Analysis of the COVID-19 testing parameters and progression of the pandemic at the district level: findings from the ICMR Hundred Million Test (HMT) database during the first wave in India

Jaya Singh Kshatri [a,#], Sidhartha Giri [a,#], Debdutta Bhattacharya [a,#], Subrata Kumar Palo [a], Ira Praharaj [a], Srikanta Kanungo [a], Jyotirmayee Turuk [a], Jyoti Ghosal [a], Trilochan Bhoi [a], Matrujyoti Pattnaik [a], Harpreet Singh [b], Samiran Panda [b], Sanghamitra Pati [a,†,*]

[a] ICMR-Regional Medical Research Center, Bhubaneswar, Odisha, India
[b] Indian Council of Medical Research, New Delhi, India

ABSTRACT

Background: India had the second-highest number of COVID-19 cases globally. We evaluated the progression of the pandemic across the lockdowns and phased reopenings at the district level during the first wave (in India).

Methods: For the analysis in this study, we used more than 100 million COVID-19 test results along with other parameters available in the Indian Council of Medical Research database from March 2020 to October 2020. The districts were stratified as high, moderate, and low caseload districts and data analysis was done for each phase of lockdown.

Findings: Of the 110.5 million tests included in the analysis, 54.79 million tests were performed using molecular methods, 53.58 million by rapid antigen tests, and 2.13 million using the indigenous TruNat platform. The proportion of positive cases among symptomatic individuals (22.6%) was significantly higher than asymptomatic individuals (8.6%). The tests conducted and proportions of positivity were significantly higher in high caseload districts; 58% of these tests were conducted using molecular methods as opposed to only one-third in low caseload districts.

Interpretation: Laboratory parameters, along with other demographic information, can help us better understand the spread of the pandemic in a country. This information can be crucial to formulating and implementing public health policies in future waves of the pandemic.

© 2022 The Authors. Published by Elsevier Ltd on behalf of International Society for Infectious Diseases.
This is an open access article under the CC BY-NC-ND license
(http://creativecommons.org/licenses/by-nc-nd/4.0/)

Introduction

COVID-19, caused by SARS-CoV-2, has spread to 226 countries, infecting approximately 505 million people and causing more than six million deaths (World Health Organization, 2022).

In India, the first case of COVID-19 was reported on January 30, 2020, and as of April 25, 2022, there have been 43,052,425 confirmed cases of COVID-19 (World Health Organization, 2022). India has recorded more than 34 million cases over 450,000 deaths in two waves (World Health Organization, 2021). Although the first wave peaked around September 2020 with a daily new caseload of approximately 100,000 cases, the second, more severe wave was at its peak in May 2021 with a record peak of 380,000 daily cases (Figure 1).

In response, the Ministry of Health and Family Welfare, Government of India, has taken several steps, including active case identification, contact tracing, ramping up testing, and establishment of new testing facilities across the country (Gupta et al., 2020). As of October 18, 2021, a total of 3003 laboratories were approved by the Indian Council of Medical Research (ICMR) for performing molecular tests for COVID-19 (real-time reverse transcription–PCR, TrueNat, cartridge-based nucleic acid amplification test [CB-NAAT]), which includes 1336 government and 1667 private labora-
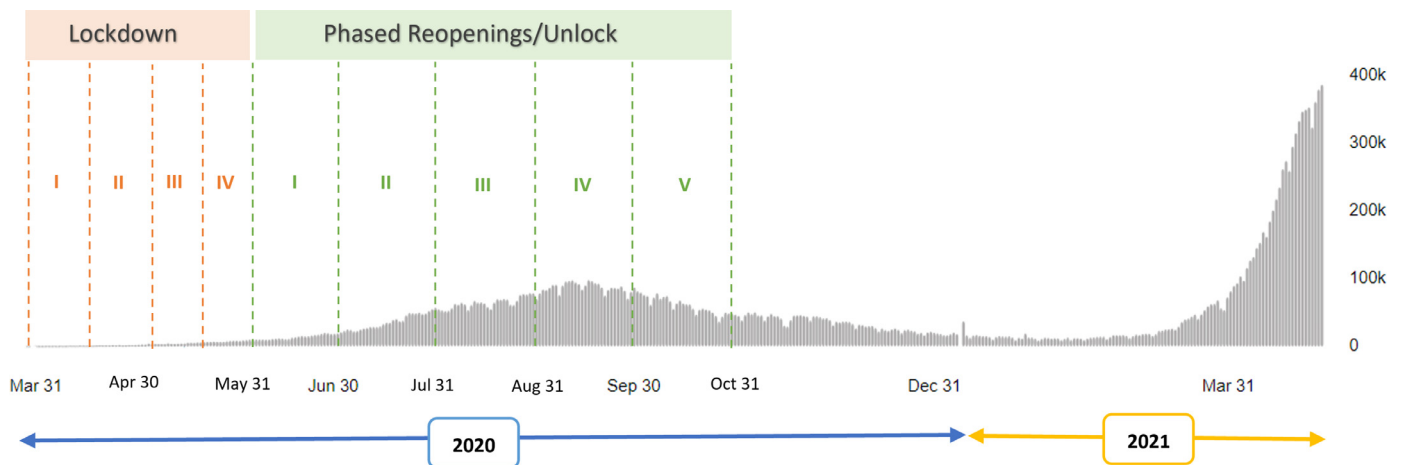
Figure 1. Daily new cases in India (March 2020-March 2021)

tories (Indian Council of Medical Research, 2021). Currently, India is undertaking testing of more than one million samples per day across the country. As of October 18, 2021, more than 590 million tests for COVID-19 were performed across the country using molecular methods and rapid antigen tests (RATs) (Indian Council of Medical Research, 2021; Ministry of Health and Family Welfare, 2021).

