Received: 4 May 2021 | Accepted: 8 July 2021

DOI: 10.1111/jors.12552

RESEARCH ARTICLE

JOURNAL OF REGIONAL SCIENCE WILEY

Infrastructure, enforcement, and COVID-19 in Mumbai slums: A first look

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Abstract

This study is among the first to investigate whether patterns of access to basic services could explain the disproportionately severe impact of COVID-19 in slums. Using geolocated containment zones and COVID-19 case data for Mumbai, India's most populous city, we find that cases and case fatality rates are higher in slums compared with formal residential buildings. Our results show that access to toilets for men is associated with lower COVID-19 prevalence. However, the effect is opposite in the case of toilets for women. This could be because limited hours for safely using toilets and higher waiting times increase the risk of exposure, and women and children sharing toilet facilities results in crowding. Proximity to water pipelines has no effect on prevalence, likely because slumdwellers are disconnected from formal water supply networks. Indoor crowding does not seem to have an effect on case prevalence. Finally, while police capacity—measured by number of police station outposts—is associated with lower prevalence in non-slum areas, indicating effective enforcement of containment, this relationship does not hold in slums. The study highlights the urgency of finding viable solutions for slum improvement and upgrading to mitigate the effects of contagion for some of the most vulnerable populations.

KEYWORDS

basic services, COVID-19, India, Mumbai, slums, spatial inequality

At the time of writing the paper, Sahil Gandhi was Postdoctoral Scholar, Lusk Center for Real Estate, Sol Price School of Public Policy, University of Southern California, Los Angeles, CA, USA and Vaidehi Tandel was Junior Fellow, IDFC Institute, Mumbai, India. The authors would like to thank Edward Coulson and an anonymous referee for helpful reviews and suggustions that improved this paper.

1 | INTRODUCTION

A wave of fast urbanization is underway in the developing world (United Nations, 2019). Historically, this process has a strong positive association with economic growth (Bettencourt, 2020; Gollin et al., 2016; Jedwab & Vollrath, 2015). Among developing countries, however, rapid urbanization is happening at lower levels of income (Glaeser, 2014). Moreover, it is sometimes happening without concurrent economic growth (see Bettencourt, 2020; Bryan et al., 2020; Castells-Quintana & Wenban-Smith, 2020; Fay & Opal, 2000; Gollin et al., 2016; Jedwab & Vollrath, 2015).

Under current conditions, millions of urban residents in developing cities still lack access to basic shelter, sanitation, and drinking water, expressing a wide gap in the living standards of the wealthy and the poor (Brelsford et al., 2017; Konteh, 2009; Sverdlik, 2011). The presence of poorly served neighborhoods is ubiquitous in cities in developing countries, with a predominant share of the one billion slum residents worldwide concentrated in these regions (United Nations, 2019). While countries may have their own definition of a slum, the UN defines them as "*communities characterized by insecure residential status, poor structural quality of housing, overcrowding, and inadequate access to safe water, sanitation, and other infrastructure*" (UN Habitat, 2003).[1]

Urban dwellers living in slum settlements are typically the most affected by natural disasters and disease outbreaks, not merely because they are poor but because of the nature of their physical and social environments (Lilford et al., 2017; Sverdlik, 2011). The COVID-19 pandemic has disproportionately affected larger cities around the world (Stier et al., 2020). Within cities, the prevalence of COVID-19 is unevenly distributed spatially with poorer neighborhoods typically witnessing more cases or higher case fatality rates (CFRs) (Malani et al., 2021; Millett et al., 2020; Schmitt-Grohé et al., 2020). With nearly all measures for lowering transmission—social distancing, frequent handwashing, and avoiding touching contaminated surfaces—being difficult or impossible to implement in these environments, slum residents have been most at risk of contracting the virus (Corburn et al., 2020).

The megacity of Mumbai, with a population of 12 million as on 2011, has been among the worst hit cities in the world. While initial outbreaks occurred in the city's upper-class neighborhoods introduced by people returning from foreign travel, the virus soon spread to the city's slums and other dense local areas (Patranabis et al., 2020).

Slums are a salient feature of housing in Indian cities. The Census of India relies on the notification and recognition of slums by local governments, state housing boards, and state governments for estimating slum populations.[2] By its account, Mumbai had about 42% of its population living in slums at the time of the last census, conducted in 2011. A study on seroprevalence in Mumbai conducted in July 2020 estimated that slums had an average seroprevalence of 54% whereas nonslum areas had a seroprevalence of 16% (Malani et al., 2021), indicating a much more intense exposure to the virus in slums.

This paper uses case data in local areas within the city of Mumbai to investigate whether inadequate access to water and sanitation in slums can help explain observed higher levels of COVID-19 prevalence. To our knowledge, this is the first statistical investigation of the connection between access to basic services in slums and the spread of COVID-19 in a developing country metropolis. Our aim is to quantify the most relevant factors that influence viral transmission in Mumbai's slums and thereby contribute to finding viable solutions for service improvement and upgrading to mitigate the effects of contagion for these most vulnerable populations.

The policy of Containment Zones adopted by the Brihanmumbai Municipal Corporation (BMC)—the local body governing Mumbai—provides a unique opportunity to understand the differential COVID-19 prevalence across the different types of housing in cities in developing countries. The policy was intended to lower the epidemic exposure of the general population by isolating infected local pockets with high prevalence. Implementing Containment

[1]Slums are not homogeneous and their definition and classification varies across countries. For instance, Gulyani et al. (2010) document the wide disparities across slums in Dakar, Johannesburg, and Nairobi. Nolan (2015) uses the definition of slums in India to show that definitions used by countries may sometimes be in conflict with the standard definition used by UN Habitat. Gilbert (2007) critiques the usage of the term "slums" and provides an overview of studies that show heterogeneity among slums.

[2]https://www.censusindia.gov.in/2011-Documents/Slum-26-09-13.pdf

Zones in slums may not affect *internal* contact rates since residents continue to access shared services, such as public toilets and water taps, and due to indoor crowding.

We focus on public toilets because of the number of factors which increase viral transmissions in using these facilities, even if fecal transmission may be rare or nonexistent, as shown by Jones et al. (2020). These factors include duration of use (higher for women compared with men[3]), crowding, design features (whether toilets are in the Asian squat or western sitting style, how many surfaces users come in contact with), ventilation, and hand washing after use (Nicol, 2020). Amoah et al. (2020) posit that transmission could happen due to contamination of contact surfaces from viral shedding through aerosol deposition and absence of adequate means to clean toilets and washing hands after use.[4] This leads to the expectation that the more crowded and poorly managed the facilities, the greater the risk of transmission. Further, slums face additional challenges of lack of access to water facilities needed for frequent hand-washing and sanitation. Many slum households rely on communal sources of water, such as water tanks and public taps, where water is available for a limited number of hours in a day. Hence, people often must place themselves at risk by gathering in large numbers around these sources for long periods (Auerbach & Thachil, 2021). Therefore, we hypothesize that Containment Zones where households have access to more toilets and piped water should see lower COVID-19 prevalence.

If access to basic services is inadequate and social distancing is not possible within the Containment Zone, even a well-enforced containment policy may not be effective in controlling cases. Therefore, we would expect better enforcement of containment to be associated with fewer cases largely in Containment Zones in nonslum areas, but not in slum areas.

The paper is structured in nine parts including Section 1. Section 2 provides an overview of the literature that investigates the nature of access to basic services and its impact in slums in developing countries and in Mumbai. Section 3 describes the COVID-19 situation in India and Mumbai, and the containment polices adopted by the government. Section 4 describes the data, Section 5 provides stylized facts including prevalence rate and CFR in slum versus nonslum containment zones, and Section 6 discusses our empirical strategy. The main findings are presented in Section 7. Section 8 discusses the limitations and scope for future research. Section 9 concludes.

