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COVID-19 Burden, Vaccination Uptake, and Hospital Capacity in a Brazilian Regional Hub City, 2020-2025: A Population-Based Ecological Study of Uberlândia, Minas Gerais

Review began 10/30/2026
Review ended 11/16/2026
Published 11/18/2026

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DOI: 10.7759/cureus.119885

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Abstract

Introduction

Five years after the start of the COVID-19 pandemic, municipal-level descriptions of how its burden evolved through the vaccination era and into the post-emergency period remain scarce for medium-sized Brazilian cities. We described COVID-19 hospitalizations, deaths, vaccination uptake, and hospital capacity in Uberlândia, a regional hub city in Minas Gerais, Brazil, from 2020 to 2025, and situated its mortality relative to other municipalities.

Methods

We conducted a population-based ecological study using routinely collected national data: severe acute respiratory infection (SARI) surveillance (SIVEP-Gripe), the Mortality Information System (SIM), individual-level vaccination records (National Immunization Program Information System (SI-PNI)), the hospital bed registry (National Registry of Health Establishments (CNES)), federal transfers, and municipal accounts, with 2022 census denominators. The study period was divided into pre-vaccine (March 2020-January 2021), vaccine rollout with Gamma/Delta circulation (February-December 2021), Omicron (2022), and endemic (2023-2025) periods. We estimated age-standardized rates, adjusted odds ratios (aORs) with 95% confidence intervals (CIs) for in-hospital death, and all-cause excess mortality, and used funnel plots to compare Uberlândia with all 853 municipalities of Minas Gerais and the 97 Brazilian regional capitals defined by the national urban hierarchy.

Results

Age-standardized COVID-19 mortality fell from 30.2 deaths per 100,000 per month during the 2021 rollout period to 0.67 per 100,000 per month in the endemic period (2023-2024; 97.8% lower; crude reduction 97.9%). In-hospital mortality among patients hospitalized with COVID-19 SARI was higher in 2021 than in the pre-vaccine period (aOR 1.77; 95% CI 1.61-1.95) and lower in the Omicron (aOR 0.64; 0.55-0.75) and endemic (aOR 0.69; 0.56-0.85) periods. As primary-series coverage among adults aged ⩾80 years increased, the share of COVID-19 deaths in this age group decreased (odds ratio 0.88 per 10 percentage points; 95% CI 0.85-0.91). In 2021, Uberlândia had the highest age-standardized COVID-19 mortality among the 34 municipalities of Minas Gerais with ⩾100,000 inhabitants and an all-cause excess of 58% above expected, exceeding the 99.8% funnel-plot control limit. Federal COVID-19 funding per capita was close to the median of comparable cities and was not correlated with excess mortality. In the endemic period, hospitalized COVID-19 patients were older than those with influenza (median 72 vs. 14 years) and had higher adjusted in-hospital mortality (aOR 2.14; 1.32-3.47), while the proportion of residents aged ⩾60 years vaccinated within each calendar year declined from 98% (2021) to 37% (2024) and 16% (2025).

Conclusions

In this descriptive ecological analysis, COVID-19 mortality in Uberlândia declined by approximately 98% after 2021, in temporal association with high vaccine coverage, while residual hospital mortality remained concentrated in older adults with declining annual vaccine uptake. The city's unusually high 2021 mortality was not accompanied by lower federal funding than in comparable cities. These findings are hypothesis-generating and cannot establish causal effects of vaccination, funding, or local health-system responses.

Categories: Epidemiology/Public Health, Internal Medicine, Infectious Disease
Keywords: brazil, covid-19, covid-19 vaccines, ecological study, excess mortality, hospitalization, intensive care units, mortality, public health surveillance, sars-cov-2

How to cite this article
Nunes L, Rocha M, Rocha S (November 18, 2026) COVID-19 Burden, Vaccination Uptake, and Hospital Capacity in a Brazilian Regional Hub City, 2020-2025: A Population-Based Ecological Study of Uberlândia, Minas Gerais. Cureus 18(11): e119885. DOI 10.7759/cureus.119885

Introduction

Brazil recorded one of the highest absolute COVID-19 death tolls worldwide, with marked heterogeneity across states and municipalities driven by differences in the timing of introduction, health-system capacity, and socioeconomic vulnerability [1,2]. The emergence of the Gamma (P.1) variant in late 2020 was followed by the country's deadliest wave in the first half of 2021 [3], which placed further strain on intensive care capacity that was already unevenly distributed across regions [4]. Vaccination began in January 2021, prioritizing older adults, and early analyses of routinely collected data suggested that deaths shifted away from the oldest age groups as their coverage increased [5,6].

After the World Health Organization declared the end of COVID-19 as a public health emergency of international concern in May 2023 [7], surveillance intensity, testing, and public attention declined. In 2024, COVID-19 vaccination was incorporated into Brazil's routine immunization schedule for priority groups, with two doses per year recommended for adults aged ⩾60 years [8], yet the extent to which these groups continue to be vaccinated, and how the residual burden of COVID-19 compares with that of other respiratory viruses, is less well described at the municipal level. Comparisons between COVID-19 and seasonal influenza among hospitalized patients in other settings have suggested a higher risk of death for COVID-19 even in later periods [9,10].