Evidence is still emerging on factors that may regulate the spread of this disease, such as the mode of transmission, the role of asymptomatic infections, rate of spread in populations, differences between urban or rural environments, and population density. Most of our understanding of COVID-19 disease transmission and dynamics is based largely on disease surveillance and epidemiologic studies carried out in different phases of the pandemic in China and the high-income countries of Europe and the United States of America (Guan et al., 2020; Richardson et al., 2020; Grasselli et al., 2020). Although there is evidence to suggest that early control measures such as lockdowns, self-isolation, surveillance testing, and contact tracing helped in curtailing the pandemic faster, this is largely based on mathematical disease models (Garba et al., 2020; Sarkar et al., 2020). However, to our knowledge, no studies using national-level testing data have been conducted to compare transmission dynamics of COVID-19 infection based on the regional severity of the pandemic and different phases of interventions (He et al., 2020). This analysis provides valuable lessons on national interventions that can inform policy decisions in the subsequent waves or other novel epidemics.

In March 2020, a centrally maintained portal was developed to enter test results for COVID-19 detection and diagnosis and demographic and some clinical details of individuals undergoing testing for COVID-19 across India. The COVID-19 testing data portal, developed and supported by the ICMR, has evolved and has incorporated changes based on the evolving testing strategies and availability of testing methods for COVID-19 diagnosis. Corresponding to the peak of the first wave (September 2020) in India, until October 31, 2020, 110.93 million COVID-19 test data entries were entered into the portal. This is currently the world's largest database of COVID-19 tests.

In this study, we aimed to describe the time-dependent progression of the number of cases diagnosed with COVID-19 in districts of India between March 2020 and October 2020 and to evaluate their association with different phases of the lockdowns, number, and type of diagnostic tests conducted per million population, and the proportion of positive results during the first wave of COVID-19 in India.

Methods

This was an ecological time-series study carried out using the ICMR Hundred Million Test database. The ICMR database is a centralized aggregated repository containing data about patient and sample details, type of testing, and test results of all individuals who have undergone COVID-19 testing in India.

Our study included all the COVID-19 tests conducted between March 1, 2020, and October 31, 2020. Earlier, in January 2020 and February 2020, three COVID-19 cases were detected in India, which were excluded in our study because of the unavailability of data in the ICMR database. Apart from summarizing the entire data descriptively at the national level (India), data were also analyzed at the district level, using district as the unit of analysis. Districts are the lowest common unit of administration in India, which includes health administration, and the district magistrate is the designated decision-making authority under the Epidemic Diseases Act of India (Government of India, 1897). We included data without limitations on age, gender, type of tests, or results. We excluded those studies lacking data entries for critical variables for our study, such as patient identification (ID), date, district name, and final result status.

Data were accessed on secure ICMR-based SQL servers by access-controlled remote tunneling. All analyses were conducted on the server itself using multiple packages of R Software on the installed server version of R and RStudio (version 1.2.5042). Data frames of the required variables were merged using the unique patient ID and a subset created on the main database. This data frame was checked for completeness and structure of the variables, and necessary standardizations were made where necessary. A separate data frame with matched names of the districts alongside their updated population structure was created, uploaded, and merged with the data frame on the server. The data frames were again divided into subsets based on the duration of the phases of "lockdowns" and "unlocking" declared by the central government and as adhered to by the districts, as given later (Table 1) (Venkata-Subramani and Roman, 2020; Ministry of Home Affairs, 2020a; Ministry of Home Affairs, 2020b; Ministry of Home Affairs, 2020c; Ministry of Home Affairs, 2020d; Ministry of Home Affairs, 2020e; Ministry of Home Affairs, 2020f).

The data frame was then aggregated to create a district-wise list of all the testing variables, such as the number and types of tests and the results. The testing statistics were converted into per million population by creating additional variables (for each type of test) such as tests per million, cases per million, the proportion of symptomatic persons among the tested, and test positivity rates.

Table 1
The phases of lockdowns and phased reopening ("Unlock" phases) in India (March-October)

Phase	Time period	Interventions	
Lockdown-I (LD-1)	March 25-April 14	Completed lockdown of nonessential services; All public transport suspended, including railways.	Face coverings/masks were made compulsory in public places, workplaces, and during transport. Food security measures and direct cash transfers to the poor. Demarcation of containment and buffer zones. Intensive contact tracing, house-to-house surveillance, and other clinical interventions based on zone.
Lockdown-II (LD-2)	April 15-May 3	Extended same measures + classified districts into red (hotspots), orange (some infection), and green (no infection) zones. Agriculture and dairy sector opened partially. Cargo sector opened. Retail shops opened at half strength.	
Lockdown-III (LD-3)	May 4-May 17	Extended same measures + Normal movement permitted in green zones, with buses limited to 50 percent capacity; in orange zones, private and hired vehicles but no public transportation; red zones under lockdown.	
Lockdown-IV (LD-4)	May 18-May 31	Extended same measures + Decentralization of the zoning of districts and demarcation of containment zones.	
Unlock-I (UL-1)	June 1-June 30	Lockdown restrictions only in containment zones, whereas activities were permitted in other zones in a phased manner. Reopening of shopping malls, religious places, hotels, and restaurants. Large gatherings still banned. No restrictions on interstate travel. Night curfew from 9 PM to 5 AM.	
Unlock-II (UL-2)	July 1-July 31	Same as above. + Limited international travel permitted; shops permitted to allow more than five persons at a time. Educational institutions, metros, recreational activities remained closed.	
Unlock-III (UL-3)	August 1-August 31	Same as above. Night curfews removed; gymnasiums and yoga centers reopen; Maharashtra and Tamil Nadu imposed a lockdown for the whole month, whereas West Bengal imposed lockdowns twice a week.	
Unlock-IV (UL-4)	September 1-September 30	Same as above + Metro Rail reopened in a graded manner; Marriage functions with gatherings of up to 50 people and funereal/last rites ceremonies with of up to 20 people permitted; Religious, entertainment, political, sports, academic functions, and gatherings of up to 100 people allowed.	
Unlock-V (UL-5)	October 1-October 31	Same as above + decentralized decision on reopening of educational interventions, cinema halls reopened at 50% capacity; Tourism sector reopened partially.	

