BMC Health Services Research

RESEARCH Open Access

Geographical access to COVID-19 testing centers in India

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Abstract

Background Geographic accessibility to testing constitutes an important part of pandemic preparedness. However, there is no data on access to COVID-19 testing centers in India. Our study looks at the current geographical accessibility to these testing centers across 36 states and union territories (UTs) and 735 districts.

Methods We acquired the testing center geocodes from the Indian Council of Medical Research. We took motorized and walking travel-time friction surface rasters from the Malaria Atlas Project 2019 and high-resolution population estimates from WorldPop 2020. Using these, we examined the density of centers per million population and the travel time to the nearest center. We assessed the Access Population Coverage (APC), defined as the proportion of the population within 30 minutes by walking and 60 minutes by motorized transport from the nearest COVID-19 testing center.

Results India has a density of 1·62 testing centers per million. The national median travel time (IQR) to the nearest COVID-19 testing center was 400·28 minutes by walking and 50·42 minutes by motorized transport. 11·08% of the population were within 30 minutes of a testing center by walking (range across districts: 0–100%). 85·88% of the population were within 60 minutes of the nearest testing center (range across districts: 0–71·86%). The APC was 81·51% within 60 minutes by motorized transport in rural vs. 97·87% in urban areas.

Conclusions There are wide disparities across states/UTs and between rural and urban areas in accessibility to testing centers. Policymakers should note these disparities when setting up new testing centers.

Trial registration Not applicable.

Keywords Pandemic preparedness, Geospatial access time, Geolocations, Accessibility, Testing

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Introduction

In March 2020, the World Health Organization (WHO) declared COVID-19 a pandemic [1]. In the last four years, COVID-19 has led to massive mortality and morbidity tolls globally, stunting or reversing the gains in population-level life expectancy in some cases [2]. The pandemic revealed a lack of systemic preparedness across countries [3]. Without evidence-based interventions such as vaccines and pharmacotherapeutics, the frontline response included screening and quarantining. For several countries, including India, this culminated in lockdowns and other mass-level movement restrictions [4]. This was partly done to provide the healthcare system an opportunity to build capacity to respond.

The central government in India imposed a nationwide lockdown on March 25, 2020, stretching to nearly 70 days [5]. Early on in the pandemic, testing was crucial alongside other public health interventions. It was observed that countries that had higher testing rates were able to effectively control the pandemic. Developed countries were seen to have higher testing rates as compared to developing countries [6]. India used Rapid Antigen (RA) and Reverse-Transcriptase Polymerase-Chain-Reaction (RT-PCR) tests. RT-PCR has higher sensitivity and specificity than the RA test, but it is also more expensive. At the peak of the first COVID-19 wave, India was testing 1–1·5 million people daily. However, this formed only around 0·1% of the total population. About 49% of these tests were RA tests [7]. As of June 1, 2020, India had completed approximately 3·8 million tests since it began testing in February. However, this was considered insufficient for population needs. As of May 30, 2020, India had tested only 0·08 COVID-19 tests per thousand people, compared to 1·16 in the USA and 1·02 in Italy [8].

To match the increasing case burden, public and private testing were rapidly scaled up [8, 9]. In 2021, there were 2,520 COVID-19 testing labs, which had a total of 7,000 RT- PCR machines in the country. During this time, 1·8 to 2 million samples per day were tested, except for Sundays when the number of samples tested decreased to 0·1–0·2 million [10]. The increasing COVID-19 cases in India demanded the need for rapid testing diagnostics. Consequently, Truenat PoC assays were developed, which shortened the result reporting time [11]. Eventually, home-based testing solutions were also explored to meet the increasing testing requirements. These were not available during the first and second waves [12].

Access to testing is an important indicator of health system capacity in the context of future pandemic preparedness [13, 14]. Availability is the extent to which facilities are present to meet patient needs. Geographical accessibility refers to the proximity of a facility within a specified time frame, indicating how easily patients can reach it. Measuring global access to healthcare is difficult because there is no comprehensive database of healthcare facilities. It has been found that a lack of motorized transportation and poor transportation infrastructure leads to increased travel times to healthcare facilities in rural areas. Populations in such areas are less likely to seek care when needed, which increases mortality and morbidity [15–19].

In this study, we aimed to assess multiple measures of geographic accessibility to COVID-19 testing centers in India, including density per million people, travel time to the nearest testing center, and the Access Population Coverage (APC). APC refers to the percentage of the population within their nearest testing center within a given time frame using a particular mode of transport. We provide accessibility estimates by walking and motorized transport for 735 districts in 36 Indian states and union territories (UTs). We also compared differences in estimates of geographical accessibility between rural and urban areas.

Methods

Data sources

We compiled the geolocations of the COVID-19 testing centers in India, extracted from the Indian Council of Medical Research (ICMR) Dashboard on 4th January 2021. High-resolution (1 km^2) United Nations (UN) adjusted population counts were obtained from the WorldPop dataset for 2020 [20]. The motorized and walking friction rasters for each square kilometer (1 km^2) were obtained using Malaria Atlas Project data for 2019 [21]. Geospatial raster data for rural and urban settlements were taken from the Urban-Rural Catchment Areas (URCA) dataset [22].

Outcomes

We investigated the testing center availability and accessibility at the national and subnational levels by using three main outcomes. We determined the center density, that is, the number of centers in a given region per 1,000,000 people residing in that region. The second outcome was the median travel time to the nearest testing center by walking and motorized transport. The third outcome was Access Population Coverage (APC), defined as the percentage of the population in a given region who are within 30 minutes of walking or 60 minutes of motorized travel time from their nearest testing centers. These outcomes were calculated for India, 36 states and union territories (UTs), and 735 districts. Additionally, these outcomes were assessed at the national and subnational levels for rural and urban areas as well.

Analysis

The data was geocoded using machine-learning techniques. We utilized 2020 motorized and walking travel-time friction surface rasters from the Malaria Atlas Project and sourced 1-square-kilometer resolution population estimates for India from WorldPop. Our analysis focused on assessing the accessibility of COVID centers across 36 states and UTs. We introduced the concept of Access Population Coverage, representing the proportion of the population residing within specified time thresholds (30 and 60 minutes) from the nearest COVID center, considering both walking and motorized travel modes.

To compute travel times, we implemented the Dijkstra algorithm, which calculated the minimum travel time required to traverse the friction surface from each grid cell to the geo-coordinates of every COVID center. We categorized access times into thresholds of 0–30 minutes for walking and 30–60 minutes for motorized vehicles.

We then created binary accessibility rasters, marking pixels that met the timeliness criteria with '1' and others with '0'. These rasters were overlaid on the population raster to estimate the population with timely access. The population figures at each pixel were multiplied by the accessibility weights (1s and 0s) to determine the number of people with access within each time threshold. The proportion of the population with timely access was calculated by dividing these numbers by the total population.

The workflow has been described in Fig. 1. The details for the same were discussed elsewhere for investigating access to surgical facilities in India [23, 24].

