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All-cause mortality during the COVID-19 pandemic in Chennai, India: an observational study

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Summary

Background India has been severely affected by the ongoing COVID-19 pandemic. However, due to shortcomings in disease surveillance, the burden of mortality associated with COVID-19 remains poorly understood. We aimed to assess changes in mortality during the pandemic in Chennai, Tamil Nadu, using data on all-cause mortality within the district.

Methods For this observational study, we analysed comprehensive death registrations in Chennai, from Jan 1, 2016, to June 30, 2021. We estimated expected mortality without the effects of the COVID-19 pandemic by fitting models to observed mortality time series during the pre-pandemic period, with stratification by age and sex. Additionally, we considered three periods of interest: the first 4 weeks of India’s first lockdown (March 24 to April 20, 2020), the 4-month period including the first wave of the pandemic in Chennai (May 1 to Aug 31, 2020), and the 4-month period including the second wave of the pandemic in Chennai (March 1 to June 30, 2021). We computed the difference between observed and expected mortality from March 1, 2020, to June 30, 2021, and compared pandemic-associated mortality across socioeconomically distinct communities (measured with use of 2011 census of India data) with regression analyses.

Findings Between March 1, 2020, and June 30, 2021, 87,870 deaths were registered in areas of Chennai district represented by the 2011 census, exceeding expected deaths by 25,990 (95% uncertainty interval 25,640–26,360) or 5.18 (5.11–5.25) excess deaths per 1000 people. Stratified by age, excess deaths numbered 21,02 (20.54–21.49) excess deaths per 1000 people for individuals aged 60–69 years, 39.74 (38.73–40.69) for those aged 70–79 years, and 96.90 (93.35–100.16) for those aged 80 years or older. Neighbourhoods with lower socioeconomic status had 0.7% to 2.8% increases in pandemic-associated mortality per 1 SD increase in each measure of community disadvantage, due largely to a disproportionate increase in mortality within these neighbourhoods during the second wave. Conversely, differences in excess mortality across communities were not clearly associated with socioeconomic status measures during the first wave. For each increase by 1 SD in measures of community disadvantage, neighbourhoods had 3.6% to 8.6% lower pandemic-associated mortality during the first 4 weeks of India’s country-wide lockdown, before widespread SARS-CoV-2 circulation was underway in Chennai. The greatest reductions in mortality during this early lockdown period were observed among men aged 20–29 years, with 58% (54–62) fewer deaths than expected from pre-pandemic trends.

Interpretation Mortality in Chennai increased substantially but heterogeneously during the COVID-19 pandemic, with the greatest burden concentrated in disadvantaged communities. Reported COVID-19 deaths greatly underestimated pandemic-associated mortality.

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Introduction India is among the most severely affected countries in the ongoing COVID-19 pandemic, with over 458,000 deaths reported by Nov 1, 2021. However, the true burden of disease is uncertain because of limitations in surveillance. Analyses informed by population-based serosurveys suggest that reported COVID-19 deaths might underestimate true mortality by a factor of seven to ten, in agreement with findings from other data sources such as household-based demographic surveys. In high-income countries, all-cause mortality data from comprehensive vital registration systems have provided insight into the extent of underreporting of deaths attributable to COVID-19, as well as disparities in pandemic-associated mortality across socioeconomic and demographic groups. However, few studies of all-cause mortality have been undertaken in India and other low-income and middle-income countries. As the extent of COVID-19 mortality and the effect of lockdown measures on other causes of death might differ in such settings compared with high-income countries, studies of this nature in India remain an important priority.

Chennai is an administrative district within the southern state of Tamil Nadu and the centre of India’s...
Research in context