Most Brazilian analyses have been national or state-level. Medium-sized regional hub cities, which concentrate referral hospital capacity for surrounding municipalities, may experience the pandemic differently from both state capitals and smaller towns, but such cities are underrepresented in the literature. Uberlândia, the second most populous municipality of Minas Gerais and a regional capital in the Brazilian urban hierarchy [11], is one such city. A previous descriptive analysis by our group, conducted as an undergraduate research project, covered only 2021 and relied on municipal bulletins with incomplete intensive care data [12]; a separate preprint examined intra-urban socioeconomic inequalities in 2020-2021 [13]. National and state-level analyses necessarily average over such local differences. To our knowledge, no previous study has followed a Brazilian regional hub city from the pre-vaccine period through the post-emergency years. We combined person-level vaccination records (including annual uptake after COVID-19 vaccination entered the routine schedule) with hospital capacity and financing data, benchmarking against comparator sets defined by external criteria, and a comparison of residual COVID-19 hospitalizations with those due to other respiratory viruses.

The objectives of this study were to describe, for residents of Uberlândia from March 2020 to December 2025: (i) the evolution of COVID-19 hospitalizations, intensive care use, and mortality across pandemic periods; (ii) vaccination coverage and annual vaccine uptake by age; (iii) hospital intensive care capacity and public health financing; (iv) the city's position relative to other municipalities, using comparison sets defined by external criteria; and (v) the profile of COVID-19 hospitalizations in the endemic period compared with influenza and respiratory syncytial virus (RSV). Given the ecological design, we aimed to describe patterns and generate hypotheses rather than to estimate causal effects.

Materials And Methods

Study design and setting

We conducted a population-based ecological study with a time-series component, using routinely collected secondary data, and report it following the REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement [14]. Uberlândia (IBGE code 3170206) is located in the Triângulo Mineiro region of Minas Gerais, southeastern Brazil, and had 713,224 residents in the 2022 census. In the 2018 Regions of Influence of Cities (REGIC) classification of the Brazilian Institute of Geography and Statistics (IBGE), it is a "Regional Capital B", the second tier of the national urban hierarchy below metropolises [11], and its hospitals receive referrals from surrounding municipalities.

Data sources

All data were publicly available, de-identified, and obtained from official repositories between 19 and 20 October 2026 (Table *1*) [15-21]. Analyses were restricted to residents of Uberlândia unless otherwise stated.

Domain	Source (custodian)	Unit / period used	Main variables
SARI hospitalizations	Influenza Epidemiological Surveillance Information System (SIVEP-Gripe), SARI database (Ministry of Health, Open Data portal)	Individual notifications, 2019-2026 (2026 partial)	Symptom onset, age, sex, comorbidities, ICU admission, invasive ventilation, final classification, outcome
Deaths	Mortality Information System, SIM (Ministry of Health)	Individual death records, 2015-2025 (2025 through August)	Date, age, sex, municipality of residence, underlying cause (ICD-10)
Vaccination	National Immunization Program information system, SI-PNI - COVID-19 campaign database (January 2021-August 2024) and routine database (September 2024–September 2026)	Individual dose records with pseudonymized person identifier	Date, dose type, vaccine, age, municipality of residence
Hospital beds	National Registry of Health Establishments, CNES (DATASUS file transfer)	Monthly bed counts by type, 2019-2026	Regular adult ICU beds; COVID-19-exclusive ICU and ventilatory-support beds
Federal transfers	Federal Transparency Portal (Comptroller General)	Monthly transfers, 2019-2022	Health-function transfers to municipal governments; COVID-19-specific budget actions
Municipal spending	Siconfi, Annual Accounts Declaration (National Treasury)	Annual, 2019-2025	Liquidated expenditure in the health function
Population and urban hierarchy	2022 Census (IBGE/SIDRA); REGIC 2018 (IBGE)	Single-year age by municipality	Denominators; regional capital classification

TABLE 1: Data sources

SIVEP-Gripe: Influenza Epidemiological Surveillance Information System [15]; SARI: severe acute respiratory infection; ICU: intensive care unit; ICD-10: International Classification of Diseases, 10th revision [22]; IBGE: Brazilian Institute of Geography and Statistics; REGIC: Regions of Influence of Cities[11]; DATASUS: Department of Informatics of the Unified Health System [18]; SIDRA: IBGE Automatic Recovery System [21].

Definitions

A COVID-19 hospitalization was a hospitalized SARI notification with a final classification of COVID-19 in the Influenza Epidemiological Surveillance Information System (SIVEP-Gripe) [15], dated by symptom onset. In-hospital death was a recorded outcome of death from SARI among notifications with a known outcome (cure or death). A COVID-19 death was a death certificate in SIM with underlying cause International Classification of Diseases, 10th revision (ICD-10) code B34.2 or U07.1/U07.2 [22,23]. All-cause mortality used all SIM records of residents. Influenza and RSV hospitalizations were SARI notifications classified as influenza, or with a positive reverse transcription polymerase chain reaction (RT-PCR) or antigen test for RSV, respectively.