2 | ACCESS TO BASIC SERVICES IN SLUMS

There is rich scholarship documenting poor access to basic services in slums throughout the developing world (Ahmad, 2020; Bogaert, 2011; De & Nag, 2016; Martinez et al., 2008; Sahasranaman & Bettencourt, 2019; Tukahirwa et al., 2013). For instance, Gulyani et al. (2006) find a wide gap in terms of piped water connections between slums in Nairobi (at 19%) compared with the city-wide estimate (at 72%). In a recent survey of slums in Indian cities of Jaipur and Bhopal, Auerbach (2020) found that 42% of respondents had access to water taps and 27% had access to sewerage connections. Mukherjee et al. (2020) highlight differential access to water based on gender, language, religion, and caste within slums in Kolkata. Moreover, small and semipermanent dwellings and poor connectivity to sewerage networks compel slumdwellers to rely on public latrines or toilets (Gulyani & Talukdar, 2009; Tumwebaze et al., 2014; Wegelin-Schuringa & Kodo, 1997). Not only are private toilets mostly absent, but also many public toilets tend to be unusable or unclean (Chidambaram, 2020; Tumwebaze et al., 2014). Slumdwellers value access to these basic services (Das et al., 2017; Kolowe, 2014) and in their absence have to adapt in a number of ways. For instance, water supply provision may happen through water kiosks, ground water, water tankers, community supply through pipes and submersible pumps, and informal arrangements for tapping into the main water pipes (Ashraf et al., 2016; Chidambaram, 2020; Gulyani et al., 2006).

[3]Anthony and Dufresne (2007) summarize the results of different studies on wait times by gender in the US. These results show that women took on average twice as much time as men in using restroom facilities.

[4]In a study of extent of surface contamination in community toilets in the city of Durban, the SARS-CoV-2 virus was found to be present on surfaces, like, tap handles, internal latches, and toilet floors (Amoah et al., 2020).

Several studies have investigated whether the absence of services that provide clean and hygienic environments have consequences for health outcomes and specifically the risk of outbreaks of communicable diseases in slums. For instance, Sur et al. (2004), in a study of diarrhea outbreaks in a slum in Kolkata in India, show that households with a private water connection inside their homes were at a lesser risk of contracting the disease compared with households who accessed a communal tap. Penrose et al. (2010) find that access to improved sanitation or water by residents in informal settlements in Tanzania's Dar es Salaam did not have a significant effect on outbreaks of cholera. In Zambia's capital city Lusaka, availability of water and sanitation facilities also had little effect on disease outbreaks, presumably because many households remained underserviced due to the high cost of connections (see Ashraf et al., 2016). Given that behavioral interventions, such as hand washing, reduce incidences of certain communicable diseases, like, diarrhea (Zwane & Kremer, 2007) as well as of airborne diseases, disruptions in water availability may increase the spread of airborne diseases (see Ashraf et al., 2017).

Governments, medical experts, and health organizations have also recommended frequent hand washing as a prophylactic measure for COVID-19 (WHO, 2020). However, in most low-income countries, a significant share of households lacks access to basic materials for hand-washing, such as soap and water (Ray, 2020). Brauer et al. (2020) estimate that 15% of the population in the urban areas of Delhi and 54% of households in Nairobi had no access to hand-washing facilities. Although Gwenzi (2020) posited that COVID-19 can also be transmitted through the fecal-oral route, Jones et al. (2020) find little evidence for this. Yet, transmission is still possible through other channels, including droplets on surfaces and aerosols or crowding at the facilities. Hence, adequate and clean sanitation facilities with running water and hand washing practices are critical for lowering the spread of the disease (Jones et al., 2020).

The formal housing market of Mumbai comprises high-end apartments, multifamily housing societies and low-income housing, including public housing and *chawls*.[5] *Chawls* are housing complexes with single room tenements of around 6–12 m^2 and shared toilets (Mukhija, 2006). These were first created as employee housing to be rented out to laborers working in factories and mills in Mumbai (Mukhija, 2006). Most of the chawls were built before 1950 and many are now dilapidated (Risbud, 2003).

Living in slums and *chawls* is typically associated with lower socioeconomic status compared with other types of housing (Bardhan et al., 2015). While slums in Mumbai differ by age, they tend to be similar in terms of their built form depending on when they came up. Taubenböck and Kraff (2014) use remote sensing to compare building density, heights, and sizes across three slum areas in central, northern, and eastern areas of Mumbai. They find that these are fairly homogeneous in terms of their structural characteristics. Typically, slums in Mumbai are densely packed, with very low floor space per capita (Anand et al., 2015) entailing crowding within houses. Slums are also poorly serviced: 73% households depend on shared public community toilets, very few households have private toilets and not all have private water taps (Anand et al., 2015). According to the Census of India 2011, only 18% slum households in Mumbai had a private toilet. A survey of slum populations in specific wards of the city shows that 65% of the respondents access a common water connection for drinking water and 84% depend on public toilets (Deshmukh, 2013). Another ward-level study of demand for toilets finds a large deficit in the number of toilet blocks (Biswas et al., 2018). More than 70% of existing toilets are in poor condition (Biswas et al., 2020). In a study conducted nearly two decades ago, Burra et al. (2003) documented differences in terms of maintenance and repair across toilet blocks in the city. Biswas et al. (2020), in a field study of community toilet blocks across different squatter settlements in Mumbai, continue to find substantial differences in toilet conditions. They also find that toilet blocks that are managed by nongovernmental organizations (NGOs) or Community-Based Organizations tend to be in better condition. Lack of private toilets and associated poor hygiene in slums have a disproportionately detrimental impact on women (Belur et al., 2017). Deficits in water access have also been documented in recent studies (Anand et al., 2015; Björkman, 2018).

[5]Photographs and descriptions of the different formal and informal housing types in Mumbai have been documented by the Collective Research Initiatives Trust in a 2007 report. https://critmumbai.files.wordpress.com/2011/10/house-types-in-mumbai-final.pdf (accessed on April 25, 2021).

A number of different solutions have been shown to be effective for improving basic services in slums. These are either bottom-up community-led efforts—such as collectively building and managing toilet blocks, leveraging political networks, and petitioning various state actors through collective action (at times with the help of NGOs) (Auerbach, 2020; Burra et al., 2003; Chidambaram, 2020; Pierce, 2020)—or enacted by the state through formal policies, such as notifying slum settlements or granting some form of tenure security (Gulyani & Talukdar, 2008; Nakamura, 2017; Nyametso, 2012; Scott et al., 2013). It is possible that the latter may be consequences of demands from slum communities themselves for regularization, and hence also result in part from bottom-up processes.

3 | COVID-19 IN MUMBAI AND INDIA: EXPERIENCE AND POLICY

At the time of writing (in mid-April 2021), India ranked second in the world in terms of total number of COVID-19 cases. Controlling for population, it was seeing around 140 daily new cases per million—above the world average of 98 cases per million.[6] Yet, the actual number of infections is likely to be far higher given low testing in the country; India ranks 115 in terms of total tests per million people.[7] Seroprevalence surveys in some Indian states show much higher prevalence, confirming that a very large number of cases have not been identified and reported. For instance, in the southern state of Karnataka (with a population of 67.5 million), a seroprevalence study estimated that around 31.5 million residents had been exposed to the coronavirus, whereas the reported cases during the period of the study were just above 320,000 (Mohanan et al., 2021).