LD = lock down; UL = unlock.

Table 2
The categories of patients tested for SARS CoV-2 in India

Category of the patient	Inclusion criteria
Influenza-like Illness (ILI)	All symptomatic (ILI symptoms) cases, including frontline workers, individuals with history of international travel in the last 14 days, returnees, and migrants within seven days of illness, in the community or those presenting to a healthcare setting.
Severe Acute Respiratory Illness (SARI)	All patients of Severe Acute Respiratory Infection (SARI), in hospital or neonates, presenting with acute respiratory/sepsis-like illness.
Symptomatic Healthcare workers (SYMP.HCW)	Symptomatic healthcare workers or those involved in containment and mitigation activities.
Asymptomatic Contacts (ASYMP. CONTACT)	Asymptomatic direct and high-risk contact of laboratory-confirmed cases such as healthcare workers in contact without adequate protection, direct and high-risk contacts in family and workplace, older individuals aged $\geq$ 65 years, immunocompromised, those with co-morbidities.
Symptomatic Contacts (SYMP. CONTACT)	Symptomatic contacts of a laboratory-confirmed case.

The categories of persons being tested were evolving throughout the study duration, and we have aggregated the categories into the major subsets as listed in Table 2.

The districts were classified into three categories based on the cumulative case rate per million using the percentile method:

- High caseload districts: top one-third of cases in each phase and the total study period.
- Moderate caseload districts: middle one-third of cases in each phase and the total study period.
- Low caseload districts: bottom one-third of cases in each phase and the total study period.

This was done for the entire dataset and the lockdown-specific subsets. Thereafter, similar but separate analyses were carried out on each of these datasets, as given later.

Descriptive statistics about the number and type of tests and their results were calculated for the whole dataset and subsets of each lockdown phase. Proportions were estimated to summarize the categorical variables. Bivariate analysis (with districts as the units) was done to assess the relationship between testing rates and positivity. Linear correlation was performed, and Pearson's correlation coefficients, along with significance levels, were estimated

for each set of analyses. Scatter plots were created for visual representation. We also created heat maps for the country with districts as units using Geographic Information System tools for visualization, QGIS software (ver.3.4.14), and the shapefiles matched to Government of India sources deployed for layering (Political map of India, 2021).

Approval from the ICMR Central Ethics Committee on Human Research (Ref. No. NCDIR/BEU/ICMR-CECHR/75/2020) was obtained for this study, and no patient identifiers were accessed during analysis or reporting.

Results

Of the 110.93 million entries made in the database between March 1, 2020, and October 31, 2020, 0.43 million samples were rejected for various reasons, including spillage, incomplete matching data, storage temperature, etc. Therefore, 110.50 million tests were included in the analysis. Among them, 54.79 million tests were performed using molecular methods such as real-time RT-PCR (rRT-PCR) and CBNAAT (GeneXpert System, Cepheid, California, USA). A total of 53.58 million were assayed using RATs, and 2.13 million test results were contributed by the TrueNat platform

Table 3

Testing profile in India during phases of lockdown and unlocking

Lockdown Phases (n=No. of districts included)	Tests conducted (in Millions)					Median Ct value (IQR)	Symptom profile (in millions)				No. of testing Labs (Cumulative)
	RT-PCR		RAT		Total (positive, % positivity)						
	Total	Positive (%)	Total	Positive			Symptomatic	% Positive	Asymptomatic	% Positive	
Before lockdown (433)	0.008	0.001 (12.5%)	0.000	0.000 (0%)	0.008 (0.001, 12.5%)	26(8)	0.003	12.3	0.005	11.5	104
I (708)	0.246	0.011 (4.5%)	0.000	0.000 (0%)	0.246 (0.011, 4.5%)	26.25(5)	0.078	8.3	0.168	9.8	236
II (716)	0.896	0.051 (5.7%)	0.000	0.000 (0%)	0.896 (0.051, 5.7%)	26(5)	0.176	11.5	0.72	7.9	426
III (720)	1.171	0.072 (6.1%)	0.000	0.000 (0%)	1.171 (0.072, 6.1%)	25(6)	0.167	16.2	1.004	6.7	530
IV (729)	1.524	0.118 (7.7%)	0.000	0.000 (0%)	1.524 (0.118, 7.7%)	24.5(5.4)	0.204	22.8	1.32	7.7	676
Unlock-I (729)	4.783	0.455 (9.5%)	0.178	0.015 (8.4%)	4.961 (0.470, 9.5%)	24(4)	0.748	26.8	4.213	8.6	1056
Unlock-II (729)	8.396	1.017 (12.1%)	2.276	0.180 (7.9%)	10.672 (1.197, 11.2%)	24(4)	1.510	24.7	9.162	11.2	1339
Unlock-III (729)	11.646	1.460 (12.5%)	12.524	0.744 (5.9%)	24.170 (2.204, 9.1%)	24.5(3.6)	1.917	22.4	22.253	10.1	1596
Unlock-IV (729)	12.424	1.722 (13.9%)	20.104	1.052 (5.2%)	32.528 (2.744, 8.5%)	24(4)	1.734	24.8	30.794	9.1	1853
Unlock-V (729)	13.699	1.231 (9.0%)	18.454	0.637 (3.5%)	32.153 (1.868, 5.81%)	25(5)	1.419	19.0	30.734	5.8	2036
Total	54.795	6.137 (11.2%)	53.588	2.633 (4.9%)	108.383 (8.77, 8.1%)	24(3)	7.956	22.6	100.427	8.5	2036

Ct = cycle threshold; IQR = interquartile range; RAT = rapid antigen test; RT-PCR = reverse transcription-polymerase chain reaction.