Vaccination indicators were computed per person using the pseudonymized identifier, which is shared between the campaign and routine SI-PNI databases (verified in the overlapping month of September 2024; records were deduplicated by person and date). We defined cumulative coverage with at least one dose, the primary series (second dose or single-dose vaccine), at least one booster, and the bivalent booster; and annual uptake as the proportion of residents who received at least one COVID-19 dose in a given calendar year. Because two doses per year have been recommended for adults aged ⩾60 years since 2024 [8], this indicator is a lenient measure of adherence to the recommended schedule in that group. Age was taken at the first recorded dose (cumulative coverage) or at the dose (annual uptake), with 2022 census denominators.

The study period was divided a priori into four calendar periods reflecting national epidemiological milestones: P1, pre-vaccine (March 2020-January 2021; vaccination in Uberlândia began on 19 January 2021); P2, vaccine rollout with Gamma and Delta circulation (February-December 2021); P3, Omicron (January-December 2022); and P4, endemic (January 2023-December 2025). Data from 2026 (through September 2026) are shown descriptively only. Because SIM records for 2025 were available only through August, COVID-19 mortality rates in P4 were calculated for January 2023-December 2024 (24 months).

Data completeness and missing data

We quantified the completeness of the key variables in each database. In SIVEP-Gripe, missing values were handled as follows: notifications without a recorded outcome of cure or death were excluded from in-hospital mortality analyses (complete-case analysis); a blank or unknown intensive care unit (ICU) or ventilatory-support field was counted as not having received that care; and, because the risk-factor field in the extracted files contained only positive or blank values, a blank field was classified as no reported risk factor or comorbidity. Schooling was not used in any analysis because of its incompleteness. The COVID-19 vaccination field of the notification form was not used either: it did not exist in P1, was only partly filled in P2, and its validity is uncertain (see Limitations). In SIM, deaths with missing age were retained in all-cause counts and excluded from age-specific rates, and the proportion of deaths with ill-defined underlying causes (ICD-10 chapter R) was tracked as an indicator of certification quality. In SI-PNI, records were restricted to COVID-19 vaccines administered to residents, and duplicate records (same person, date, and dose) were removed. No imputation was performed. Changes in surveillance over time were assessed through the annual proportion of hospitalized SARI notifications without an identified etiology.

Statistical analysis

Rates

Crude and age-standardized (direct method, 2022 Brazilian census population as the standard; eight age groups) hospitalization and death rates were expressed per 100,000 residents per month to allow comparison of periods of different lengths.

In-Hospital Outcomes

Among COVID-19 hospitalizations with a known outcome, we fitted logistic regression models, reported as adjusted odds ratios (aORs), for in-hospital death and, separately, ICU admission, with period as the exposure of interest and adjustment for age group, sex, and the presence of any reported risk factor or comorbidity. Pediatric age groups were combined (0-17 years) because of sparse events. Covariates were chosen a priori as established predictors of in-hospital death from COVID-19 that are available in SIVEP-Gripe for all periods. Individual vaccination status, circulating variant, and clinical management were not included because they changed along with the calendar periods and are part of what the period contrasts describe; the aORs are therefore descriptive comparisons of case-mix-adjusted outcomes between periods, not estimates of the effect of any single factor.

Age Distribution of Deaths and Vaccine Coverage

Following previous Brazilian analyses [5], we modeled the monthly number of COVID-19 deaths among residents aged ⩾80 years out of all COVID-19 deaths (binomial generalized linear model, April 2020-December 2021, months with five or more deaths) as a function of primary-series coverage in the ⩾80 group and in adults aged 18-59 years. This analysis describes a shift in the age distribution of deaths and does not estimate vaccine effectiveness.

Excess Mortality

Expected monthly all-cause deaths for 2020-2024 were predicted from a Poisson model fitted to the pre-pandemic months (January 2015-February 2020) with a linear trend and month indicators, with standard errors scaled for overdispersion (quasi-Poisson); this follows established approaches using pre-pandemic trends [24,25]. Excess was reported as observed minus expected deaths and as the P-score (excess as a percentage of expected deaths), with 95% prediction intervals (PIs) obtained by simulation from the fitted model (parameter uncertainty and overdispersed monthly variation; 50,000 draws). The year 2025 was excluded because SIM records were available only through August 2025.

Comparison With Other Municipalities

To avoid arbitrary selection of comparators, two comparison sets were defined by external criteria, independent of the outcome data: (i) all 853 municipalities of Minas Gerais, displayed in funnel plots [26]; and (ii) the 97 Brazilian regional capitals of REGIC 2018 [11] (for urban arrangements, the principal municipality). For each municipality we computed the indirectly age-standardized COVID-19 mortality ratio (SMR; observed/expected deaths, applying state or national age-specific rates to the local 2022 population) and the all-cause observed/expected ratio, with expected deaths from a municipality-specific log-linear Poisson trend fitted to 2015-2019. Funnel-plot control limits (95% and 99.8%) were derived from the Poisson distribution and, when overdispersion was present, from a multiplicative overdispersion factor estimated from 10%-winsorized z-scores [26]. Among regional capitals, we compared federal COVID-19 transfers per capita (2020-2022) and the change in municipal health expenditure per capita (2019 to 2021) and examined their Spearman correlation with all-cause excess mortality for 2020-2022.