Evidence before this study
We searched the terms “coronavirus disease 2019”, “COVID-19”, “all-cause”, “excess”, “deaths”, “mortality”, and “disparity” in PubMed and Google Scholar to identify studies published in English up to Sept 1, 2021, addressing the effect of the COVID-19 pandemic on deaths due to all causes, across all countries and settings, as well as studies addressing variation in COVID-19 burden across different socioeconomic groups within countries. Multiple studies of excess all-cause mortality have been undertaken in the USA, nationally and within major cities, and within both individual European countries and all countries served by the European Centre for Disease Prevention and Control, at various points in the pandemic. As of June 30, 2021, such settings recorded roughly one to two excess deaths per 1000 people associated with the COVID-19 pandemic. In New Zealand, where widespread SARS-CoV-2 transmission has not occurred, reductions in all-cause mortality have occurred during the COVID-19 pandemic. High-quality studies of excess mortality in low-income and middle-income countries were less widely available; one study generated a real-time, updated database of excess mortality estimates for 103 countries and territories based on publicly available all-cause mortality data, but information on the reliability, timeliness, and completeness of vital registration systems generating the underlying information was not readily available. We found no studies of excess all-cause mortality in India. Lastly, numerous studies have reported on ethnic and socioeconomic disparities in COVID-19 incidence and mortality, primarily in the USA and UK. Expect for large-scale studies addressing community-level predictors of variation in COVID-19 burden in Brazil and one study addressing differences in SARS-CoV-2 seroprevalence in slum and non-slum communities within Mumbai, we found no studies comparing the burden of COVID-19 (including COVID-19 mortality) across socioeconomically distinct communities within low-income and middle-income countries.

Added value of this study
In Chennai, India, where a well functioning civil registration system is in place for mortality surveillance, there were 5·2 excess deaths per 1000 individuals overall through the COVID-19 pandemic; excess mortality was substantially higher in older age groups. We observed greater increases in mortality in communities with lower socioeconomic status during the second wave of infections, but not during the first wave. We also observed reductions in all-cause mortality concentrated among young adult men and within communities of low socioeconomic status immediately after the country-wide lockdown in March 24, 2020, before SARS-CoV-2 transmission was widespread. Although lockdown-associated reductions in adult mortality were transient, we observed reduced mortality among children in Chennai throughout the pandemic.

Implications of all the available evidence
By comparison with higher-income settings, Chennai had substantial excess mortality during the COVID-19 pandemic despite the younger age distribution of its residents, with a more than two-times higher burden of excess deaths per 1000 people. COVID-19 pandemic-associated mortality in this setting is considerably underestimated by deaths reported among confirmed COVID-19 cases. Socioeconomically disadvantaged communities shouldered a greater burden of deaths during the pandemic in Chennai than higher-resource communities, although nonpharmaceutical interventions might have reduced deaths due to certain causes before widespread SARS-CoV-2 transmission was underway.

Methods

Death registrations
The CRS operates under the aegis of the Registration of Births and Deaths Act of 1969, which mandates the registration of all births and deaths in India and provides standardised elements for data collection and reporting. Throughout India, vital statistics are recorded through a network of local registration units under a decentralised model, which states and districts are expected to customise to develop effective strategies for their distinct contexts. In Tamil Nadu, a Coordinating Committee operates within each administrative district of the state to coordinate vital registration across government departments. Heads of affected households, in conjunction with executive officers of lower administrative subunits (taluks, blocks, or villages), have legal responsibility for notification of deaths in their respective areas. In Chennai district, the Coordinating Committee consists of the Collector and Deputy Commissioner of Commercial Taxes, Heads of Health and Education Departments, and the District Commissioner of Police, and is responsible for developing strategies for all-cause mortality surveillance in the 370 wards and 34 sub-districts of the district.

We analysed comprehensive death records from Chennai district from Jan 1, 2016, to June 30, 2021, with the aim of measuring changes in mortality during the period of the COVID-19 pandemic. We further examined differences in pandemic-associated mortality across socioeconomically distinct communities within Chennai, overall, and during specific periods of the pandemic.
To define predicted mortality, we fitted generalised linear models with a negative binomial link function to...
Articles

Between Jan 1, 2016, and June 30, 2021, 336 816 deaths were reported to have occurred in Chennai, including 264 858 among individuals who resided within PIN code areas corresponding to pre-2019 district boundaries. Of the 264 858 deaths, 176 988 occurred before March 1, 2020, and 87 870 (of 88 107 expected with lagged reporting; appendix 2 p 27) occurred during the pandemic period.

