -66.4                                              | -23.0                                           | -1.8                                            | -1.7                            | -11.8            | -28.0           |
| Telangana                     | -4.8                                             | -63.2                                              | -3.8                                            | -3.2                                            | -3.8                            | -18.4            | -33.7           |
| Tripura                       | -4.7                                             | -55.7                                              | -24.9                                           | -8.6                                            | -7.9                            | -14.2            | -30.3           |
| Uttar Pradesh                 | -3.1                                             | -66.1                                              | -26.1                                           | -4.4                                            | -2.7                            | -18.1            | -51.9           |
| Uttarakhand                   | 3.2                                              | -55.3                                              | -12.9                                           | 14.0                                            | 22.7                            | 2.3              | -42.7           |
| West Bengal                   | -8.2                                             | -67.8                                              | -29.2                                           | -4.1                                            | -3.5                            | -10.9            | -39.2           |

Source: Own calculation based on data from Google COVID-19 Community Mobility Reports (Saha et al., 2020c).
workplace mobility drop in high variation during the 1st phase of the second wave of COVID-19 in India. The states where the maximum increase of mean residential mobility in the pre-lockdown (15th February to 24th March 2020) period was Kerala (5.3%), Maharashtra (5.3%), Delhi (4.6%), Goa (4.3%). The residential mobility was increased from the baseline during the lockdown period when all the people were stayed in their home, in this period highest mean residential mobility were found in Maharashtra (32.2%), Puducherry (30.5%), Chandigarh (30.7%), Delhi (30.4%) Gujarat (30.4%) and Telangana (28.6%). The states which had the lowest mean increase in residential mobility from the baseline during the lockdown period were Mizoram (10.5%), Arunachal Pradesh (13%), Bihar (13.1%), Tamil Nadu (13.2%), and Manipur (13.4%). The residential mobility increased during this period because of the mobility towards the home during the lockdown. This study is consistent with the study in India (Saha and Chouhan, 2021b). When the unlock period started the increasing rate of residential mobility slowed down but high mean residential mobility from the baseline were found in Maharashtra (16.5%), Puducherry (15.9%), Kerala (15.6%) Tamil Nadu (14.1%), and Karnataka (13.2%). The states where the mean residential mobility record lowest increase from the baseline percentage during the unlock Period were Arunachal Pradesh (-15.9%), Puducherry (-15.9%), Kerala (15.6%) Tamil Nadu (14.1%), and Karnataka (13.2%). The states which had the lowest mean increase in residential mobility from the baseline during the unlock Period were Mizoram (-10.5%), Arunachal Pradesh (-13%), Bihar (13.1%), Tamil Nadu (13.2%), and Manipur (13.4%). The residential mobility increased during this period because of the mobility towards the home during the lockdown. This study is consistent with the study in India (Saha and Chouhan, 2021b). When the unlock period started the increasing rate of residential mobility slowed down but high mean residential mobility from the baseline were found in Maharashtra (16.5%), Puducherry (15.9%), Kerala (15.6%) Tamil Nadu (14.1%), and Karnataka (13.2%). The states where the mean residential mobility record lowest increase from the baseline percentage during the unlock Period were Arunachal Pradesh (-15.9%), Puducherry (-15.9%), Kerala (15.6%) Tamil Nadu (14.1%), and Karnataka (13.2%). The states which had the lowest mean increase in residential mobility from the baseline during the unlock Period were Mizoram (-10.5%), Arunachal Pradesh (-13%), Bihar (13.1%), Tamil Nadu (13.2%), and Manipur (13.4%). The residential mobility increased during this period because of the mobility towards the home during the lockdown. This study is consistent with the study in India (Saha and Chouhan, 2021b). When the unlock period started the increasing rate of residential mobility slowed down but high mean residential mobility from the baseline were found in Maharashtra (16.5%), Puducherry (15.9%), Kerala (15.6%) Tamil Nadu (14.1%), and Karnataka (13.2%) (Table 6). 4.6. Changes in residential mobility during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 Table 7 represents the mean change of residential mobility from the baseline mean percentage during pre lockdown, lockdown, unlock period, and during the second wave periods of COVID-19 in India. The states where the maximum increase of mean residential mobility in the pre-lockdown (15th February to 24th March 2020) period was Kerala (5.3%), Maharashtra (5.3%), Delhi (4.6%), Goa (4.3%). The residential mobility was increased from the baseline during the lockdown period when all the people were stayed in their home, in this period highest mean residential mobility were found in Maharashtra (32.2%), Puducherry (30.5%), Chandigarh (30.7%), Delhi (30.4%) Gujarat (30.4%) and Telangana (28.6%). The states which had the lowest mean increase in residential mobility from the baseline during the lockdown period were Mizoram (10.5%), Arunachal Pradesh (13%), Bihar (13.1%), Tamil Nadu (13.2%), and Manipur (13.4%). The residential mobility increased during this period because of the mobility towards the home during the lockdown. This study is consistent with the study in India (Saha and Chouhan, 2021b). When the unlock period started the increasing rate of residential mobility slowed down but high mean residential mobility from the baseline were found in Maharashtra (16.5%), Puducherry (15.9%), Kerala (15.6%) Tamil Nadu (14.1%), and Karnataka (13.2%). The states where the mean residential mobility record lowest increase from the baseline percentage during the unlock Period were Arunachal Pradesh (-15.9%), Puducherry (-15.9%), Kerala (15.6%) Tamil Nadu (14.1%), and Karnataka (13.2%). The states which had the lowest mean increase in residential mobility from the baseline during the unlock Period were Mizoram (-10.5%), Arunachal Pradesh (-13%), Bihar (13.1%), Tamil Nadu (13.2%), and Manipur (13.4%). The residential mobility increased during this period because of the mobility towards the home during the lockdown. This study is consistent with the study in India (Saha and Chouhan, 2021b). When the unlock period started the increasing rate of residential mobility slowed down but high mean residential mobility from the baseline were found in Maharashtra (16.5%), Puducherry (15.9%), Kerala (15.6%) Tamil Nadu (14.1%), and Karnataka (13.2%) (Table 6).
Pradesh (6.7%), Himachal Pradesh (6.8%), Bihar (7.1%), Punjab (7.8%), Rajasthan (8.8%) and Nagaland (9.4%).

