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Supplementary appendix 2

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SUPPORTING INFORMATION

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

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Text S1: Supplementary methods—Model selection.

Models took the functional form

$$E[Y_t|X_t] = \exp\left(\beta_0 + \beta_1 t + \beta_2 \sin\left(\frac{2\pi t}{365.25}\right) + \beta_3 \cos\left(\frac{2\pi t}{365.25}\right) + \dots + \log(\text{pop}_t)\right),$$

where Y_t indicates the outcome variable of the two-week moving average count of deaths at time t (defined here on a continuous scale), pop_t indicates the population at time t , and sine and cosine transformations were defined for covariates corresponding to 1, 2, 3, and 4 periods per year (or period lengths of 12 months, 6 months, 4 months, and 3 months; the equation above includes a 12-month period, i.e. 365.25 days, for illustration). To correct observed death counts (Y_t) for lagged reporting of the most recent data, we divided observed counts for each date by the proportion of deaths expected to be reported by that day, based on the distribution of times from death date to report date during 2019, the last pre-pandemic year (**Figure S2**).

Boundaries of Chennai were redrawn in 2019, enlarging the area and population of the administrative district. To account for this change, and to exclude deaths among residents of other districts (e.g., those who died while receiving healthcare in Chennai), we included in our analyses only decedents who resided in postal index number (PIN) code areas within the pre-2019 district boundaries. We used projections of the district population, by age and sex, within the pre-2019 administrative boundaries based on 2011 Census of India data (available from: <https://www.census.gov/geographies/mapping-files/time-series/demo/international-programs/subnationalpopulation.html>). Because redistricting resulted in an expansion of the district area and population, and merging of administrative functions across previously distinct jurisdictions, we allowed for the possibility that this change affected deaths reporting by fitting regression models which included or did not include a distinct intercept for the period after Chennai's redistricting:

$$E[Y_t|X_t] = \exp\left(\beta_0 + \beta_1 t + \beta_2 \sin\left(\frac{2\pi t}{365.25}\right) + \beta_3 \cos\left(\frac{2\pi t}{365.25}\right) + \dots + \beta_k I[t > t_{\text{Redistrict}}] + \log(\text{pop}_t)\right).$$

We compared within-sample (January, 2016 to February, 2020) and predictive fit (pre-lockdown period of March 1-23, 2020) for models with and without the β_k parameter on the basis of least squares, in addition to comparing values of the Bayesian information criterion (BIC) to include a penalty for overfitting (**Table S6**). Models including the β_k offered superior performance on all metrics (BIC, within-sample fit, and predictive fit), and predictions based on these models were considered our primary estimates. We also generated predictions based on the alternative formulation (i.e., models fit without allowing for the β_k parameter) as a sensitivity analysis, obtaining similar results to those from our primary analyses (**Table S7, Table S8, Table S9, Figure S3, Figure S4**).

Text S2: Supplementary methods—Analyses of community socioeconomic attributes.

Socioeconomic variables measured at the PIN code level on the basis of Census of India data are listed in **Table S2** and broadly included household density (average persons per household), physical condition of dwelling structures (proportions of households occupying non-permanent dwelling structures; proportion of households occupying dilapidated or unlivable dwelling structures; and proportion of households with unfinished flooring), water and sanitation (proportion of households lacking on-site water or latrines, and proportion of households practicing open defecation), access to improved energy sources (proportion of households lacking electric lighting and proportion of households reliant on solid cooking fuels), indicators of household wealth (proportion of households lacking bank accounts or key assets used as a wealth index), and the proportion of residents belonging to scheduled castes or tribes. All variables were analyzed in their original form without logarithmic or polynomial transformations. We also measured population density as the total population estimated to reside within a 2.5km radius of the postal office corresponding to each PIN code, based on rasterized population estimates at a 0.00833° grid resolution (available from: <https://doi.org/10.7927/gya1-wp91>).

We measured the unadjusted association of each of these measures of community socioeconomic status (X) by fitting regression models expressing

$$E \left[\log \frac{Y_{\text{observed}}}{Y_{\text{predicted}}} \right] = \beta_0 + \beta_1 X.$$

Here, $Y_{\text{predicted}}$ was estimated for each PIN code according to the negative binomial regression approach described in **Text S1**. Our framework aimed to test the hypothesis that pandemic-associated mortality differed across PIN code areas in association with community socioeconomic status, as measured by each of the 13 distinct socioeconomic variables (**Figure 3, Table S15**). As we did not hypothesize that each measured attribute of communities independently contributed to differences in COVID-19 burden, the objective of our analysis was not to obtain causal inferences based on adjusted associations of each community attribute with mortality outcomes, controlling for all 12 other measures of community socioeconomic status. As a complementary approach to assess associations of pandemic-associated mortality with community socioeconomic status, we used principal component analysis (PCA) to decompose the 13 distinct socioeconomic variables into simpler indices of community socioeconomic status.

From our principal component analysis (**Table S17**), the first two principal components were considered to measure community disadvantage on the basis that they accounted for 80.7% and 12.4% of variance, respectively, across all 13 original indicators, and were directionally correlated with measures we considered to indicate poverty; values of Spearman's correlation parameter (ρ) ranged from 0.34–0.97 (with 10/13 variables showing $\rho > 0.7$) for PC1, while for PC2, ρ was positive for 11/13 variables with values of 0.17–0.61 (we obtained $\rho = -0.03$ and $\rho = -0.25$ for the correlation of PC2 with the proportion of households occupying dilapidated structures and population density, respectively). Subsequent principal components were not considered to strongly measure community socioeconomic status, as they individually accounted for <3% of variance across the socioeconomic variables analyzed, and showed directionally inconsistent relationships with these measures.

We estimated adjusted associations of relative mortality with principal component measures of community socioeconomic status (PC1 and PC2), controlling for community attributes represented by the other principal components, according to the regression equation

$$E \left[\ln \frac{Y_{\text{observed}}}{Y_{\text{predicted}}} \right] = \beta_0 + \beta_1 \text{PC}_1 + \beta_2 \text{PC}_2 + \beta_3 \text{PC}_3 + \dots + \beta_{13} \text{PC}_{13}.$$

To propagate uncertainty in our estimates of association, we constructed parameter distributions across values obtained when fitting models using 2,000 independent draws from the distribution of $Y_{\text{predicted}}$ for each PIN code area (**Table S18**). We repeated analyses in datasets subset to deaths among individuals aged ≥ 50 years, whose deaths were more likely to be attributable to COVID-19 (**Table S16, Table S19**).

Table S1: Testing, cases, and deaths by district in Tamil Nadu as of 30 June, 2021.

District	Population (est.)	Tests		Cases diagnosed		Reported COVID-19 deaths	
		Total	Per 1,000 population	Total	Per 1,000 population	Total	Per 1,000 population
Ariyalur	811,540	18285	22.5	14861	18.3	211	0.3
Chennai ¹	4,995,398	2667777	534.0	532529	106.6	8187	1.6
Coimbatore	3,717,522	102107	27.5	219504	59.0	2041	0.5
Cuddalore	2,801,447	36434	13.0	57944	20.7	762	0.3
Dharmapuri	1,619,910	163803	101.1	24502	15.1	208	0.1
Dindigul	2,321,834	27800	12.0	31615	13.6	592	0.3
Erode	2,420,705	66240	27.4	89632	37.0	589	0.2
Kancheepuram	4,298,262	37505	8.7	70232	16.3	1176	0.3
Kanyakumari	2,010,719	79600	39.6	58969	29.3	987	0.5
Karur	1,144,369	17190	15.0	22029	19.2	342	0.3
Krishnagiri	2,020,863	14284	7.1	39870	19.7	303	0.1
Madurai	3,266,226	97279	29.8	72279	22.1	1108	0.3
Nagapattinam	1,737,742	20984	12.1	17850	10.3	266	0.2
Namakkal	1,856,155	24758	13.3	44657	24.1	418	0.2
Nilgiris	790,576	45839	58.0	28353	35.9	164	0.2
Perambalur	607,634	7981	13.1	11056	18.2	198	0.3
Pudukkottai	1,739,777	20835	12.0	26966	15.5	321	0.2
Ramanathapuram	1,455,004	23389	16.1	19619	13.5	333	0.2
Salem	3,743,332	79660	21.3	87864	23.5	1472	0.4
Sivaganga	1,439,580	25824	17.9	17689	12.3	189	0.1
Thanjavur	2,586,418	67445	26.1	63575	24.6	708	0.3
Theni	1,339,385	45839	34.2	42319	31.6	493	0.4
Thiruvallur	4,007,844	67948	17.0	111025	27.7	1705	0.4
Thiruvarur	1,359,139	67445	49.6	36814	27.1	327	0.2
Thoothukkudi	1,881,504	49288	26.2	54331	28.9	378	0.2
Tiruchirappalli	2,926,558	92586	31.6	69244	23.7	910	0.3
Tirunelveli	3,308,134	54208	16.4	47207	14.3	410	0.1
Tiruppur	2,665,069	36301	13.6	82373	30.9	757	0.3
Tiruvannamalai	2,649,825	76170	28.7	49339	18.6	597	0.2
Vellore	4,231,690	47936	11.3	46919	11.1	1047	0.2
Viluppuram	3,718,410	52064	14.0	42464	11.4	330	0.1
Virudhunagar	2,088,029	28620	13.7	44536	21.3	528	0.3

¹Population projections for 2020-21 based on the 2019 redistricting of Chennai are not yet available.

Table S2: Description of socioeconomic indicators included in the analysis.

Category	Indicator	Description	Median (mean); range
Population density			
	Household crowding	Average number of persons per room across all households in the ward	2.0 (2.0); 1.3-3.7
	Population density	Population inhabiting each raster cell (at 0.00833° resolution)	252 (463); 0-65,190
Housing quality			
	Non-permanent housing structures	Proportion of households occupying makeshift or temporary dwelling structures, %	6.2 (9.1); 1.7-46.9
	Dilapidated or unlivable dwelling structures	Proportion of households occupying dwelling structures not deemed to be in "good" condition (i.e., structures classed as being in dilapidated or unlivable condition), %	17.1 (19.8); 10.5-96.9
	Households with unfinished flooring	Proportion of households occupying dwelling structures with mud or exposed earth flooring, %	0.8 (2.0); 0.0-32.3
Water, sanitation, and hygiene			
	Households lacking on-site water	Proportion of households for which the primary source of drinking water is not located on the dwelling premises, %	24.4 (30.7); 3.4-100.0
	Households practicing open defecation	Proportion of households whose members defecate in the open as a primary	0.6 (8.0); 0.0-87.1
	Households lacking on-site latrines	Proportion of households without a flush toilet or pit latrine for waste disposal located on the dwelling premises, %	5.1 (11.6); 0.1-87.1
Fuel and energy			
	Households lacking electric lighting	Proportion of households without electric lighting in the dwelling premises, %	0.7 (1.5); 0.1-17.7
	Households reliant on solid cooking fuels	Proportion of households using firewood, crop fuel, coal, or other solid fuel sources for cooking, %	3.5 (6.2); 1.1-71.0
Wealth and marginalization			
	Population belonging to scheduled castes or tribes	Proportion of individuals belonging to groups recognized by the 1976 Scheduled Castes and Scheduled Tribes Orders (Amendment) Act, %	13.3 (16.2); 1.7-51.5
	Households lacking bank accounts	Proportion of households not availing of banking services, %	23.1 (27.5); 4.1-75.0
	Households lacking key index assets	Proportion of households lacking all of the following assets: a computer (with or without internet connection), phone (mobile or landline), bicycle, scooter/motorcycle/moped, and car/jeep/van, %	0.8 (1.3); 0.1-11.3

Associations of each community characteristic with excess mortality during various stages of the pandemic are presented in **Figure 3**, **Table S15**, and **Table S16**. Median, mean, and range for the population density variable summarize all raster cells country-wide.

Table S3: Expected and observed deaths among males during the COVID-19 pandemic in Chennai.