To understand how accessibility metrics matter for outcomes of population health interest, we investigated the association between APC values and COVID-19 confirmation rates (calculated as confirmed cases divided by total population times 100) at the state and district levels. We chose case confirmation rates since they are the relevant epidemiological surveillance parameter in an evolving pandemic for access to testing. Additionally, we had reliable data on this measure at the state and district levels, which was not available for several other potential epidemiological parameters. We obtained the state and district COVID-19 confirmation rates from a previously published study on early demographic and epidemiology characteristics during the COVID-19 pandemic in 2020 [25]. We matched these data for state and district names. We evaluated the ecological relationship between the APC values for COVID-19 testing centers within 30 minutes by walking and 60 minutes by motorized transport, and the COVID-19 confirmation rate, using Spearman

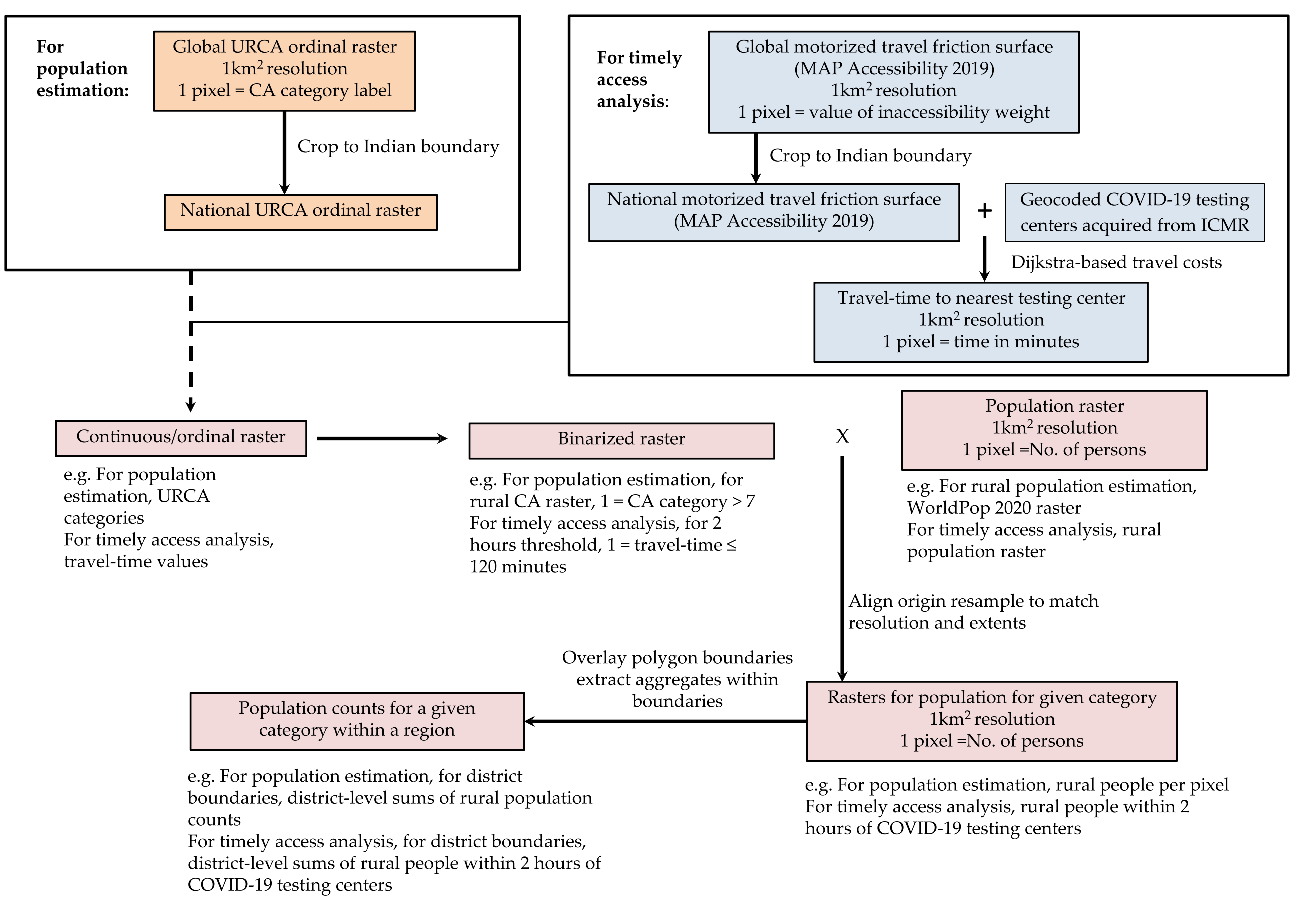

Fig. 1 Raster-based estimation pipeline used for creating criteria-specific regional population counts

Rank correlations (represented by 'R'). We used an alpha threshold of 5% to determine the statistical significance of the correlation.

Results

Availability of COVID-19 testing centers

As of January 2021, India had a total of 2236 testing centers (Fig. 2a). Of these, 1879 were located in urban areas while 357 were in rural areas. Considering a total population of 1·38 billion, 1·62 centers were available per million people in the country. The relative availability was starkly greater in urban areas (5·06 centers per million people) as compared to rural areas (0·35 centers per million people). Tamil Nadu has the highest difference (175) in the availability of COVID-19 testing centers between urban (203) and rural areas (28) (Supplementary Fig. 1a).

Among states/UTs of India, the highest density of testing centers per million population was observed for Lakshadweep (50·69). Bihar has the lowest density of testing centers at 0·49. The data for UTs of Jammu, Kashmir, and Ladakh were unavailable (Fig. 2b). Arunachal Pradesh had the highest density of urban testing centers per million population at 100·12. Lakshadweep had a density of 0 in urban areas (Fig. 2c). The density of COVID-19

Fig. 2 Availability of COVID-19 testing centers in India. **a**. Geographic location of COVID-19 testing centers in India. COVID-19 testing centers density per million population for **b**. States and union territories **c**. Urban areas in states and union territories, and **d**. Rural areas in states and union territories. The states/UTs of Jammu and Kashmir and Ladakh are not mentioned as data for COVID-19 testing centers were not available

testing centers in rural areas was highest in Lakshadweep at 58·73 (Fig. 2d). The density of COVID-19 testing centers in rural areas was 0 in Sikkim, Chandigarh, Delhi, and Dadra & Nagar Haveli.

Shi Yomi district in Arunachal Pradesh had the highest number of total centers per million population at 81·42. (Supplementary Fig. 1b). 99 districts had a density of 0 testing centers per million.

Median access time to reach the nearest COVID-19 testing center

We calculated the median access time required to reach the nearest COVID-19 testing center by walking and motorized transport.

Walking

The national median (interquartile range) access time to reach the nearest COVID-19 testing center by walking was 400·28 (244·52, 617·17) minutes. In urban areas, the median (IQR) time to reach the nearest testing center by walking was 153·54 (44·67, 327·69) minutes. In rural areas, the national median (IQR) time to reach the nearest testing center was 405·47 (251·21, 620·34) minutes by walking (Fig. 3a, Supplementary Fig. 2a).