During the second wave in India 11th February to March 2021, the mean increases of residential mobility quite lowest compare to the previous period such as pre-lockdown, lockdown, and unlock period from the baseline but in April and 1st to 9th May, the mean percentage of residential mobility increased. The states that had the maximum mean increase from the baseline during April 2021 were Chhattisgarh (28%), Maharashtra (23.9%), Madhya Pradesh (23.4%), and Gujarat (16.8%). The minimum mean increase in residential mobility states from the baseline wasAndhra Pradesh (5.3%), Punjab (6.2%), Nagaland (7.6%), Mizoram (9%), and Manipur (10.4%). During the second wave in May 2021 (1st to 9th) the highest mean increase of residential mobility from the baseline recorded states were Chhattisgarh (32%), Kerala (31.3%), Madhya Pradesh (30.2%), Meghalaya (28.6%), and Goa (27.8%). The states that record the minimum mean increase of residential mobility during May 2021 were Arunachal Pradesh (10.8%), Punjab (15.8%), Nagaland (16.2%), Tripura (17.8%), and Mizoram (17.9%) (Table 7).

Source: Own calculation based on data from Google COVID-19 Community Mobility Reports (Saha et al., 2020c).

4.7. Daily change in stringency index and new confirmed cases of COVID-19 in India

Fig. 1 shows the stringency index throughout pre-lockdown, lockdown, Unlock and the second wave of COVID-19 in India. The stringency index is a composite measurement of nine different indicators, the value of this index range from 0 to 100. The highest value (100) indicates the higher stringency or strictest response and the lower value (0) indicates the lower stringency. During the pre-lockdown period, the lower value of the stringency index indicates the mobility was normal and all the economic activity also normal. After some time when the impact of the COVID-19 virus was increasing and also the daily active cases, the government imposed the lockdown. During the lockdown period, the highest value evidenced that the country enforced the strictest nationwide lockdown. In this period the stringency value increased (value ranges 80 to 100). This highest value indicates the action of the