Period	Age group	Expected deaths (95% UI)	Observed deaths	Excess deaths (95% UI)	Excess mortality ratio (95% UI)	Excess mortality per 1000 (95% UI)
March, 2020 to June, 2021	0-9 years	520 (500, 540)	354	-170 (-190, -150)	0.68 (0.65, 0.70)	-0.54 (-0.61, -0.48)
	10-19 years	480 (460, 500)	321	-160 (-180, -140)	0.67 (0.64, 0.69)	-0.50 (-0.56, -0.44)
	20-29 years	1,180 (1,150, 1,210)	1012	-170 (-200, -140)	0.86 (0.84, 0.88)	-0.37 (-0.43, -0.30)
	30-39 years	2,120 (2,080, 2,160)	2,345	220 (180, 260)	1.10 (1.08, 1.13)	0.48 (0.39, 0.57)
	40-49 years	3,930 (3,860, 4,000)	4,958	1,030 (960, 1,100)	1.26 (1.24, 1.29)	2.55 (2.38, 2.73)
	50-59 years	6,040 (5,930, 6,130)	8,411	2,370 (2,280, 2,480)	1.39 (1.37, 1.42)	7.45 (7.16, 7.78)
	60-69 years	7,440 (7,320, 7,570)	11,605	4,170 (4,040, 4,290)	1.56 (1.53, 1.59)	25.08 (24.30, 25.81)
	70-79 years	7,250 (7,130, 7,380)	11,702	4,450 (4,320, 4,570)	1.61 (1.59, 1.64)	51.13 (49.66, 52.54)
	≥80 years	6,330 (6,220, 6,440)	9,694	3,360 (3,250, 3,480)	1.53 (1.50, 1.56)	154.28 (149.08, 159.52)
	All ages	35,290 (35,050, 35,530)	50,402	15,460 (15,210, 15,700)	1.44 (1.43, 1.45)	6.07 (5.98, 6.17)
Initial lockdown (24 March to 20 April, 2020)	0-9 years	27 (23, 31)	22	-5 (-10, -1)	0.82 (0.70, 0.96)	-0.02 (-0.03, 0.00)
	10-19 years	25 (22, 29)	15	-10 (-14, -7)	0.60 (0.51, 0.69)	-0.03 (-0.04, -0.02)
	20-29 years	65 (58, 72)	27	-38 (-45, -31)	0.42 (0.38, 0.46)	-0.08 (-0.10, -0.07)
	30-39 years	114 (106, 123)	79	-35 (-44, -26)	0.69 (0.64, 0.75)	-0.08 (-0.09, -0.06)
	40-49 years	210 (200, 230)	175	-40 (-50, -20)	0.82 (0.76, 0.88)	-0.10 (-0.14, -0.06)
	50-59 years	320 (300, 350)	283	-40 (-60, -20)	0.88 (0.82, 0.94)	-0.12 (-0.20, -0.06)
	60-69 years	380 (360, 410)	390	10 (-20, 30)	1.02 (0.96, 1.09)	0.05 (-0.11, 0.21)
	70-79 years	380 (350, 410)	387	10 (-20, 40)	1.03 (0.95, 1.10)	0.12 (-0.21, 0.41)
	≥80 years	330 (310, 360)	384	50 (30, 80)	1.17 (1.08, 1.26)	2.56 (1.36, 3.71)
	All ages	1,860 (1,800, 1,910)	1,762	-80 (-140, -30)	0.95 (0.93, 0.98)	-0.03 (-0.05, -0.01)
Wave 1 (May to August, 2020)	0-9 years	120 (110, 130)	77	-45 (-55, -36)	0.63 (0.59, 0.68)	-0.14 (-0.18, -0.12)
	10-19 years	115 (106, 124)	62	-50 (-60, -40)	0.54 (0.50, 0.59)	-0.16 (-0.19, -0.14)
	20-29 years	290 (280, 310)	218	-70 (-90, -60)	0.75 (0.71, 0.78)	-0.16 (-0.19, -0.13)
	30-39 years	510 (490, 530)	486	-20 (-40, 0)	0.95 (0.92, 0.99)	-0.05 (-0.09, -0.01)
	40-49 years	910 (880, 940)	1,001	100 (60, 130)	1.10 (1.07, 1.14)	0.24 (0.16, 0.31)
	50-59 years	1,370 (1,330, 1,410)	1,889	520 (480, 560)	1.38 (1.34, 1.42)	1.65 (1.51, 1.79)
	60-69 years	1,670 (1,620, 1,730)	2,516	840 (790, 890)	1.50 (1.46, 1.55)	5.13 (4.80, 5.43)
	70-79 years	1,650 (1,590, 1,700)	2,723	1,080 (1,020, 1,140)	1.65 (1.60, 1.72)	12.54 (11.90, 13.23)
	≥80 years	1,380 (1,320, 1,430)	2,153	780 (720, 830)	1.56 (1.51, 1.63)	36.26 (33.80, 38.72)
	All ages	8,010 (7,900, 8,130)	11,125	3,180 (3,070, 3,290)	1.40 (1.38, 1.42)	1.26 (1.21, 1.30)
Wave 2 (March to June, 2021)	0-9 years	120 (110, 130)	74	-40 (-50, -30)	0.63 (0.58, 0.68)	-0.14 (-0.17, -0.11)
	10-19 years	120 (110, 130)	90	-27 (-35, -18)	0.77 (0.72, 0.83)	-0.08 (-0.11, -0.06)
	20-29 years	290 (270, 300)	277	-10 (-20, 0)	0.96 (0.92, 1.01)	-0.02 (-0.05, 0.01)
	30-39 years	500 (490, 520)	874	370 (350, 390)	1.73 (1.67, 1.80)	0.79 (0.75, 0.83)
	40-49 years	920 (890, 960)	1,863	940 (910, 980)	2.02 (1.95, 2.10)	2.32 (2.24, 2.41)
	50-59 years	1,410 (1,360, 1,460)	3,066	1,660 (1,610, 1,700)	2.17 (2.11, 2.25)	5.14 (4.99, 5.28)
	60-69 years	1,720 (1,670, 1,780)	4,322	2,600 (2,550, 2,660)	2.52 (2.43, 2.59)	15.47 (15.12, 15.79)
	70-79 years	1,690 (1,630, 1,750)	4,283	2,590 (2,530, 2,650)	2.53 (2.44, 2.62)	29.38 (28.67, 30.03)
	≥80 years	1,460 (1,410, 1,520)	3,418	1,950 (1,900, 2,010)	2.34 (2.25, 2.43)	87.99 (85.56, 90.43)
	All ages	8,230 (8,120, 8,360)	18,267	10,180 (10,050, 10,300)	2.24 (2.20, 2.27)	3.98 (3.93, 4.03)

UI: uncertainty interval, generated based on parameter uncertainty and stochastic variability in model-based predicted death counts. Estimates based on an alternative model formulation are presented in Table S7.

Table S4: Expected and observed deaths among females during the COVID-19 pandemic in Chennai.

Period	Age group	Expected deaths (95% UI)	Observed deaths	Excess deaths (95% UI)	Excess mortality ratio (95% UI)	Excess mortality per 1000 (95% UI)
March, 2020 to June, 2021	0-9 years	460 (440, 480)	314	-140 (-160, -120)	0.69 (0.66, 0.72)	-0.51 (-0.57, -0.44)
	10-19 years	430 (390, 470)	257	-170 (-210, -130)	0.60 (0.55, 0.67)	-0.56 (-0.70, -0.43)
	20-29 years	540 (520, 560)	517	-20 (-40, 0)	0.96 (0.93, 1.00)	-0.05 (-0.08, -0.01)
	30-39 years	810 (790, 830)	944	140 (110, 160)	1.17 (1.14, 1.20)	0.31 (0.26, 0.37)
	40-49 years	1,630 (1,590, 1,660)	2,388	760 (730, 800)	1.47 (1.44, 1.50)	1.95 (1.86, 2.04)
	50-59 years	3,280 (3,220, 3,340)	5,061	1,780 (1,730, 1,840)	1.54 (1.52, 1.57)	5.79 (5.60, 5.96)
	60-69 years	5,520 (5,420, 5,620)	8,424	2,910 (2,800, 3,010)	1.53 (1.50, 1.56)	17.05 (16.43, 17.62)
	70-79 years	6,920 (6,790, 7,040)	9,986	3,070 (2,940, 3,200)	1.44 (1.42, 1.47)	30.03 (28.81, 31.31)
	≥80 years	7,830 (7,670, 7,970)	9,799	1,970 (1,820, 2,130)	1.25 (1.23, 1.28)	59.16 (54.67, 63.88)
	All ages	27,390 (27,160, 27,630)	37,690	10,530 (10,280, 10,750)	1.38 (1.37, 1.40)	4.26 (4.16, 4.35)
Initial lockdown (24 March to 20 April, 2020)	0-9 years	27 (22, 32)	18	-9 (-14, -4)	0.68 (0.57, 0.81)	-0.03 (-0.05, -0.01)
	10-19 years	15 (10, 23)	10	-5 (-13, 0)	0.65 (0.44, 0.97)	-0.02 (-0.04, 0.00)
	20-29 years	32 (28, 37)	18	-14 (-19, -10)	0.56 (0.49, 0.64)	-0.03 (-0.04, -0.02)
	30-39 years	40 (35, 45)	52	12 (7, 17)	1.31 (1.16, 1.47)	0.03 (0.02, 0.04)
	40-49 years	90 (80, 100)	89	2 (-7, 9)	1.02 (0.93, 1.11)	0.00 (-0.02, 0.02)
	50-59 years	170 (160, 190)	179	5 (-7, 17)	1.03 (0.96, 1.10)	0.02 (-0.02, 0.05)
	60-69 years	280 (260, 310)	295	10 (-10, 30)	1.04 (0.97, 1.12)	0.07 (-0.06, 0.19)
	70-79 years	380 (350, 410)	380	0 (-20, 30)	1.01 (0.94, 1.09)	0.03 (-0.24, 0.30)
	≥80 years	400 (370, 430)	440	40 (10, 70)	1.11 (1.02, 1.20)	1.30 (0.31, 2.20)
	All ages	1,440 (1,390, 1,490)	1,481	60 (10, 110)	1.04 (1.01, 1.08)	0.02 (0.00, 0.04)
Wave 1 (May to August, 2020)	0-9 years	100 (90, 110)	80	-20 (-30, -10)	0.82 (0.76, 0.89)	-0.06 (-0.09, -0.03)
	10-19 years	100 (90, 130)	59	-40 (-70, -30)	0.58 (0.47, 0.70)	-0.14 (-0.22, -0.09)
	20-29 years	120 (110, 130)	129	5 (-3, 13)	1.04 (0.98, 1.11)	0.01 (-0.01, 0.03)
	30-39 years	190 (180, 200)	196	11 (0, 21)	1.06 (1.00, 1.12)	0.02 (0.00, 0.05)
	40-49 years	380 (370, 400)	519	140 (120, 150)	1.35 (1.30, 1.41)	0.35 (0.31, 0.39)
	50-59 years	780 (750, 800)	1,117	340 (320, 370)	1.44 (1.40, 1.49)	1.12 (1.04, 1.21)
	60-69 years	1,270 (1,230, 1,310)	1,884	620 (570, 660)	1.49 (1.43, 1.54)	3.66 (3.39, 3.91)
	70-79 years	1,570 (1,510, 1,620)	2,300	730 (680, 790)	1.47 (1.42, 1.52)	7.29 (6.75, 7.86)
	≥80 years	1,780 (1,710, 1,850)	2,196	420 (350, 490)	1.24 (1.19, 1.28)	12.81 (10.70, 14.85)
	All ages	6,280 (6,170, 6,380)	8,480	2,240 (2,140, 2,350)	1.36 (1.34, 1.38)	0.91 (0.87, 0.96)
Wave 2 (March to June, 2021)	0-9 years	103 (95, 112)	65	-40 (-50, -30)	0.63 (0.58, 0.68)	-0.14 (-0.17, -0.11)
	10-19 years	100 (80, 120)	68	-30 (-50, -10)	0.72 (0.59, 0.85)	-0.09 (-0.16, -0.04)
	20-29 years	130 (120, 140)	152	20 (10, 30)	1.18 (1.10, 1.26)	0.05 (0.03, 0.07)
	30-39 years	190 (180, 200)	356	170 (160, 180)	1.92 (1.82, 2.03)	0.39 (0.37, 0.42)
	40-49 years	390 (370, 410)	929	540 (520, 550)	2.38 (2.28, 2.48)	1.37 (1.33, 1.41)
	50-59 years	800 (770, 820)	2107	1,310 (1,280, 1,340)	2.65 (2.56, 2.74)	4.20 (4.11, 4.29)
	60-69 years	1,320 (1,270, 1,360)	3324	2,010 (1,960, 2,050)	2.52 (2.44, 2.61)	11.60 (11.34, 11.86)
	70-79 years	1,680 (1,630, 1,740)	3662	1,980 (1,920, 2,040)	2.18 (2.11, 2.25)	19.12 (18.58, 19.67)
	≥80 years	1,890 (1,820, 1,960)	3346	1,460 (1,380, 1,530)	1.77 (1.70, 1.84)	42.84 (40.62, 44.89)
	All ages	6,590 (6,480, 6,710)	14,009	7,510 (7,390, 7,620)	2.14 (2.10, 2.18)	3.02 (2.97, 3.07)

UI: uncertainty interval, generated based on parameter uncertainty and stochastic variability in model-based predicted death counts. Estimates based on an alternative model formulation are presented in **Table S8**.

Table S5: All-cause mortality for various age ranges among children and adolescents.

Age (years)	Calendar period in reference year (2019) and pandemic years (2020, 2021)										
	January-June			July-December		Early lockdown (24 March-20 April)		Wave 1 (May to August)		Wave 2 (March to June)	
	2019 (ref.)	2020	2021	2019 (ref.)	2020	2019 (ref.)	2020	2019 (ref.)	2020	2019 (ref.)	2021
0-1	64	81	52	108	73	6	15	55	42	43	35
2-4	114	107	106	163	116	23	15	79	69	70	65
5-9	105	57	66	124	100	8	10	68	46	65	38
10-14	95	54	91	98	72	12	7	57	37	57	57
15-19	178	113	153	161	171	32	18	105	84	116	101

Data in the table convey total deaths over each respective period for a reference year (2019) and the subsequent pandemic years (2020 and 2021, as applicable); numbers within these subgroups were too sparse for regression analyses of age-stratified time series.

Table S6: Measures of fit for alternative model formulations.

Model formulation	BIC	Mean squared error in predictions	
		Within-sample period (January, 2016 to February, 2020)	Out-of-sample, pre-lockdown period (March 1-22, 2020)
Without accounting for secular change after redistricting	14,037.5	420.2	34.7
Accounting for secular change after redistricting	13,989.8	402.5	22.2

Alternative model formulations are described in **Text S1**.

Table S7: Expected and observed deaths during the COVID-19 pandemic in Chennai, for models without secular reporting changes amid redistricting.

Period	Age group	Expected deaths (95% UI)	Observed deaths	Excess deaths (95% UI)	Excess mortality ratio (95% UI)	Excess mortality per 1000 (95% UI)
March, 2020 to June, 2021	0-9 years	950 (930, 980)	668	-290 (-310, -260)	0.70 (0.68, 0.72)	-0.48 (-0.53, -0.44)
	10-19 years	940 (900, 990)	579	-360 (-410, -320)	0.61 (0.58, 0.65)	-0.59 (-0.67, -0.51)
	20-29 years	1,690 (1,660, 1,720)	1,530	-160 (-190, -130)	0.91 (0.89, 0.92)	-0.18 (-0.21, -0.14)
	30-39 years	2,950 (2,900, 3,000)	3,291	340 (300, 390)	1.12 (1.10, 1.14)	0.38 (0.33, 0.44)
	40-49 years	5,690 (5,600, 5,760)	7,350	1,660 (1,590, 1,750)	1.29 (1.28, 1.31)	2.10 (2.00, 2.21)
	50-59 years	9,860 (9,730, 9,970)	13,475	3,620 (3,500, 3,740)	1.37 (1.35, 1.38)	5.78 (5.59, 5.97)
	60-69 years	13,900 (13,730, 14,090)	20,033	6,130 (5,940, 6,300)	1.44 (1.42, 1.46)	18.21 (17.65, 18.72)
	70-79 years	15,620 (15,420, 15,840)	21,687	6,060 (5,850, 6,270)	1.39 (1.37, 1.41)	32.06 (30.93, 33.12)
	≥80 years	15,130 (14,930, 15,330)	19,494	4,360 (4,170, 4,560)	1.29 (1.27, 1.31)	79.08 (75.51, 82.73)
	All ages	66,720 (66,330, 67,140)	88,107	21,950 (21,540, 22,340)	1.33 (1.32, 1.34)	4.37 (4.29, 4.45)
Initial lockdown (24 March to 20 April, 2020)	0-9 years	53 (47, 59)	40	-13 (-19, -7)	0.76 (0.68, 0.85)	-0.02 (-0.03, -0.01)
	10-19 years	42 (36, 50)	25	-20 (-30, -10)	0.60 (0.50, 0.70)	-0.03 (-0.04, -0.02)
	20-29 years	96 (88, 103)	45	-50 (-60, -40)	0.47 (0.44, 0.51)	-0.06 (-0.07, -0.05)
	30-39 years	160 (150, 170)	131	-20 (-40, -10)	0.84 (0.79, 0.90)	-0.03 (-0.04, -0.02)
	40-49 years	310 (290, 330)	264	-40 (-60 -30)	0.86 (0.81, 0.91)	-0.06 (-0.08, -0.03)
	50-59 years	520 (490, 550)	462	-60 (-80, -30)	0.89 (0.85, 0.94)	-0.09 (-0.14, -0.05)
	60-69 years	710 (670, 740)	685	-20 (-60, 10)	0.97 (0.92, 1.02)	-0.06 (-0.17, 0.04)
	70-79 years	810 (770, 860)	767	-50 (-90, 0)	0.94 (0.89, 1.00)	-0.24 (-0.49, -0.02)
	≥80 years	770 (730, 810)	824	60 (10, 100)	1.07 (1.02, 1.14)	1.02 (0.26, 1.83)
	All ages	3,460 (3,380, 3,540)	3,243	-190 (-280, -110)	0.94 (0.92, 0.97)	-0.04 (-0.06, -0.03)
Wave 1 (May to August, 2020)	0-9 years	220 (200, 230)	157	-60 (-70, -50)	0.73 (0.69, 0.77)	-0.10 (-0.12, -0.08)
	10-19 years	220 (200, 250)	121	-100 (-130, -80)	0.54 (0.49, 0.60)	-0.17 (-0.21, -0.13)
	20-29 years	410 (400, 430)	347	-60 (-80, -50)	0.84 (0.81, 0.88)	-0.07 (-0.09, -0.05)
	30-39 years	700 (680, 720)	683	-20 (-40, 0)	0.98 (0.95, 1.01)	-0.02 (-0.04, 0.01)
	40-49 years	1,320 (1,280, 1,360)	1,522	210 (170, 250)	1.16 (1.12, 1.19)	0.26 (0.21, 0.31)
	50-59 years	2,260 (2,200, 2,310)	3,006	750 (700, 800)	1.33 (1.30, 1.37)	1.21 (1.13, 1.30)
	60-69 years	3,130 (3,060, 3,210)	4,401	1,270 (1,190, 1,340)	1.40 (1.37, 1.44)	3.82 (3.58, 4.04)
	70-79 years	3,500 (3,420, 3,590)	5,023	1,530 (1,440, 1,610)	1.44 (1.40, 1.47)	8.18 (7.70, 8.62)
	≥80 years	3,350 (3,260, 3,430)	4,349	1,000 (920, 1,090)	1.30 (1.27, 1.33)	18.49 (16.95, 20.10)
	All ages	15,100 (14,930, 15,270)	19,609	4,620 (4,460, 4,790)	1.31 (1.29, 1.32)	0.93 (0.89, 0.96)
Wave 2 (March to June, 2021)	0-9 years	210 (200, 230)	139	-70 (-90, -60)	0.65 (0.61, 0.68)	-0.13 (-0.15, -0.11)
	10-19 years	220 (200, 250)	158	-60 (-90, -40)	0.71 (0.64, 0.78)	-0.10 (-0.15, -0.07)
	20-29 years	410 (390, 420)	430	20 (10, 40)	1.05 (1.01, 1.09)	0.02 (0.01, 0.04)
	30-39 years	700 (680, 720)	1,230	530 (510, 560)	1.77 (1.72, 1.82)	0.59 (0.57, 0.62)
	40-49 years	1,360 (1,320, 1,400)	2,795	1,440 (1,400, 1,480)	2.06 (2.00, 2.12)	1.80 (1.75, 1.85)
	50-59 years	2,390 (2,330, 2,450)	5,177	2,790 (2,730, 2,840)	2.17 (2.11, 2.22)	4.39 (4.30, 4.48)
	60-69 years	3,350 (3,280, 3,430)	7,649	4,290 (4,220, 4,370)	2.28 (2.23, 2.33)	12.59 (12.36, 12.82)
	70-79 years	3,860 (3,770, 3,960)	7,944	4,080 (3,990, 4,180)	2.06 (2.01, 2.11)	21.28 (20.79, 21.77)
	≥80 years	3,670 (3,570, 3,770)	6,764	3,090 (3,000, 3,200)	1.84 (1.80, 1.90)	55.01 (53.29, 56.82)
	All ages	16,170 (16,010, 16,350)	32,286	16,350 (16,170, 16,520)	2.01 (1.99, 2.03)	3.24 (3.21, 3.28)