Compared to the national median access time, 18 states/UTs had a shorter travel time to reach the nearest testing center by walking. For three states/UTs Lakshadweep, Chandigarh, and Delhi the median (IQR) travel time to reach a testing center by walking was less than 60 minutes, that is 8·57 (4·28, 10·95) minutes, 24·23 (14·65, 36·82) minutes, and 40·65 (22·17, 88·74)

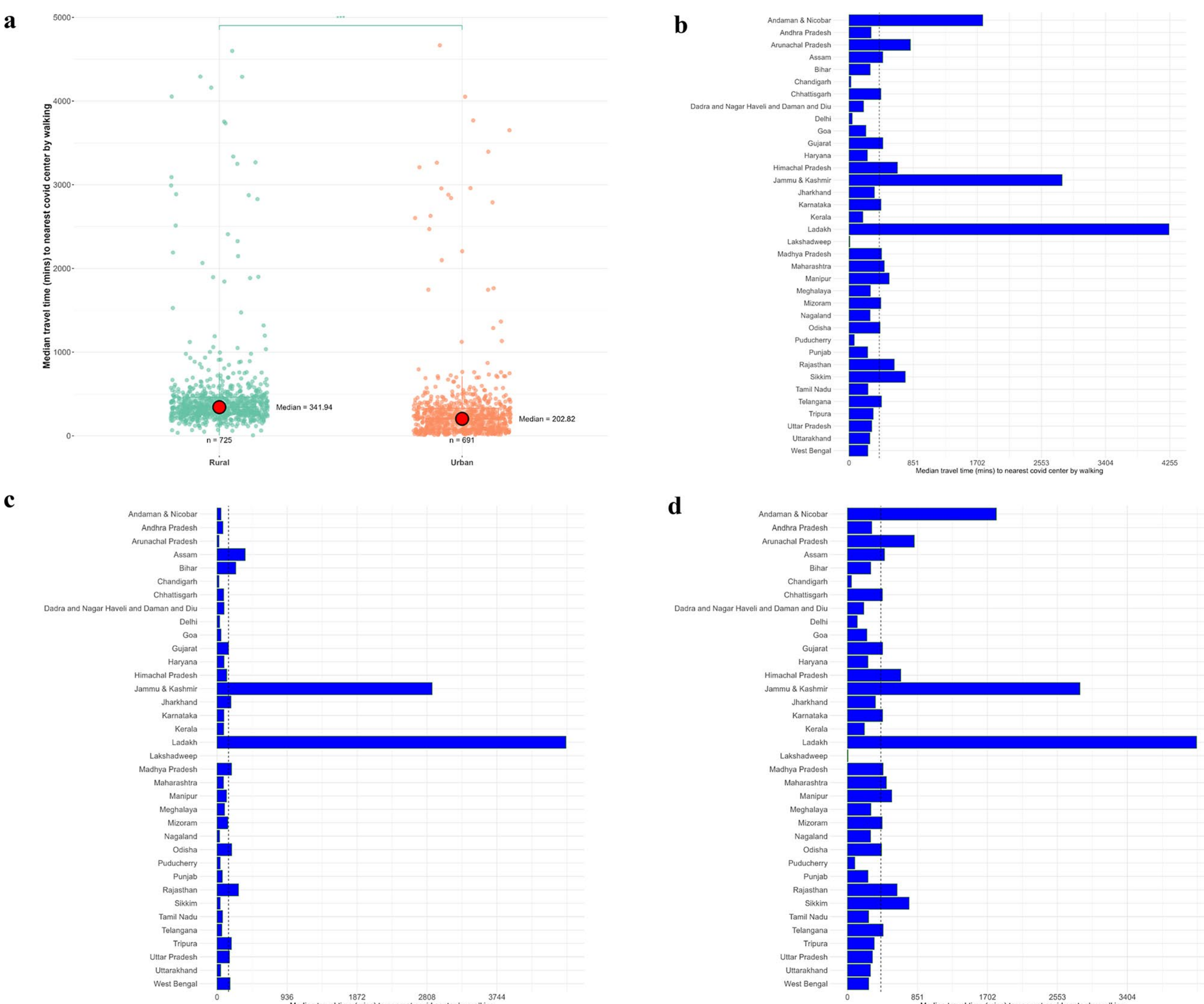

Fig. 3 Median access time to reach the nearest COVID-19 testing center by walking. **a**. Box plots of median travel time to reach the nearest COVID-19 testing center by walking in rural vs urban areas. Median travel time (in minutes) to the nearest COVID-19 testing center by walking for **b**. States and union territories, **c**. Urban areas in states and union territories and **d**. Rural areas in states and union territories. The black dotted lines in the figures represent the national median travel time

minutes respectively. The UT of Ladakh had the longest median (IQR) travel time by walking of 4244·18 (1101·17, 3573·49) minutes (Fig. 3b).

Urban populations of nine states/UTs were found to have less than 60 minutes of travel time to reach the nearest testing center by walking. The urban population in Chandigarh had the lowest median (IQR) time to reach the nearest testing center by walking at 24·23 (14·65, 33·81) minutes. The urban population of Ladakh had the highest walking time of 4666·18 (4661·46, 4673·06) minutes to reach the nearest testing center (Fig. 3c). In rural areas, the median (IQR) time to reach the nearest testing center by walking varied from 5·47 (2·74, 8·21) in Lakshadweep to 4243·91 (3573·59, 4943·43) minutes in Ladakh (Fig. 3d).

At the district level, 484 (65·85%) districts had a shorter travel time by walking to the nearest testing center compared to the national average (400·28 minutes). The median travel time to access the nearest testing center by walking for 12 districts was found to be less than 30 minutes. Lakshadweep (Lakshadweep) had the shortest median (IQR) travel time of 8·57 (4·28, 10.95) minutes by walking to reach the nearest testing center. Muzaffarabad (Jammu and Kashmir) had the longest median (IQR) travel time of 4599·11 (4400·69, 4659·64) minutes (Supplementary Fig. 2b).

In urban areas, Kullu in Himachal Pradesh had the shortest median (IQR) time by walking at 4·74 (2·37, 7·11) minutes. Urban areas of Kargil in Ladakh had the longest median travel time by walking at 2329·94 (1164·97, 3494·91) minutes (Supplementary Fig. 2c). In rural areas, Lakshadweep had the shortest median time by walking at 5·47 (2·74, 8·21) minutes. Rural areas in Muzaffarabad of Jammu and Kashmir had the longest walking time at 4599·11 (4400·69, 4659·64) minutes (Supplementary Fig. 2d).

Motorized transport

The national median (interquartile range) time to reach the nearest COVID-19 testing center by motorized transport was 50·42 (30·06, 83·65) minutes. In urban areas, the national median (IQR) time to reach the nearest testing center was 15·17 (4·24, 33·16) minutes, whereas in rural areas it was 405·47 (251·21, 620·34) minutes by motorized transport (Fig. 4a, Supplementary Fig. 3a).