In terms of the geography of the spread, COVID-19 prevalence seems to be disproportionately concentrated in a few states and larger cities. The state of Maharashtra alone (with 9.3% of the Indian population) accounts for approximately 25% of all COVID-19 cases in the country, and the top five states of Maharashtra, Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh have more than 50% of all cases.[8]

By mid-April 2021, India reported around 177,000 confirmed COVID-19 deaths, which translates to a mortality rate of 127 per million and 1.2% CFR. For comparison, the USA had a mortality rate of 1746 per million and a CFR of 1.8%.[9] While the low number of deaths and low CFR is likely due to underreporting and poor quality of cause of death data, other factors, like, having a young population, cross-reactive immunity from other coronaviruses, and survivorship bias may also be playing a role (see Cai et al., 2021).

Throughout the period of the pandemic, Indian governments at the federal, state, and local level have implemented policies to restrict or ban travel and social gatherings; instituted protocols for containment, testing, and contact tracing; augmented capacity of public healthcare facilities; and organized mass messaging campaigns exhorting citizens to adopt preventive behaviors, such as mask wearing, hand washing, and maintaining social distancing.[10] A pan-India survey of respondents found that while some practices, like, mask wearing and avoiding shaking hands, had very high uptake, others like frequent and thorough hand washing or social distancing were only followed by around 50% of respondents (Chakrawarty et al., 2020). The most severe of these policies was a 38-day country-wide lockdown, announced on March 24, 2020. While the lockdown was in place, state and local governments were responsible for enforcing restrictions on movement, identifying and declaring areas with large clusters of cases as Containment Zones and carrying out testing and contact tracing.

[6] https://ourworldindata.org/coronavirus/country/india?country=~IND. Raw data are from COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University.

[7] https://www.worldometers.info/coronavirus/

[8] https://www.covid19india.org/

[9] https://www.worldometers.info/coronavirus/

[10] An exhaustive list of every central and state government notification is available here: https://prsindia.org/covid-19/notifications

The first COVID-19 case in Mumbai was detected on March 11, 2020.[11] At the time of announcing a country-wide lockdown in late March 2020, Mumbai was witnessing the highest increase in the number of COVID-19 cases in the state of Maharashtra. The municipal government adopted a host of strategies outlined by the Ministry of Health, Government of India, including the policy of Containment Zones.[12] This involved either creating a perimeter around a geographic location in the city where cases were detected, or identifying specific housing complexes or neighborhoods where a case or cluster of cases were found, and sealing off these areas to reduce the movement of people. Specifically, residents were forbidden from leaving their Containment Zone and no one from the outside was permitted to enter. The city police were entrusted with enforcing these restrictions.

Areas declared as Containment Zones were to be released either after a period of 2 weeks or after the outbreak was controlled, whichever was later. During this period, officials were to screen all residents within the Containment Zones, and test and isolate persons with symptoms. In Mumbai, authorities classified Containment Zones into two categories based on the type of dwellings being sealed: (i) slums and *chawls*, and (ii) sealed buildings.

It is now well understood that effective management of COVID-19 outbreaks should rely on increased testing and screening. The testing policy in Mumbai has changed often: for instance, on April 12, 2020, the state government revised its testing protocol to allow only symptomatic and high-risk asymptomatic contacts to be tested (Livemint, 2020). Within a week, the BMC reverted to the policy of testing all asymptomatic contacts between the fifth and 14th day of quarantine (The Hindu, 2020). For all of May, tests ranged between 4000 and 4500/day in the city (The Indian Express, 2020). The administration also specifically focused on Dharavi, a large slum located in the heart of Mumbai with a population density of 277,136/km^2.[13] In the first few months, around 540,000 of Dharavi's million residents were screened (Golechha, 2020).

Comparing the distribution of slum population and the distribution of COVID-19 cases in slum Containment Zones across the 24 administrative wards of the city, we find, more or less, that wards having a high share of the city's slum population (between 7.6% and 10.5%) also have high shares of cases in slum containment zones (see Figure 1). The correlation between share of slum population and slum cases share across wards is 0.58. The highest share of cases in slum containment zones (13%) is found in the G North ward, which is home to Dharavi—a large slum. This could be due to the increased focus of the municipal administration on detecting and controlling cases in this slum in the early months of the pandemic. Ward S, which has many slum pockets and the highest share of the city's slum population (10.3%), had around 2% of the total cases in slum containment zones.

4 | DATA

The BMC has released information about the location of Containment Zones on its web portal.[14] We also obtained additional information about Containment Zones at two distinct points in time—May 22, 2020 and June 2, 2020. This information includes estimates of local population and dwelling units within each Containment Zone, number of positive cases, and number of persons screened. The May data set includes number of deaths in the Containment Zones but this information has not been included in the later data set. The June data set contains information on 9072 Containment Zones accounting for 38,375 of the 41,986 total cases reported in Mumbai till that date. Location information (latitude and longitude) is available for a subset of the Containment Zones. The data set

[11]A year later, in mid-April 2021, the city had more than 570,000 positive cases and around 12,300 deaths.

[12]For details regarding containment policies, see Government of India, Ministry of Health and Family Welfare (2020).

[13]We use the population density estimate reported in Golechha (2020).

[14]http://stopcoronavirus.mcgm.gov.in/

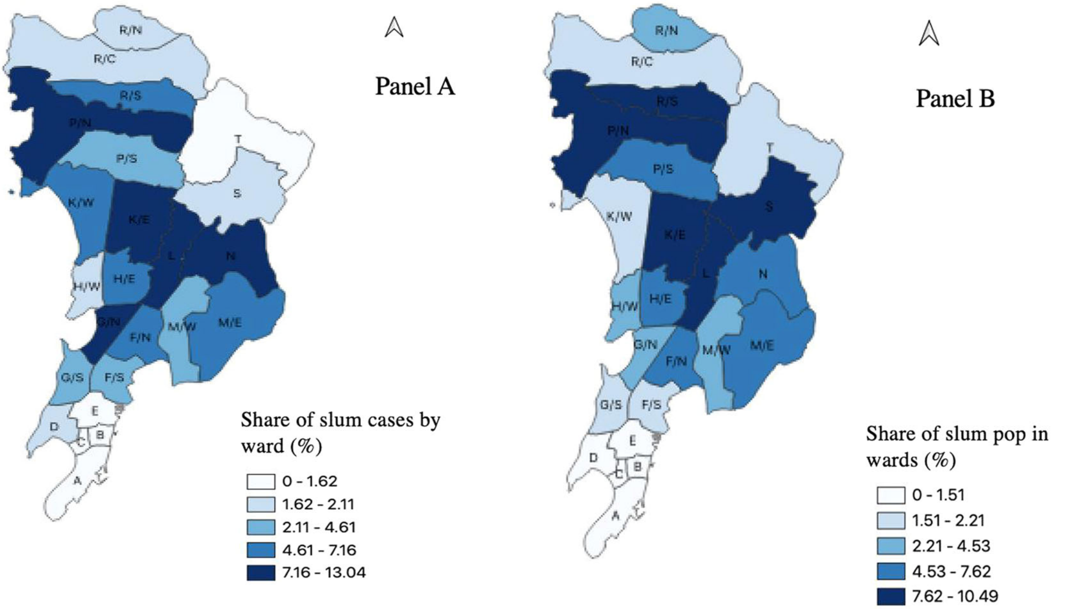

FIGURE 1 Wardwise share of cases in slum and share of slum population. *Source*: Ward slum population from 2011 Census of India and Ward cases in slum from BMC. *Note*: Panel A depicts the distribution of cases in slums across Mumbai's administrative wards and Panel B depicts the distribution of Mumbai's slum population across wards

provides geolocations for only around 6% of the sealed buildings in seven out of the 24 administrative wards.[15] The coverage in terms geolocation for slums and *chawls* is much better. We used geolocations of Containment Zones, together with a geospatial layer for slum settlements in Mumbai to identify Containment Zones within slums. Figure 2 shows a map of typical Containment Zones within a slum. The average population size of a slum Containment Zone is 6863, and the largest Containment Zone has 73,955 people.