UI: uncertainty interval, generated based on parameter uncertainty and stochastic variability in model-based predicted death counts. Sex-stratified estimates are presented in **Table S8** and **Table S9**.

Table S8: Expected and observed deaths among males during the COVID-19 pandemic in Chennai, for models without secular reporting changes amid redistricting.

Period	Age group	Expected deaths (95% UI)	Observed deaths	Excess deaths (95% UI)	Excess mortality ratio (95% UI)	Excess mortality per 1000 (95% UI)
March, 2020 to June, 2021	0-9 years	510 (490, 530)	354	-160 (-180, -140)	0.69 (0.66, 0.72)	-0.52 (-0.58, -0.45)
	10-19 years	480 (460, 500)	321	-160 (-180, -140)	0.67 (0.64, 0.70)	-0.50 (-0.56, -0.44)
	20-29 years	1,200 (1,170, 1,220)	1012	-180 (-210, -160)	0.85 (0.83, 0.87)	-0.40 (-0.46, -0.34)
	30-39 years	2,140 (2,100, 2,180)	2,345	200 (160, 240)	1.10 (1.07, 1.12)	0.44 (0.35, 0.52)
	40-49 years	4,020 (3,940, 4,090)	4,958	940 (870, 1,020)	1.23 (1.21, 1.26)	2.34 (2.16, 2.52)
	50-59 years	6,350 (6,240, 6,450)	8,411	2,060 (1,960, 2,170)	1.32 (1.30, 1.35)	6.47 (6.16, 6.81)
	60-69 years	7,870 (7,750, 8,010)	11,605	3,730 (3,600, 3,860)	1.47 (1.45, 1.50)	22.45 (21.64, 23.21)
	70-79 years	7,940 (7,820, 8,090)	11,702	3,760 (3,610, 3,880)	1.47 (1.45, 1.50)	43.19 (41.48, 44.62)
	≥80 years	6,810 (6,690, 6,940)	9,694	2,890 (2,750, 3,000)	1.42 (1.40, 1.45)	132.33 (126.28, 137.60)
	All ages	37,320 (37,040, 37,600)	50,402	13,420 (13,150, 13,700)	1.36 (1.35, 1.37)	5.27 (5.16, 5.38)
Initial lockdown (24 March to 20 April, 2020)	0-9 years	27 (23, 32)	22	-5 (-10, -1)	0.83 (0.70, 1.00)	-0.02 (-0.03, 0.00)
	10-19 years	25 (22, 29)	15	-10 (-14, -7)	0.60 (0.51, 0.70)	-0.03 (-0.05, -0.02)
	20-29 years	65 (59,72)	27	-40 (-50, -30)	0.41 (0.37, 0.46)	-0.08 (-0.10, -0.07)
	30-39 years	120 (110, 130)	79	-40 (-50, -30)	0.69 (0.53, 0.74)	-0.08 (-0.10, -0.06)
	40-49 years	220 (200, 240)	175	-40 (-60, -30)	0.80 (0.74, 0.86)	-0.11 (-0.15, -0.07)
	50-59 years	340 (310, 360)	283	-50 (-80, -30)	0.84 (0.79, 0.90)	-0.17 (-0.24, -0.10)
	60-69 years	400 (370, 430)	390	-10 (-40, 20)	0.98 (0.91, 1.04)	-0.06 (-0.24, 0.10)
	70-79 years	410 (380, 440)	387	-20 (-50, 10)	0.95 (0.89, 1.03)	-0.22 (-0.59, 0.12)
	≥80 years	350 (320, 380)	384	40 (10, 60)	1.10 (1.02, 1.19)	1.67 (0.33, 2.85)
	All ages	1,940 (1,880, 2,000)	1,762	-170 (-230, -110)	0.91 (0.88, 0.94)	-0.07 (-0.09, -0.04)
Wave 1 (May to August, 2020)	0-9 years	120 (110, 130)	77	-40 (-50, -30)	0.64 (0.60, 0.69)	-0.14 (-0.17, -0.11)
	10-19 years	115 (107, 124)	62	-50 (-60, -40)	0.54 (0.50, 0.58)	-0.16 (-0.19, -0.14)
	20-29 years	300 (280, 310)	218	-80 (-90, -60)	0.74 (0.70, 0.77)	-0.17 (-0.20, -0.14)
	30-39 years	510 (500, 530)	486	-30 (-50, -10)	0.95 (0.91, 0.98)	-0.06 (-0.10, -0.02)
	40-49 years	920 (890, 960)	1,001	80 (40, 110)	1.09 (1.05, 1.13)	0.20 (0.11, 0.28)
	50-59 years	1,430 (1,390, 1,480)	1,889	460 (410, 500)	1.32 (1.28, 1.36)	1.45 (1.31, 1.59)
	60-69 years	1,760 (1,710, 1,820)	2,516	750 (690, 810)	1.43 (1.38, 1.47)	4.59 (4.21, 4.92)
	70-79 years	1,780 (1,720, 1,840)	2,723	940 (880, 1,000)	1.53 (1.48, 1.58)	10.96 (10.24, 11.64)
	≥80 years	1,470 (1,420, 1,530)	2,153	680 (630, 730)	1.46 (1.41, 1.51)	31.85 (29.22, 34.15)
	All ages	8,420 (8,310, 8,540)	11,125	2,780 (2,660, 2,890)	1.33 (1.31, 1.35)	1.10 (1.05, 1.14)
Wave 2 (March to June, 2021)	0-9 years	115 (106, 125)	74	-40 (-50, -30)	0.64 (0.59, 0.70)	-0.13 (-0.16, -0.11)
	10-19 years	120 (110, 130)	90	-30 (-40, -20)	0.77 (0.71, 0.83)	-0.09 (-0.11, -0.06)
	20-29 years	290 (280, 310)	277	-20 (-30, 0)	0.94 (0.90, 0.99)	-0.04 (-0.07, -0.01)
	30-39 years	510 (490, 530)	874	360 (340, 380)	1.71 (1.65, 1.78)	0.78 (0.74, 0.82)
	40-49 years	950 (920, 990)	1,863	910 (870, 940)	1.96 (1.88, 2.03)	2.25 (2.16, 2.33)
	50-59 years	1,510 (1,460, 1,570)	3,066	1,550 (1,500, 1,610)	2.03 (1.96, 2.10)	4.82 (4.65, 4.98)
	60-69 years	1,860 (1,800, 1,920)	4,322	2,460 (2,400, 2,520)	2.32 (2.25, 2.40)	14.62 (14.26, 14.97)
	70-79 years	1,920 (1,850, 1,990)	4,283	2,360 (2,300, 2,430)	2.23 (2.15, 2.31)	26.80 (26.02, 27.57)
	≥80 years	1,620 (1,560, 1,680)	3,418	1,800 (1,740, 1,860)	2.11 (2.03, 2.19)	81.04 (78.19, 83.50)
	All ages	8,900 (8,780, 9,020)	18,267	9,510 (9,390, 9,640)	2.07 (2.04, 2.10)	3.72 (3.67, 3.77)

UI: uncertainty interval, generated based on parameter uncertainty and stochastic variability in model-based predicted death counts.

Table S9: Expected and observed deaths among females during the COVID-19 pandemic in Chennai, for models without secular reporting changes amid redistricting.

Period	Age group	Expected deaths (95% UI)	Observed deaths	Excess deaths (95% UI)	Excess mortality ratio (95% UI)	Excess mortality per 1000 (95% UI)
March, 2020 to June, 2021	0-9 years	440 (420, 460)	314	-130 (-140, -110)	0.71 (0.69, 0.74)	-0.44 (-0.51, -0.38)
	10-19 years	460 (420, 510)	257	-200 (-250, -160)	0.56 (0.51, 0.61)	-0.68 (-0.83, -0.54)
	20-29 years	490 (480, 510)	517	20 (10, 40)	1.05 (1.01, 1.08)	0.05 (0.01, 0.09)
	30-39 years	810 (780, 830)	944	140 (120, 160)	1.17 (1.14, 1.21)	0.32 (0.27, 0.37)
	40-49 years	1,670 (1,630, 1,700)	2,388	720 (680, 760)	1.43 (1.40, 1.46)	1.85 (1.75, 1.94)
	50-59 years	3,510 (3,450, 3,570)	5,061	1,550 (1,490, 1,610)	1.44 (1.42, 1.47)	5.03 (4.84, 5.22)
	60-69 years	6,030 (5,910, 6,140)	8,424	2,390 (2,290, 2,510)	1.40 (1.37, 1.42)	14.03 (13.41, 14.72)
	70-79 years	7,670 (7,540, 7,820)	9,986	2,310 (2,170, 2,440)	1.30 (1.28, 1.32)	22.65 (21.25, 23.94)
	≥80 years	8,320 (8,170, 8,470)	9,799	1,480 (1,330, 1,630)	1.18 (1.16, 1.20)	44.39 (39.94, 48.93)
	All ages	29,400 (29,140, 29,680)	37,690	8,520 (8,240, 8,770)	1.29 (1.28, 1.30)	3.44 (3.33, 3.55)
Initial lockdown (24 March to 20 April, 2020)	0-9 years	26 (22, 31)	18	-8 (-13, -4)	0.69 (0.59, 0.83)	-0.03 (-0.04, -0.01)
	10-19 years	16 (12, 25)	10	-6 (-15, -2)	0.61 (0.41, 0.87)	-0.02 (-0.05, -0.01)
	20-29 years	30 (26, 35)	18	-12 (-17, -8)	0.60 (0.52, 0.68)	-0.03 (-0.04, -0.02)
	30-39 years	40 (35, 45)	52	12 (7, 17)	1.31 (1.15, 1.48)	0.03 (0.02, 0.04)
	40-49 years	90 (80, 100)	89	0 (-10, 10)	1.00 (0.91, 1.09)	0.00 (-0.02, 0.04)
	50-59 years	180 (170, 200)	179	0 (-20, 10)	0.98 (0.91, 1.05)	-0.01 (-0.06, 0.03)
	60-69 years	310 (280, 330)	295	-10 (-40, 10)	0.97 (0.89, 1.04)	-0.06 (-0.21, 0.07)
	70-79 years	410 (380, 440)	380	-30 (-60, 0)	0.94 (0.87, 1.01)	-0.26 (-0.56, 0.03)
	≥80 years	420 (390, 450)	440	20 (-10, 50)	1.05 (0.98, 1.14)	0.63 (-0.30, 1.64)
	All ages	1,520 (1,470, 1,570)	1,481	-20 (-70, 30)	0.99 (0.95, 1.02)	-0.01 (-0.03, 0.01)
Wave 1 (May to August, 2020)	0-9 years	94 (86, 103)	80	-14 (-23, -6)	0.85 (0.78, 0.93)	-0.05 (-0.08, -0.02)
	10-19 years	110 (90, 130)	59	-50 (-70, -30)	0.54 (0.45, 0.65)	-0.17 (-0.24, -0.11)
	20-29 years	115 (108, 123)	129	14 (6, 21)	1.12 (1.05, 1.20)	0.03 (0.01, 0.05)
	30-39 years	190 (180, 200)	196	10 (0, 20)	1.06 (1.000, 1.12)	0.03 (0.00, 0.05)
	40-49 years	390 (380, 410)	519	130 (110, 140)	1.33 (1.27, 1.38)	0.33 (0.28, 0.37)
	50-59 years	820 (790, 850)	1,117	290 (270, 320)	1.36 (1.31, 1.41)	0.97 (0.88, 1.06)
	60-69 years	1,370 (1,320, 1,420)	1,884	510 (470, 560)	1.37 (1.33, 1.43)	3.05 (2.78, 3.34)
	70-79 years	1,720 (1,660, 1,780)	2,300	580 (520, 640)	1.34 (1.29, 1.39)	5.81 (5.19, 6.39)
	≥80 years	1,880 (1,810, 1,950)	2,196	320 (250, 390)	1.17 (1.13, 1.21)	9.79 (7.56, 11.79)
	All ages	6,680 (6,580, 6,790)	8,480	1,840 (1,730, 1,950)	1.28 (1.25, 1.30)	0.74 (0.70, 0.79)
Wave 2 (March to June, 2021)	0-9 years	100 (90, 110)	65	-34 (-42, -26)	0.66 (0.60, 0.71)	-0.12 (-0.15, -0.09)
	10-19 years	110 (90, 130)	68	-40 (-60, -20)	0.65 (0.53, 0.78)	-0.12 (-0.20, -0.06)
	20-29 years	115 (108, 123)	152	37 (29, 44)	1.32 (1.24, 1.41)	0.08 (0.06, 0.10)
	30-39 years	190 (180, 200)	356	170 (160, 180)	1.93 (1.82, 2.04)	0.39 (0.37, 0.42)
	40-49 years	410 (390, 420)	929	520 (510, 540)	2.29 (2.20, 2.40)	1.33 (1.29, 1.38)
	50-59 years	880 (850, 910)	2107	1,230 (1,200, 1,260)	2.40 (2.32, 2.49)	3.94 (3.85, 4.04)
	60-69 years	1,490 (1,450, 1,540)	3324	1,830 (1,780, 1,880)	2.23 (2.15, 2.30)	10.59 (10.30, 10.87)
	70-79 years	1,950 (1,880, 2,010)	3662	1,720 (1,660, 1,790)	1.88 (1.83, 1.95)	16.58 (15.99, 17.24)
	≥80 years	2,050 (1,980, 2,130)	3346	1,290 (1,220, 1,370)	1.63 (1.57, 1.69)	37.97 (35.74, 40.21)
	All ages	7,280 (7,160, 7,400)	14,009	6,830 (6,700, 6,940)	1.94 (1.91, 1.97)	2.75 (2.70, 2.79)

UI: uncertainty interval, generated based on parameter uncertainty and stochastic variability in model-based predicted death counts.