| Expected deaths | Observed deaths | Excess deaths | Excess mortality ratio | Excess mortality per 1000 people |
|------------------|-----------------|---------------|------------------------|---------------------------------|
| Ages 0–9 years   | 668             | -310 (-340 to -280) | 0.68 (0.66 to 0.70) | -0.53 (-0.57 to -0.48) |
| Ages 10–19 years | 157             | -60 (-70 to -50)    | 0.72 (0.68 to 0.76) | -0.11 (-0.13 to -0.09) |
| Ages 20–29 years | 347             | -70 (-90 to -50)    | 0.83 (0.80 to 0.87) | -0.08 (-0.10 to -0.06) |
| Ages 30–39 years | 683             | -10 (-30 to -10)    | 0.98 (0.95 to 1.01) | -0.01 (-0.04 to -0.01) |
| Ages 40–49 years | 152             | 230 (190 to 270)    | 1.18 (1.15 to 1.21) | 0.29 (0.25 to 0.34) |
| Ages 50–59 years | 3006            | 860 (810 to 910)    | 1.40 (1.37 to 1.44) | 1.39 (1.31 to 1.48) |
| Ages 60–69 years | 3040            | 4610 (4540 to 4680)| 2.52 (2.46 to 2.58) | 4.39 (4.18 to 4.59) |
| Ages 70–79 years | 3120            | 1810 (1730 to 1890)| 1.56 (1.53 to 1.60) | 9.71 (9.28 to 10.14) |
| Ages ≥80 years   | 3150            | 1200 (1100 to 1280)| 1.38 (1.34 to 1.42) | 22.09 (20.41 to 23.66) |
| All ages         | 19 609          | 5430 (5270 to 5590)| 1.38 (1.36 to 1.40) | 1.09 (1.06 to 1.12) |

First wave (May 1 to Aug 31, 2020)

| Ages 0–9 years   | 220              | 157             | -60 (-70 to -50)    | 0.72 (0.68 to 0.76) | -0.11 (-0.13 to -0.09) |
| Ages 10–19 years | 220              | 121             | -100 (-120 to -70)  | 0.56 (0.51 to 0.62) | -0.15 (-0.19 to -0.12) |
| Ages 20–29 years | 420              | 347             | -70 (-90 to -50)    | 0.83 (0.80 to 0.87) | -0.08 (-0.10 to -0.06) |
| Ages 30–39 years | 690              | 683             | -10 (-30 to -10)    | 0.98 (0.95 to 1.01) | -0.01 (-0.04 to -0.01) |
| Ages 40–49 years | 1290             | 152             | 230 (190 to 270)    | 1.18 (1.15 to 1.21) | 0.29 (0.25 to 0.34) |
| Ages 50–59 years | 2140             | 3006            | 860 (810 to 910)    | 1.40 (1.37 to 1.44) | 1.39 (1.31 to 1.48) |
| Ages 60–69 years | 2940             | 4400            | 1460 (1390 to 1520)| 1.50 (1.46 to 1.53) | 4.39 (4.18 to 4.59) |
| Ages 70–79 years | 3120             | 5033            | 1810 (1730 to 1890)| 1.56 (1.53 to 1.60) | 9.71 (9.28 to 10.14) |
| Ages ≥80 years   | 3150             | 4349            | 1200 (1100 to 1280)| 1.38 (1.34 to 1.42) | 22.09 (20.41 to 23.66) |
| All ages         | 14 290           | 19 609          | 5430 (5270 to 5590)| 1.38 (1.36 to 1.40) | 1.09 (1.06 to 1.12) |

Second wave (March 1 to June 30, 2021)

| Ages 0–9 years   | 220              | 139             | -80 (-100 to -70)    | 0.63 (0.59 to 0.67) | -0.14 (-0.16 to -0.12) |
| Ages 10–19 years | 210              | 158             | -50 (-80 to -40)     | 0.75 (0.67 to 0.81) | -0.09 (-0.12 to -0.06) |
| Ages 20–29 years | 420              | 430             | 10 (0 to 30)         | 1.01 (0.99 to 1.07) | 0.01 (0.00 to 0.03) |
| Ages 30–39 years | 690              | 1230            | 540 (520 to 560)     | 1.79 (1.73 to 1.84) | 0.60 (0.58 to 0.63) |
| Ages 40–49 years | 1310             | 2795            | 1480 (1440 to 1520)| 2.13 (2.07 to 2.19) | 1.86 (1.81 to 1.90) |
| Ages 50–59 years | 2210             | 5177            | 2970 (2910 to 3030)| 2.34 (2.29 to 2.41) | 4.68 (4.60 to 4.77) |
| Ages 60–69 years | 3040             | 7649            | 4610 (4540 to 4680)| 2.52 (2.46 to 2.58) | 13.51 (13.31 to 13.72) |
| Ages 70–79 years | 3370             | 7944            | 4570 (4490 to 4650)| 2.36 (2.30 to 2.41) | 23.83 (24.21 to 24.26) |
| Ages ≥80 years   | 3350             | 6764            | 3410 (3330 to 3500)| 2.02 (1.97 to 2.07) | 60.70 (59.13 to 62.22) |
| All ages         | 14 820           | 32 286          | 17 700 (17 520 to 17 870)| 2.19 (2.17 to 2.22) | 3.51 (3.48 to 3.54) |