Table 7

| States and union territories | Residential mobility (% change from baseline) |
|-------------------------------|---------------------------------------------|
|                               | Pre-lockdown period (15th February to 24th March 2020) | Lockdown period (25th March to 31st May 2020) | Unlock period (1st June to 10th February 2021) | During the second wave (11th to 28th February 2021) |
| Andaman and Nicobar Islands   | 4.0                                         | 24.1                                        | 12.3                                         | 4.8                                                   |
| Andhra Pradesh                | 2.8                                         | 24.4                                        | 12.3                                         | 4.2                                                   |
| Assam                         | 1.7                                         | 13.0                                        | 6.7                                          | 3.7                                                   |
| Bihar                         | 0.4                                         | 13.1                                        | 11.2                                         | 9.2                                                   |
| Chandigarh                    | 3.8                                         | 30.7                                        | 11.3                                         | 3.8                                                   |
| Chhattisgarh                  | 3.0                                         | 20.0                                        | 11.1                                         | 7.4                                                   |
| Dadra and Nagar               | 2.2                                         | 25.2                                        | 9.7                                          | 5.2                                                   |
| Daman and Diu                 | 2.8                                         | 27.1                                        | 10.9                                         | 3.7                                                   |
| Delhi                         | 4.6                                         | 30.4                                        | 12.5                                         | 5.0                                                   |
| Goa                           | 4.3                                         | 23.6                                        | 13.0                                         | 5.2                                                   |
| Gujarat                       | 3.7                                         | 30.4                                        | 11.7                                         | 4.9                                                   |
| Haryana                       | 2.6                                         | 25.8                                        | 10.3                                         | 5.1                                                   |
| Himachal Pradesh              | 1.1                                         | 15.0                                        | 6.8                                          | 6.6                                                   |
| Jharkhand                     | 1.5                                         | 19.6                                        | 10.5                                         | 8.3                                                   |
| Karnataka                     | 4.1                                         | 26.7                                        | 13.2                                         | 7.7                                                   |
| Kerala                        | 5.3                                         | 26.7                                        | 15.6                                         | 8.5                                                   |
| Madhya Pradesh                | 2.8                                         | 23.7                                        | 11.0                                         | 7.7                                                   |
| Maharashtra                   | 5.3                                         | 32.2                                        | 16.5                                         | 9.6                                                   |
| Manipur                       | 0.6                                         | 13.4                                        | 11.2                                         | 6.1                                                   |
| Meghalaya                     | 1.5                                         | 18.2                                        | 12.8                                         | 9.2                                                   |
| Mizoram                       | 1.6                                         | 10.5                                        | 9.7                                          | 3.6                                                   |
| Nagaland                      | 1.4                                         | 14.1                                        | 9.4                                          | 5.8                                                   |
| Odisha                        | 2.1                                         | 18.4                                        | 11.5                                         | 7.6                                                   |
| Puducherry                    | 3.8                                         | 30.5                                        | 15.9                                         | 6.1                                                   |
| Punjab                        | 2.2                                         | 21.4                                        | 7.8                                          | 2.1                                                   |
| Rajastan                      | 2.0                                         | 21.2                                        | 8.8                                          | 6.3                                                   |
| Sikkim                        | 1.4                                         | 21.2                                        | 11.7                                         | 8.3                                                   |
| Tamil Nadu                    | 2.9                                         | 13.2                                        | 14.1                                         | 6.2                                                   |
| Telangana                     | 4.2                                         | 28.6                                        | 13.1                                         | 6.5                                                   |
| Tripura                       | 2.2                                         | 17.3                                        | 10.6                                         | 7.1                                                   |
| Uttar Pradesh                 | 1.9                                         | 21.2                                        | 10.3                                         | 7.5                                                   |
| Uttarakhand                   | 2.5                                         | 21.0                                        | 9.6                                          | 5.5                                                   |
| West Bengal                   | 2.9                                         | 23.0                                        | 12.8                                         | 7.6                                                   |

Source: Own calculation based on data from Google COVID-19 Community Mobility Reports (Saha et al., 2020c).

Fig. 1. Daily change in stringency index and new confirmed cases during pre-lockdown, lockdown, Unlock, and the second wave of COVID-19 in India, 2020-21.
government to stop the movement of the people and also to stop the economic activities. In this context similar work has been done at the global level which shows the effect of stringency on economic activities (Aggarwal et al., 2021). Another important fact is that in this period the people are also following the social distancing rules and regulations to control the spread of the COVID-19.

After the end of the lockdown period when the unlock period started the stringency value decreased which indicates that the government gave the relaxations in movement and also the other activities. In this period the response of the government was not strictest for this reason the stringency value decreased. The present study is related to the work in Europe (Gros et al., 2021). But after some time the value of stringency increased because of the sudden spiked in daily COVID-19 cases in India from February to May 2021, which was the second wave of COVID-19. During this period higher value indicates the strictest response of the people as well as the government. The government again imposed some rules and regulations for the movement of the people and other activities, the people also maintain the social distancing rules.