Table S10: Expected and observed deaths during the COVID-19 pandemic in Chennai, for models fitted to 7-day moving average mortality time series.

Period	Age group	Expected deaths (95% UI)	Observed deaths	Excess deaths (95% UI)	Excess mortality ratio (95% UI)	Excess mortality per 1000 (95% UI)
March, 2020 to June, 2021	0-9 years	1,050 (1,010, 1,100)	668	-380 (-430, -340)	0.63 (0.61, 0.66)	-0.65 (-0.72, -0.58)
	10-19 years	920 (860, 970)	579	-340 (-390, -280)	0.63 (0.60, 0.67)	-0.54 (-0.63, -0.46)
	20-29 years	1,800 (1,750, 1,850)	1,530	-270 (-310, -220)	0.85 (0.83, 0.88)	-0.29 (-0.35, -0.24)
	30-39 years	2,950 (2,890, 3,010)	3,291	340 (280, 400)	1.12 (1.09, 1.14)	0.38 (0.31, 0.45)
	40-49 years	5,600 (5,500, 5,690)	7,350	1,750 (1,660, 1,850)	1.31 (1.29, 1.34)	2.21 (2.09, 2.33)
	50-59 years	9,430 (9,280, 9,560)	13,475	4,050 (3,920, 4,200)	1.43 (1.41, 1.45)	6.46 (6.25, 6.70)
	60-69 years	12,970 (12,790, 13,170)	20,033	7,060 (6,870, 7,240)	1.54 (1.52, 1.57)	20.96 (20.39, 21.50)
	70-79 years	14,130 (13,920, 14,350)	21,687	7,560 (7,330, 7,760)	1.54 (1.51, 1.56)	39.97 (38.78, 41.05)
	≥80 years	14,100 (13,900, 14,320)	19,494	5,390 (5,170, 5,600)	1.38 (1.36, 1.40)	97.71 (93.69, 101.42)
	All ages	62,950 (62,500, 63,350)	88,107	25,730 (25,320, 26,170)	1.41 (1.40, 1.42)	5.13 (5.04, 5.21)
Initial lockdown (24 March to 20 April, 2020)	0-9 years	52 (45, 62)	40	-12 (-22, -5)	0.77 (0.65, 0.90)	-0.02 (-0.04, -0.01)
	10-19 years	40 (30, 50)	25	-20 (-30, -10)	0.59 (0.47, 0.74)	-0.03 (-0.05, -0.01)
	20-29 years	100 (90, 110)	45	-60 (-70, -50)	0.45 (0.40, 0.50)	-0.06 (-0.07, -0.05)
	30-39 years	160 (140, 170)	131	-20 (-40, -10)	0.84 (0.78, 0.91)	-0.03 (-0.04, -0.01)
	40-49 years	310 (290, 330)	264	-40 (-70, -20)	0.86 (0.80, 0.93)	-0.05 (-0.09, -0.03)
	50-59 years	510 (480, 540)	462	-40 (-80, -20)	0.91 (0.86, 0.97)	-0.07 (-0.12, -0.03)
	60-69 years	670 (630, 710)	685	10 (-30, 50)	1.02 (0.96, 1.09)	0.04 (-0.09, 0.16)
	70-79 years	760 (720, 800)	767	10 (-40, 50)	1.01 (0.95, 1.07)	0.04 (-0.19, 0.28)
	≥80 years	730 (690, 780)	824	90 (50, 140)	1.13 (1.06, 1.20)	1.72 (0.88, 2.52)
	All ages	3,330 (3,240, 3,420)	3,243	-60 (-150, 30)	0.98 (0.96, 1.01)	-0.01 (-0.03, 0.01)
Wave 1 (May to August, 2020)	0-9 years	230 (210, 250)	157	-70 (-90, -50)	0.69 (0.63, 0.74)	-0.12 (-0.15, -0.09)
	10-19 years	220 (190, 240)	121	-100 (-120, -70)	0.56 (0.50, 0.63)	-0.15 (-0.20, -0.11)
	20-29 years	430 (410, 460)	347	-80 (-110, -60)	0.80 (0.76, 0.85)	-0.09 (-0.12, -0.07)
	30-39 years	700 (670, 730)	683	-10 (-40, 10)	0.98 (0.94, 1.02)	-0.01 (-0.05, 0.01)
	40-49 years	1,290 (1,250, 1,340)	1,522	230 (180, 270)	1.18 (1.14, 1.22)	0.29 (0.23, 0.35)
	50-59 years	2,160 (2,100, 2,230)	3,006	840 (780, 910)	1.39 (1.35, 1.43)	1.36 (1.26, 1.46)
	60-69 years	2,930 (2,850, 3,020)	4,401	1,470 (1,390, 1,550)	1.50 (1.46, 1.54)	4.43 (4.17, 4.66)
	70-79 years	3,190 (3,090, 3,280)	5,023	1,840 (1,740, 1,930)	1.58 (1.53, 1.62)	9.85 (9.34, 10.34)
	≥80 years	3,130 (3,030, 3,230)	4,349	1,220 (1,120, 1,320)	1.39 (1.35, 1.44)	22.58 (20.71, 24.40)
	All ages	14,280 (14,090, 14,470)	19,609	5,450 (5,260, 5,640)	1.38 (1.36, 1.40)	1.09 (1.05, 1.13)
Wave 2 (March to June, 2021)	0-9 years	230 (210, 250)	139	-90 (-1100, -70)	0.61 (0.56, 0.66)	-0.15 (-0.19, -0.12)
	10-19 years	220 (200, 240)	158	-60 (-90, -40)	0.73 (0.65, 0.81)	-0.10 (-0.14, -0.06)
	20-29 years	430 (410, 460)	430	0 (-30, 20)	0.99 (0.94, 1.05)	0.00 (-0.03, 0.02)
	30-39 years	690 (660, 720)	1,230	540 (510, 570)	1.78 (1.71, 1.85)	0.60 (0.57, 0.63)
	40-49 years	1,320 (1,270, 1,370)	2,795	1,480 (1,430, 1,520)	2.12 (2.05, 2.20)	1.85 (1.79, 1.91)
	50-59 years	2,240 (2,170, 2,310)	5,177	2,940 (2,870, 3,010)	2.31 (2.25, 2.39)	4.63 (4.53, 4.74)
	60-69 years	3,030 (2,950, 3,120)	7,649	4,620 (4,530, 4,700)	2.52 (2.45, 2.60)	13.53 (13.28, 13.78)
	70-79 years	3,340 (3,250, 3,440)	7,944	4,600 (4,510, 4,700)	2.38 (2.31, 2.45)	23.99 (23.51, 24.48)
	≥80 years	3,320 (3,220, 3,420)	6,764	3,440 (3,340, 3,540)	2.04 (1.98, 2.10)	61.23 (59.42, 62.98)
	All ages	14,820 (14,620, 15,020)	32,286	17,700 (17,500, 17,900)	2.19 (2.17, 2.22)	3.51 (3.47, 3.55)

UI: uncertainty interval, generated based on parameter uncertainty and stochastic variability in model-based predicted death counts. Accompanying model predictions are presented in **Figure S5**.

Table S11: Expected and observed deaths during the COVID-19 pandemic in Chennai, for models fitted to 28-day moving average mortality time series.

Period	Age group	Expected deaths (95% UI)	Observed deaths	Excess deaths (95% UI)	Excess mortality ratio (95% UI)	Excess mortality per 1000 (95% UI)
March, 2020 to June, 2021	0-9 years	960 (940, 980)	668	-290 (-310, -270)	0.70 (0.68, 0.71)	-0.49 (-0.53, -0.46)
	10-19 years	880 (840, 920)	579	-300 (-340, -260)	0.66 (0.63, 0.69)	-0.48 (-0.55, -0.43)
	20-29 years	1,700 (1,670, 1,730)	1,530	-170 (-200, -140)	0.90 (0.88, 0.91)	-0.19 (-0.22, -0.16)
	30-39 years	2,900 (2,860, 2,940)	3,291	390 (350, 430)	1.13 (1.12, 1.15)	0.44 (0.39, 0.48)
	40-49 years	5,500 (5,430, 5,560)	7,350	1,850 (1,790, 1,920)	1.34 (1.32, 1.35)	2.34 (2.26, 2.42)
	50-59 years	9,270 (9,170, 9,360)	13,475	4,200 (4,120, 4,310)	1.45 (1.44, 1.47)	6.71 (6.57, 6.87)
	60-69 years	12,900 (12,760, 13,040)	20,033	7,140 (7,000, 7,270)	1.55 (1.54, 1.57)	21.19 (20.77, 21.59)
	70-79 years	14,050 (13,900, 14,210)	21,687	7,640 (7,480, 7,790)	1.54 (1.53, 1.56)	40.39 (39.55, 41.18)
	≥80 years	14,040 (13,880, 14,210)	19,494	5,460 (5,290, 5,610)	1.39 (1.37, 1.40)	98.87 (95.81, 101.74)
	All ages	62,190 (61,880, 62,480)	88,107	26,480 (26,190, 26,800)	1.43 (1.42, 1.44)	5.28 (5.22, 5.34)
	Initial lockdown (24 March to 20 April, 2020)	0-9 years	53 (49, 58)	40	-13 (-18, -9)	0.75 (0.69, 0.81)
10-19 years		37 (32, 43)	25	-12 (-18, -7)	0.68 (0.58, 0.78)	-0.02 (-0.03, -0.01)
20-29 years		97 (90, 104)	45	-52 (59, -45)	0.47 (0.43, 0.50)	-0.06 (-0.07, -0.05)
30-39 years		150 (140, 160)	131	-20 (-30, -10)	0.86 (0.82, 0.91)	-0.02 (-0.03, -0.01)
40-49 years		300 (280, 320)	264	-30 (-50, -20)	0.89 (0.84, 0.93)	-0.04 (-0.06, -0.02)
50-59 years		500 (480, 520)	462	-40 (-60, -20)	0.93 (0.89, 0.96)	-0.06 (-0.09, -0.03)
60-69 years		670 (640, 700)	685	20 (-10, 50)	1.02 (0.98, 1.07)	0.05 (-0.04, 0.14)
70-79 years		750 (720, 780)	767	20 (-20, 50)	1.02 (0.98, 1.07)	0.08 (-0.09, 0.25)
≥80 years		730 (700, 770)	824	90 (60, 120)	1.12 (1.07, 1.18)	1.69 (1.05, 2.30)
All ages		3,290 (3,220, 3,350)	3,243	-20 (-90, 40)	0.99 (0.97, 1.01)	0.00 (-0.02, 0.01)
Wave 1 (May to August, 2020)		0-9 years	220 (210, 230)	157	-65 (-75, -56)	0.71 (0.68, 0.74)
	10-19 years	220 (200, 240)	121	-90 (-110, -80)	0.56 (0.51, 0.61)	-0.15 (-0.18, -0.13)
	20-29 years	410 (400, 420)	347	-60 (-80, -50)	0.85 (0.82, 0.88)	-0.07 (-0.08, -0.05)
	30-39 years	680 (660, 700)	683	0 (-20, 20)	1.00 (0.98, 1.03)	0.00 (-0.02, 0.02)
	40-49 years	1,270 (1,240, 1,300)	1,522	250 (220, 280)	1.20 (1.17, 1.23)	0.32 (0.28, 0.36)
	50-59 years	2,140 (2,090, 2,180)	3,006	870 (830, 910)	1.41 (1.38, 1.44)	1.41 (1.34, 1.48)
	60-69 years	2,930 (2,870, 2,990)	4,401	1,480 (1,420, 1,530)	1.50 (1.47, 1.53)	4.44 (4.26, 4.61)
	70-79 years	3,180 (3,120, 3,250)	5,023	1,840 (1,770, 1,910)	1.58 (1.55, 1.61)	9.87 (9.50, 10.22)
	≥80 years	3,120 (3,050, 3,200)	4,349	1,230 (1,150, 1,300)	1.39 (1.36, 1.43)	22.73 (21.28, 24.10)
	All ages	14,170 (14,030, 14,300)	19,609	5,560 (5,420, 5,700)	1.39 (1.38, 1.41)	1.11 (1.09, 1.14)
	Wave 2 (March to June, 2021)	0-9 years	220 (210, 230)	139	-80 (-90, -70)	0.63 (0.61, 0.66)
10-19 years		200 (190, 220)	158	-40 (-60, -30)	0.80 (0.73, 0.85)	-0.07 (-0.09, -0.04)
20-29 years		410 (400, 430)	430	20 (0, 30)	1.04 (1.01, 1.08)	0.02 (0.00, 0.03)
30-39 years		680 (660, 700)	1,230	550 (530, 570)	1.82 (1.77, 1.87)	0.62 (0.59, 0.64)
40-49 years		1,290 (1,260, 1,320)	2,795	1,510 (1,470, 1,540)	2.17 (2.12, 2.22)	1.89 (1.85, 1.92)
50-59 years		2,200 (2,150, 2,250)	5,177	2,980 (2,930, 3,020)	2.35 (2.30, 2.40)	4.69 (4.62, 4.77)
60-69 years		3,030 (2,970, 3,090)	7,649	4,620 (4,560, 4,680)	2.53 (2.48, 2.58)	13.54 (13.37, 13.73)
70-79 years		3,340 (3,270, 3,410)	7,944	4,600 (4,540, 4,670)	2.38 (2.33, 2.43)	24.00 (23.65, 24.35)
≥80 years		3,330 (3,250, 3,400)	6,764	3,440 (3,360, 3,510)	2.03 (1.99, 2.08)	61.15 (59.79, 62.47)
All ages		14,690 (14,550, 14,840)	32,286	17,830 (17,690, 17,980)	2.21 (2.19, 2.24)	3.54 (3.51, 3.56)

UI: uncertainty interval, generated based on parameter uncertainty and stochastic variability in model-based predicted death counts. Accompanying model predictions are presented in **Figure S6**.