Table 4

Testing profile in districts of varying caseloads

Caseload categories	Tests conducted and positive results per million population				Symptomatic persons tested. (% of total tested)	Total districts
	RT-PCR		RAT			
	Total	Positive (%)	Total	Positive (%)		
Low	7.477	0.348 (4.7%)	15.030	0.225 (1.5%)	1.226 (14.1%)	244
Moderate	14.221	1.046 (7.4%)	14.611	0.516 (3.5%)	1.647 (10.4%)	244
High	33.097	4.743 (14.3%)	23.948	1.893 (7.9%)	5.084 (13.3%)	241
Total	54.795	6.137 (11.2%)	53.588	2.633 (4.9%)	7.956 (12.7%)	729

RAT = rapid antigen test; RT-PCR = reverse transcription-polymerase chain reaction.

(Molbio, Goa, India) for SARS-CoV-2, an indigenously developed portable chip-based rRT-PCR technology which has been deployed in many district level laboratories for COVID-19 diagnosis in India. A total of 8.98 million tests (8.12%) were reported positive, 0.6 million tests were inconclusive, and the rest negative. Among these, only 7.95 million (7.16%) tests were from symptomatic individuals, and the remaining were from asymptomatic individuals. The positivity rate among symptomatic individuals (22.6%) was significantly higher than asymptomatic individuals (8.6%). The time-series summary of the tests conducted and the results segregated by phases of lockdowns and unlocking are listed in Table 3.

Upon categorizing the districts based on their caseload (cases per million), we found that the tests conducted and positivity rate were significantly higher in high caseload districts than in moderate and low caseload districts (Figure S1). The types of tests also varied across districts. Whereas two-thirds of the tests in low burden districts were assayed using the RAT method, 58% of the tests in high caseload districts were assayed using molecular methods. Table 4 lists the details of testing according to the caseload categories.

Most of the districts shifted from one caseload category to another over the time series, except a few that retained their high

burden status across the phases. Fig. 2 shows the geographical classification of the overall positivity rates. Fig. 3 shows the distribution of districts based on caseload categories.

Although there was a very strong overall correlation between tests conducted per million population in the district and the number of cases detected (r = 0.97; P <0.001), the correlation was not consistent across the time series. The correlation was stronger among high burden districts during the initial phases of the lockdowns; however, with time, as the daily testing numbers increased, it became nonsignificant. This was analyzed separately according to the case burden of the district and shown in Fig. 4.

Among the entries assessed, 19.74 million tests were categorized into one of the patient types as listed in Table 2. Among them, severe acute respiratory infection (SARI) and influenza-like illness (ILI) constituted 5.75 million cases, symptomatic healthcare workers tested were 2.10 million, and contacts of known cases were 11.89 million. Although most of the categories of patients tested remain relatively constant across the time series, the proportion of symptomatic contacts being tested increased significantly around the peak as opposed to the proportion of asymptomatic contacts being tested during lockdowns. Fig. 5 provides the distribution across the time series.
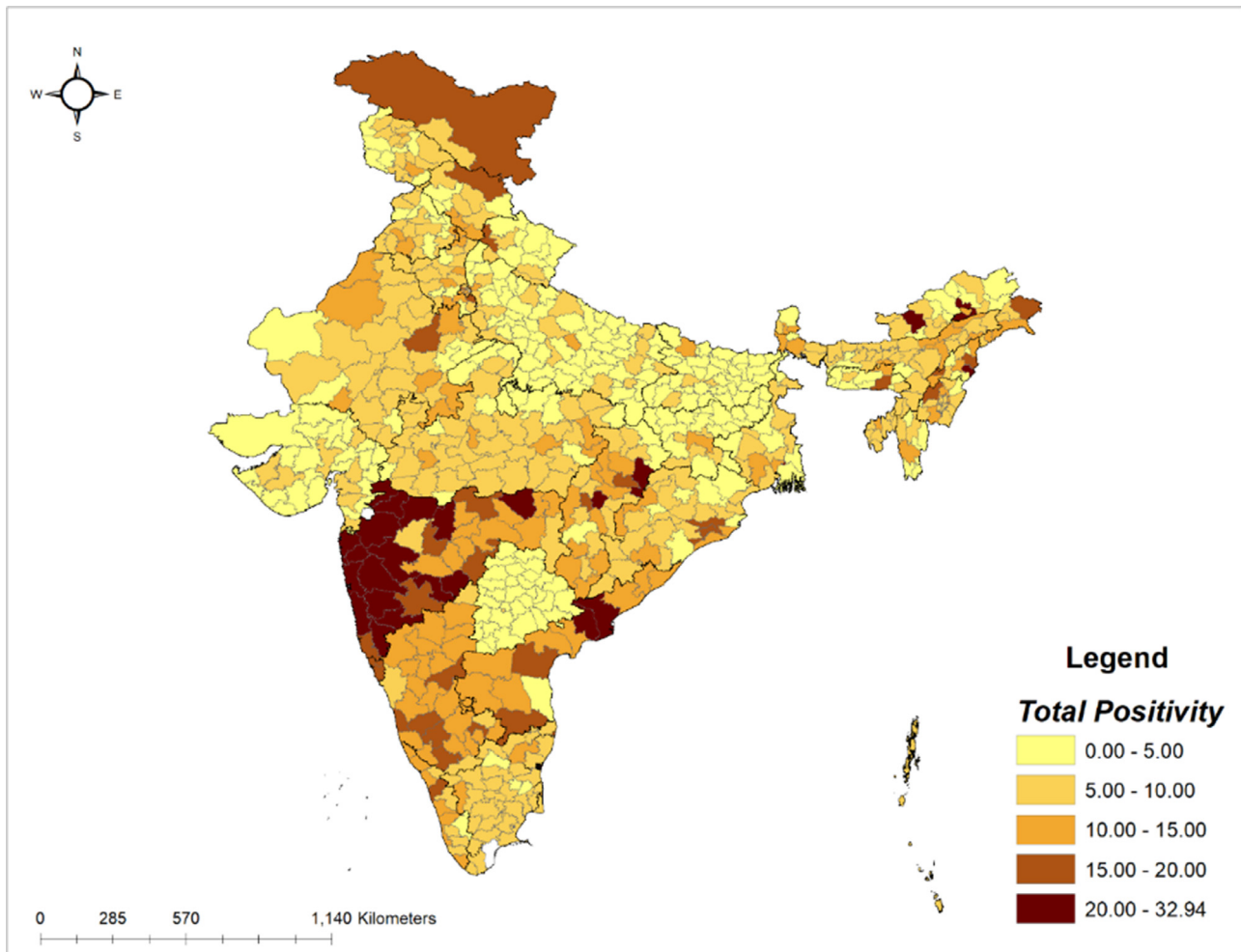
Figure 2. Positivity rates across the districts in India (March 2020-October 2020)