The data on the number of public toilet seats are available from surveys of public toilets conducted by the BMC that are provided on its public Geographical Information System (GIS) portal.[16] These surveys were conducted under the directives of the Government of India, which mandates the mapping of public utilities under the *Swachh Bharat* (Clean India) Mission.[17] The location of the public toilet complex, number of seats (for men and women), status of the toilets, the agencies responsible for building them, and source of water are available. This data set has information for 8417 public toilet complexes having 79,876 seats: 41,031 for men and 38,845 for women. Around 49% of the toilet complexes are owned by the BMC and around 20% are owned by various state government departments.[18] The average Euclidean distance from the center of a slum Containment Zone to the nearest public toilet is 100 m. On average the nearest public toilet has just 10 total toilet seats.

The locations of the water pipelines are also obtained from the public GIS portal of the BMC. This data set covers 4290.7 km of water distribution pipes of three kinds—primary, secondary, and tertiary—in Mumbai. The tertiary pipelines form the last-mile network that serve the end user. The median Euclidean distance between the closest tertiary pipeline and the center of the Containment Zone is 271 m.

[15]We do not know why such few sealed buildings were geotagged and the potential selection issues in geotagged buildings. The most likely explanation is differences in the capacity of ward administrators.

[16]https://dpremarks.mcgm.gov.in/dp2034/6

[17]Government of India, Ministry of Housing and Urban Affairs (2017). Guidelines for Swachh Bharat Mission—Urban, Clause 11.3.4 http://swachhbharaturban.gov.in/writereaddata/SBM_GUIDELINE.pdf

[18]The rest are either owned by the Central Government or classified as "other."

FIGURE 2 Map of containment zones in Ambewadi slum, Mumbai. *Note*: In Panel A, blocks with red borders are containment zones. The larger block with the white border is extent of the slum. The smaller blocks with white borders are formal buildings within the slum. Panel B shows the location of the slum in Mumbai

We use a public map of the police station zones to identify the police zones for Mumbai.[19] Police stations provide data on the number of *chowkis* (or police station outposts) and police personnel on their websites. The data for control variables is from the Census of India for the year 2011.

Table 1 presents the summary statistics of variables used in the analysis.

5 | PREVALENCE OF COVID-19 BY HOUSING TYPOLOGIES IN MUMBAI

Table 2 provides prevalence and CFR by type of Containment Zones. Panel A shows prevalence, deaths, and CFR for all Containment Zones. Panel B provides this data for geocoded Containment Zones across three types, specifically, slums, *chawls*, and sealed buildings. We use the May data set since it provides data on deaths.

We immediately observe that the CFRs are much higher for slums and *chawls* compared with sealed buildings. Among the geocoded Containment Zones, CFRs in slums are only slightly higher than in *chawls* and then sealed buildings. [20] An important caveat while comparing these estimates is that we use only 6% of the total observations for sealed buildings, for which there may be selection issues.

We check for a scaling relation between number of cases and population (Sahasranaman & Bettencourt, 2019). For this, we use log of number of cases and the log of approximate population in the Containment Zone. Figure 3 shows that this relationship is sublinear for all three types of Containment Zones.[21] However, slums have the

[19]https://mumbaipolice.gov.in/Police_map

[20]The CFR will depend on how well cases are reported. Infection Fatality Rates (IFRs), however, are likely to be much lower. A study on seroprevalence in Mumbai estimates the IFR for slums to be 0.076% and for nonslums to be 0.263% (Malani et al. 2021). Both CFR and IFR measurements could be underestimates if deaths are not reported accurately.

[21]A Breusch–Pagan test for heteroskedasticity fails to find heteroskedasticity in the error terms.

TABLE 1 Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Log of cases per 1000	298	1.84	1.42	−2.03	6.78
# Of toilet seats (500 m)	298	437.48	318.92	0	1729
# Of toilet seats for women (500 m)	298	214.36	158.42	0	812
# Of toilet seats for men (500 m)	298	223.12	167.04	0	917
Distance to the nearest tertiary pipeline (m)	298	521.51	522.77	5.17	2750.95
# Of police chowki in the jurisdiction	289	3.78	0.58	2.00	6.00
Indoor crowding	295	4.97	3.09	1.22	54.08
Literacy rate	298	79.61	3.24	72.73	90.26
% Scheduled caste population	298	6.85	3.52	0.88	19.14
% Scheduled tribe population	298	0.88	0.40	0.08	3.80
% Households using electricity	298	96.67	1.37	90.80	99.60
% Households using LPG fuel	298	73.13	10.10	29.72	94.41
% Households with bank accounts	298	83.60	7.01	53.64	98.89
% Households owning radio	298	32.23	8.09	22.50	67.41
% Households owning a television	298	82.78	4.96	63.43	95.00
% Households owning a computer	298	26.60	9.72	10.04	69.91
% Households owning a computer with internet	298	15.49	8.41	3.79	57.41
% Households living in permanent structure	298	94.00	4.19	57.90	98.92
% Households owning scooter or motorbike	298	12.71	4.11	2.58	30.80
% Households owning a car or vehicle	298	10.27	7.13	2.86	53.80

Note: This table presents summary statistics of the variables used in our regressions. Each observation is a Containment Zone.

Abbreviation: LPG, liquefied petroleum gas.

highest increase rate (elasticity) of cases with population, followed by *chawls*. This indicates that population size matters in the case of slums and *chawls* since it may lead to more indoor crowding as well as crowding around shared community facilities.

6 | EMPIRICAL STRATEGY

We use ordinary least-squares (OLS) regression to estimate the relationship between COVID-19 prevalence and access to basic services within Containment Zones in slums. The baseline equation we estimate is

$$\log(\text{Casesper } 1000_i) = \alpha + \beta_1 \text{Num\_toiletseats}_i + \beta_2 \text{Dist\_pipe}_i + \beta_3 \gamma_i + \varepsilon, \tag{1}$$

where Casesper 1000_i is the number of cases per 1000 population for every slum Containment Zone_i, Num_toiletseats_i is the number of toilet seats within a radius of 500 m (measured as a Euclidean distance) from the center of the Containment Zone, and Dist_pipe_i is the distance to the nearest tertiary water pipeline.

TABLE 2 Cases and deaths across Containment Zones in Mumbai (as on May 22, 2020)

Type of containment zone	Number of containment zones	Number of positive cases	Number of deaths	Case fatality rate (%)
Panel A: All containment zones				
Sealed building	3613	6903	337	4.88
Slum/chawl	1030	10,523	759	7.21
All	4643	17,426	1096	6.28
Panel B: Geocoded containment zones				
Sealed building	240	383	25	6.53
Slum	330	4541	336	7.34
Chawl	529	5367	389	7.24
All geocoded	1099	10,291	750	7.28

Note: We use May 2020 data for this table because it has data on deaths. Of the 1030 slum/chawl CZs we could geocode 859 and correctly identify which are slums or which are *chawls*.

We also estimate the baseline specification with two separate variables for the number of toilet seats for men and number of toilet seats for women within 500 m. The rationale for this is that use, duration, and considerations of safety and cleanliness of sanitation facilities differ for men and women. γ_i is a vector of controls that measure the living conditions and socioeconomic status of the population in the census section corresponding to each slum Containment Zone. These controls include the number of police *chowkis* in the police zone corresponding to the Containment Zone, proportion of population belonging to historically marginalized groups—Scheduled Castes (SC) and Scheduled Tribes (ST), literacy rate, proportion of households living in a permanent structure, proportion of households using electricity, proportion of households using liquefied petroleum gas (LPG) as a kitchen fuel,[22] proportion of households using banking services and proportions of households owning a radio, television, computer with internet, a computer without internet, a scooter or a motorcycle, a car, jeep, or van, at the census section level.