Table S12: Annualized life tables for males in Chennai, 2019-2021.

Age group	Year	Deaths	Mortality per 1000 (95% UI)	Life expectancy at entry (95% CI), years
0-4 years	2019	236	1.4 (1.3, 1.6)	68.0 (67.9, 68.2)
	2020	200	1.2 (1.0, 1.4)	66.9 (66.8, 67.1)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	227	1.4 (1.2, 1.6)	64.6 (64.4, 64.7)
	2021 (assuming Jul.-Dec. per 2020) ²	192	1.2 (1.0, 1.3)	63.9 (63.8, 64.0)
5-9 years	2019	115	0.8 (0.7, 1.0)	63.5 (63.3, 63.7)
	2020	76	0.5 (0.4, 0.7)	62.3 (62.2, 62.5)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	95	0.7 (0.5, 0.8)	60.0 (59.9, 60.2)
	2021 (assuming Jul.-Dec. per 2020) ²	77	0.5 (0.4, 0.7)	59.3 (59.1, 59.4)
10-14 years	2019	96	0.6 (0.5, 0.8)	58.7 (58.6, 58.9)
	2020	50	0.3 (0.3, 0.4)	57.5 (57.4, 57.6)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	96	0.6 (0.5, 0.8)	55.2 (55.1, 55.3)
	2021 (assuming Jul.-Dec. per 2020) ²	77	0.5 (0.4, 0.6)	54.4 (54.3, 54.5)
15-19 years	2019	203	1.2 (1.0, 1.4)	53.9 (53.8, 54.1)
	2020	148	0.9 (0.7, 1.0)	52.6 (52.5, 52.7)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	172	1.0 (0.9, 1.2)	50.4 (50.2, 50.5)
	2021 (assuming Jul.-Dec. per 2020) ²	173	1.0 (0.9, 1.2)	49.6 (49.4, 49.7)
20-24 years	2019	348	1.7 (1.5, 1.8)	49.2 (49.1, 49.4)
	2020	266	1.3 (1.1, 1.4)	47.8 (47.7, 48.0)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	330	1.6 (1.4, 1.7)	45.6 (45.5, 45.7)
	2021 (assuming Jul.-Dec. per 2020) ²	312	1.5 (1.3, 1.6)	44.8 (44.7, 44.9)
25-29 years	2019	457	1.9 (1.7, 2.1)	44.6 (44.5, 44.8)
	2020	380	1.6 (1.4, 1.7)	43.1 (43.0, 43.2)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	469	1.9 (1.8, 2.1)	40.9 (40.8, 41.1)
	2021 (assuming Jul.-Dec. per 2020) ²	458	1.9 (1.7, 2.0)	40.1 (40.0, 40.2)
30-34 years	2019	592	2.5 (2.3, 2.7)	40.0 (39.9, 40.2)
	2020	589	2.5 (2.3, 2.7)	38.4 (38.3, 38.6)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	713	3.0 (2.8, 3.2)	36.3 (36.2, 36.4)
	2021 (assuming Jul.-Dec. per 2020) ²	739	3.1 (2.9, 3.3)	35.5 (35.3, 35.6)
35-39 years	2019	936	4.3 (4.0, 4.6)	35.5 (35.4, 35.7)
	2020	831	3.8 (3.5, 4.1)	33.9 (33.8, 34.0)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	1,150	5.2 (4.9, 5.5)	31.8 (31.7, 32.0)
	2021 (assuming Jul.-Dec. per 2020) ²	1,124	5.1 (4.8, 5.4)	31.0 (30.9, 31.1)
40-44 years	2019	1,058	5.2 (4.9, 5.6)	31.2 (31.1, 31.4)
	2020	1,167	5.7 (5.4, 6.0)	29.5 (29.4, 29.6)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	1,496	7.3 (6.9, 7.7)	27.6 (27.5, 27.7)
	2021 (assuming Jul.-Dec. per 2020) ²	1,567	7.6 (7.3, 8.0)	26.7 (26.6, 26.8)
45-49 years	2019	1,703	9.0 (8.6, 9.5)	27.0 (26.9, 27.1)
	2020	1,660	8.7 (8.3, 9.1)	25.3 (25.1, 25.4)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	2,222	11.5 (11.0, 12.0)	23.5 (23.4, 23.7)
	2021 (assuming Jul.-Dec. per 2020) ²	2,276	11.8 (11.3, 12.2)	22.7 (22.6, 22.8)
50-54 years	2019	1,954	12.2 (11.7, 12.7)	23.1 (23.0, 23.2)
	2020	2,205	13.4 (12.8, 13.9)	21.3 (21.1, 21.4)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	2,698	16.2 (15.6, 16.8)	19.8 (19.7, 19.9)
	2021 (assuming Jul.-Dec. per 2020) ²	2,862	17.1 (16.5, 17.8)	18.9 (18.8, 19.0)
55-59 years	2019	2,257	15.8 (15.1, 16.4)	19.4 (19.3, 19.5)
	2020	2,681	18.2 (17.5, 18.9)	17.6 (17.5, 17.7)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	3,255	22.2 (21.4, 22.9)	16.2 (16.1, 16.3)
	2021 (assuming Jul.-Dec. per 2020) ²	3,577	24.5 (23.7, 25.2)	15.3 (15.3, 15.4)
60-64 years	2019	2,490	26.3 (25.2, 27.3)	15.8 (15.7, 15.9)
	2020	3,246	33.2 (32.1, 34.4)	14.0 (13.9, 14.1)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	3,830	38.5 (37.3, 39.7)	12.9 (12.8, 13.0)
	2021 (assuming Jul.-Dec. per 2020) ²	4,357	43.8 (42.6, 45.1)	12.0 (11.9, 12.1)
65-69 years	2019	2,761	43.8 (42.3, 45.4)	12.7 (12.6, 12.8)
	2020	3,459	53.2 (51.4, 54.9)	11.1 (11.0, 11.2)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	4,439	65.3 (63.4, 67.2)	10.1 (10.0, 10.2)
	2021 (assuming Jul.-Dec. per 2020) ²	4,858	71.3 (69.3, 73.2)	9.4 (9.3, 9.5)
70-74 years	2019	2,564	55.8 (53.7, 57.9)	10.2 (10.1, 10.3)
	2020	3,705	78.0 (75.6, 80.5)	8.7 (8.6, 8.8)

	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	4,439	88.4 (85.9, 90.9)	8.0 (7.9, 8.1)
	2021 (assuming Jul.-Dec. per 2020) ²	5,346	103.8 (101.0, 106.5)	7.3 (7.3, 7.4)
75-79 years				
	2019	2,282	62.7 (60.2, 65.1)	7.7 (7.6, 7.8)
	2020	2,876	76.2 (73.6, 78.8)	6.7 (6.6, 6.8)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	3,682	90.0 (87.2, 92.8)	6.1 (6.1, 6.2)
	2021 (assuming Jul.-Dec. per 2020) ²	4,202	101.6 (98.5, 104.6)	5.7 (5.7, 5.8)
≥80 years				
	2019	4,432	218.6 (212.9, 224.3)	4.6 (4.5, 4.7)
	2020	5,716	269.2 (263.1, 275.1)	3.7 (3.6, 3.8)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	7,796	307.7 (301.6, 313.8)	3.3 (3.2, 3.3)
	2021 (assuming Jul.-Dec. per 2020) ²	8,867	342.3 (336.1, 348.4)	2.9 (2.9, 3.0)

UI: Uncertainty interval. Estimated life year losses among individuals experiencing pandemic-associated mortality in 2020 and 2021 are presented in **Table S14**.

¹Estimates apply mortality rates (scaled to 2021 population projections) from 2019 for the months of July to December.

²Estimates apply mortality rates (scaled to 2021 population projections) from 2020 for the months of July to December.

Table S13: Annualized life tables for females in Chennai, 2016-2021.

Age group	Year	Deaths	Mortality per 1000 (95% UI)	Life expectancy at entry (95% CI), years
0-4 years	2019	194	1.3 (1.1, 1.5)	73.6 (73.4, 73.8)
	2020	160	1.1 (0.9, 1.2)	72.5 (72.3, 72.6)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	192	1.2 (1.0, 1.4)	70.0 (69.8, 70.1)
	2021 (assuming Jul.-Dec. per 2020) ²	144	0.9 (0.8, 1.1)	69.4 (69.3, 69.6)
5-9 years	2019	95	0.7 (0.6, 0.9)	69.1 (68.9, 69.2)
	2020	64	0.5 (0.4, 0.6)	67.8 (67.7, 68.0)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	81	0.6 (0.5, 0.7)	65.4 (65.2, 65.6)
	2021 (assuming Jul.-Dec. per 2020) ²	75	0.6 (0.4, 0.7)	64.7 (64.6, 64.9)
10-14 years	2019	83	0.6 (0.5, 0.7)	64.3 (64.2, 64.5)
	2020	62	0.5 (0.3, 0.6)	63.0 (62.8, 63.2)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	82	0.6 (0.5, 0.7)	60.6 (60.4, 60.7)
	2021 (assuming Jul.-Dec. per 2020) ²	74	0.5 (0.4, 0.7)	59.9 (59.8, 60.0)
15-19 years	2019	122	0.7 (0.6, 0.9)	59.5 (59.3, 59.7)
	2020	121	0.7 (0.6, 0.9)	58.1 (58.0, 58.3)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	131	0.8 (0.7, 0.9)	55.7 (55.6, 55.9)
	2021 (assuming Jul.-Dec. per 2020) ²	141	0.9 (0.7, 1.0)	55.0 (54.9, 55.2)
20-24 years	2019	183	0.9 (0.8, 1.0)	54.7 (54.6, 54.9)
	2020	147	0.7 (0.6, 0.8)	53.4 (53.2, 53.5)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	180	0.9 (0.7, 1.0)	51.0 (50.8, 51.1)
	2021 (assuming Jul.-Dec. per 2020) ²	170	0.8 (0.7, 0.9)	50.3 (50.1, 50.4)
25-29 years	2019	213	0.9 (0.8, 1.0)	49.9 (49.8, 50.1)
	2020	218	0.9 (0.8, 1.0)	48.5 (48.4, 48.7)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	243	1.0 (0.9, 1.1)	46.2 (46.0, 46.3)
	2021 (assuming Jul.-Dec. per 2020) ²	259	1.1 (1.0, 1.2)	45.5 (45.3, 45.6)
30-34 years	2019	218	1.0 (0.9, 1.1)	45.2 (45.0, 45.3)
	2020	214	1.0 (0.9, 1.1)	43.7 (43.6, 43.9)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	287	1.3 (1.1, 1.4)	41.4 (41.2, 41.5)
	2021 (assuming Jul.-Dec. per 2020) ²	271	1.2 (1.1, 1.4)	40.7 (40.6, 40.8)
35-39 years	2019	331	1.6 (1.4, 1.8)	40.4 (40.2, 40.5)
	2020	348	1.7 (1.5, 1.8)	38.9 (38.8, 39.1)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	455	2.2 (2.0, 2.4)	36.6 (36.5, 36.8)
	2021 (assuming Jul.-Dec. per 2020) ²	451	2.1 (1.9, 2.3)	35.9 (35.8, 36.1)
40-44 years	2019	414	2.1 (1.9, 2.4)	35.7 (35.5, 35.8)
	2020	505	2.6 (2.4, 2.8)	34.2 (34.1, 34.4)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	684	3.5 (3.2, 3.7)	32.0 (31.9, 32.1)
	2021 (assuming Jul.-Dec. per 2020) ²	726	3.7 (3.4, 3.9)	31.3 (31.2, 31.4)
45-49 years	2019	697	3.7 (3.5, 4.0)	31.0 (30.9, 31.2)
	2020	814	4.3 (4.0, 4.6)	29.7 (29.5, 29.8)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	1,065	5.6 (5.3, 5.9)	27.5 (27.4, 27.7)
	2021 (assuming Jul.-Dec. per 2020) ²	1,118	5.9 (5.5, 6.2)	26.8 (26.7, 26.9)
50-54 years	2019	884	5.4 (5.1, 5.8)	26.6 (26.4, 26.7)
	2020	1,072	6.4 (6.0, 6.8)	25.3 (25.1, 25.4)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	1,375	8.2 (7.8, 8.6)	23.2 (23.1, 23.4)
	2021 (assuming Jul.-Dec. per 2020) ²	1,493	8.9 (8.5, 9.4)	22.5 (22.4, 22.7)
55-59 years	2019	1,314	10.0 (9.5, 10.6)	22.2 (22.1, 22.4)
	2020	1,568	11.6 (11.1, 12.2)	21.0 (20.9, 21.1)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	2,243	16.3 (15.6, 17.0)	19.1 (19.0, 19.2)
	2021 (assuming Jul.-Dec. per 2020) ²	2,397	17.4 (16.8, 18.1)	18.5 (18.3, 18.6)
60-64 years	2019	1,610	17.2 (16.4, 18.1)	18.2 (18.1, 18.4)
	2020	2,014	20.9 (20.0, 21.8)	17.1 (17.0, 17.2)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	2,659	27.2 (26.2, 28.3)	15.5 (15.4, 15.6)
	2021 (assuming Jul.-Dec. per 2020) ²	2,877	29.5 (28.5, 30.6)	14.9 (14.8, 15.0)
65-69 years	2019	2,053	30.1 (28.9, 31.4)	14.7 (14.5, 14.8)
	2020	2,434	34.5 (33.2, 35.9)	13.7 (13.6, 13.8)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	3,102	44.2 (42.7, 45.7)	12.4 (12.3, 12.5)
	2021 (assuming Jul.-Dec. per 2020) ²	3,294	47.1 (45.5, 48.6)	11.9 (11.8, 12.0)
70-74 years	2019	2,243	41.4 (39.7, 43.1)	11.7 (11.5, 11.8)
	2020	2,988	53.4 (51.5, 55.2)	10.8 (10.7, 11.0)

	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	3,457	62.6 (60.6, 64.5)	9.9 (9.8, 10.0)
	2021 (assuming Jul.-Dec. per 2020) ²	3,866	70.5 (68.4, 72.6)	9.4 (9.3, 9.5)
75-79 years				
	2019	2,215	52.2 (50.0, 54.3)	8.8 (8.6, 8.9)
	2020	2,592	59.0 (56.8, 61.2)	8.4 (8.3, 8.5)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	2,971	68.4 (66.1, 70.8)	7.6 (7.5, 7.7)
	2021 (assuming Jul.-Dec. per 2020) ²	3,190	73.8 (71.4, 76.2)	7.4 (7.3, 7.5)
≥80 years				
	2019	5,476	177.1 (172.9, 181.3)	5.6 (5.5, 5.8)
	2020	5,961	183.9 (179.7, 188.1)	5.4 (5.3, 5.6)
	2021 (assuming Jul.-Dec. per 2019 baseline) ¹	6,520	212.1 (207.8, 216.6)	4.7 (4.6, 4.8)
	2021 (assuming Jul.-Dec. per 2020) ²	6,706	218.9 (214.5, 223.4)	4.6 (4.5, 4.7)

UI: Uncertainty interval. Estimated life year losses among individuals experiencing pandemic-associated mortality in 2020 and 2021 are presented in **Table S14**.