Endemic Period

COVID-19, influenza, and RSV hospitalizations in 2023-2025 were described by age, comorbidity, ICU admission, and in-hospital mortality, and in-hospital death and ICU admission were compared between COVID-19 and influenza with logistic regression adjusted for age group, sex, and comorbidity.

Comparison of Vaccine Uptake With the State

To assess whether trends in annual uptake were specific to Uberlândia, we compared the number of COVID-19 doses administered to residents aged ⩾60 years per 100 residents of that age in Uberlândia and in Minas Gerais in 2025-2026 (routine SI-PNI database).

Sensitivity Analyses

We assessed the robustness of the in-hospital death model by (i) adding recorded race/skin color as a proxy for socioeconomic position; (ii) restricting the analysis to laboratory-confirmed cases; (iii) restricting it to patients with at least one reported risk factor; and (iv) reclassifying notifications without a known outcome as all survivors or all deaths. To evaluate the fixed 2022 census denominators, crude COVID-19 mortality rates by period were recalculated with year-specific populations from the IBGE annual municipal population estimates (SIDRA table 6579), using the census for 2022 and linear interpolation for 2023. Expected all-cause deaths were re-estimated with three alternative baselines: the pre-pandemic monthly mean without a trend; separate linear trends for three age groups (0-59, 60-79, and ⩾80 years), summed; and a model of death rates with the annual population as an offset.

Software and Inference

Analyses used Python 3.14 (Python Software Foundation, Wilmington, DE, USA) with the pandas 3.0, DuckDB 1.5, statsmodels 0.15, and SciPy 1.18 libraries. Estimates are reported with 95% confidence intervals (CIs). Given the descriptive aim and the number of comparisons, p-values were not adjusted for multiplicity and are interpreted as exploratory. The code used for data extraction and analysis is available from the corresponding author upon reasonable request.

Ethical considerations

This study used exclusively public-domain, de-identified secondary data, with no access to identifiable information and no contact with participants. In accordance with Brazilian National Health Council Resolution 510/2016 (Article 1, sole paragraph, items II and III), research that uses publicly accessible or public-domain information is not subject to registration or review by the research ethics committee system [27]; therefore, ethics committee approval and informed consent were not required.

Results

Overall burden and pandemic periods

From March 2020 to December 2025, 13,883 COVID-19 SARI hospitalizations were recorded among residents of Uberlândia, and 3,396 deaths with COVID-19 as the underlying cause were certified in 2020-2024 (Figure *1A*). Indicators by period are shown in Table *2*. The highest rates occurred in P2, when age-standardized COVID-19 mortality reached 30.2 deaths per 100,000 per month, compared with 10.2 in P1, 2.8 in P3, and 0.67 in P4 (2023-2024, the years with complete SIM records). Relative to P2, age-standardized mortality in the endemic period was 97.8% lower (crude rate 29.3 vs. 0.63 per 100,000 per month; 97.9% lower). Age-specific rates in each period are shown in Figure *2*.

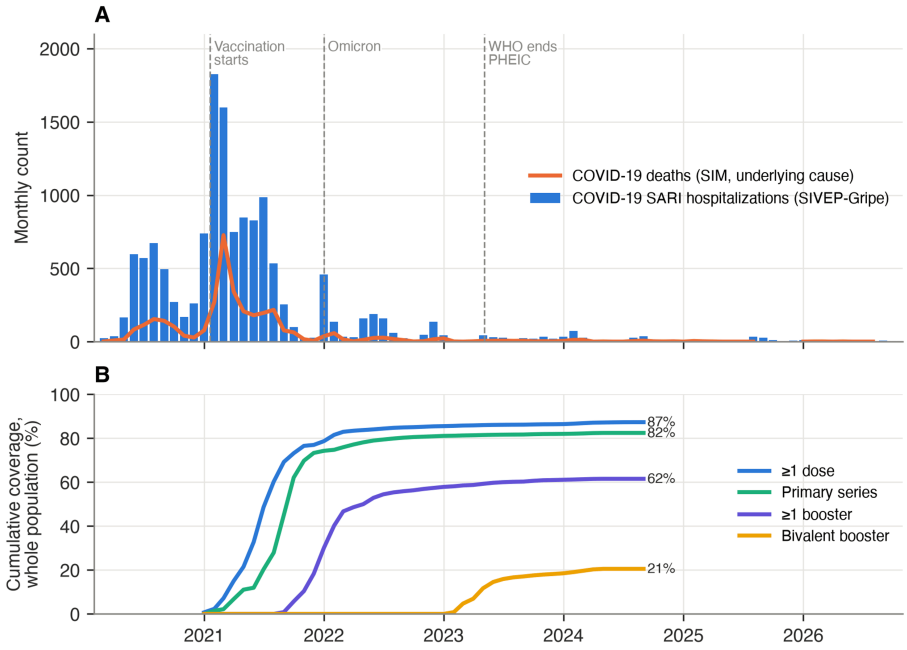


FIGURE 1: Monthly COVID-19 SARI hospitalizations (SIVEP-Gripe) and COVID-19 deaths (SIM, underlying cause) among residents of Uberlândia, March 2020–September 2026 (A), and cumulative vaccination coverage of the whole population, January 2021-August 2024 (B)

SARI: severe acute respiratory infection; SIVEP-Gripe: Influenza Epidemiological Surveillance Information System [15]; SIM: Mortality Information System [16]; WHO: World Health Organization; PHEIC: Public Health Emergency of International Concern. Cumulative coverage is shown until August 2024, the end of the COVID-19 campaign database [17]; later doses are described as annual uptake in a following figure. No SIM death records were available for September–December 2025 or after August 2026.