Data are n or value (95% UI). 95% UIs were generated based on parameter uncertainty and stochastic variability in model-based predicted death counts (summed across once per 2 weeks estimates, as presented in figure 1 and figure 2). We present sex-stratified counts and rates of deaths in appendix 2 (pp 7–8). Overall and sex-stratified estimates based on an alternative modelling framework are also presented in appendix 2 (pp 11–13). UI=uncertainty interval.

Table 1: Expected and observed deaths during the COVID-19 pandemic in Chennai

Results

Between Jan 1, 2016, and June 30, 2021, 336 816 deaths were reported to have occurred in Chennai, including 264 858 among individuals who resided within PIN code areas corresponding to pre-2019 district boundaries. Of the 264 858 deaths, 176 988 occurred before March 1, 2020, and 87 870 (of 88 107 expected with lagged reporting; appendix 2 p 27) occurred during the pandemic period.
Under a continuation of pre-pandemic trends, 62,690 (95% UI 62,320–63,030) deaths were expected within the same population (table 1, figure 1). We estimated that 25,990 (25,640–26,360) excess deaths occurred in total during the pandemic period, or 5.18 (5.11–5.25) excess deaths per 1000 people.

Total excess deaths numbered 5430 (5270–5590) during the first wave and 17,700 (17,530–17,870) during the second wave (table 1). At the peak of the first and second waves (during 2-week periods surrounding June 9, 2020, and May 10, 2021), observed deaths outnumbered expected deaths by factors of 2.26 (2.01–2.54) in the first wave and 4.75 (4.26–5.36) in the second wave (figure 1).

Throughout the pandemic period, Chennai district recorded 8167 deaths among confirmed COVID-19 cases within its full population (inclusive of the PIN code areas included in our analyses and areas annexed in the 2019 redistricting), with 2530 occurring during the first wave and 4037 occurring during the second wave (appendix 2 p 26). Therefore, reported deaths under-estimated total pandemic-associated mortality by a factor of at least 3·18 (3·14–3·23) overall, and by factors of at least 2·15 (2·08–2·21) during the first wave and 4·38 (4·34–4·43) during the second wave.

Among men and women, excess deaths numbered 6·07 per 1000 men (5·98–6·17) and 4·26 per 1000 women (4·16–4·35; appendix 2 pp 7–8). Departures from expected mortality differed substantially across ages and by sex (figure 2). Although increased mortality was evident for individuals aged 30 years or older, we estimated that 32% (30–34) fewer deaths occurred than expected in children aged 0–9 years, 36% (33–39) among individuals aged 10–19 years, and 11% (9–13) in those aged 20–29 years, on the basis of pre-pandemic mortality rates (table 1). Among children, the greatest reductions in mortality were evident at ages 5–9 years (appendix 2 p 9). At older ages, observed deaths translated to increases in all-cause mortality of between 12% (11–14) at ages 30–39 years and 55% (53–57) at ages 60–69 years, with similar age-specific patterns observed among men and women (appendix 2 pp 7–8). Total excess mortality spanned 0·40 (0·35–0·45) to 96·90 (93·35–100·16) deaths per 1000 individuals between ages 30–39 years and age 80 years or older (table 1).

Analyses done with an alternative model formulation to account for changes associated with Chennai’s 2019 redistricting provided a marginally poorer fit for the pre-lockdown period of 2020 (appendix 2 pp 10, 28–29). Under this analysis approach, overall and age-specific and sex-specific estimates of excess deaths were similar to those of our primary analysis (appendix 2 pp 11–13), as were the results of sensitivity analyses fitting prediction models to time series aggregated with shorter (7-day) and longer (28-day) windows for the moving average (appendix 2 pp 14–15, 30–31).

Increased mortality was apparent for men and women aged 40–49 years and older during the first wave, whereas, during the second wave, increases were evident for men from ages 30–39 years and older and for women from ages 20–29 years and older (appendix 2 pp 7–8). Among individuals aged 20–29 years and 30–39 years, deaths declined immediately after lockdown measures were implemented on March 24, 2020 (figure 2). The greatest reduction in mortality occurred in men aged 20–29 years, with 58% (54–62) fewer deaths than expected during the early lockdown period; reduced mortality was apparent...
through ages 50–59 years among men during the early lockdown.