¹Estimates apply mortality rates (scaled to 2021 population projections) from 2019 for the months of July to December.

²Estimates apply mortality rates (scaled to 2021 population projections) from 2020 for the months of July to December.

Table S14: Mean life years lost among individuals experiencing pandemic-associated mortality in 2020 and 2021, relative to life expectancy in 2019.

Sex	Year	Mean life years lost (95% UI)
Both sexes		
	2020	14.0 (13.8, 14.2)
	2021	16.2 (16.0, 16.3)
Males		
	2020	12.7 (12.5, 13.0)
	2021	15.5 (15.3, 15.6)
Females		
	2020	15.8 (15.5, 16.2)
	2021	17.1 (16.9, 17.4)

UI: Uncertainty interval. Life tables underlying life expectancy estimates are presented in **Table S12** and **Table S13** for males and females, respectively. We obtained estimates of the average years of life lost among individuals who died in association with the COVID-19 pandemic by taking a weighted average of estimated years of life remaining for each age group during 2019, with weights defined by the representation of each age group among all excess fatalities during 2020 and 2021. While this approach provides a general assessment of years of life lost due to COVID-19, it should be noted that estimates may overstate life years lost of individuals who died due to COVID-19 experienced other comorbid conditions which could lead to shorter baseline life expectancy.

Table S15: Unadjusted associations of excess mortality with community socioeconomic attributes.

Category	Measurement	Percent change in excess mortality (95% UI), per 1-standard deviation increase in covariate			
		<u>Total period</u> March, 2020 to June, 2021	<u>Early lockdown</u> 24 March to 20 April, 2020	<u>First wave</u> May to August, 2020	<u>Second wave</u> March to June, 2021
Population density	Household crowding	2.8 (2.0, 3.6)	-7.8 (-9.5, -5.9)	1.0 (0.0, 2.1)	6.3 (5.1, 7.7)
	Population density	1.3 (0.7, 2.0)	-5.2 (-6.6, -3.5)	-0.8 (-1.7, 0.1)	3.7 (2.7, 4.8)
Housing quality	Non-permanent housing structures	1.0 (0.4, 1.6)	-7.9 (-9.3, -6.5)	-1.5 (-2.3, -0.7)	4.5 (3.5, 5.4)
	Dilapidated or unlivable dwelling structures	1.6 (0.9, 2.3)	-3.6 (-5.3, -1.9)	0.4 (-0.5, 1.4)	4.1 (3.2, 5.3)
	Households with unfinished flooring	0.7 (0.2, 1.2)	-5.4 (-6.6, -4.3)	-1.3 (-2.0, -0.7)	2.8 (2.1, 3.5)
Water, sanitation, and hygiene	Households lacking on-site water	2.3 (1.7, 2.9)	-6.5 (-8.0, -5.2)	-1.5 (-2.3, -0.7)	7.0 (6.0, 7.9)
	Households practicing open defecation	0.9 (0.3, 1.5)	-6.9 (-8.3, -5.5)	-0.9 (-1.7, -0.1)	3.6 (2.7, 4.5)
	Households lacking on-site latrines	2.5 (1.8, 3.1)	-7.5 (-8.9, -6.0)	-0.1 (-0.9, 0.8)	6.4 (5.4, 7.3)
Fuel and energy	Households lacking electric lighting	1.8 (1.2, 2.4)	-4.9 (-6.3, -3.6)	-1.5 (-2.3, -0.3)	5.3 (4.5, 6.2)
	Households reliant on solid cooking fuels	1.0 (0.5, 1.4)	-5.4 (-6.5, -4.3)	-1.9 (-2.6, -1.3)	3.7 (3.1, 4.5)
Wealth and marginalization	Population belonging to scheduled castes or tribes	2.4 (1.8, 3.1)	-7.6 (-9.1, -6.1)	0.3 (-0.5, 1.3)	6.3 (5.3, 7.4)
	Households lacking bank accounts	1.8 (1.1, 2.4)	-8.6 (-10.0, -7.2)	-1.2 (-2.1, -0.4)	5.7 (4.7, 6.6)
	Households lacking key index assets	1.1 (0.6, 1.6)	-4.5 (-5.7, -3.3)	-0.2 (-0.9, 0.5)	3.1 (2.4, 3.9)

Estimates are obtained based on regression models fit across draws from the distribution of excess mortality measures. Values are corrected for lagged reporting of deaths based on 2019 observations (**Figure S2**). We present numerical estimates for predictors of excess deaths among individuals aged ≥ 50 years in **Table S16**. Deaths are aggregated by PIN code areas; analyses include PIN code areas for which ≥ 1000 deaths were registered over the study period. Measures of excess mortality by PIN code area are plotted in **Figure S7**.

Table S16: Unadjusted associations of excess mortality with community socioeconomic attributes among individuals aged 50 years and older.

Category	Measurement	Percent change in excess mortality (95% UI), per 1-standard deviation increase in covariate			
		Total period March, 2020 to June, 2021	Early lockdown 24 March to 20 April, 2020	First wave May to August, 2020	Second wave March to June, 2021
Population density	Household crowding	2.3 (1.5, 3.1)	-9.4 (-11.0, -7.7)	0.2 (-0.9, 1.2)	6.0 (4.9, 7.3)
	Population density	2.5 (1.8, 3.3)	-3.8 (-5.4, -1.7)	-0.1 (-1.1, 1.0)	4.9 (3.8, 6.0)
Housing quality	Non-permanent housing structures	1.8 (1.1, 2.5)	-6.9 (-8.3, -5.3)	-1.4 (-2.3, -0.4)	5.6 (4.6, 6.6)
	Dilapidated or unlivable dwelling structures	2.6 (1.8, 3.4)	-2.9 (-4.6, -0.8)	1.1 (0.1, 2.3)	5.3 (4.1, 6.4)
	Households with unfinished flooring	0.8 (0.3, 1.3)	-6.1 (-7.3, -4.9)	-1.5 (-2.2, -0.8)	3.4 (2.7, 4.2)
	Households lacking on-site water	2.6 (2.0, 3.3)	-6.2 (-7.6, -4.6)	-1.8 (-2.7, -1.0)	7.7 (6.8, 8.7)
Water, sanitation, and hygiene	Households practicing open defecation	1.5 (0.9, 2.2)	-6.0 (-7.5, -4.4)	-0.7 (-1.6, 0.2)	4.6 (3.6, 5.5)
	Households lacking on-site latrines	2.6 (2.0, 3.4)	-7.9 (-9.4, -6.3)	-0.3 (-1.2, 0.6)	6.9 (5.9, 8.0)
Fuel and energy	Households lacking electric lighting	2.3 (1.7, 3.0)	-4.7 (-6.1, -3.1)	-1.6 (-2.4, -0.7)	6.1 (5.2, 7.1)
	Households reliant on solid cooking fuels	1.0 (0.5, 1.6)	-6.3 (-7.4, -5.0)	-2.2 (-2.9, -1.5)	4.4 (3.7, 5.2)
Wealth and marginalization	Population belonging to scheduled castes or tribes	2.1 (1.5, 2.8)	-7.4 (-8.9, -5.9)	-0.1 (-0.9, 0.8)	6.5 (5.5, 7.5)
	Households lacking bank accounts	1.9 (1.3, 2.6)	-8.8 (-10.2, -7.2)	-1.7 (-2.6, -0.9)	6.2 (5.3, 7.2)
	Households lacking key index assets	0.9 (0.4, 1.5)	-4.6 (-5.9, -3.2)	-0.5 (-1.2, 0.3)	3.3 (2.5, 4.0)

Estimates are obtained based on regression models fit across draws from the distribution of excess mortality measures. Values are corrected for lagged reporting of deaths based on 2019 observations (**Figure S2**). Deaths are aggregated by PIN code areas; analyses include PIN code areas for which ≥ 1000 deaths were registered over the study period. Measures of excess mortality by PIN code area are plotted in **Figure S7**.

Table S17: Principal component analysis of community socioeconomic attributes.

Predictor	Spearman correlation												
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
Household crowding	0.34	0.52	-0.31	0.44	-0.17	0.30	-0.23	0.09	-0.14	-0.01	0.01	-0.35	-0.02
Population density	0.97	-0.25	-0.04	-0.01	-0.02	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Nonpermanent dwellings (%)	0.90	0.30	0.08	0.10	0.06	-0.15	0.12	0.22	0.01	-0.01	0.00	0.00	0.00
Dilapidated or unlivable dwellings (%)	0.81	-0.03	-0.26	0.29	0.35	0.11	0.21	-0.03	-0.01	0.00	0.00	0.00	0.00
Unfinished flooring (%)	0.78	0.20	0.43	-0.15	-0.32	0.05	0.10	-0.01	-0.16	-0.08	-0.03	0.00	0.00
Lacking on-site water (%)	0.73	0.61	-0.20	-0.23	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Practicing open defecation (%)	0.89	0.27	0.32	0.04	0.08	-0.15	0.02	-0.03	0.00	0.00	0.00	0.00	0.00
Lacking on-site latrines (%)	0.87	0.38	0.24	0.07	0.09	0.14	-0.09	0.02	0.00	0.00	0.00	0.00	0.00
Lacking electric lighting (%)	0.87	0.17	0.10	-0.02	-0.14	0.20	0.13	-0.08	0.23	-0.25	-0.06	0.00	0.00
Using solid cooking fuels (%)	0.78	0.24	0.36	-0.09	-0.36	0.14	0.22	-0.01	0.02	0.03	0.00	0.00	0.00
Scheduled castes/tribes (%)	0.39	0.58	0.02	0.03	0.01	0.24	-0.17	0.16	-0.21	-0.13	-0.02	-0.14	0.56
Lacking bank accounts (%)	0.65	0.59	-0.24	0.37	-0.19	-0.04	-0.04	-0.01	0.00	0.00	0.00	0.00	0.00
Lacking key index assets (%)	0.73	0.44	0.28	-0.02	-0.24	0.01	0.08	-0.04	-0.05	-0.29	0.21	0.00	0.00
Proportion of variance explained	0.807	0.124	0.029	0.018	0.011	0.005	0.004	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cumulative proportion of variance explained	0.807	0.932	0.961	0.979	0.990	0.995	0.999	>0.999	>0.999	>0.999	>0.999	>0.999	>0.999

Values indicate measures of Spearman correlation (ρ) for each community socioeconomic variable and the indicated principal component. The bottom two rows indicate the proportion of variance explained by each principal component, individually and cumulatively; the consistent associations of principal component 1 (PC1) and PC2 with measures of community disadvantage motivated consideration of these two variables as independent measures of relative disadvantage for the primary analyses presented in **Figure 3**. Numerical estimates of the association of each principal component variable with the outcome of relative mortality, at the PIN code level, are presented in **Table S18** (for all individuals) and **Table S19** (for individuals aged ≥ 50 years).

Table S18: Unadjusted and adjusted associations of excess mortality with principal component variables.

Measure	Percent change in excess mortality (95% UI), per 1-standard deviation increase in covariate							
	Total period		Early lockdown (24 March to 20 April, 2020)		First wave (May to August, 2020)		Second wave (March to June, 2021)	
	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
PC1	1.7 (1.0, 2.3)	1.7 (1.0, 2.3)	-6.2 (-7.6, -4.7)	-6.2 (-7.6, -4.7)	-0.9 (-1.7, 0.0)	-0.9 (-1.7, 0.0)	4.7 (3.8, 5.7)	4.7 (3.8, 5.7)
PC2	1.3 (0.6, 1.9)	1.3 (0.6, 1.9)	-5.0 (-6.7, -3.4)	-5.0 (-6.7, -3.4)	-0.8 (-1.7, 0.0)	-0.8 (-1.7, 0.0)	4.4 (3.3, 5.4)	4.4 (3.3, 5.4)
PC3	-1.1 (-1.6, -0.5)	-1.1 (-1.6, -0.5)	-0.3 (-1.8, 1.1)	-0.3 (-1.8, 1.1)	0.6 (-0.2, 1.4)	0.6 (-0.2, 1.4)	-2.5 (-3.4, -1.6)	-2.5 (-3.4, -1.6)
PC4	-0.3 (-0.8, 0.2)	-0.3 (-0.8, 0.2)	-3.5 (-4.8, -2.2)	-3.5 (-4.8, -2.2)	1.4 (0.7, 2.1)	1.4 (0.7, 2.1)	-1.1 (-1.8, -0.3)	-1.1 (-1.8, -0.3)
PC5	0.7 (0.1, 1.2)	0.7 (0.1, 1.2)	2.5 (1.1, 4.0)	2.5 (1.1, 4.0)	2.9 (2.1, 3.6)	2.9 (2.1, 3.6)	0.8 (0.0, 1.6)	0.8 (0.0, 1.6)
PC6	3.7 (2.7, 4.7)	3.7 (2.7, 4.7)	2.0 (-0.3, 4.5)	2.0 (-0.3, 4.5)	2.4 (1.2, 3.8)	2.4 (1.2, 3.8)	5.7 (4.2, 7.4)	5.7 (4.2, 7.4)
PC7	-2.5 (-3.2, -1.8)	-2.5 (-3.2, -1.8)	4.9 (3.0, 6.7)	4.9 (3.0, 6.7)	-2.0 (-3.0, -1.1)	-2.0 (-3.0, -1.1)	-3.2 (-4.3, -2.3)	-3.2 (-4.3, -2.3)
PC8	0.2 (-0.3, 0.8)	0.2 (-0.3, 0.8)	-4.9 (-6.2, -3.5)	-4.9 (-6.2, -3.5)	-1.0 (-1.8, -0.3)	-1.0 (-1.8, -0.3)	1.7 (0.9, 2.5)	1.7 (0.9, 2.5)
PC9	0.4 (-0.2, 0.9)	0.4 (-0.2, 0.9)	-0.5 (-2.0, 0.9)	-0.5 (-2.0, 0.9)	-2.8 (-3.6, -2.0)	-2.8 (-3.6, -2.0)	2.3 (1.5, 3.2)	2.3 (1.5, 3.2)
PC10	0.2 (-0.3, 0.7)	0.2 (-0.3, 0.7)	-2.8 (-4.1, -1.5)	-2.8 (-4.1, -1.5)	-1.3 (-2.0, -0.6)	-1.3 (-2.0, -0.6)	1.6 (0.9, 2.3)	1.6 (0.9, 2.3)
PC11	0.4 (-0.2, 1.0)	0.4 (-0.2, 1.0)	7.1 (5.6, 8.8)	7.1 (5.6, 8.8)	4.5 (3.7, 5.4)	4.5 (3.7, 5.4)	-2.0 (-2.8, -1.2)	-2.0 (-2.8, -1.2)
PC12	0.5 (0.0, 1.0)	0.5 (0.0, 1.0)	2.2 (0.8, 3.6)	2.2 (0.8, 3.6)	-0.7 (-1.4, 0.1)	-0.7 (-1.4, 0.1)	0.1 (-0.6, 1.0)	0.1 (-0.6, 1.0)
PC13	-0.2 (-0.7, 0.4)	-0.2 (-0.7, 0.4)	-2.2 (-3.6, -0.8)	-2.2 (-3.6, -0.8)	-0.7 (-1.4, 0.0)	-0.7 (-1.4, 0.0)	0.7 (-0.1, 1.5)	0.7 (-0.1, 1.5)

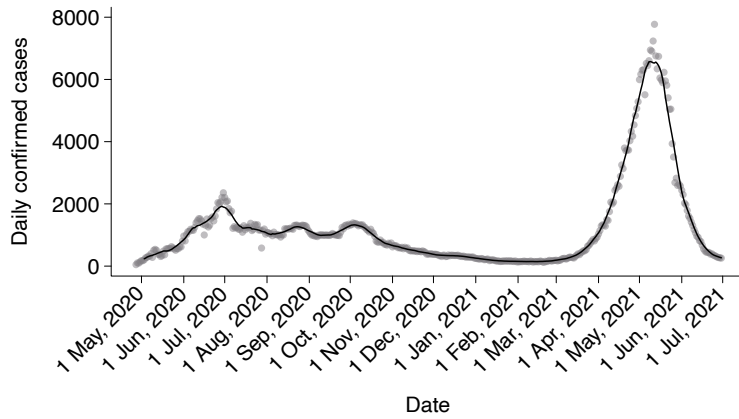
Estimates are obtained based on regression models fit across draws from the distribution of excess mortality measures; unadjusted estimates correspond to models including each principal component as a single explanatory variable, while adjusted estimates control for all principal components (the absence of correlation among principal components accounts for similarity in adjusted and unadjusted estimates). Values are corrected for lagged reporting of deaths based on 2019 observations (**Figure S2**). We present corresponding estimates for models fitted to data from individuals aged ≥ 50 years in **Table S19**. Deaths are aggregated by PIN code areas; analyses include PIN code areas for which ≥ 1000 deaths were registered over the study period. Measures of excess mortality by PIN code area are plotted in **Figure S7**.