The choice of 500 m as a benchmark follows the guidelines of the Government of India's *Swachh Bharat* Mission to end open defecation, which state that for a ward or area to be Open Defecation Free, "*All occupants of those households that do not have space to construct a toilet must have access to a functional community toilet within a distance of 500 meters*."[23,24] While 500 m may be thought of as too far, recall that it takes on average 6 min to walk this distance.[25] It may also be reasonable to use 400 or 300 m as the distance cutoff. However, toilets within shorter distances of 100 or 200 m, may not adequately serve the population.[26] Around 29% of slum Containment Zones and 13% of slum Containment Zones have no toilet seats within 100 and 200 m from the center, respectively. Further, according to our data set, the average number of toilet seats within 100 m from the center of a slum Containment Zone is just 32. Given that the average population in a slum Containment Zone is 6863, if we use 100 m as a cutoff, we would have one toilet seat serving approximately 214 residents on average. Similarly, the

[22]Extremely poor households tend to use other means, such as firewood, cattle dung, or kerosene as cooking fuel.

[23]Government of India, Ministry of Housing and Urban Affairs (2017). Guidelines for Swachh Bharat Mission—Urban, Annexure 5: ODF Protocol http://swachhbharaturban.gov.in/writereaddata/SBM_GUIDELINE.pdf.

[24]While we use 500 m as a threshold distance in the context of India, the preferred distance to public toilet facilities for users may be very different and vary across countries or cultures (see Cardone et al., 2018).

[25]We went through the literature for studies that report the distance that people are comfortable traversing to reach a public toilet in Mumbai but we could not find such a study.

[26]A 2017 survey of women in two slum settlements in Mumbai found that just 67% of the respondents said they could access a toilet within 100 m whereas 97% said they could access a toilet within 500 m (Belur et al., 2017).

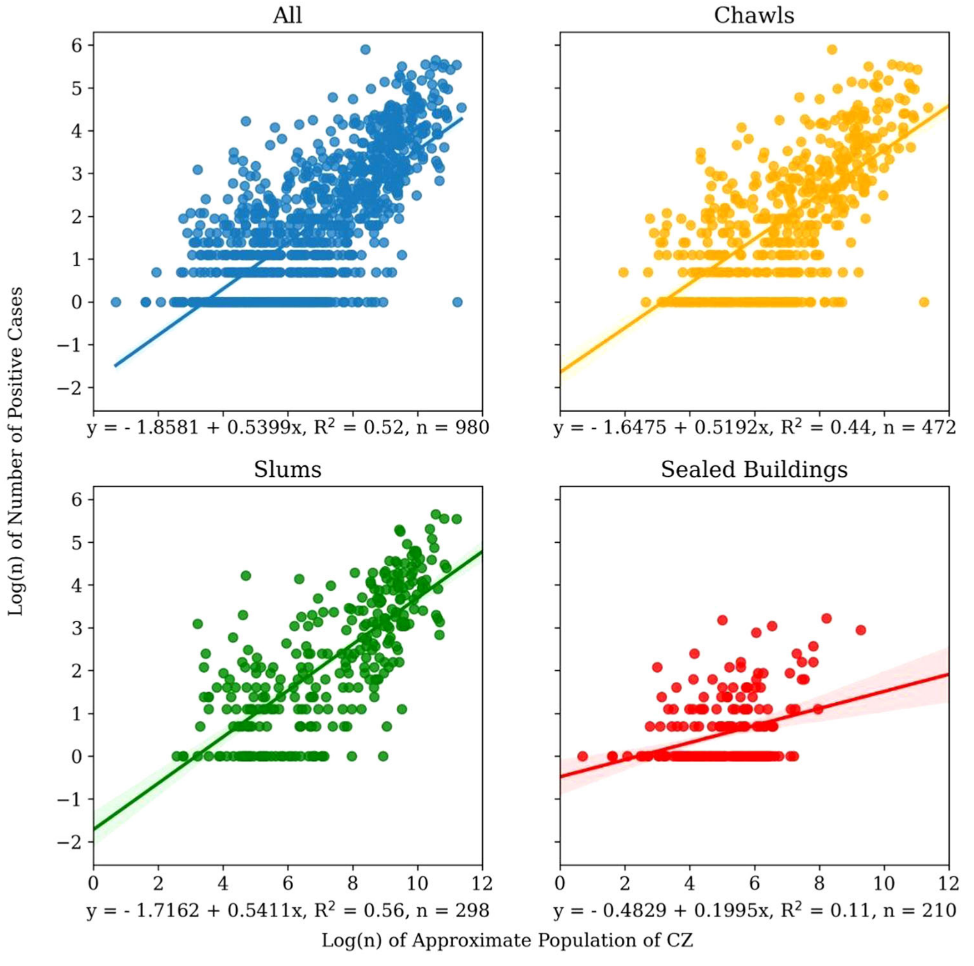

FIGURE 3 Population and number of positive cases for classified containment zones. *Note*: Of the 1116 Containment Zones geocoded from the June data set, 136 had missing values for either positive cases or population in the Containment Zones or both. Some Containment Zones reported 1 positive case (and hence have log of cases as 0)

average number of toilet seats within 200 m from the center of a slum Containment Zone is 102, and one toilet seat serves 67 residents on average. The *Swachh Bharat* Mission guidelines stipulate that there should be at least one seat per 25 women and one seat per 35 men. Using 500 m as a threshold satisfies this benchmark since with 437 seats on average, one seat serves approximately 16 people.[27] Nevertheless these numbers reveal terrible deficits in present access to sanitation facilities for slum populations in Mumbai.

As a robustness check, we run the regression in Equation (1) using different distance cutoffs, starting at 100 m and going up to 600 m, at 100 m intervals.

Several studies have shown that transmission may be rapid in densely populated or crowded areas, leading to higher case rates. However, this is tricky to measure since residential population density may not adequately

[27]We have reported averages in this paper using our data but there are bound to be wide differences across slum settlements. A 2018 survey of slums in one ward in Mumbai conducted by the researchers from a public university revealed that a single toilet seat served 154 persons and that, under these conditions, every household was found to have access to a toilet within 500 m of the household (The Wire, 2018). https://thewire.in/government/behind-mumbais-self-declared-odf-status-overused-inadequate-and-crumbling-toilets

capture crowding or "effective density" from an epidemiological perspective (Malpezzi, 2020). Hence, instead of population density, we examine whether indoor crowding, which is the ratio of population to the number of dwelling units in the Containment Zone, is associated with higher case prevalence. The new estimation regression is as follows:

$$\log(\text{Casesper } 1000_i) = \alpha + \beta_1 \text{Num\_toiletseats}_i + \beta_2 \text{Dist\_pipe}_i + \beta_3 \text{Indoor\_crowding}_i + \beta_4 \gamma_i + \varepsilon. \quad (2)$$

Finally, we estimate the relationship between enforcement and prevalence of COVID-19. Enforcement is defined as the ability to effectively prohibit ingress and egress from the Containment Zone and is proxied by the number of police station outposts or *chowkis* in the police zone corresponding to each Containment Zone. We estimate this for all Containment Zones together and separately for slums and nonslums using the regression equation:

$$\text{Casesper } 1000_i = \alpha + \beta_1 \text{Num\_policechowkis}_i + \beta_2 \zeta_i + \beta_3 \gamma_i + \varepsilon, \quad (3)$$

where the dependent variable is cases per 1000 within Containment Zone$_i$, and the main explanatory variable is the number of police *chowkis* for Containment Zone$_i$. ζ_i is a vector of controls for amenities, like, number of toilet seats and distance to pipelines and γ_i is the vector of controls for socioeconomic indicators described in the baseline specification.

7 | RESULTS

7.1 | Basic services and COVID-19 prevalence in slums

Table 3 presents the results with respect to the relationship between access to services and log of cases per 1000.