Discussion

This study aimed to evaluate the progression of the first wave of the COVID-19 pandemic in India during the phased lockdowns and reopenings, using laboratory parameters from more than 110 million tests performed using molecular and rapid antigen detection methods between March 2020 to October 2020. To date, India has performed the second-highest number of tests to detect COVID-19 worldwide (World Health Organization, 2022). The study used individual patient data collected using a centralized mechanism in India. The overall positivity for COVID-19 in India during the period was 9.42%. Currently, India has the second-highest number of COVID-19 cases globally after the United States (World Health Organization, 2022).

There was a variation in the positivity rate during the surveillance period, which varied from 12.5% before lockdown, increased to 13.1% in July 2020, and subsequently decreased after the peak of the first wave to 6.4% in October 2020. The proportion of symptomatic individuals tested for COVID-19 decreased from 40.2% before the lockdown to only 4.5% during October 2020. However, the proportion of COVID-19 positive cases among symptomatic cases increased during the surveillance period. In contrast, the proportion of positive cases among asymptomatic individuals tested decreased from 11.5% before lockdown to only 5.8% during October 2020. This decrease in the overall positivity rate coincided with an increase in the number of daily tests conducted in India.

Similar findings have been reported recently from a study on transmission dynamics of COVID-19 from two southern states, Tamil Nadu and Andhra Pradesh (Laxminarayan et al., 2020). The dynamic testing strategy also played a role in this, as during the initial phase of testing in India, only people with an international travel history were tested, which was then subsequently expanded in a step-wise manner to currently include universal voluntary testing (Indian Council of Medical Research, 2021). The role of rapidly increasing the testing capabilities to mitigate disease spread is highlighted in the findings. The study shows that during the initial lockdown, there was a need to increase testing across districts irrespective of caseloads. However, there is possibly a threshold beyond which increased testing rates do not seem to provide additional benefit in detecting positive cases. Therefore, the use of testing parameters in planning and mitigating measures for the spread of a pandemic is highlighted in the findings.