Table S19: Unadjusted and adjusted associations of excess mortality with principal component variables among individuals aged 50 years and older.

Measure	Percent change in excess mortality (95% UI), per 1-standard deviation increase in covariate							
	Total period		Early lockdown (24 March to 20 April, 2020)		First wave (May to August, 2020)		Second wave (March to June, 2021)	
	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
PC1	2.6 (2.0, 3.4)	2.6 (2.0, 3.4)	-5.2 (-6.7, -3.3)	-5.2 (-6.7, -3.3)	-0.4 (-1.4, 0.6)	-0.4 (-1.4, 0.6)	5.9 (4.9, 7.0)	5.9 (4.9, 7.0)
PC2	0.4 (-0.3, 1.0)	0.4 (-0.3, 1.0)	-6.4 (-8.2, -4.6)	-6.4 (-8.2, -4.6)	-2.0 (-3.0, -1.1)	-2.0 (-3.0, -1.1)	4.0 (2.9, 5.1)	4.0 (2.9, 5.1)
PC3	-1.7 (-2.3, -1.1)	-1.7 (-2.3, -1.1)	-1.6 (-3.2, 0.0)	-1.6 (-3.2, 0.0)	0.4 (-0.5, 1.2)	0.4 (-0.5, 1.2)	-2.9 (-3.8, -2.0)	-2.9 (-3.8, -2.0)
PC4	-0.6 (-1.1, 0.0)	-0.6 (-1.1, 0.0)	-4.3 (-5.6, -2.9)	-4.3 (-5.6, -2.9)	1.3 (0.5, 2.1)	1.3 (0.5, 2.1)	-1.2 (-2.1, -0.3)	-1.2 (-2.1, -0.3)
PC5	1.1 (0.5, 1.6)	1.1 (0.5, 1.6)	3.4 (1.9, 4.9)	3.4 (1.9, 4.9)	3.6 (2.7, 4.4)	3.6 (2.7, 4.4)	0.9 (0.0, 1.7)	0.9 (0.0, 1.7)
PC6	2.5 (1.7, 3.4)	2.5 (1.7, 3.4)	-2.6 (-4.6, -0.2)	-2.6 (-4.6, -0.2)	1.5 (0.3, 2.8)	1.5 (0.3, 2.8)	4.6 (3.3, 6.1)	4.6 (3.3, 6.1)
PC7	-2.2 (-2.9, -1.5)	-2.2 (-2.9, -1.5)	4.6 (2.7, 6.4)	4.6 (2.7, 6.4)	-1.6 (-2.5, -0.6)	-1.6 (-2.5, -0.6)	-2.5 (-3.5, -1.5)	-2.5 (-3.5, -1.5)
PC8	0.4 (-0.2, 1.0)	0.4 (-0.2, 1.0)	-4.5 (-5.9, -3.1)	-4.5 (-5.9, -3.1)	-1.3 (-2.1, -0.5)	-1.3 (-2.1, -0.5)	1.8 (1.0, 2.7)	1.8 (1.0, 2.7)
PC9	0.9 (0.3, 1.5)	0.9 (0.3, 1.5)	1.9 (0.2, 3.5)	1.9 (0.2, 3.5)	-2.8 (-3.6, -2.0)	-2.8 (-3.6, -2.0)	2.6 (1.7, 3.6)	2.6 (1.7, 3.6)
PC10	0.5 (-0.1, 1.0)	0.5 (-0.1, 1.0)	-3.8 (-5.0, -2.4)	-3.8 (-5.0, -2.4)	-1.4 (-2.1, -0.6)	-1.4 (-2.1, -0.6)	2.1 (1.3, 2.9)	2.1 (1.3, 2.9)
PC11	-0.2 (-0.8, 0.4)	-0.2 (-0.8, 0.4)	8.2 (6.3, 9.9)	8.2 (6.3, 9.9)	4.9 (3.9, 5.8)	4.9 (3.9, 5.8)	-3.4 (-4.3, -2.5)	-3.4 (-4.3, -2.5)
PC12	0.3 (-0.3, 0.8)	0.3 (-0.3, 0.8)	1.0 (-0.5, 2.5)	1.0 (-0.5, 2.5)	-1.0 (-1.8, -0.2)	-1.0 (-1.8, -0.2)	0.0 (-0.8, 0.8)	0.0 (-0.8, 0.8)
PC13	0.3 (-0.3, 0.8)	0.3 (-0.3, 0.8)	1.2 (-0.3, 2.6)	1.2 (-0.3, 2.6)	0.0 (-0.8, 0.8)	0.0 (-0.8, 0.8)	1.4 (0.6, 2.3)	1.4 (0.6, 2.3)

Estimates are obtained based on regression models fit across draws from the distribution of excess mortality measures; unadjusted estimates correspond to models including each principal component as a single explanatory variable, while adjusted estimates control for all principal components (the absence of correlation among principal components accounts for similarity in adjusted and unadjusted estimates). Values are corrected for lagged reporting of deaths based on 2019 observations (**Figure S2**). Deaths are aggregated by PIN code areas; analyses include PIN code areas for which ≥ 1000 deaths were registered over the study period. Measures of excess mortality by PIN code area are plotted in **Figure S7**.

A. Reported COVID-19 cases



B. Reported COVID-19 deaths

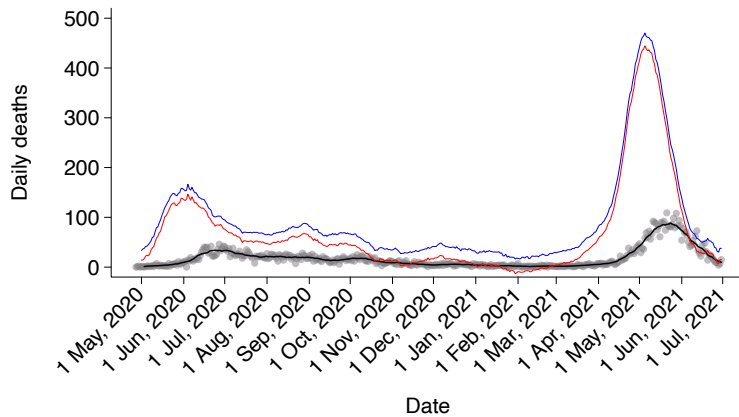


Figure S1: Reported COVID-19 cases and deaths in Chennai. We illustrate 14-day moving average rates of new daily confirmed (**A**) COVID-19 cases and (**B**) reported deaths (black lines); points illustrate daily reported values without averaging. Blue and red lines in the second panel denote the estimated number of excess deaths (two-week moving average), by date of death, based on models fitted with and without corrections for changes in mortality reporting following the 2019 redistricting, respectively.

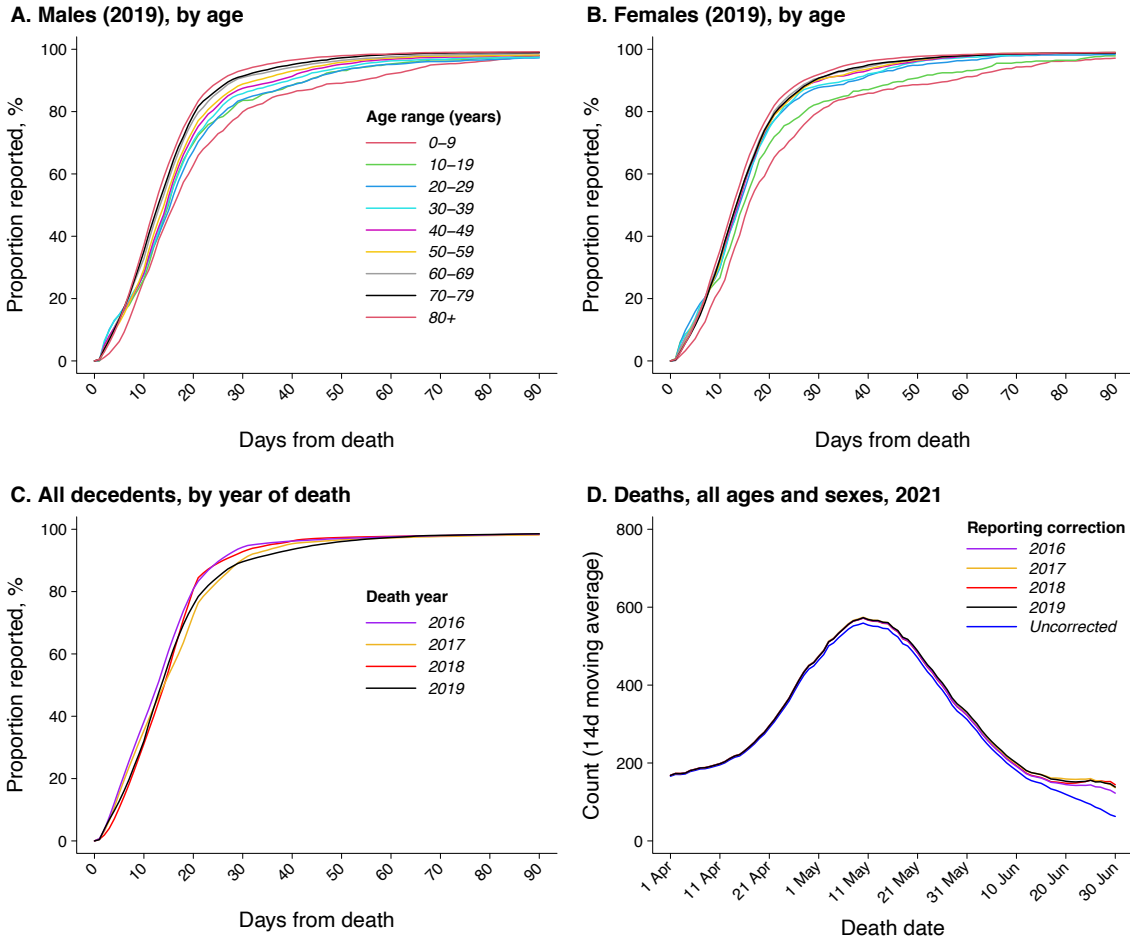


Figure S2: Lagged reporting of cases and deaths in the Civil Registration System, 2016-19. We illustrate the cumulative proportion of deaths reported, by days from individuals' death date, for (A) males and (B) females, separately by age, for the year 2019. Below, we illustrate (C) the cumulative proportion of deaths reported, by days from individuals' death date, for each calendar year (2016-19) before the COVID-19 pandemic. Last, we illustrate (D) the 14-day moving average of deaths for the period of 1 April to 30 June, 2021, applying corrections based on the reporting lags observed from 2016-19.

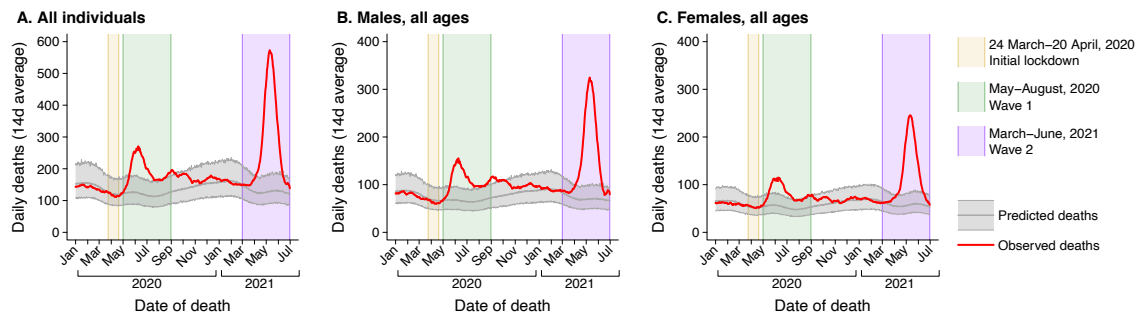


Figure S3: Excess mortality during the COVID-19 pandemic in Chennai, for models without secular reporting changes after redistricting. We plot 14-day moving average estimates of daily mortality in 2020 and 2021 (red), corrected for lagged reporting based on 2019 observations (**Figure S2**). Gray lines and shaded areas illustrate model-based expectations of the 14-day moving average, according to pre-pandemic observations, together with 95% uncertainty intervals. Corresponding estimates of excess deaths are presented in **Table S7**, **Table S8**, and **Table S9**.