We find no relationship between prevalence of cases in the Containment Zones and total number of toilet seats within 500 m or distance to the nearest water pipeline (columns 1 and 2). Columns 3 and 4 report the results of the relationship between number of toilet seats by gender and prevalence.

The relationship is negative and significant for the number of toilets seats for men. The sign of the coefficient for men is as expected—with more toilet seats available, social distancing becomes more feasible and this may be associated with fewer cases.

The coefficient is positive and significant for the number of toilets seats for women. A possible explanation for this counterintuitive result is that women share sanitation facilities with children and tend to go in groups for safety while men use these facilities alone.[28] Measuring access only in terms of number of toilet seats for women does not capture aspects, like, safety, duration of use (including wait times), or cleanliness, which matter for women but not as much for men. For instance, women are likely to access sanitation facilities at specific times of the day for safety, which may preclude effective social distancing. Belur et al. (2017), in a survey of 142 women in two slum areas in Mumbai, find that 64% of women accessed toilets between 8 a.m. and 12 noon. According to one report, a woman living in a slum has to wait nearly 20 min for her turn.[29] In this sense, the present levels of sanitation facilities meant for women in slums may actually lead to crowding and enhanced COVID-19 transmission.

Our results continue to remain significant after adding controls for different socioeconomic indicators and level of enforcement, measured by the number of police station outposts (see column 4). As seen in columns 5 and 6, indoor crowding does not seem to have an effect on case prevalence. Adding this variable does not change the results for basic amenities significantly. Among the controls, the coefficient for share of population belonging to

[28] Belur et al. (2017) report that women shared their toilets with all female children and a fifth of the male children.

[29] https://swachhindia.ndtv.com/open-defecation-free-mumbai-odf-public-toilets-status-ground-reality-31199/

TABLE 3 Impact of toilets and water network on cases in slums

Variables	Dep. variable: log of cases per 1000 (1)	(2)	(3)	(4)	(5)	(6)
# Of toilet seats (500 m)	0.000234	−5.06e − 05			−3.70e − 05	
	(0.000253)	(0.000269)			(0.000270)	
# Of toilet seats for women (500 m)			0.00441***	0.00292**		0.00301**
			(0.00118)	(0.00126)		(0.00126)
# Of toilet seats for men (500 m)			−0.00371***	−0.00282***		−0.00287***
			(0.00105)	(0.00104)		(0.00105)
Distance to the nearest tertiary pipeline	−9.35e − 05	−0.000244	−0.000132	−0.000231	−0.000239	−0.000227
	(0.000176)	(0.000165)	(0.000172)	(0.000164)	(0.000166)	(0.000164)
Indoor crowding					−0.0138	−0.0134
					(0.0122)	(0.0124)
Constant	1.791***	6.567	1.797***	7.626	7.138	8.147
	(0.168)	(13.51)	(0.165)	(13.17)	(13.84)	(13.46)
Controls	N	Y	N	Y	Y	Y
Observations	298	289	298	289	287	287
R^2	0.004	0.154	0.038	0.168	0.159	0.174

Note: Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, and *p < 0.1
Each observation is a Containment Zone. Dependent variable is the log of COVID-19 cases per 1000 population in slum Containment Zones. The independent variables of interest are the number of public toilet seats in total and by gender within 500 m from the center of the Containment Zone and the distance to pipelines. Controls in columns 2, 4, 5, and 6 include the number of police chowkis in the zone, proportion of SC and ST population, literacy rate, proportion of households using electricity as the primary source of light, proportion of households using LPG as the main kitchen fuel, proportion of households that make use of banking services, proportion of households living in a permanent structure, and proportions of households that own a radio, television, computer with internet, a computer without internet, a scooter or a motorcycle and a car, jeep or a van at the census section level. The Greater Mumbai region has 88 Census Sections. Containment Zones for which police zones could not be determined have not been considered in these regressions. Columns 5 and 6 include indoor crowding as a control. Containment Zones that do not have information on indoor crowding are not considered for these regressions.
Abbreviations: LPG, liquefied petroleum gas; SC, Scheduled Castes; ST, Scheduled Tribes.

Scheduled Tribes (ST) is negative and significant and the coefficient for share of population having bank accounts is positive and significant for all runs (see Table A1). The coefficient for share of households owning a scooter or motorbike is negative and significant.

Tables A2a and A2b present the results for regression equation (1) using different distance cutoffs. At 100, 200, and 300 m, the coefficient for a number of toilet seats for men and women is not statistically significantly different from zero. Around 28% of Containment Zones and 13% of Containment Zones have 0 toilet seats within 100 and 200 m respectively. The average number of toilet seats within 100, 200, and 300 m are 32, 102, and 196, respectively. At 400, 500, and 600 m an increase in the number of toilet seats for men is associated with lower case prevalence, while an increase in the number of toilet seats for women is associated with higher case prevalence.

TABLE 4 Impact of police enforcement capacity on cases in slums and nonslum areas

Variables	Dep. variable: cases per 1000					
	All		Slums		Nonslums	
	(1)	(2)	(3)	(4)	(5)	(6)
# Of police chowkis in the jurisdiction	−15.35***	−13.39**	−9.549	−5.718	−17.88***	−15.51*
	(5.239)	(6.156)	(7.880)	(6.197)	(6.615)	(7.967)
Constant	81.83***	212.9	59.02*	−546.1	91.94***	311.2
	(21.08)	(224.4)	(32.36)	(1303)	(26.49)	(205.7)
Amenity controls	N	Y	N	Y	N	Y
Controls	N	Y	N	Y	N	Y
Observations	968	968	289	289	679	679
R^2	0.023	0.060	0.006	0.111	0.040	0.078

Note: Robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$
Each observation is a Containment Zone. Dependent variable is the number of COVID-19 cases per 1000 population in a Containment Zone. The independent variable is the number of police chowkis within the police zone corresponding to each Containment Zone. Containment Zones for which police zones could not be determined have not been considered. Controls for columns 2, 4, and 6 include the proportion of SC and ST population, literacy rate, proportion of households using electricity as the primary source of light, proportion of households using LPG as the primary kitchen fuel, proportion of households that make use of banking services, proportion of households living in a permanent structure, and proportions of households that own a radio, television, computer with internet, a computer without internet, a scooter or a motorcycle and a car, jeep or a van at the census section level. The Greater Mumbai region has 88 Census Sections. Amenity controls for columns 2, 4, and 6 include number of publicly accessible toilet seats by gender within 500 m of the Containment Zone and distance to water pipelines.
Abbreviations: LPG, liquefied petroleum gas; SC, Scheduled Castes; ST, Scheduled Tribes.

Following Briscoe et al. (1986), who reported that a combination of water supply, sanitation, and health education has the greatest effect on controlling diarrhea outbreaks, Table A3 (columns 5 and 6) includes an interaction term between the number of toilet seats within 500 m and distance to water pipes. The coefficient for the interaction term is not significant and adding the interaction term does not change the results for the main variables of interest.

7.2 | Enforcement

Table 4 shows results for the relationship between effective enforcement, as proxied by the number of police station *chowkis*, and prevalence of COVID-19, measured by cases per 1000. In case of *chawls* and sealed buildings, having a greater number of *chowkis* in the police station zone of the Containment Zone is associated with fewer cases.

Effective enforcement will reduce interactions between individuals in the Containment Zone and the outside population. For cases to be brought under control, contact within the population in the Containment Zone must decline as well. This is possible in the case of formal housing where there is little to no indoor crowding and people can maintain social distancing by staying indoors. Thus, effective enforcement combined with decline in interactions within Containment Zones is associated with fewer cases. In the case of slums, even if enforcement is effective, there is no reduction in interactions between individuals within the Containment Zones likely due to continued use of shared public facilities.