Indicator	P1 Pre-vaccine (Mar 2020–Jan 2021)	P2 Rollout, Gamma/Delta (Feb–Dec 2021)	P3 Omicron (2022)	P4 Endemic (2023–2025)
Months	11	11	12	36
SARI hospitalizations, n	4,000	7,770	1,434	679
Hospitalizations /100,000/month, age-standardized	51.8	99.6	17.5	2.8
Median age of hospitalized patients, years	60	55	70	72
Hospitalized aged ≥60 years, %	50.2	39.7	65.6	68.0
ICU admission, %	16.2	21.0	22.2	21.9
Invasive ventilation, %	6.2	12.9	7.7	8.1
In-hospital mortality, %	23.5	29.1	22.2	23.5
COVID-19 deaths (SIM), n	764	2,301	224	107*
Deaths /100,000/month, crude	9.74	29.33	2.62	0.63*
Deaths /100,000/month, age-standardized	10.23	30.19	2.79	0.67*
Deaths aged ≥80 years, %	30.0	17.6	52.2	41.1*
Median age at death, years	72	65	80	78*

TABLE 2: COVID-19 hospitalizations and deaths among residents of Uberlândia by pandemic period

SARI: severe acute respiratory infection; ICU: intensive care unit; SIM: Mortality Information System [16]. Standard population: Brazil, 2022 census [21]. *SIM records for 2025 were available only through August; P4 deaths and death rates therefore refer to January 2023-December 2024 (24 months).

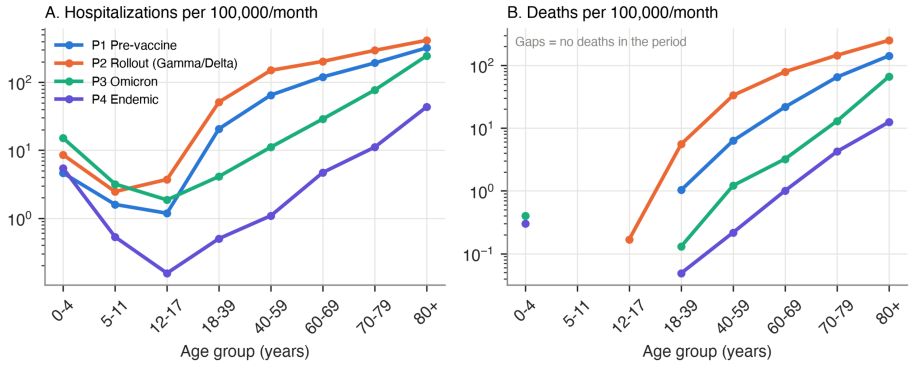


FIGURE 2: Age-specific COVID-19 hospitalization (A) and death (B) rates per 100,000 per month, by pandemic period (logarithmic scale)

P1: pre-vaccine period; P2: vaccine rollout with Gamma and Delta circulation; P3: Omicron period; P4: endemic period; SIM: Mortality Information System [16]. Death rates in P4 refer to 2023–2024, the years with complete SIM records.

In-hospital outcomes

After adjustment for age, sex, and comorbidity, the odds of in-hospital death among patients hospitalized with COVID-19 SARI were higher in P2 than in P1 (aOR 1.77; 95% CI 1.61-1.95) and lower in P3 (aOR 0.64; 0.55-0.75) and P4 (aOR 0.69; 0.56-0.85). The adjusted odds of ICU admission were higher in all subsequent periods than in P1 (P2 aOR 1.52, 1.37-1.68; P3 1.33, 1.14-1.55; P4 1.32, 1.07-1.63). Older age (≥80 vs. 18-39 years: aOR 7.33, 6.10-8.81), male sex (1.51, 1.39-1.64), and reported comorbidity (4.10, 3.66-4.60) were

associated with in-hospital death. The full models are shown in Appendix 1.

Vaccination coverage and age distribution of deaths

Vaccination followed age-descending priority (Figure *3A*). By June 2021, primary-series coverage was 90.6% among residents aged ≥80 years and 89.2% among those aged 70-79, compared with 3-4% among adults aged 18-59. By August 2024, 87.3% of the population had received at least one dose, 82.4% had completed the primary series, 61.5% had received at least one booster, and 20.5% had received a bivalent booster; coverage was lowest in children aged 0-4 years (32.4% with at least one dose) (Figures *1B*, *3A*).