4.8. State and union territory wise mean changes of different community mobility during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India

Fig. 2 shows the fluctuations of different types of mobility such as residential, retail and recreational, grocery and pharmacy, parks, transit stations, and workplaces throughout pre-lockdown, lockdown, unlock, and the second wave of COVID-19 pandemic in India. During the pre-lockdown period, most of the states witnessed all the mobility decrease from the baseline except residential mobility which was slightly increased from the baseline. The highest increase was seen in the states of Kerala, Maharashtra, Delhi, and Goa. The residential mobility was increased from the baseline during the period of lockdown among all the states. The graph clearly shows the increasing trend of residential mobility in all the states such as Maharashtra, Puducherry, Chandigarh, Delhi, and Gujarat. The status of residential mobility during all the periods (pre-lockdown, lockdown, and second-wave) was satisfactory because in all periods the mobility happened and decreased from the baseline. The graph, clearly depicted that the country-level average of residential mobility was increased from the baseline on the other hand all the mobility decreased from the baseline.

Retail and recreational mobility which was highly dropped from the baseline during all the period (pre-lockdown, lockdown, unlock, and second wave), the dropping rate was highest during the lockdown period. In this period, the highest fall was found in Chandigarh, Delhi, Maharashtra, Telangana, and Gujararat. It is normal that during this period whole country was shut down so the dropping rate was also high, when the unlock period started the mobility was also started and the falling rate minimized. But when the second wave of COVID-19 hit India the mobility was highly dropped to the baseline. The mobility of grocery and pharmacy happened during all the period because it was the essential mobility; most of the states recorded the low falling rate from the baseline. The dropping rate was medium during the pre-lockdown period but in the lockdown period, the dropping rate was high in states or UTs like Delhi, Goa, Gujarat, Andaman & Nicobar Islands, Meghalaya, Nagaland, and Puducherry due to following the strictly social distancing norms. The country-level picture clearly shows that the grocery and pharmacy mobility highly dropped from the baseline during the lockdown period and then the mobility increased during the time of unlocking and second wave period from February to April but in May it was decreased from the baseline. The above graph depicted that parks mobility was highly decreased from the baseline during all the periods except in pre-lockdown period, during pre-lockdown period Arunachal Pradesh, Himachal Pradesh, Manipur, and Mizoram depicted that parks mobility slightly decreased from the baseline the cause behind the lowest dropped in these states may be the mountainous environment. When the lockdown was imposed the park’s mobility highly decreased.
from the baseline among all the states and UTs except Jammu & Kashmir and the decreasing trend continued to the second wave of the period. The transit stations and workplace mobility were dropped during the period of lockdown, and the second wave but in the pre-lockdown period the motilities were predominant which we can see from the graph that the falling rate minimum from the baseline. After the imposition of lockdown transit stations and workplace mobility highly decreased from the baseline it clearly shows that the people maintain the social distancing regulation and rules. During the first and second phases of the second wave, some states indicate the transit station’s mobility increased from the baseline like Uttarakhand, Sikkim, Meghalaya, Manipur, and Andaman & Nicobar Islands (Fig. 2).

4.9. Spatial pattern of variations in retail and recreational mobility and active COVID-19 cases in India

Fig. 3 represents states and UTs wise spatial variations of retail and recreational mobility from the baseline during the period of pre-lockdown, lockdown, unlocks, and the second wave in India. It is found that during the pre-lockdown period across India all the states record a slight decrease in retail and recreational mobility from the baseline because the daily active case of COVID-19 was the lowest. During this period the high mean retail and recreational mobility was found in Himachal Pradesh, Sikkim, Meghalaya, and Mizoram. But when the Government of India imposed the lockdown all over India due to the daily high spike of COVID-19 active cases the mean mobility of retail and recreational highly dropped from the baseline. At this time states like Maharashtra, Telangana, and Gujarat reported a high spiked of COVID-19 cases and the active cases were also high for that reason the retail and recreational mobility also highly decreased from the baseline but in north-eastern states like Arunachal Pradesh, Nagaland, Manipur, and Meghalaya the mean retail and recreational mobility was minimum from the baseline due to less active cases of COVID-19.

During the lockdown, the variation of mobility from the baseline was highest because the people were aware of COVID-19 and they maintain the social distance from others. After the lockdown ends and unlocks period started, the dropping rate of mean retail and recreational mobility was improved in Rajasthan, Punjab, Haryana, Himachal Pradesh, Uttarakhand, Delhi, Uttar Pradesh, Bihar, and Jharkhand. In India when the second wave hit all over the country and daily COVID-19 cases were increasing the mean retail and recreational mobility dropped from the baseline. During the months February, March, and April 2021 of the second wave, all the states, and UTs record the medium and low mobility across the country due to the increasing rate of active COVID-19 cases, and people are maintaining the social distancing norms but in May 2021 some states like Bihar, Assam, Arunachal Pradesh, and Tamil Nadu recorded the highest mean mobility compared to the other states and UTs of India (Fig. 3).