In this 8-month surveillance period, the positivity for COVID-19 by rRT-PCR was more than twice of that detected using RAT (6.1/54.8 vs 2.6/53.6 million tests, respectively). This is probably because of the lower sensitivity of RATs in detecting COVID-19 infections, which has been reported in several studies (sensitivity ranging from 30-50%), although a few studies have reported the sensitivity of these tests to be >80% (Lambert-Niclot et al., 2020; Scohy et al., 2020; Guptaet al., 2021; Chaimayo et al., 2020). The lower sensitivity of RATs could also have contributed to the apparent low burden settings in our surveillance (with lower positivity
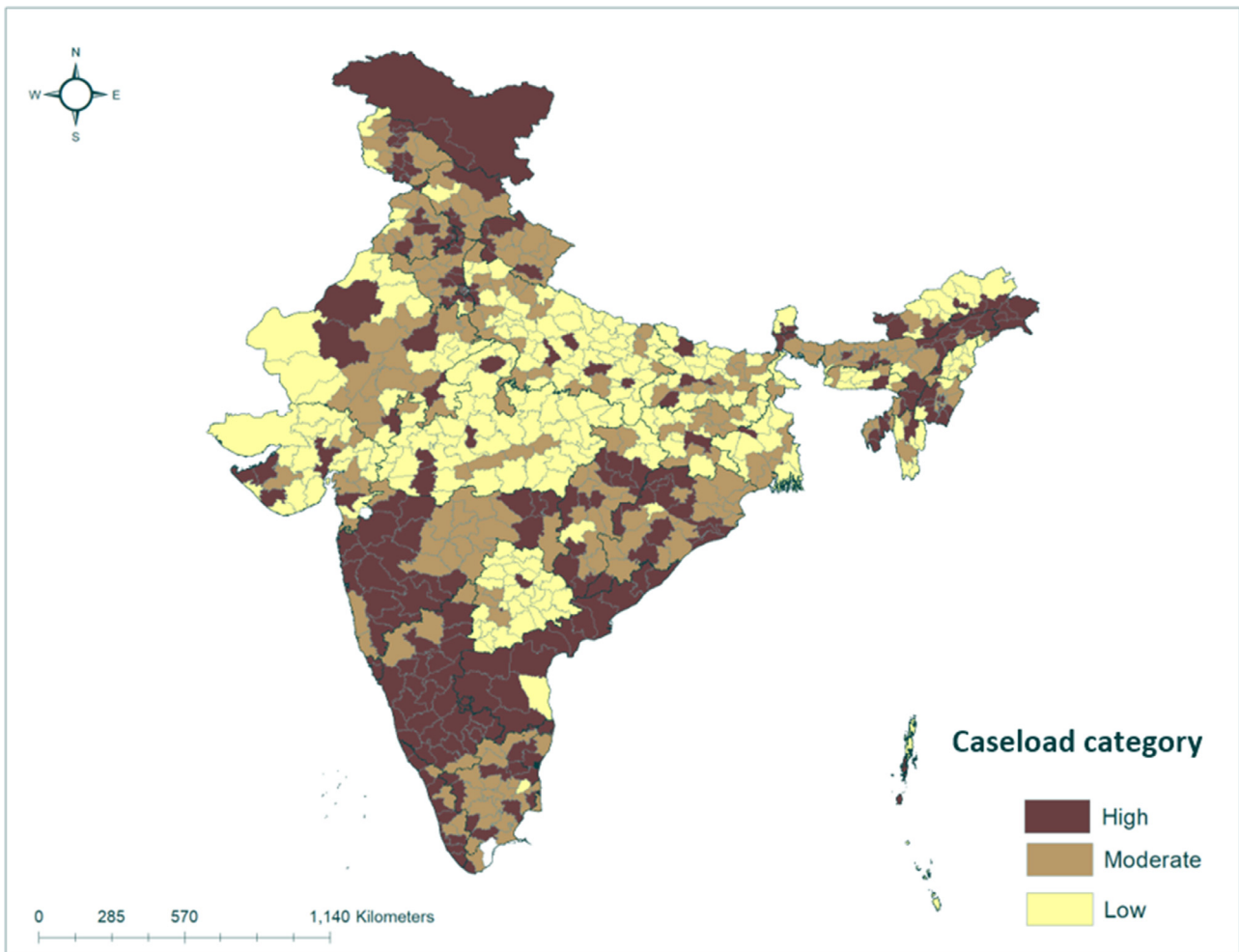
Figure 3. Caseload categories among the districts in India (March 2020-October 2020)

rates), where the proportion of RATs performed was approximately twice that of rRT-PCR.

Initially, there was a strong correlation between tests conducted and positive cases reported, implying the need for increased testing capacity to detect more positive cases which would otherwise be undetected and contribute to transmission. This finding was stronger in high caseload districts. However, this correlation was not significant once the testing capacity was rapidly increased across all categories of districts. This implies that positivity rates can be a reasonable marker for the need for additional testing in particular pockets and inflection points where the cases detected had stabilized despite increased testing and could be used to calibrate the surge in testing capacity. Moreover, ILI, SARI, and other cases in Fig. 5 imply that increasing transmission and subsequent testing conducted focused on the high number of symptomatic contacts, thereby possibly having increased positivity in Unlock Phase I.

To the best of our knowledge, this is the first study where laboratory parameters from an entire country as large as India have been used to evaluate the spread of COVID-19 infection; and to assess if such parameters could be used to understand the progression of the pandemic in a country. One of the limitations of this study is the technical variation in the rRT-PCR and rapid antigen kits used for testing across the country because of the use of kits from several manufacturers. Another limitation is that there was no indication that some of the datasets may have been counted twice. It is possible that a sample is tested first by RAT and then by RT-PCR. In that way, it is introducing the error of overestimation. However, most of these molecular and rapid antigen kits have been validated and found satisfactory by centers approved by the ICMR for validation purposes.