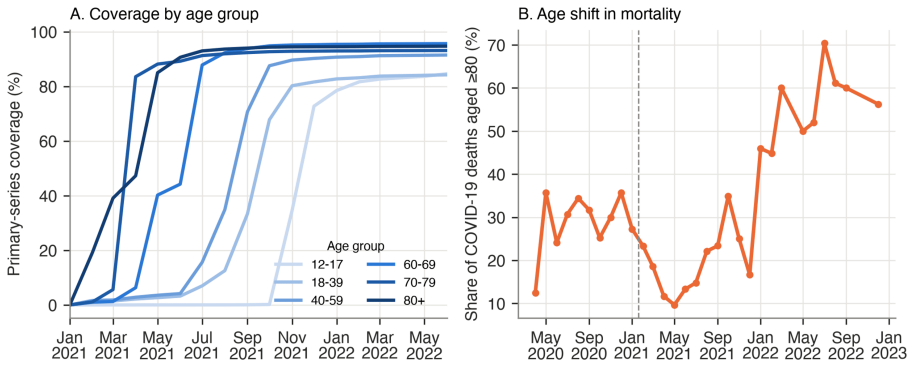


FIGURE 3: Primary-series vaccination coverage by age group, January 2021-June 2022 (A), and monthly share of COVID-19 deaths among residents aged ≥80 years, 2020-2022 (B)

Coverage is the proportion of residents in each age group who had completed the primary series (second dose or single-dose vaccine), with 2022 census denominators [21]. Dashed line in panel B: start of vaccination (January 2021).

The proportion of COVID-19 deaths occurring at ≥80 years fell from 30.0% in P1 to 17.6% in P2 and rose again to 52.2% in P3 (Table *2*, Figure *3B*). Between April 2020 and December 2021 (21 months; 3,064 deaths), each 10-percentage-point increase in primary-series coverage among residents aged ≥80 years was associated with lower odds that a death occurred in this age group (odds ratio 0.88; 95% CI 0.85-0.91), whereas increasing coverage among adults aged 18-59 years was associated with higher odds (1.22; 1.15-1.30); that is, during these months the age distribution of deaths shifted toward groups that were vaccinated later.

Annual uptake declined after the primary campaign (Figure *4*). The proportion of residents aged ≥60 years who received at least one COVID-19 dose within the calendar year was 98.4% in 2021, 73.9% in 2022, 49.5% in 2023, 36.5% in 2024, and 16.3% in 2025; from January to September 2026 it was 13.2%. Among residents aged ≥80 years, annual uptake was 15.8% in 2025, and among children aged 0-4 years, 9.1%. Uptake among adults aged 18-59 years, who as a group are not a priority population in the routine schedule, was below 3% from 2025 onward. The decline was not specific to Uberlândia: in 2025, 11.7 COVID-19 doses per 100 residents aged ≥60 years were administered in Minas Gerais as a whole, compared with 18.2 per 100 in Uberlândia.

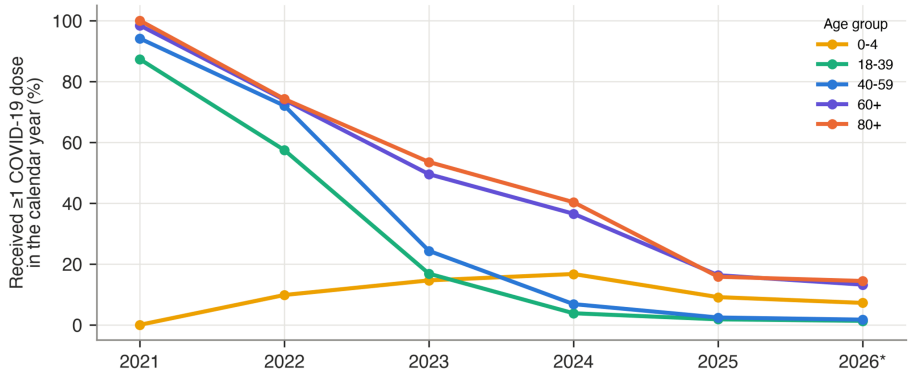


FIGURE 4: Proportion of residents receiving at least one COVID-19 vaccine dose in each calendar year, by age group, 2021-2026 (2026: January-September)

Annual uptake is the proportion of residents in each age group who received at least one COVID-19 dose within the calendar year, with 2022 census denominators [21]. Asterisk: partial year (data through September 2026).

All-cause excess mortality

Observed all-cause deaths were above expected values in every year from 2020 to 2024 (Figure *5*). Excess deaths were 511 in 2020 (95% PI 268 to 741; P-score 12.5%), 2,414 in 2021 (2,131 to 2,680; 58.3%), 320 in 2022 (-13 to 628; 7.6%), 362 in 2023 (-22 to 712; 8.5%), and 490 in 2024 (48 to 895; 11.3%); the prediction intervals for 2022 and 2023 included zero. In 2020-2022, excess deaths were of similar magnitude to deaths certified as COVID-19 (3,246 vs. 3,289), whereas in 2023-2024 excess deaths (852) exceeded certified COVID-19 deaths (107). Meanwhile, the proportion of deaths with ill-defined underlying causes (ICD-10 chapter R) increased from 2.0-3.7% in 2015-2019 to 6.2% in 2021 and 8.0% in 2022, remaining at 5.2% in 2024 (Appendix 2).