As compared to the national median time, 18 (50%) states/UTs had a shorter travel time to access the nearest testing center by motorized travel. The median travel time in the UT of Lakshadweep was found to be the shortest at 0·92 (0·46, 1·24) minutes. Ladakh had the longest median travel time at 697·85 (517·72, 990·61) minutes. The median travel times were under 30 minutes in 10 states/UTs. The median travel time was under 60 minutes in 25 states/UTs (Fig. 4b).

Among states/UTs the shortest median (IQR) travel time to reach the nearest testing center in urban areas was noted in Chandigarh at 2·80 (1·83, 3·63) minutes, and the longest in Ladakh at 411·94 (411·69, 419·23) minutes (Fig. 4c). In rural areas, the median travel time by motorized transport ranged from 0·80 (0·4, 1·2) minutes in Lakshadweep to 4243·91 (3573·59, 4943·43) minutes in Ladakh (Fig. 4d).

Among districts, Lakshadweep (Lakshadweep) had the shortest travel time at 0·92 (0·46, 1·24) minutes. Anjaw, Arunachal Pradesh had the longest travel time of 1288·25 (863·4, 1766·56) minutes. 463 (62·99%) districts had a shorter median travel time compared to the national value (Supplementary Fig. 3b).

In urban areas, the median travel times to the nearest testing center ranged from 0·27 (0·14, 0·41) minutes in Raigarh, Maharashtra, to 205·75 (102·88, 308·63) minutes in Kargil, Ladakh (Supplementary Fig. 3c). In rural areas, the shortest median (IQR) time required to access the nearest testing center was 0·49 (0·24, 0·73) minutes for Chennai (Tamil Nadu) and the longest at 1285·52 (857·70, 1763·58) minutes for Anjaw, Arunachal Pradesh (Supplementary Fig. 3d). Urban areas in 712 (96·87%) districts and rural areas in 548 (74·56%) districts were within 60 minutes of a COVID-19 testing center by motorized transport.

Access population coverage (APC)

Percentage of the population within 30 minutes by walking

Nationally, 11·08% of the people were within 30 minutes of walking to their nearest COVID-19 testing center. 38·29% of the population in urban areas were within 30 minutes by walking to their nearest COVID-19 testing centre. In contrast, the APC was 1·03% for rural areas. At the state/UT level, Chandigarh had the highest APC of 74·15%, and Ladakh and Jammu and Kashmir had the lowest at 0%. Only nine states/UTs had values greater than 15% (Fig. 5a). At the district level, Shahdara had the highest APC of 87·33%. In 87 districts (11·8%) the APC was 0% (Fig. 5b).

At the state/UT level, for urban areas, Chandigarh had the highest APC of 75·06%. Urban areas in Ladakh and Jammu and Kashmir had an APC of 0%. The APC of urban areas in Lakshadweep was not computable (Fig. 5c). For rural areas, Lakshadweep had the highest population coverage of 15·98%. Rural areas of three states/UTs: Ladakh, Jammu and Kashmir, and Chandigarh had an APC of 0% (Fig. 5d).

At the district level, in urban areas, the APC within 30 minutes of walking to the nearest COVID-19 testing center was 100% for four districts. These are Debagarh in Orissa, Namsai in Arunachal Pradesh, Kolasib in Mizoram, and Lower Subansiri in Arunachal Pradesh. The APC was 0% in urban areas of 102 (13·8%) districts.

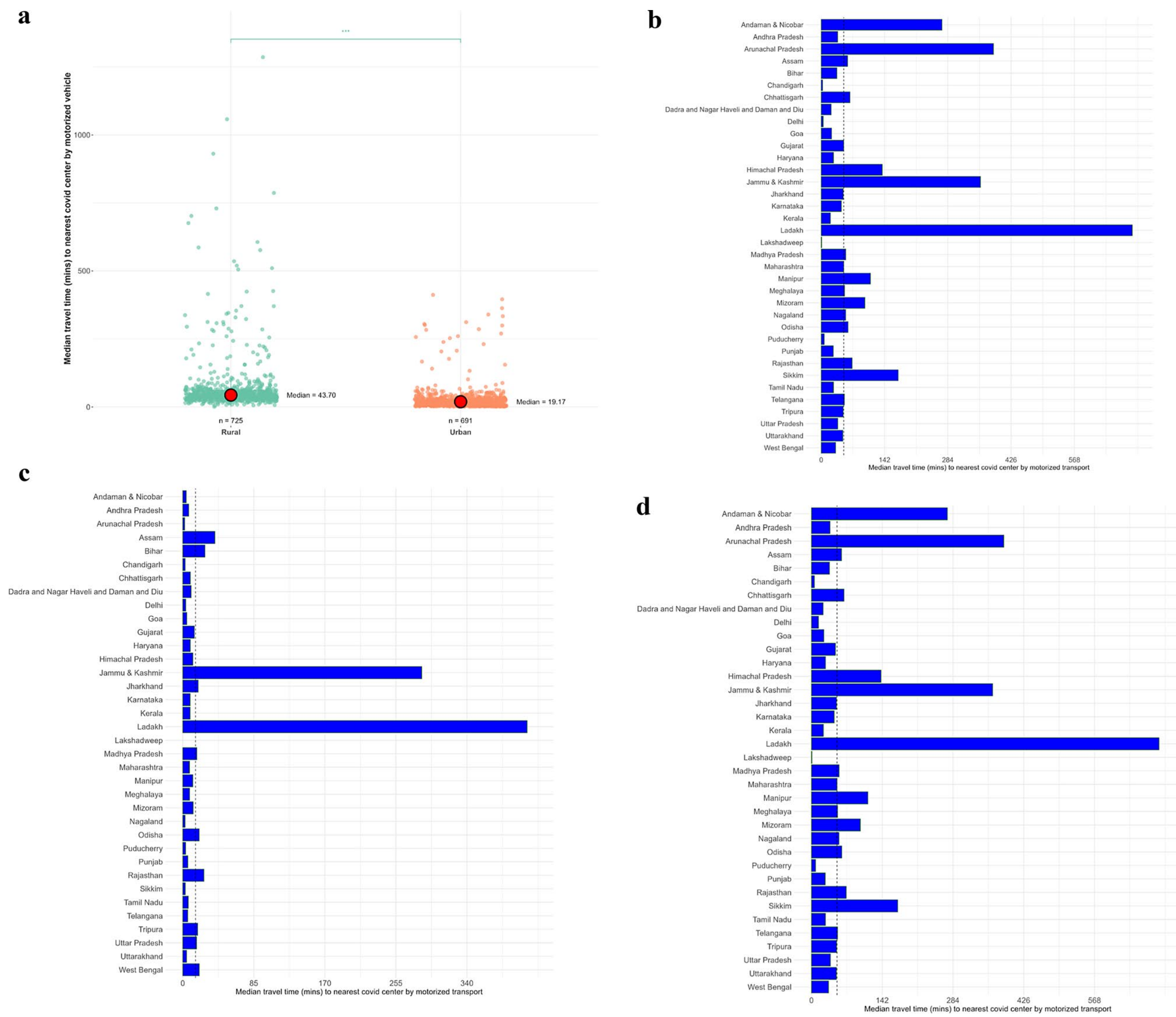

Fig. 4 Median access time to reach the nearest COVID-19 testing center by motorized transport. **a**. Box plots of median travel time to reach the nearest COVID-19 testing center by motorized transport in rural vs urban areas. Median travel time (in minutes) to the nearest COVID-19 testing center by motorized transport for **b**. States and union territories, **c**. Urban areas in states and union territories and **d**. Rural areas in states and union territories. The black dotted lines in the figures represent the national median travel time

The urban APC was not computable for 44 districts (Fig. 5e). Rural areas in Lepa Rada, in Arunachal Pradesh, had the highest APC of 33·43%. Rural areas in 128 districts (17·4%) had an APC of 0%. The rural APC of seven districts was not computable (Fig. 5f).