8 | LIMITATIONS AND FUTURE RESEARCH

While some of our results show significant correlations, we stop short of making any causal claims regarding the relationships between access to basic services and case prevalence. This is due to limitations in the data and potentially omitted variables that may bias our findings.

We identify two limitations in the data, which could affect measurement of case prevalence. First, our data is a snapshot of the early period of the pandemic during a time of complete lockdown in the city and we have not been able to observe the same type of data over a longer time. The second limitation pertains to testing policy. Case prevalence depends on the testing strategy adopted. If testing is low uniformly across the city, the reported case prevalence will not give a true picture of the actual prevalence. Further, although the testing policies announced by the BMC applied to all of Mumbai, in practice, there may have been differences in implementation across areas. For instance, there was a well-organized effort by authorities to test and screen residents of Dharavi (Golechha, 2020), which may not have happened in other slum areas. Omitted variables, such as community response, policy response, or behavioral changes (like, increase in mask wearing) could also bias our results.

A future research agenda directly emerges from these limitations. The first priority for future research would be getting data over a longer time horizon and better ways to control for differences in testing and containment policies across time. Further, to better understand the epidemiological role of access to adequate water in the spread of COVID-19 in slums, we need to measure access in different ways, instead of distance to water pipes. This includes accounting for different sources of water supply (which include water taps inside the house, public water taps, wells, or water tankers) and duration of water supply. An important policy research agenda would be to examine the effectiveness of policies granting different types of property rights to slums. This would involve studying whether “recognized” slums—that is, slums which are considered eligible for basic municipal services—had better amenities, such as toilets and piped water relative to nonrecognized slums.

9 | CONCLUSION

Conditions, like, poor quality housing, high levels of indoor crowding, and lack of adequate infrastructure, such as water supply and sanitation, make those living in slums more vulnerable to communicable diseases and epidemics. Data on COVID-19 seroprevalence and fatalities suggests that slums in Mumbai have experienced more pervasive outbreaks. Our study, using data on cases within Containment Zones in the period between March and June 2020, examines whether lack of access to basic services in slums is associated with higher COVID-19 cases.

Using data on the number of public toilet seats by gender, distance to water supply pipes, and number of police station outposts, together with geospatial information on Containment Zones, their population and number of cases, we test the hypothesis of whether slums with better access to basic services had fewer cases. In general, we failed to find evidence of a statistical relationship between distance to water supply pipelines and COVID-19 prevalence. The fact that distance to water pipes shows no effect on local case prevalence is consistent with the findings of Penrose et al. (2010) in the case of cholera outbreaks in Dar es Salaam and Ashraf et al. (2017), which found that existence of a water distribution network has no effect on disease outbreaks when most households remain disconnected to the pipes. Many slum households in Mumbai continue to be disconnected from water pipes and rely on other sources, including water tankers. Hence, physical proximity to water pipes may not be a good measure of actual access to adequate water. We further find that more public toilet seats for men are associated with fewer cases in slums but that the relationship runs in the opposite direction for women. Higher number of toilet seats for men may promote increased social distancing but this may not be the possible for women, who, as previous studies show, may prefer to access facilities during restricted times for reasons of safety and are more likely to share toilets with children. We also find that home indoor crowding is not significantly associated with prevalence of cases in slums. Finally, we find that while police enforcement capacity seems to matter in curbing cases in nonslum areas, there is no observable effect in slum areas.

While the general importance of access to basic services in slums is well understood, this study highlights the urgent need for urban policymakers to prioritize slum improvement to promote health resilience in times of crisis. The empirical evidence makes a case, in our view, for improving the conditions in slums in several specific ways. Better access to toilets, especially for women, and provision of water connections with adequate water supply should help tackling not just the COVID-19 pandemic but also outbreaks of other communicable diseases and improve general health associated with better hygiene and safety.

FUNDING INFORMATION

No external funding was used for this study.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in Municipal Corporation of Greater Mumbai at https://portal.mcgm.gov.in/irj/portal/anonymous. These data were derived from the following resources available in the public domain:

- Municipal Corporation of Greater Mumbai, https://dpremarks.mcgm.gov.in/dp2034/6
- Municipal Corporation of Greater Mumbai, https://stopcoronavirus.mcgm.gov.in/
- Census of India, https://censusindia.gov.in/

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How to cite this article: Tandel, V., Gandhi, S., Patranabis, S., Bettencourt, L. M. A., & Malani, A. (2022). Infrastructure, enforcement, and COVID-19 in Mumbai slums: A first look. *Journal of Regional Science*, 62, 645–669. https://doi.org/10.1111/jors.12552

APPENDIX A

See Tables A1–A3

TABLE A1 Impact of toilets and water network on cases in slums

Variables	Dep. variable: log of cases per 1000 (1)	(2)	(3)	(4)	(5)	(6)
# Of toilet seats (500 m)	0.000234	−5.06e − 05			−3.70e − 05	
	(0.000253)	(0.000269)			(0.000270)	
# Of toilet seats for women (500 m)			0.00441***	0.00292**		0.00301**
			(0.00118)	(0.00126)		(0.00126)
# Of toilet seats for men (500 m)			−0.00371***	−0.00282***		−0.00287***
			(0.00105)	(0.00104)		(0.00105)
Distance to the nearest tertiary pipeline	−9.35e − 05	−0.000244	−0.000132	−0.000231	−0.000239	−0.000227
	(0.000176)	(0.000165)	(0.000172)	(0.000164)	(0.000166)	(0.000164)
# Of police chowki in the jurisdiction		−0.0609		−0.0261	−0.0573	−0.0255
		(0.145)		(0.146)	(0.148)	(0.149)
Literacy rate		−0.126		−0.129	−0.126	−0.129
		(0.125)		(0.123)	(0.127)	(0.125)
% Scheduled caste pop		0.0116		0.0339	0.00366	0.0269
		(0.0323)		(0.0333)	(0.0340)	(0.0347)
% Scheduled tribe pop		−0.841***		−0.789***	−0.792***	−0.740***
		(0.241)		(0.236)	(0.247)	(0.243)
% Households using electricity		0.0486		0.0497	0.0343	0.0352
		(0.108)		(0.107)	(0.109)	(0.107)
% Households using LPG fuel		0.000172		0.0102	−0.00734	0.00188
		(0.0468)		(0.0455)	(0.0473)	(0.0455)
% Households with bank accounts		0.122**		0.115**	0.121**	0.114**
		(0.0548)		(0.0547)	(0.0560)	(0.0561)
% Households owning radio		0.0318		0.0407	0.0315	0.0406
		(0.0257)		(0.0262)	(0.0256)	(0.0261)
% Households owning a television		−0.0887		−0.113	−0.0759	−0.0992
		(0.0732)		(0.0709)	(0.0748)	(0.0721)

TABLE A1 (Continued)

Variables	Dep. variable: log of cases per 1000 (1)	(2)	(3)	(4)	(5)	(6)
% Households owning a computer		0.0134		0.0129	0.0469	0.0483
		(0.131)		(0.126)	(0.137)	(0.131)
% Households owning a computer with internet		−0.0145		−0.0260	−0.0402	−0.0553
		(0.156)		(0.153)	(0.158)	(0.155)
% Households living in permanent structure		−0.00985		−0.00761	−0.00655	−0.00401
		(0.0582)		(0.0570)	(0.0589)	(0.0576)
% Households owning scooter or motorbike		−0.112**		−0.105*	−0.140**	−0.132**
		(0.0546)		(0.0541)	(0.0632)	(0.0619)
% Households owning a car or vehicle		0.00249		0.0160	0.00248	0.0184
		(0.0719)		(0.0717)	(0.0742)	(0.0738)
Indoor crowding					−0.0138	−0.0134
					(0.0122)	(0.0124)
Constant	1.791***	6.567	1.797***	7.626	7.138	8.147
	(0.168)	(13.51)	(0.165)	(13.17)	(13.84)	(13.46)
Observations	298	289	298	289	287	287
R^2	0.004	0.154	0.038	0.168	0.159	0.174

Note: Robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$
Each observation is a Containment Zone. Dependent variable is the log of COVID-19 cases per 1000 population in slum Containment Zones. The independent variables of interest are the number of public toilet seats in total and by gender within 500 m of the Containment Zone and the distance to pipelines. Columns 5 and 6 include indoor crowding as a control. Containment Zones that do not have information on indoor crowding are not considered for these regressions.