In conclusion, the use of laboratory parameters along with other demographic information could help in better planning during a pandemic, for implementation of better testing management, and containment measures for preventing the spread of the pandemic. The lessons learned from the first wave of the pandemic in India could provide critical input in policy decisions on national and sub-national interventions, including the utility of lockdowns, required to understand and implement appropriate policies for similar pandemics in the future.
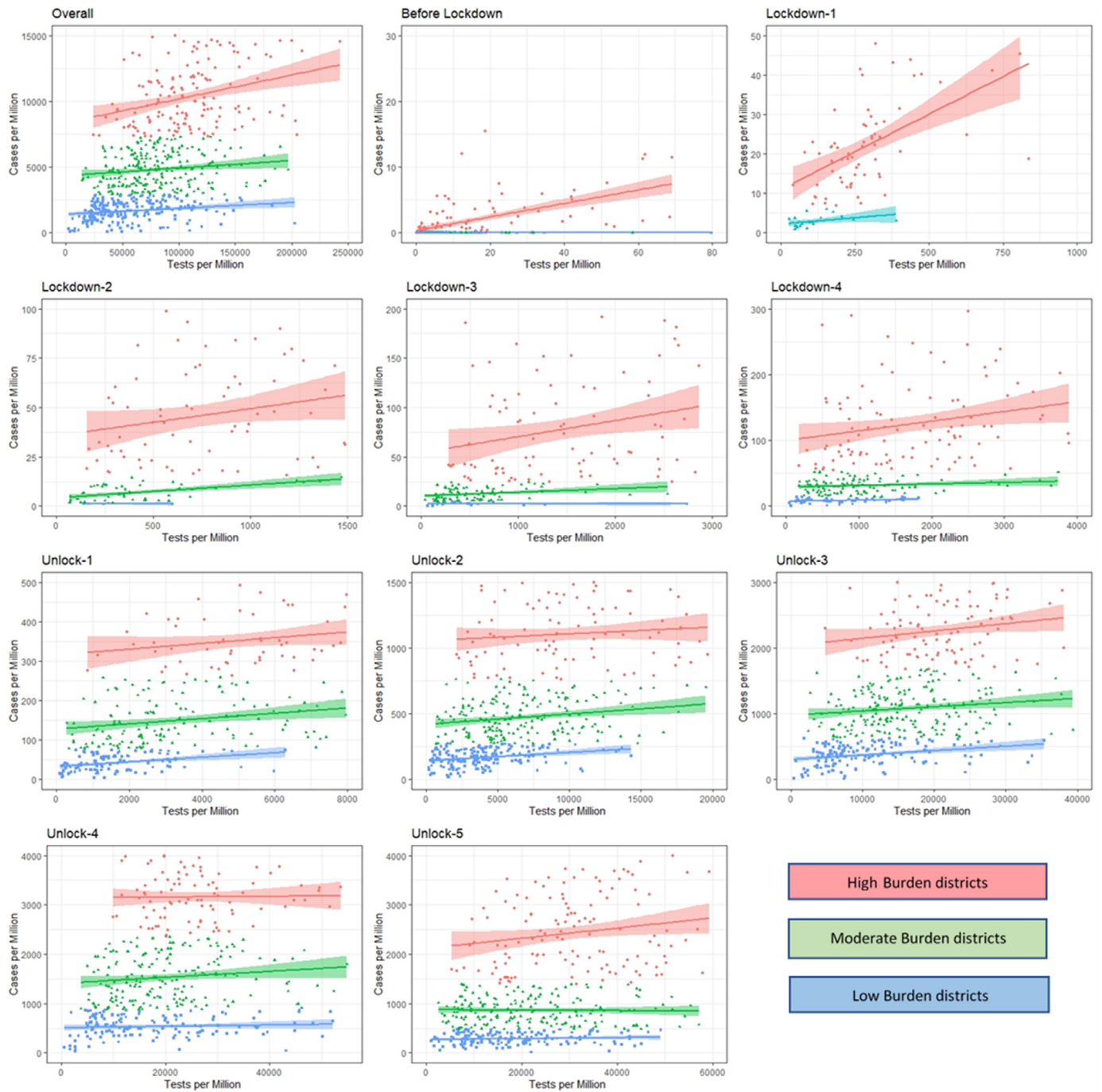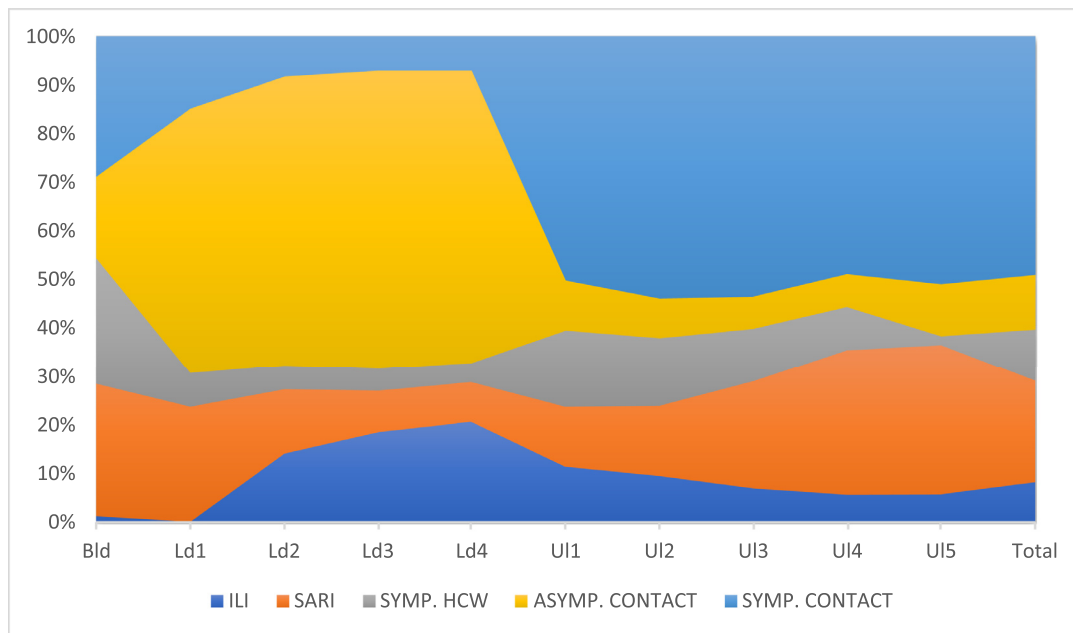
Funding

Ethics approval

Figure 4. Phase-wise correlation between tests per million and cases per million

Influenza Like Illness (ILI), Severe Acute Respiratory Illness (SARI), Symptomatic Healthcare workers (SYMP.HCW),
Asymptomatic contacts (ASYMP. CONTACT), Symptomatic Contacts (SYMP. CONTACT)

Figure 5. Patient categories being tested in phases of lockdown and unlock
ASYMP.CONTACT = asymptomatic contacts; ILI = influenza-like illness; SARI = severe acute respiratory illness; SYMP.CONTACT = symptomatic contacts;
SYMP.HCW = symptomatic healthcare workers.

Author contributions

SP, SP[2] and JSK conceptualized and designed the study. Data collection was executed by HS. TB, JG and MP did the analysis and wrote the initial draft of the manuscript which was reviewed by SG, DB, SKP, IP, SK and JT. All authors read and approved the final manuscript.