Percentage of the population within 60 minutes by motorized transport

Nationally, 85·88% of the people were within 60 minutes by motorized transport to their nearest COVID-19 testing center. 97·87% of the population in urban areas were within 60 minutes of their nearest COVID-19 testing center. In contrast, the APC was 81·51% for rural areas. At the state/UT level, Chandigarh and Delhi had the highest APC of 100% and Ladakh had the lowest at 0%. 15 states/UTs had values greater than 90% (Fig. 6a). At the district level, 28 (3·8%) districts had an APC of 100%. In another 28 districts (3·8%), the APC was 0% (Fig. 6b).

At the state/UT level, for urban areas, 11 states had an APC of 100%. These are Punjab, Tamil Nadu, Uttarakhand, Manipur, Nagaland, Mizoram, Arunachal Pradesh, Sikkim, Delhi, Andhra Pradesh, and Haryana. Urban areas in Ladakh and Jammu and Kashmir had an APC of 0%. The APC of urban areas in Lakshadweep was not computable (Fig. 6c). Rural areas of Chandigarh had the highest population coverage of 100%. Rural areas of Ladakh had the lowest APC of 0% (Fig. 6d).

At the district level, for urban areas, the APC was 100% for 401 districts. The APC was 0% in the urban areas of 28 districts. The urban APC was not computable for 44

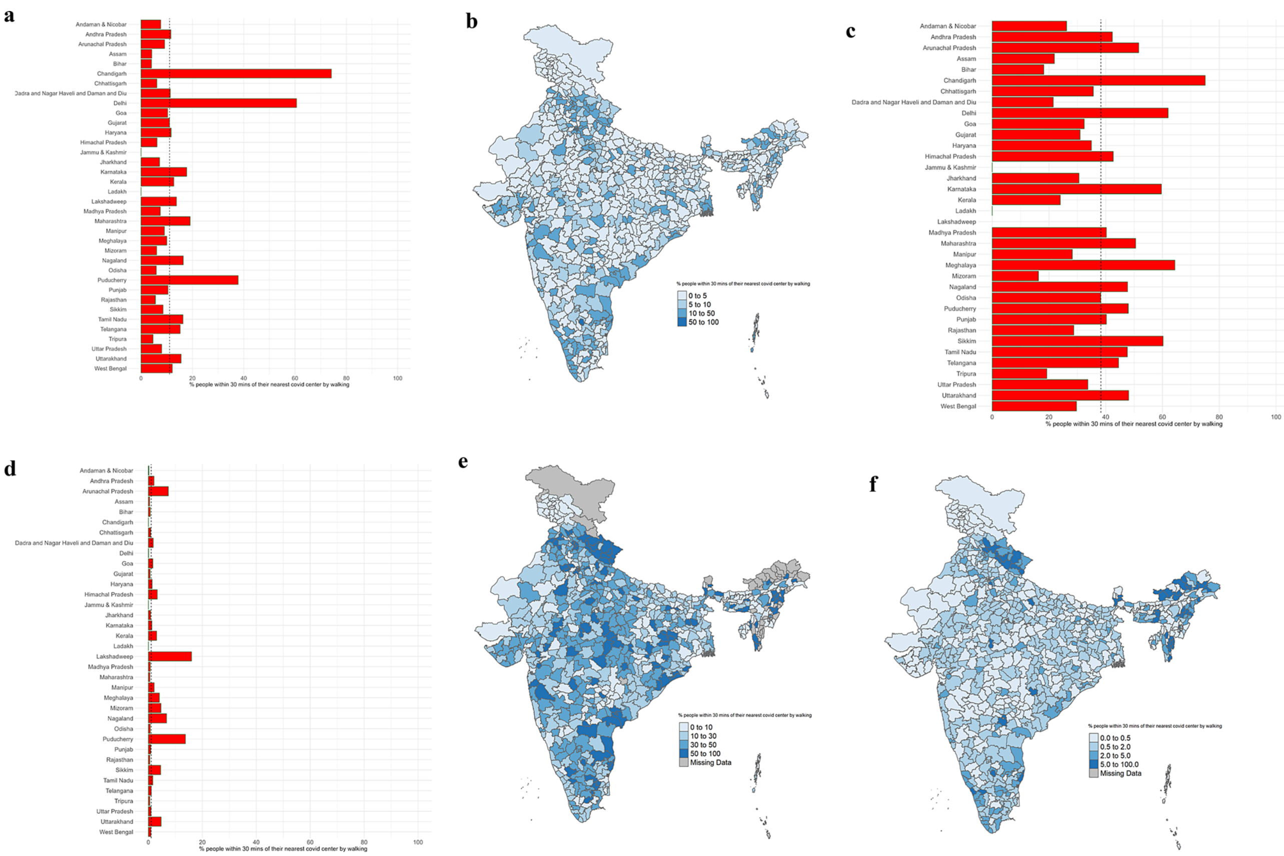

Fig. 5 Access population coverage (APC) within 30 minutes by walking. apc values to access the nearest COVID-19 testing center within 30 minutes by walking for **a**. States and union territories with the national value of 11·08% (black dotted line). **b**. Districts. APC values to access the nearest COVID-19 testing center within 30 minutes by walking for **c**. Urban areas in states and union territories, **d**. Rural areas in states and union territories. The black dotted line represents a national value of 38·29% for urban areas and 1·03% for rural areas. APC values to access the nearest COVID-19 testing center within 30 minutes by walking for **e**. Urban areas, and **f**. Rural areas in districts

districts (Fig. 6e). Rural areas in eight districts had an APC of 100%. Rural areas in 30 districts had an APC of 0%. The rural APC of seven districts was not computable (Fig. 6f).

Association with COVID-19 confirmation rates

COVID-19 case confirmation rates at the state and district levels are presented in Fig. 7a–b. At the state level, the APC for walking was significantly correlated to the confirmation rate with a Spearman correlation coefficient (R) of 0·41 ($n = 34$, $p < 0{\cdot}05$) (Fig. 8a). The APC for motorized transport did not show a statistically significant correlation to the confirmation rate ($R = 0{\cdot}33$, $n = 34$, $p > 0{\cdot}05$) (Fig. 8b).