Abbreviation: LPG, liquefied petroleum gas.

TABLE A2a Impact of toilets and water network on cases in slums using different distance cutoffs

Variables	Dep. variable: log of cases per 1000					
	(1)	(2)	(3)	(4)	(5)	(6)
# Of toilet seats within radius (m)						
100	0.00204					
	(0.00202)					
200		0.000314				
		(0.000894)				
300			−5.61e − 05			
			(0.000534)			
400				−0.000108		
				(0.000360)		
500					−5.06e − 05	
					(0.000269)	
600						−0.000127
						(0.000199)
Distance to the nearest tertiary pipeline	−0.000238	−0.000239	−0.000242	−0.000244	−0.000244	−0.000249
	(0.000165)	(0.000165)	(0.000164)	(0.000165)	(0.000165)	(0.000165)
Constant	5.805	6.259	6.593	6.592	6.567	6.656
	(13.57)	(13.46)	(13.49)	(13.52)	(13.51)	(13.49)
Controls	Y	Y	Y	Y	Y	Y
Observations	289	289	289	289	289	289
R^2	0.157	0.155	0.154	0.155	0.154	0.155
Avg # of toilet seats within distance cutoff	32	102	196	308	437	598

Note: Robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

Each observation is a Containment Zone. Dependent variable is the log of COVID-19 cases per 1000 population in slum Containment Zones. The independent variables of interest are the number of public toilet seats in total within 100-600 m of the Containment Zone and the distance to pipelines. Controls include the number of police chowkis in the zone, proportion of SC and ST population, literacy rate, proportion of households using electricity as the primary source of light, proportion of households using LPG as the main kitchen fuel, proportion of households that make use of banking services, proportion of households living in a permanent structure, and proportions of households that own a radio, television, computer with internet, a computer without internet, a scooter or a motorcycle and a car, jeep or a van at the census section level. The Greater Mumbai region has 88 Census Sections. Containment Zones for which police zones could not be determined have not been considered in these regressions.

Abbreviations: LPG, liquefied petroleum gas; SC, Scheduled Castes; ST, Scheduled Tribes.

TABLE A2b Impact of toilets for men and women and water network on cases in slums using different distance cutoffs

Variables	Dep. variable: log of cases per 1000 (1)	(2)	(3)	(4)	(5)	(6)
# Of toilet seats by gender within radius (m)						
Women 100	0.00376					
	(0.0103)					
Men 100	0.000347					
	(0.00983)					
Women 200		−0.00110				
		(0.00517)				
Men 200		0.00166				
		(0.00517)				
Women 300			0.00256			
			(0.00221)			
Men 300			−0.00257			
			(0.00219)			
Women 400				0.00328***		
				(0.00159)		
Men 400				−0.00333***		
				(0.00138)		
Women 500					0.00292***	
					(0.00126)	
Men 500					−0.00282***	
					(0.00104)	
Women 600						0.00202***
						(0.000944)
Men 600						−0.00211***
						(0.000788)
Distance to the nearest tertiary pipeline	−0.000239	−0.000243	−0.000236	−0.000237	−0.000231	−0.000223
	(0.000166)	(0.000164)	(0.000165)	(0.000165)	(0.000164)	(0.000165)
Constant	5.968	5.957	7.563	7.731	7.626	7.301
	(13.65)	(13.47)	(13.38)	(13.26)	(13.17)	(13.24)
Controls	Y	Y	Y	Y	Y	Y
Observations	289	289	289	289	289	289

(Continues)

TABLE A2b (Continued)

Variables	Dep. variable: log of cases per 1000 (1)	(2)	(3)	(4)	(5)	(6)
R^2	0.157	0.155	0.157	0.164	0.168	0.167
Avg # of toilet seats for women within distance cutoff	16	50	96	152	214	293
Avg # of toilet seats for men within distance cutoff	16	52	100	157	223	305

Note: Robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$
Each observation is a Containment Zone. Dependent variable is the log of COVID-19 cases per 1000 population in slum Containment Zones. The independent variables of interest are the number of public toilet seats by gender within 100-600 m of the Containment Zone and the distance to pipelines. Controls include the number of police chowkis in the zone, proportion of SC and ST population, literacy rate, proportion of households using electricity as the primary source of light, proportion of households using LPG as the main kitchen fuel, proportion of households that make use of banking services, proportion of households living in a permanent structure, and proportions of households that own a radio, television, computer with internet, a computer without internet, a scooter or a motorcycle and a car, jeep or a van at the census section level. The Greater Mumbai region has 88 Census Sections. Containment Zones for which police zones could not be determined have not been considered in these regressions.

Abbreviations: LPG, liquefied petroleum gas; SC, Scheduled Castes; ST, Scheduled Tribes.

TABLE A3 Impact of toilets and water network on cases in slums with interaction between number of toilet seats and distance to pipeline

Variables	Dep. variable: log of cases per 1000 (1)	(2)	(3)	(4)	(5)	(6)
# Of toilet seats (500 m)	0.000234	−5.06e − 05			−7.75e − 05	
	(0.000253)	(0.000269)			(0.000346)	
# Of toilet seats for women (500 m)			0.00441***	0.00292**		0.00290**
			(0.00118)	(0.00126)		(0.00126)
# Of toilet seats for men (500 m)			−0.00371***	−0.00282***		−0.00283***
			(0.00105)	(0.00104)		(0.00108)
Distance to the nearest tertiary pipeline	−9.35e − 05	−0.000244	−0.000132	−0.000231	−0.000267	−0.000245
	(0.000176)	(0.000165)	(0.000172)	(0.000164)	(0.000274)	(0.000274)
# Toilet seats∗Distance to pipeline					4.80e − 08	2.86e − 08
					(4.55e − 07)	(4.52e − 07)
Constant	1.791***	6.567	1.797***	7.626	6.476	7.572
	(0.168)	(13.51)	(0.165)	(13.17)	(13.48)	(13.13)

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TABLE A3 (Continued)

Variables	Dep. variable: log of cases per 1000					
	(1)	(2)	(3)	(4)	(5)	(6)
Controls	N	Y	N	Y	Y	Y
Observations	298	289	298	289	289	289
R^2	0.004	0.154	0.038	0.168	0.154	0.168

Note: Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, and *p < 0.1
Each observation is a Containment Zone. Dependent variable is the log of COVID-19 cases per 1000 population in slum Containment Zones. The independent variables of interest are the number of public toilet seats in total and by gender within 500 m of the Containment Zone and the distance to pipelines. Controls in columns 2, 4, 5, and 6 include the number of police chowkis in the zone, proportion of SC and ST population, literacy rate, proportion of households which use electricity as the primary source of light, proportion of households that use LPG as the main kitchen fuel, proportion of households that make use of banking services, proportion of households living in a permanent structure, and proportions of households that own a radio, television, computer with internet, a computer without internet, a scooter or a motorcycle and a car, jeep or a van at the census section level. The Greater Mumbai region has 88 Census Sections. Containment Zones for which police zones could not be determined have not been considered in these regressions. Columns 5 and 6 include the interaction term between number of accessible toilet seats and distance to pipeline.

Abbreviations: LPG, liquefied petroleum gas; SC, Scheduled Castes; ST, Scheduled Tribes.

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