On the basis of 2019 mortality data, pre-pandemic life expectancy at birth in Chennai was 70·7 years (70·5–70·8), 68·0 years (67·9–68·2) for men and 73·6 years (73·4–73·8) for women (table 2, appendix 2 pp 16–19). Observed mortality during 2020 corresponded to a 1·2-year (1·0–1·3) decline in mean life expectancy at birth relative to 2019 levels, whereas in 2021, estimated declines ranged from 3·6 years (3·4–3·8) to 4·2 years (4·1–4·4) under scenarios corresponding to 2019-level or 2020-level mortality during the months of July to December. For individuals who had a pandemic-associated death, mean life-year losses totalled 12·7 years (12·5–13·0) in 2020 and 15·5 years (15·3–15·6) years in 2021 for men, and 15·8 years (15·5–16·2) in 2020 and 17·1 years (16·9–17·4) in 2021 for women (appendix 2 p 20).

70 PIN code areas had 1000 or more deaths observed over the study period. Observed mortality within each of these PIN code areas ranged from 6·7% (1·2–11·4) lower to 69·7% (58·1–82·2) higher than expected levels during the first wave (appendix 2 p 32), but differences were not consistently associated with socioeconomic attributes of communities (figure 3, appendix 2 p 21).
During the second wave, observed deaths within each PIN code area ranged from 54-6% (47-3–62-8) to 301-8% (250-8–466-8) higher than expected levels. On average, each increase by 1 SD in census-derived measures of community socioeconomic deprivation was associated with a 2-8% to 7-0% increase in mortality over pre-pandemic levels. These socioeconomic disparities in pandemic-associated mortality were likewise evident for the overall pandemic period, with 0-7% to 2-8% higher mortality observed per 1 SD increase in each measure of community socioeconomic deprivation. Similar patterns were evident in analyses of deaths among individuals aged 50 years or older, among whom deaths were more likely to be attributable to COVID-19 (appendix 2 p 22). During the first 4 weeks of the lockdown period, and before SARS-CoV-2 transmission was widespread within Chennai, observed deaths within each PIN code area were between 62-3% (56-3–66-8) lower and 37-9% (23-0–58-0) higher than expected levels. For every increase by 1 SD in measures of community socioeconomic deprivation, PIN code areas had 3-6% to 8-6% lower mortality than expected on the basis of pre-pandemic observations.

We identified similar associations in analyses relating pandemic-associated mortality in each PIN code area to principal component variables strongly associated with community-level measures of disadvantage (figure 3, appendix 2 pp 23–25). Plotted estimates of pandemic-associated mortality over time for communities stratified by socioeconomic status decile are presented in appendix 2 (p33).

Discussion

We estimated that 5-2 excess deaths occurred per 1000 residents during the COVID-19 pandemic in Chennai, representing a 41% increase over typical mortality levels. Most excess deaths occurred during the second wave of the pandemic, when mortality peaked at levels 4-75-times higher than pre-pandemic observations. However, fewer deaths were registered among children than expected on the basis of pre-pandemic observations. Communities with lower socioeconomic status had reductions in mortality during the early lockdown, but also had the greatest increases in mortality during the second wave. Therefore, such communities had a disproportionate burden of excess deaths overall. These observations provide insight into the impact of the pandemic across demographic groups in an urban setting within India, where knowledge of morbidity and mortality associated with COVID-19 remains incomplete.

Our estimates of excess mortality during the COVID-19 pandemic in Chennai exceed those from numerous higher-income settings. Although the USA, UK, Italy, and Spain have older populations than that of India, these countries recorded 1-6–2-1 excess deaths per 1000 residents through June, 2021, compared with 5-2 in Chennai. Seroprevalence studies in Chennai identified 41% prevalence of antibody reactivity in October–November, 2020, and 82% in June–July, 2021, at the conclusion of the first and second waves. Our findings show considerable excess mortality associated with this uncontrolled SARS-CoV-2 spread, confirming predictions from early modelling studies and underscoring the practical limitations of efforts to mitigate COVID-19 mortality through shielding of older or high-risk individuals amid extensive community transmission. The high burden of COVID-19 associated mortality in this setting, and the concentration of excess deaths in socio-economically disadvantaged communities, casts doubt on hygiene-related hypotheses of reduced SARS-CoV-2 severity in low-income and middle-income countries due to prevalent immunity from other infections. Assuming that most observed excess deaths were COVID-19-related fatalities, the infection-fatality ratio in Chennai corresponding to 5-2 deaths per 1000 people and 82% seroprevalence as of July, 2021, would be 0-6%, resembling estimates from demographically similar settings.