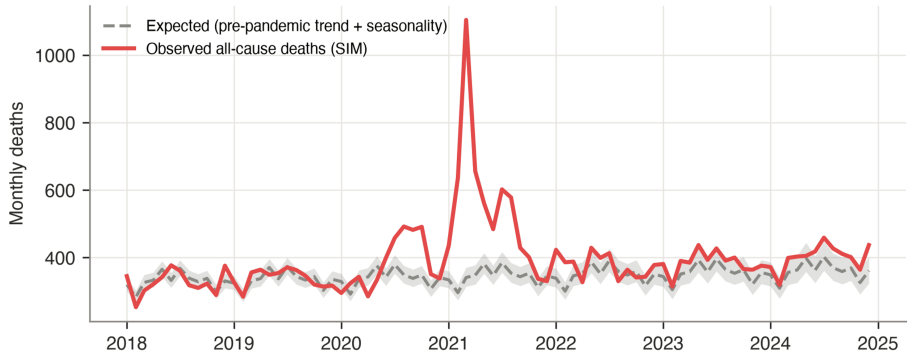


FIGURE 5: Observed and expected monthly all-cause deaths, 2018-2024; expected values from a pre-pandemic (January 2015-February 2020) Poisson model with trend and seasonality (shaded area: 95% CI of the expected mean)

CI: confidence interval; SIM: Mortality Information System [16].

Hospital capacity and financing

Before the pandemic, Uberlândia had 181 regular adult ICU beds (December 2019; 32.6 per 100,000 adults). COVID-19-exclusive adult ICU beds peaked at 134 between March and December 2021, when total registered adult ICU capacity reached 313 beds (179 regular and 134 COVID-19-exclusive); an additional 72 COVID-19 ventilatory-support beds, not counted as ICU beds, were registered in the same period (Figure *6*). Residents with symptom onset in February and March 2021 accounted for 352 and 316 COVID-19 ICU admissions, respectively, exceeding the number of adult ICU beds registered in those months (286 and 313). COVID-19-exclusive beds were reduced in 2022 and were no longer registered from 2023; in September 2026, the city

had 169 adult ICU beds (30.4 per 100,000 adults), fewer than in December 2019 (181) but more than in January 2019 (147). Hospitals in Uberlândia also admitted non-residents, who accounted for 8.2-12.7% of COVID-19 hospitalizations and 16.0-19.8% of COVID-19 ICU admissions in these hospitals in 2020-2023.

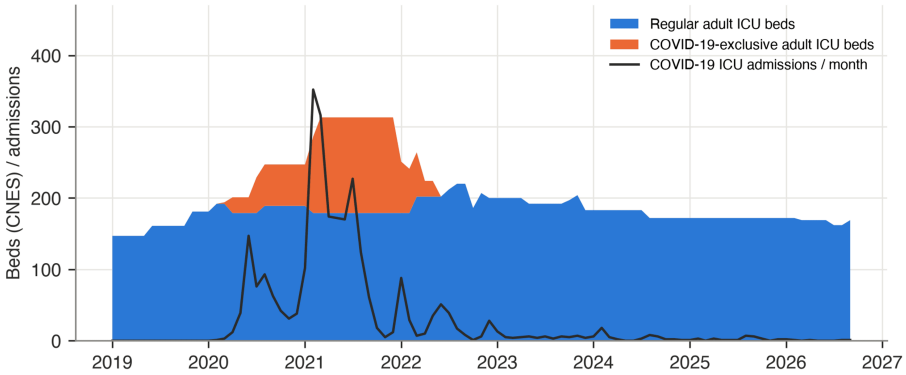


FIGURE 6: Registered adult ICU beds (regular and COVID-19-exclusive) and monthly COVID-19 ICU admissions of residents, 2019-2026

ICU: intensive care unit. Bed counts are from the National Registry of Health Establishments (CNES) [18]; admissions are from the Influenza Epidemiological Surveillance Information System (SIVEP-Gripe) [15], dated by symptom onset.

The municipal government received Brazilian reais (BRL) 83.8 million (2020), 57.5 million (2021), and 5.2 million (2022) in federal transfers specifically tagged for COVID-19, totaling BRL 205 per inhabitant in 2020-2022. Liquidated municipal health expenditure increased from BRL 883 per inhabitant in 2019 to BRL 1,360 in 2021 (+54%).

Comparison with other municipalities

Among the 853 municipalities of Minas Gerais, Uberlândia's age-standardized COVID-19 mortality ratio for 2020-2022 was 1.66 (14th highest; above the 99.8% overdispersion-adjusted control limit) and for 2021 was 1.74, the highest among the 34 municipalities with ⩾100,000 inhabitants (Figure *7A*). Its all-cause observed/expected ratio was 1.58 in 2021 (highest among municipalities with ⩾100,000 inhabitants; above the 99.8% limit) and 1.26 for 2020-2022 (seventh among these municipalities) (Figure *7B*). In 2023-2024, the COVID-19 mortality ratio remained above the control limit (SMR 2.03), whereas all-cause mortality was within the limits (observed/expected 1.10).