At the district level, we observed that the APC for walking was significantly correlated to the confirmation rate ($R = 0{\cdot}15$, $n = 626$, $p < 0{\cdot}05$) (Fig. 8c). The APC for motorized transport was significantly correlated to the confirmation rate ($R = 0{\cdot}19$, $n = 626$, $p < 0{\cdot}05$) (Fig. 8d).

Discussion

Summary of findings

In this study, we calculated multiple measures of geographical accessibility to COVID-19 testing centers. Nationally, India had an average density of 1·62 testing centers per million people in the country. The median travel time to the nearest COVID-19 testing center was 400·8 minutes by walking and 50·42 minutes by motorized transport. The APC was 11·08% within 30 minutes by walking and 85·88% within 60 minutes by motorized transport.

We also noted significant disparities in the availability and accessibility of COVID-19 testing centers between rural and urban areas. There were only 0·35 centers per million in rural areas in comparison to 5·69 centers per million in urban areas. The APC by walking within 30 minutes was 1·03% in rural areas and 38·29% in urban areas. This is a worrisome finding, as close to 70% of India's population resides in rural areas [26]. However, the APC by motorized travel within 60 minutes was 97·87% in urban areas and 81·51% in rural areas. This indicates that 18·49% of the rural Indian population

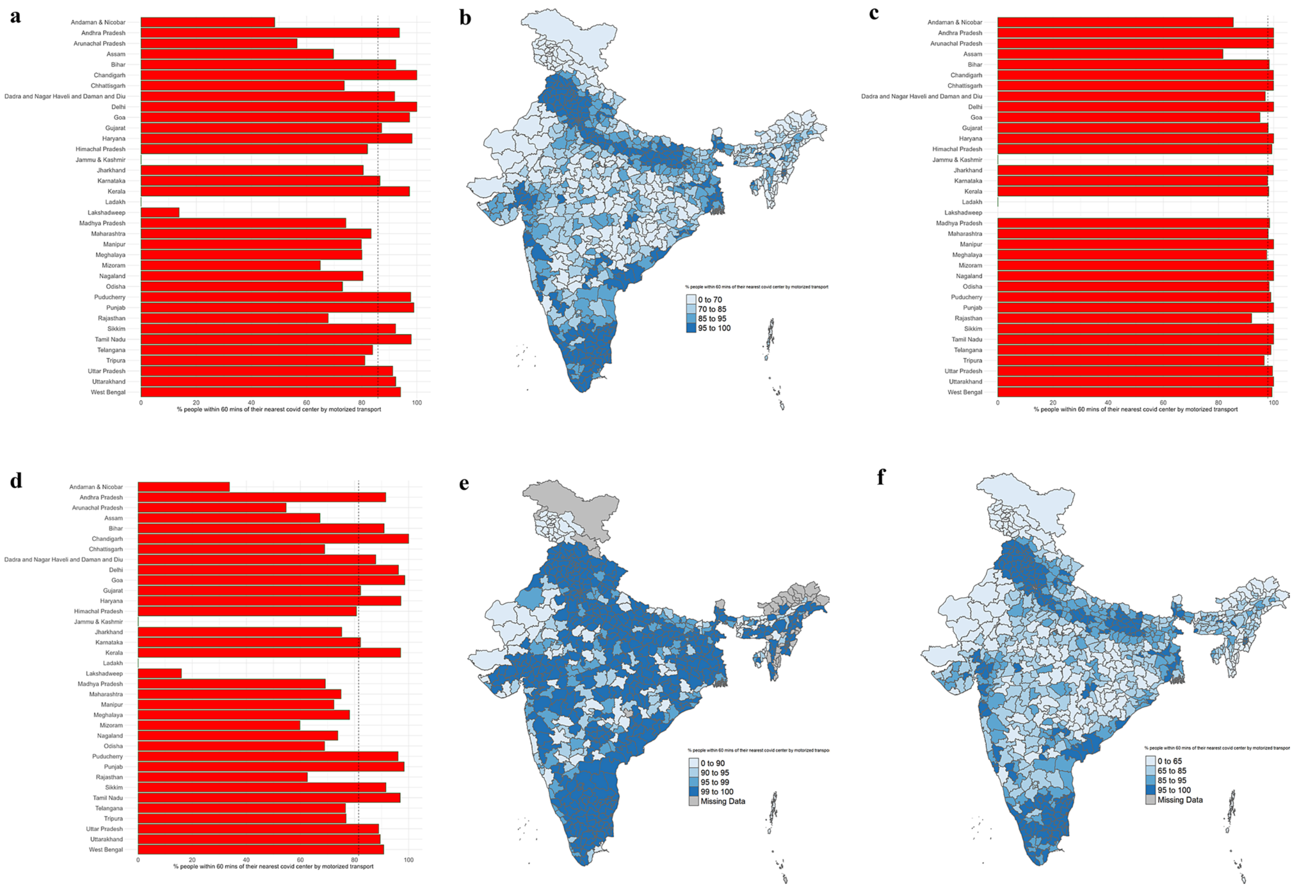

Fig. 6 Access population coverage (APC) within 60 minutes by motorized transport. APC values to access the nearest COVID-19 testing center within 60 minutes by motorized transport for **a**. States and union territories with the national value of 85·88% (black dotted line). **b**. Districts. APC values to access the nearest COVID-19 testing center within 60 minutes by motorized transport for **c**. In urban areas in states and union territories, the black dotted line represents the national value of 97·87% for urban area **d**. Rural areas in states and union territories. The black dotted line represents the national value of 81·51% for rural areas. APC values to access the nearest COVID-19 testing center within 60 minutes by motorized transport for **e**. Urban areas in districts, and **f**. Rural areas in districts

had no access to the COVID-19 testing centers within 60 minutes of motorized travel. In addition to the lower number of centers in rural areas, poorer road infrastructure in rural areas also probably contributes to this disparity in accessibility [27]. Our study has identified quite a few states/UTs in need of policy attention as well. The northernmost UTs, Ladakh and Jammu & Kashmir, had an APC of 0% within 30 minutes by walking. Ladakh also has an APC of 0% within 60 minutes by motorized transport. The absence of testing centers in these UTs and the terrain in these regions limit access to testing. At the state level, the APC for walking within 30 minutes of travel time was significantly correlated with the confirmation rate. At the district level, the APC values for both walking and motorized travel were significantly correlated with the confirmation rate. As expected, these findings show that geographic access to testing centers was reflected in the population-level case confirmation rates - an important parameter in epidemiologic surveillance in the COVID-19 pandemic.