4.10. Spatial pattern of variations in grocery and pharmacy mobility and active COVID-19 cases in India

Fig. 4 represents the changes of mean grocery and pharmacy mobility from the baseline during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19. The variation of mean mobility of grocery and pharmacy from the country’s baseline was lowest during the pre-lockdown period. All the states recorded high mobility in the pre-lockdown period except Kerala where the mobility was medium because of the increasing COVID-19 cases during this time. The states such as Arunachal Pradesh, Nagaland, Manipur, and Meghalaya have also recorded the medium mean mobility of grocery and pharmacy from the baseline. In India when the COVID-19 cases gradually increased all over states and UTs and lockdown was imposed to control the pandemic and increase the social distancing, then mobility was quite decreased from the baseline. In northern and north-western states like Uttar Pradesh, Bihar, Rajasthan displays the high mobility of grocery and pharmacy. As grocery and pharmacy essential for living for that reason almost every state displays the medium mean grocery and pharmacy mobility during the time of lockdown. The state-wise spatial variations of mean grocery and pharmacy mobility from the baseline were not so high in the time of unlocking period. Across India, almost every state showed medium mobility except Uttar Pradesh and Bihar where the high mobility of grocery and pharmacy was found.

From the middle of February 2021 when the second wave started in
India the mobility of grocery and pharmacy was medium up to May 2021. In February 2021 of the second wave, Andhra Pradesh and Bihar have high mobility rest of the part of the country showed medium mobility of grocery and pharmacy. During March 2021 of the second wave of COVID-19 due to the high surge of active cases, all the states and UTs depict medium mobility of grocery and pharmacy except some north-eastern states like Meghalaya, Manipur, Mizoram, and Nagaland where the mobility was low. During the month April and May 2021 of the second wave of COVID-19 pandemic southern states like Andhra Pradesh, Tamil Nadu, Kerala, and northern states like Uttar Pradesh, Bihar, had the high mean grocery and pharmacy mobility due to a slightly decreasing rate of active COVID-19 cases (Fig. 4).

4.11. Spatial pattern of variations in parks mobility and active COVID-19 cases in India

Fig. 5 shows the overall spatial variations scenario of parks mobility from the baseline during the period of pre-lockdown, lockdown, unlock,
and the second wave of COVID-19 pandemic in India. The park mobility during the pre-lockdown period was high in Himachal Pradesh, Arunachal Pradesh, and Mizoram due to the hilly environment and the lowest mobility found in Maharashtra, Karnataka, Tamil Nadu, Bihar, and West Bengal because the active COVID-19 cases were increased. But when the lockdown period started the people were confined in the home the mean park mobility dropped largely from the baseline. During the lockdown period, hilly states like Himachal Pradesh and most of the north-eastern states recorded the highest mobility otherwise rest of the part of the country had experienced medium to low mobility it depicted that the people maintained the social distancing norms.

After the lockdown period over though the unlock period started people were strictly following the social distancing rules and that was the reason, the high mobility was found only in Bihar, Odisha, and some north-eastern states. The overall status of mean park mobility during the month February and March 2021 of the second wave of COVID-19 was almost the same but in the month April and May 2021, there were decreases in mean park mobility among the states, most of the states recorded medium to low mobility (Fig. 5).

4.12. Spatial pattern of variations in transit stations mobility and active COVID-19 cases in India

Fig. 6 represents state and UTs wise spatial variations of transit stations mobility from the baseline during the period of pre-lockdown, Lockdown, unlock, and the second wave of COVID-19 pandemic in India. The dropping rate of mean transit station mobility from the baseline was lowest during the pre-lockdown period. In this time, the high mobility which indicates by the red colour of transit stations found in Himachal Pradesh, Uttarakhand, Bihar, Jharkhand, Manipur, and Mizoram, except these states all other parts of the country displayed medium and low mobility. When the COVID-19 active cases were rising fluently and lockdown imputed all over the country the mean of transit stations mobility highly decreased from the baseline. In this period the highest number of states recorded the medium and low mobility of transit stations except for Himachal Pradesh, Meghalaya, Manipur, and Mizoram where the mean transit station mobility was high.