Conflicts of interest

The authors have no competing interests to declare.

Acknowledgments

We would like to thank all the staff and scientists of all the laboratories and health care staff involved in the testing throughout India.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijid.2022.06.027.

References

Chaimayo C, Kaewnaphan B, Tanlieng N, Athipanyasilp N, Sirijatuphat R, Chayakulkeeree M, et al. Rapid SARS-CoV-2 antigen detection assay in comparison with real-time RT-PCR assay for laboratory diagnosis of COVID-19 in Thailand. Virol J 2020;17:177.
Garba SM, Lubuma JM-S, Tsanou B. Modeling the transmission dynamics of the COVID-19 pandemic in South Africa. Math Biosci 2020;328.
Government of India. The Epidemic Diseases Act, 1897. India; 1897 https://www.indiacode.nic.in/bitstream/123456789/2326/1/A1897_03.pdf accessed 9 December 2021.
Grasselli G, Zangrillo A, Zanella A, Antonelli M, Cabrini L, Castelli A, et al. Baseline characteristics and outcomes of 1591 patients infected with SARS-CoV-2 admitted to ICUs of the Lombardy Region, Italy. JAMA 2020;323:1574–81.
Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, et al. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med 2020;382:1708–20.
Gupta A, Khurana S, Das R, Srigyan D, Singh A, Mittal A, et al. Rapid chromatographic immunoassay-based evaluation of COVID-19: a cross-sectional, diagnostic test accuracy study & its implications for COVID-19 management in India. Indian J Med Res 2021;153:126–31.
Gupta N, Potdar V, Praharaj I, Giri S, Sapkal G, Yadav P, et al. Laboratory preparedness for SARS-CoV-2 testing in India: harnessing a network of virus research & diagnostic laboratories. Indian J Med Res 2020;151:216–25.
He X, Lau EHY, Wu P, Deng X, Wang J, Hao X, et al. Temporal dynamics in viral shedding and transmissibility of COVID-19. Nat Med 2020;26:672–5.
Indian Council of Medical Research. https://www.icmr.gov.in/, 2021 (accessed 10 November 2021).
Indian Council of Medical Research. Information of testing strategy; 2021 https://www.icmr.gov.in/cteststrat.html accessed 14 December 2021.
Lambert-Niclot S, Cuffel A, Le Pape S, Vauloup-Fellous C, Morand-Joubert L, Roque-Afonso AM, et al. Evaluation of a rapid diagnostic assay for detection of SARS-CoV-2 antigen in nasopharyngeal swabs. J Clin Microbiol 2020;58 e00977-20.
Laxminarayan R, Wahl B, Dudala SR, Gopal K, Mohan C, Neelima S, et al. Epidemiology and transmission dynamics of COVID-19 in two Indian states. Science 2020;370:691–7.
Ministry of Health Affairs, Government of India. Guidelines for Phase-1 lockdown (Order number 40-3/2020-D) Dated-24/03/2020. p. 1–14, https://www.mha.gov.in/sites/default/files/PR_Consolidated%20Guideline%20of%20MHA_28032020%20%281%29_1_0.PDF, 2020 (accessed 9 December 2021).
Ministry of Health Affairs, Government of India. MHA order dated 15.04.2020, with revised consolidated guidelines. p. 1–15, https://www.mha.gov.in/sites/default/files/MHA%20order%20dt%2015.04.2020%2C%20with%20Revised%20Consolidated%20Guidelines_compressed%20%283%29.pdf, 2020 (accessed 9 December 2021).
Ministry of Health Affairs, Government of India. No. 40-3/2020-DM-I(A) dated 1st May, 2020; 2020 https://www.mha.gov.in/sites/default/files/MHA%20Order%20Dt.%201.5.2020%20to%20extend%20Lockdown%20period%20for%202%20weeks%20w.e.f.%204.5.2020%20with%20new%20guidelines.pdf accessed 9 December 2021.
Ministry of Health Affairs, Government of India. No. 40-3/2020-DM-I(A), 17th May, 2020; 2020 https://www.mha.gov.in/sites/default/files/MHAOrderextension_1752020_0.pdf accessed 9 December 2021.
Ministry of Health Affairs, Government of India. No. 40-3/2020-DM-I(A), 29th August 2020; 2020 https://www.mha.gov.in/sites/default/files/MHAOrder_Unlock4_29082020.pdf accessed 9 December 2021.
Ministry of Health Affairs, Government of India. Order No. 40-3/2020-DM-I(A), 30th Sept, 2020; 2020 https://www.mha.gov.in/sites/default/files/MHAOrderDt_30092020.pdf accessed 9 December 2021.
Political map of India. https://surveyofindia.gov.in/documents/polmap-eng-11012021.jpg, 2021 (accessed 11 December 2021).
Richardson S, Hirsch JS, Narasimhan M, Crawford JM, McGinn T, Davidson KW, et al.

Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City area. JAMA 2020;323:2052–9.

Sarkar K, Khajanchi S, Nieto JJ. Modeling and forecasting the COVID-19 pandemic in India. Chaos Solitons Fractals 2020;139.

Scohy A, Anantharajah A, Bodéus M, Kabamba-mukadi B, Verroken A, Rodriguez-villalobos H. Low performance of rapid antigen detection test as frontline testing for COVID-19 diagnosis. J Clin Virol 2020;129.

Venkata-Subramani M, Roman J. The coronavirus response in India – World's largest lockdown. Am J Med Sci 2020;360:742–8.

World Health Organisation. Coronavirus disease (COVID-19). https://covid19.who.int/, XXX (accessed 25 April 2022).

World Health Organisation. Coronavirus disease (COVID-19). https://covid19.who.int/region/searo/country/in, XXX (accessed 25 April 2022).