The positive direction of these correlations and the statistical significance provide preliminary evidence for the expected relationship between the access population coverage and case confirmation rates. Crudely, districts and states with greater population-level geographic access to COVID-19 testing centers also seem to have higher case confirmation rates, early on in the pandemic. However, this should not be interpreted causally because the current analysis does not control for confounding or other sources of nonexchangeability. Further, it should be noted that the strength of correlation varies across geographic scales (districts and states) and modes of transport (walking and motorized travel). Such variation can be attributed to several factors, including ceiling effects in the distribution of motorized APCs, clustering effects across districts, etc. Exploring these is beyond the scope of the current study. However, future studies should use APC as an exposure to assess its predictive and causal value for pandemic-related population health outcomes. Beyond the variation in the strength, the consistency of

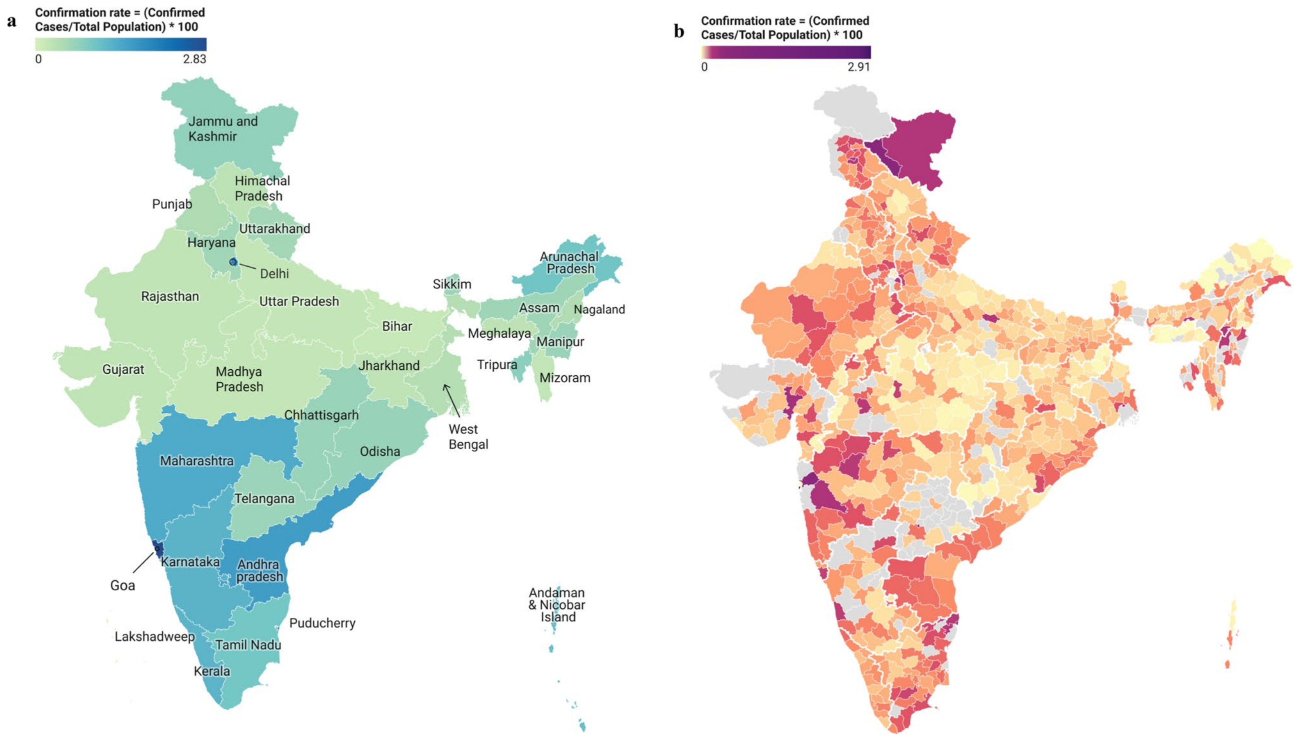

Fig. 7 State and district level maps depicting the spatial distribution of COVID-19 case confirmation rates. **a**. Confirmation rate [(confirmed cases/total population) *100] for COVID-19 cases at state level. **b**. Confirmation rate [(confirmed cases/total population) *100] for COVID-19 cases at district level. Districts without data are noted in grey. Some regions (e.g., Nicobar Islands) had data, but could not be assigned a boundary per the 2021 district map

direction of correlation is arguably more important in such exploratory analysis.

Literature in context

A recent study estimated the density of COVID-19 testing centers at 3 centers per million in Nepal, higher than our estimate of 1·62 in India. Similarly, the national APC by walking within 30 minutes was 16·83% compared to 11·08% in India. However, the national APC within 60 minutes by motorized transport was higher in India at 85·88% compared to 61·83% in Nepal. A major reason for this can be the hilly terrain in Nepal, which can slow down movement by motorized transport. The wide disparity in availability and accessibility between states/UTs noted by us corresponds to Nepal as well. For instance, 50 out of 89 (56·17%) of all COVID-19 testing centers in Nepal were in the Bagmati province. The APC within 60 minutes by motorized transport ranged from 82·69% in Bagmati to 6·35% in Karnali.[14]

Implications

Density can help us understand the distribution of testing centers by population. However, it does not give insight into the geographical accessibility to testing in the country. We assessed travel times instead of distances because the time taken to reach a testing center is dependent on many factors besides distance, such as terrain, quality of roads, and traffic. However, travel times do not take the population of a region into account. APC combines population with time and informs us about the proportion of the population that can access testing centers. We recommend that APC be used to assess testing capacity and guide national policy in the future.

The ecological disruptions posed by climate change can increase vulnerability to pathogens. A recent systematic review noted that 58% of all infectious diseases known to have impacted humanity in recorded history can be aggravated by climatic hazards triggered by greenhouse gas emissions [28]. As our vulnerability to pathogens increases, the role of pandemic preparedness in health system capacity building becomes paramount. Testing is an important component of health surveillance systems, which can support evidence-informed decision-making before and during pandemics. Laboratory testing capacity, therefore, constitutes an important component of pandemic preparedness. The WHO strongly advises member states that have developed their laboratory capacities during the COVID-19 pandemic to continue sustaining those gains. In addition, the brief also advises member states to include other respiratory pathogens such as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), Respiratory Syncytial Virus (RSV), and other relevant pathogens in their sentinel surveillance systems [29]. Assessment of testing capacity, therefore,