Fig. 6 depicted that a large number of states show low and medium mobility except for Himachal Pradesh which recorded the high transit stations mobility during the unlock period. In months February, March, and April 2021 of the second wave of COVID-19 shows that the mean mobility of transit stations in every state was displayed the medium to low mean mobility of transit stations due to the surge of COVID-19 active cases across the country but in the month May 2021 some states such as Tamil Nadu, Telangana, Himachal Pradesh, Bihar, and Arunachal Pradesh had the high mean transit stations mobility compared to the other states and UTs of India.

4.13. Spatial pattern of variations in workplaces mobility and active COVID-19 cases in India

Fig. 7 presents the changes pattern of mean workplaces mobility from the baseline during the time of pre-lockdown, lockdown, unlock, and the second wave of COVID-19 in India. In India before the lockdown, the mean workplace mobility largely decreased from the baseline, every state of the country indicated low workplace mobility except some states like Sikkim, Arunachal Pradesh, and Nagaland where the mobility of the workplace was high. When the lockdown started the trends of mobility towards the workplaces reduced, it clearly shows due to lockdown and increasing active cases of COVID-19 most of the states fill with green and yellow colours which indicate low workplace mobility.

At the time of unlocking there was a certain improvement of workplace mobility compared to the lockdown phase. In February, March, and April 2021 of the second wave of COVID-19 the scenario of workplace mobility same no high workplace mobility happened. Only in May 2021 of the second wave, some states like Tamil Nadu, Himachal Pradesh, West Bengal, Assam, and Arunachal Pradesh indicate high workplace mobility compared to the other states and UTs, where low to medium workplaces mobility was found (Fig. 7).

4.14. Spatial pattern of variations in residential mobility and active COVID-19 cases in India

Fig. 8 represents the states and UTs wise variations in mean
residential mobility from the baseline during the pre-lockdown, lockdown, unlock, and the second wave of COVID-19 pandemic in India. In this figure the high residential mobility is shown by the green colour, low mobility is shown by red, and medium mobility is shown by yellow colour. High residential mobility was found during the pre-lockdown phase in Gujarat, Maharashtra, Karnataka, Kerala, and Telangana. At the same time, low residential mobility is found in the northern part and north-eastern part of India. During the lockdown period, the mean increase of residential mobility was high from the baseline. Compare to the pre-lockdown phase it displayed that high residential mobility states were the same but some states such as Uttar Pradesh, Rajasthan, Gujarat, and Jharkhand improved from low residential mobility to medium residential mobility. So it is clear that during the lockdown when the other mobility decreases from the baseline but only residential mobility increases during this period. The southern part of India consistently showed high residential
mobility during in unlocking period (lessen compared to the lockdown period) though the active cases were also increasing. Some states like Rajasthan and Punjab were decreased from the medium to low residential zone compared to pre lockdown phase. When the second wave hit a small number of states recorded low residential mobility during February 2021, otherwise all the states were in high and medium residential mobility zone. But in March and April 2021 of the second wave only the middle portion of India displayed the high mobility zone, the rest of the part indicates low and medium mobility. Compare to the early months of the second wave, in May 2021 most of the parts of the country indicate high residential mobility except the north-eastern (exclude Meghalaya) and south-eastern states of India (Fig. 8).

5. Conclusion

This study assesses spatial-temporal variations in community mobility during the lockdown, unlock, and second wave of COVID-19 in India. Identifying the spatial variations in community mobility, allows the spatial distribution and temporal change to be explored in the states and UTs of India. Analyzing the states and union territory-wise spatial variation in different types of mobility provides those concerned with non-medical measures with the ability to target and to tailor better outcomes through states or UTs specific activities. Mapping of spatial-temporal variations in human mobility behaviour would be useful to know which states and UTs should be targeted and tailored policies should be implemented by the states or UTs of India. Understanding the spatial-temporal dynamics of community mobility and COVID-19 new active cases is important to its mitigation or to flatten the curve in future days by targeting and tailoring the area-specific policies and strictly maintaining the non-medical social distancing measures.

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Credit authorship contributions

Jay Saha: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Supervision; Validation; Visualization; Writing – original draft; Writing – review & editing.

Sabbir Mondal: Conceptualization; Formal analysis; Investigation; Methodology; Writing – original draft.

Pradip Chouhan: Conceptualization; Formal analysis; Investigation; Supervision; Validation; Visualization; Writing - original draft.

Ethical Approval

This study was based on secondary sources of data. So, there is no need for ethical approval.

Declaration of Competing interests

The author declares that have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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