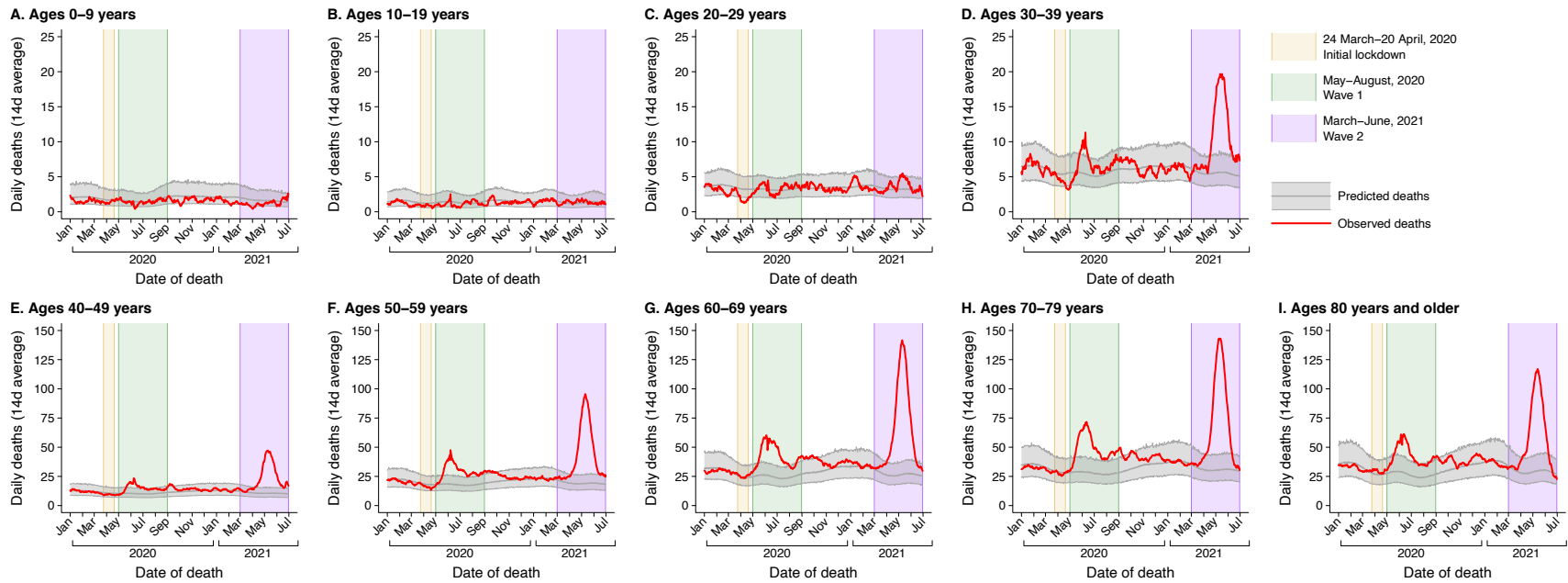


Figure S4: Age-specific excess mortality during the COVID-19 pandemic in Chennai, for models without secular reporting changes after redistricting. We plot 14-day moving average estimates of daily mortality in 2020 and 2021 by age (red), corrected for lagged reporting based on 2019 observations (**Figure S2**). Gray lines and shaded areas illustrate model-based expectations of the 14-day moving average, according to pre-pandemic observations, with 95% uncertainty. Corresponding estimates of excess deaths are presented in **Table S7**, **Table S8**, and **Table S9**.

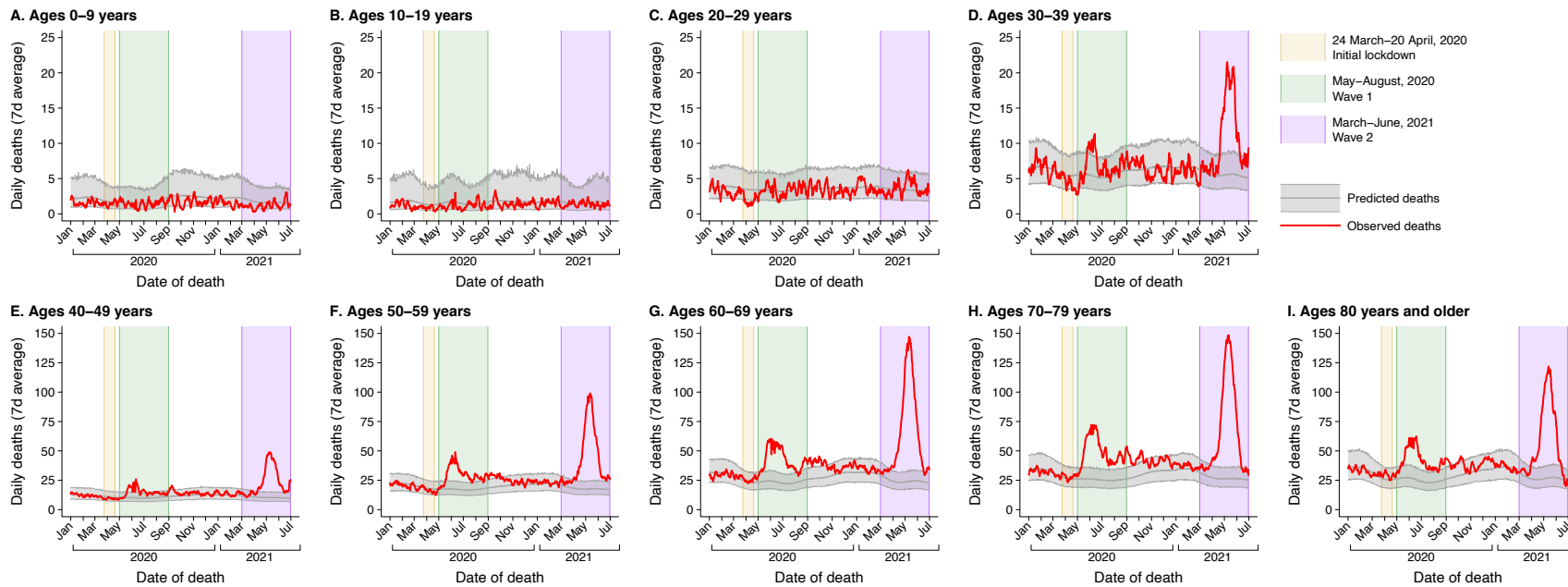


Figure S5: Age-specific excess mortality during the COVID-19 pandemic in Chennai, for models fitted to 7-day moving average time series. We plot 7-day moving average estimates of daily mortality in 2020 and 2021 by age (red), corrected for lagged reporting based on 2019 observations (**Figure S2**). Gray lines and shaded areas illustrate model-based expectations of the 7-day moving average, according to pre-pandemic observations, with 95% uncertainty. Corresponding estimates of excess deaths are presented in **Table S10**.

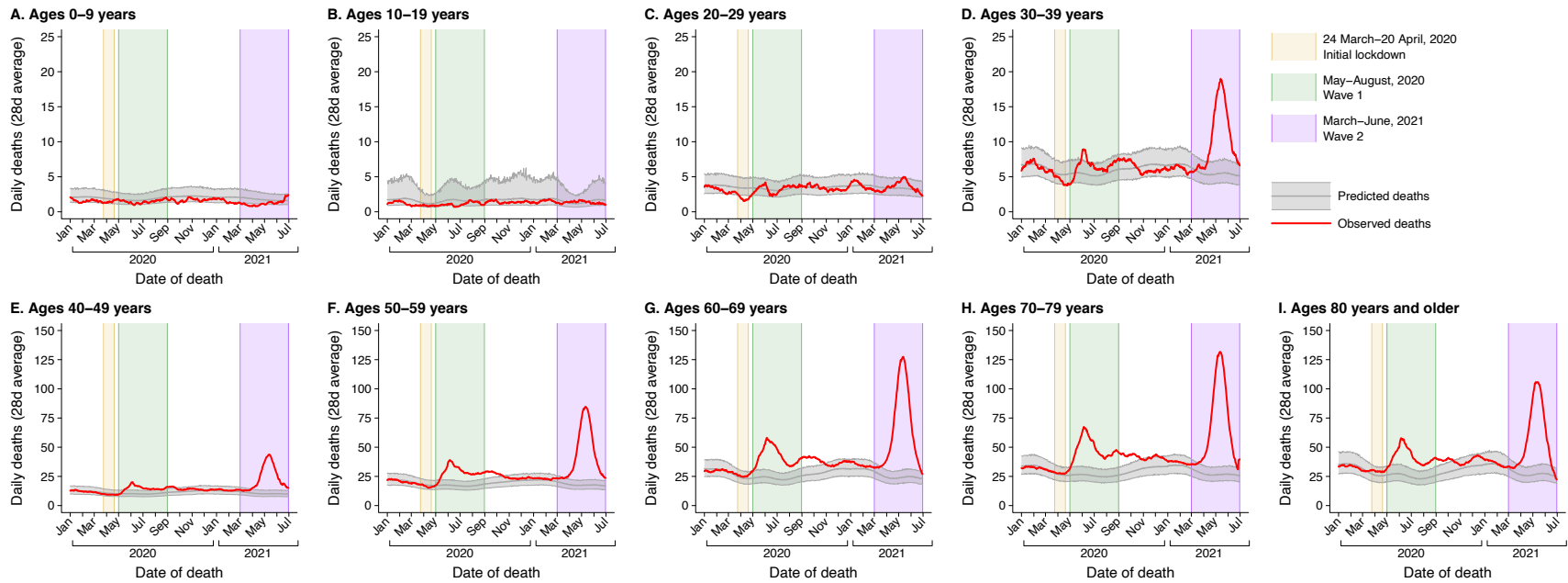


Figure S6: Age-specific excess mortality during the COVID-19 pandemic in Chennai, for models fitted to 28-day moving average time series. We plot 28-day moving average estimates of daily mortality in 2020 and 2021 by age (red), corrected for lagged reporting based on 2019 observations (**Figure S2**). Gray lines and shaded areas illustrate model-based expectations of the 28-day moving average, according to pre-pandemic observations, with 95% uncertainty. Corresponding estimates of excess deaths are presented in **Table S11**.

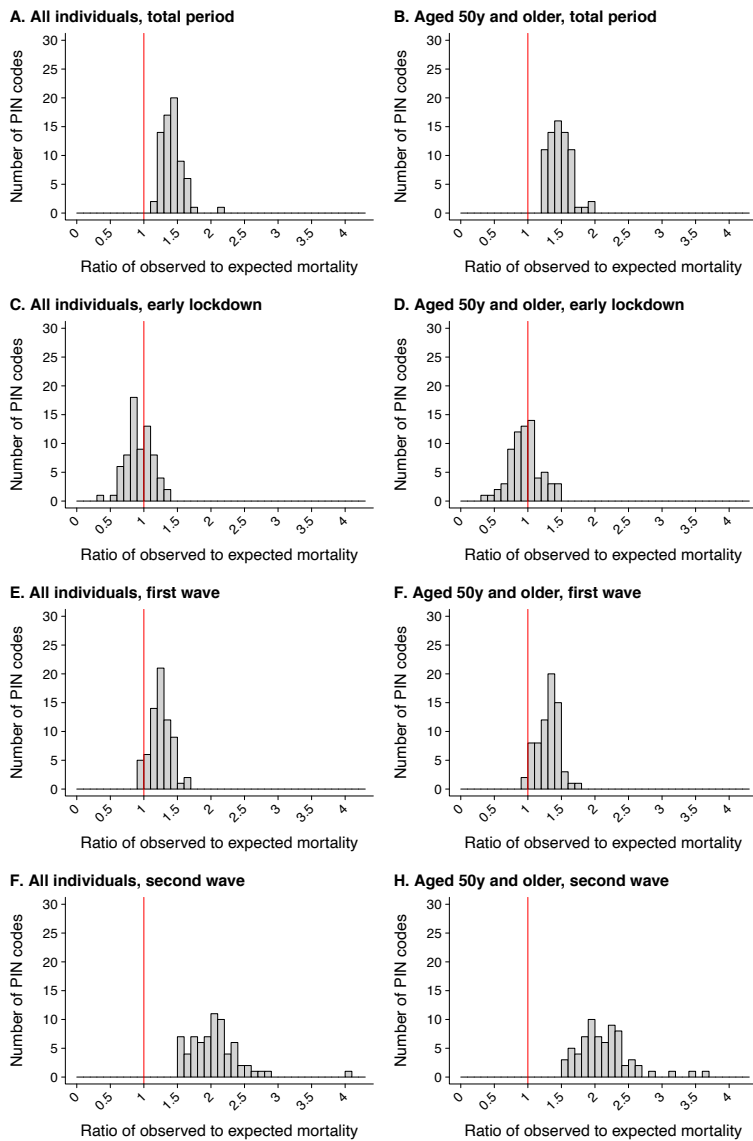


Figure S7: Distribution of observed to expected mortality across PIN code areas. We illustrate the distribution of the ratio of observed to expected mortality for all individuals and for individuals aged ≥ 50 years, during **(A-B)** the total pandemic period (March, 2020 to June, 2021); **(C-D)** the first four weeks of the country-wide lockdown (24 March to 20 April, 2020); **(E-F)** the first wave (May-August, 2020); and **(G-H)** the second wave (March-June, 2021). Associations of PIN code area characteristics with excess mortality estimates are presented in **Figure 3**, **Table S15**, and **Table S16**, while estimates of associations with principal components of the community socioeconomic attributes are presented in **Table S18** and **Table S19**.

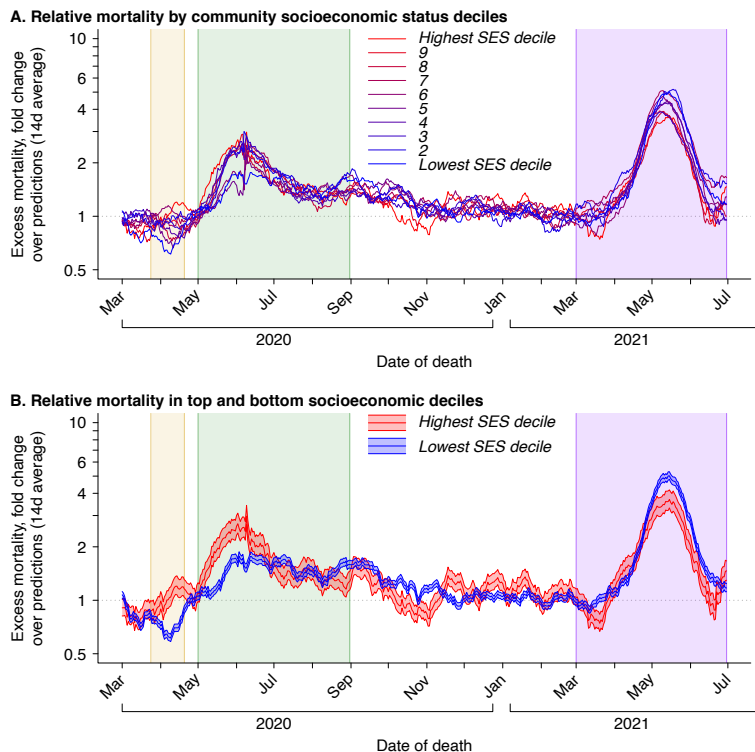


Figure S8: Relative mortality during the COVID-19 pandemic according to community socioeconomic status (SES) decile. We illustrate estimates of relative mortality (defined as observed over predicted deaths, calculated as a 14-day moving average) for PIN code areas grouped according to socioeconomic status decile, as measured by values of the first principal component derived across all 13 socioeconomic status measures (**Figure 3; Table S17**). The top panel (**A**) illustrates median estimates of relative mortality, calculated against trends projected from pre-pandemic observations, with a color gradient from blue (lowest-socioeconomic status decile) to red (highest socioeconomic status decile). The bottom panel (**B**) illustrates the highest and lowest deciles with accompanying 95% uncertainty intervals (shaded areas).