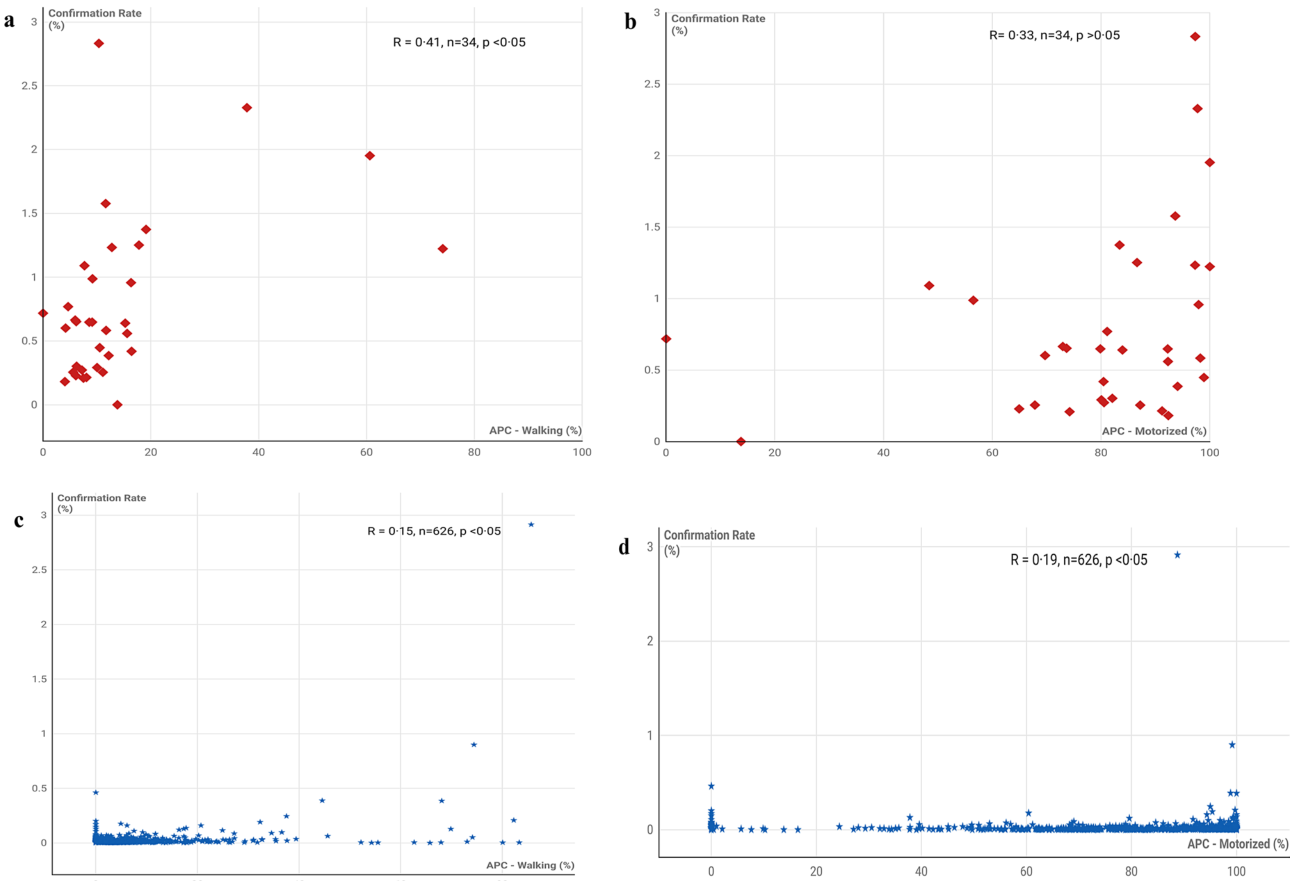

Fig. 8 Scatterplots depicting bivariate distribution of COVID-19 case confirmation rates (%) and access population coverage (APC) values (%) by walking and motorized transport at state and district levels. The confirmation rate is given by: (confirmed cases/total population) *100. The *R* values represent the Spearman correlation coefficients. We used an alpha threshold of 0.05 for the associated p-values. **a**. Correlation between confirmation rate and apc values within 30 minutes by walking. Each point represents a state/union territory. The number of states and union territories is noted by n. **b**. Correlation between confirmation rate and apc values within 60 minutes by motorized transport. Each point represents a state/union territory. The number of states and union territories is noted by n. **c**. Correlation between confirmation rate and apc values within 30 minutes by walking. Each point represents a district. The number of districts is noted by n. **d**. Correlation between confirmation rate and apc values within 60 minutes by motorized transport. Each point represents a district. The number of districts is noted by n

can help with future planning in the context of pandemic preparedness.

Disparities in access to testing centers can be addressed by the strategic placement of new testing centers. Tools such as Location Access Models (LAMs) can optimize the placement of testing centers, enhancing accessibility [30]. While home-based testing might be considered to improve accessibility, it comes at the price of increased human resource utilization and transportation costs to convey testing samples. In a country as large as India, without scaling up testing infrastructure, home-based testing is not sustainable. Improvement of roadway infrastructure, particularly in rural areas, via schemes such as Pradhan Mantri Gram Sadak Yojana (PMGSY) [31] can improve accessibility to healthcare infrastructure, including testing services.

Limitations and strengths

The study has multiple limitations. First, our study inherited the assumptions and limitations of the parent datasets, such as the ICMR dataset, URCA, Worldpop, and MAP rasters. Second, the APC estimates did not account for access to motorized transport. In 2011, only 21% of Indian households owned two-wheelers, and 4.7% owned cars, jeeps, or vans [32]. Third, we did not account for the effective readiness of testing laboratories (such as the availability of skilled technicians to address testing and sampling requirements). Fourth, our study estimated travel times and APCs by walking and motorized transport on land, not taking other means of transport into account. This could have affected accessibility estimates, particularly in regions where other means of transport are more popular. Fifth, we did not investigate access measures specific to demographic groups such as age, gender, and socioeconomic status. Future studies should take these factors into account to provide a more complete picture of geographical accessibility to testing in the country.

Despite these limitations, our study has many strengths. We developed a novel method using multiple outcome measures to assess the geographical accessibility to COVID-19 testing centers in India. Our study comprehensively analyzed the densities of testing centers per million, the median travel time to the nearest testing center by walking and motorized transport, and the APC of testing centers in 36 states/UTs and 735 districts in India. We also assessed geographical accessibility to testing centers in rural and urban areas, increasing granularity. We present a library of over 8000 accessibility estimates across sub-national regions and different analytical scenarios. Our findings are replicable, use globally available data, and are comparable to studies using similar data sources. Our study also validated the geolocation of all the testing centers in the country, increasing the strength of our findings.

Conclusion

Assessment of availability and accessibility to testing is important in the context of pandemic preparedness. Our study found a wide disparity in access to testing between states/UTs and districts and between rural and urban areas. Policymakers should note these disparities when setting up new testing centers in the context of future pandemic preparedness.

Abbreviations

UTs	Union Territories
APC	Access Population Coverage
WHO	World Health Organization
RT-PCR	Reverse-Transcriptase Polymerase Chain Reaction
ICMR	Indian Council of Medical Research
UN	United Nations
URCA	Urban-Rural Catchment Area

Supplementary information

The online version contains supplementary material available at https://doi.org/10.1186/s12913-025-13657-x.

Supplementary Material 1

Acknowledgements

We acknowledge Jash Gujarathi for helping with the initial data curation and analysis. We would also like to thank Dr. Nandita Saikia for providing the data on COVID-19 confirmation rates.

Author contributions

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Funding

No funding was received to conduct this study

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

Siddhesh Zadey represents the Association for Socially Applicable Research (ASAR) on the drafting committee of the Maharashtra State Mental Health Policy and the Global Alliance for Surgical, Obstetric, Trauma, and Anesthesia Care (G4 Alliance). He serves as the chair of the Asia Working Group of the G4 Alliance. He is on the board of ASAR and the advisory board of Nivarana. He has previously received honoraria from Think Global Health and The Hindu. Other authors declare no competing interests.

Received: 27 April 2025 / Accepted: 21 October 2025
Published online: 28 November 2025

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