Few studies have addressed socioeconomic disparities in COVID-19 burden within India and other low-income and middle-income countries. Our findings of greater excess mortality in disadvantaged communities, particularly during the second wave, might reflect the need to work outside the home in such communities and the higher risk of transmission within crowded housing. Lower access to care in disadvantaged communities might also contribute to excess mortality, particularly if severe shortages in health-care capacity exacerbated pre-existing disparities in health-care access during the severe second wave. By contrast, we did not identify greater excess mortality in

### Table 2: Life expectancy losses during the COVID-19 pandemic in Chennai

|            | Mean life expectancy at birth, years | Decrease in life expectancy relative to 2019, years |
|------------|-------------------------------------|--------------------------------------------------|
| Overall    |                                     |                                                  |
| 2019       | 70·7 (70·0–71·4)                    | (ref)                                            |
| 2020       | 69·5 (69·4–69·6)                    | 1·2 (0·9–1·5)                                    |
| 2021       | 67·1 (66·7–67·5)                    | 3·6 (3·4–3·8)                                    |
|            | 66·4 (66·2–66·6)                    | 4·2 (4·1–4·4)                                    |
| Men        |                                     |                                                  |
| 2019       | 68·0 (67·9–68·2)                    | (ref)                                            |
| 2020       | 66·9 (66·8–67·1)                    | 1·1 (0·8–1·3)                                    |
| 2021       | 64·6 (64·4–64·7)                    | 3·5 (3·2–3·7)                                    |
|            | 63·9 (63·8–64·0)                    | 4·1 (3·9–4·4)                                    |
| Women      |                                     |                                                  |
| 2019       | 73·6 (73·4–73·8)                    | (ref)                                            |
| 2020       | 72·5 (72·3–72·6)                    | 1·1 (0·9–1·4)                                    |
| 2021       | 70·0 (69·8–70·1)                    | 3·6 (3·4–3·9)                                    |
|            | 69·4 (69·3–69·6)                    | 4·2 (4·0–4·4)                                    |

Data are estimates (95% uncertainty interval). Life tables underlying life expectancy estimates are presented in appendix 2 (pp 13–16) for men and women. Estimated life year losses for individuals who had a pandemic-associated death in 2020 and 2021 are also presented in appendix 2 (p 15). *Estimates apply mortality rates (scaled to 2021 population projections) from 2019 for the months of July to December. †Estimates apply mortality rates (scaled to 2021 population projections) from 2020 for the months of July to December.
disadvantaged communities during the first wave, potentially reflecting a higher likelihood of SARS-CoV-2 introduction and early spread within communities with greater risk of pre-lockdown SARS-CoV-2 importation through inter-state or international travel. A seroprevalence study in June–July, 2020, identified higher cumulative prevalence of SARS-CoV-2 infection within slum communities of Mumbai than in other neighborhoods.19 Although the study also reported higher estimates of the infection-fatality ratio in non-slum communities, findings...
should be interpreted cautiously due to differences in the age distribution of slum and non-slum settings and the potential for weaker case-based surveillance in slums.12 Prevalent naturally-acquired immunity in communities hit hard by early waves of SARS-CoV-2 transmission might have affected which settings were most vulnerable to having cases and deaths after the emergence of the delta variant, which is associated with enhanced transmissibility and clinical severity.13 It is important to note that our variant, which is associated with enhanced transmissibility having cases and deaths after the emergence of the delta variant, which is associated with enhanced transmissibility and clinical severity.13 It is important to note that our aggregation of deaths by PIN code area might obscure socioeconomic distinctions across communities in Chennai, where formal and makeshift housing are often closely interspersed. Direct comparisons of outcomes among residents of slum and non-slum communities might yield additional insights into differences in COVID-19 burden at extreme ends of the socioeconomic spectrum.20

The reasons for mortality reductions among children and young adult men during the early lockdown merit consideration. Unintentional injuries are the leading single cause of death among Indian adults younger than 40 years, particularly among men,21 and occur disproportionately in communities of lower socioeconomic status.22 Therefore, our findings might reflect reduced incidence of road accidents, falls, occupational injuries, and other similar causes of death as a result of lockdown-associated measures, including a ban on alcohol sales. Reported increases in the proportion of medically unattended births23 might also help to explain why young adult women and men did not have commensurate changes in mortality during the early lockdown period and first wave in our analyses. We also identified sustained reductions in mortality throughout the pandemic period for individuals aged 0–9 years and 10–19 years, including during the second wave. Communicable diseases are the leading cause of death within these age groups in India and account for 87% of deaths among children younger than 5 years. Reductions in transmission of both respiratory24,25 and enteric infections26,27 have been reported elsewhere after implementation of non-pharmaceutical interventions and might explain our observations. Lockdown measures in India have also been associated with decreased access to health care and exacerbation of common non-communicable or chronic conditions28 including cancer,29 diabetes,30 tuberculosis,31 and others.21,31 Longer-term studies remain important to determine the effect of these changes on mortality.

Although we cannot rule out the possibility that the COVID-19 pandemic interrupted the functioning of civil mortality registration, potentially to different extents across socioeconomically distinct communities, several factors support the external validity of our findings. Expected and observed deaths were in close alignment before the lockdown and during the period between the two COVID-19 waves. During the early lockdown, reductions in mortality were more pronounced among men than among women, whereas Indian vital surveillance systems are generally more susceptible to under-ascertainment of female mortality.32 Lastly, previous analyses have suggested greater degrees of underreporting of COVID-19 deaths among older age groups in India,33 by contrast with the observed concentration of excess all-cause mortality among older age groups at the start of lockdowns and throughout the pandemic period. Deaths among older adults might owe, partly, to delayed presentation to medical facilities, including among individuals with silent hypoxemia.34 Breakdowns in all-cause death registrations would lead our study to underestimate all-cause mortality during the pandemic, leading to conservative conclusions about excess deaths and life-year losses associated with COVID-19. Factors contributing to under-ascertainment of COVID-19 deaths during the pandemic in India merit closer investigation.

Our study has limitations. We analysed deaths due to all causes; determining the proportion of excess deaths attributable to interruptions in care for conditions other than COVID-19 remains a priority, although prospective studies might be needed to support reliable ascertainment of cause of death.35 Chennai residents who died in other districts might be missed by CRS data; however, the combination of inter-state and inter-district travel restrictions during the COVID-19 pandemic and the concentration of tertiary health-care facilities in Chennai reduce the likelihood of undercounting due to this factor. Our analyses of differences in mortality across communities relied on socioeconomic data from the most recent census of India, undertaken in 2011. As built environments and standards of living have changed within communities since then, estimated measures of association are probably dampened by misclassification. Community characteristics should be interpreted as indicators of relative disadvantage rather than precise measurements of current conditions.

We identified substantial mortality associated with the COVID-19 pandemic in Chennai, India, exceeding estimates of per-capita excess deaths from higher-income settings despite India’s younger age distribution.4 Studies of all-cause mortality provide a valuable opportunity to overcome limitations affecting COVID-19 burden estimates from other data sources, and they provide additional context for estimation of pandemic-associated mortality by incorporating deaths potentially missed by COVID-19 surveillance, deaths attributable to delayed health-care seeking for other conditions, and deaths associated with other conditions occurring secondary to COVID-19.5 Similar assessments should be undertaken in other low-income and middle-income settings, as well as in other parts of India, to understand demographic effects of the pandemic and to inform efforts aimed at enhancing mitigation, including expanded vaccine distribution to populations where access remains inadequate.

Contributors

JAL did the literature search. JAL, AM, and RL did the study design. AM, TN, TSS, CMB, and JAL analysed the data. JAL wrote the original draft. All authors contributed to data interpretation and to the
review and editing of the manuscript. TSS, TN, and JAL accessed and verified the data. All authors had final responsibility for the decision to submit for publication.

Declaration of interests
We declare no competing interests.

Data sharing
Aggregated civil registration system data on births and deaths are available online at the district level for all districts of Tamil Nadu (http://www.crsrn.org/birth_death_tn/). Public sharing of disaggregated mortality records used in this analysis was not permitted by the Directorate of Health and Preventive Medicine of Tamil Nadu. Individuals wishing to access these data and accompanying data dictionaries should contact the Directorate of Health and Preventive Medicine of Tamil Nadu (dphtm.tn@nic.in) to share analysis protocols and enter into a formal data access agreement.

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