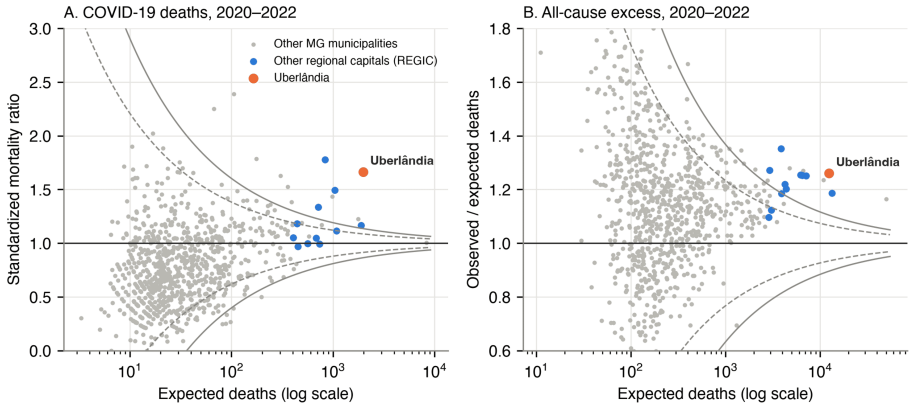


FIGURE 7: Funnel plots of the age-standardized COVID-19 mortality ratio (A) and all-cause observed/expected deaths (B), 2020-2022, for all 853 municipalities of Minas Gerais

Each point is a municipality; a value of 1 indicates mortality equal to that expected. The control limits (dashed, 95%; solid, 99.8%) narrow as the number of expected deaths increases, because random variation is smaller in larger populations; points outside the limits indicate values unlikely to be explained by chance alone, without identifying their cause. MG: Minas Gerais; REGIC: Regions of Influence of Cities [11].

Among the 97 Brazilian regional capitals (Table *3*, Figure *8*), Uberlândia ranked seventh for all-cause excess in 2021 (observed/expected 1.58; median 1.35) and 21st for COVID-19 mortality in 2020-2022 (SMR 1.38; median 1.11). It ranked 41st for federal COVID-19 transfers per capita (BRL 205; median 179) and ninth for growth in municipal health spending between 2019 and 2021 (+54%; median +28%). Across regional capitals, all-cause excess mortality in 2020-2022 was not correlated with federal COVID-19 transfers per capita (Spearman ρ 0.02; p = 0.87), with growth in health spending (ρ −0.03; p = 0.77), or with baseline health spending in 2019 (ρ 0.16; p = 0.13).

Indicator	Uberlândia	Median of 97	Rank (1 = highest)
COVID-19 SMR, 2020-2022 (national reference rates)	1.38	1.11	21
COVID-19 SMR, 2021	1.64	1.08	10
COVID-19 SMR, 2023–2024	2.03	1.06	9
All-cause observed/expected, 2021	1.58	1.35	7
All-cause observed/expected, 2020-2022	1.26	1.21	24
Federal COVID-19 transfers per capita, 2020–2022 (BRL)	205	179	41
Municipal health expenditure per capita, 2019 (BRL)	883	849	44
Change in health expenditure per capita, 2019-2021 (%)	+54	+28	9

TABLE 3: Position of Uberlândia among the 97 Brazilian regional capitals (REGIC 2018)

SMR: standardized mortality ratio (indirect standardization); REGIC: Regions of Influence of Cities [11]; BRL: Brazilian reais.

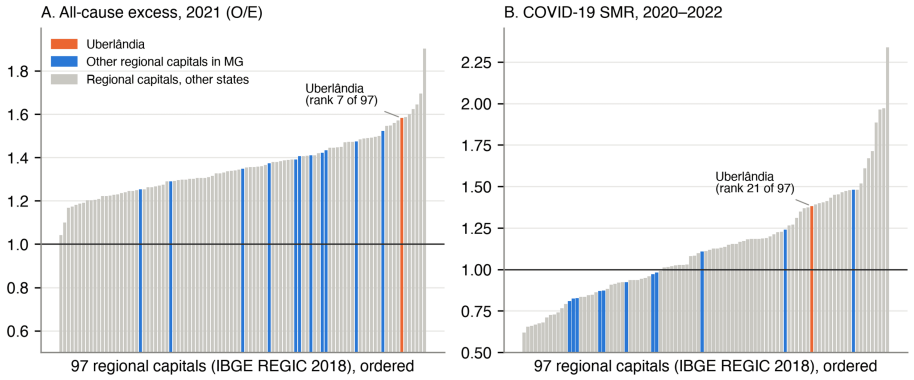


FIGURE 8: All-cause observed/expected deaths in 2021 (A) and COVID-19 SMR 2020-2022 (B) for the 97 Brazilian regional capitals

SMR: standardized mortality ratio (indirect standardization, national age-specific reference rates); MG: Minas Gerais; O/E: observed/expected deaths. Regional capitals as defined in the 2018 Regions of Influence of Cities (REGIC) classification of the Brazilian Institute of Geography and Statistics (IBGE) [11].

Endemic period: COVID-19 compared with influenza and RSV

In 2023-2025, 679 COVID-19, 357 influenza, and 229 RSV SARI hospitalizations were recorded among residents (Table *4*, Figure *9*). COVID-19 hospitalizations predominated until 2024, whereas influenza produced the largest seasonal peaks in 2025 and 2026. Patients hospitalized with COVID-19 were older (median 72 vs. 14 years for influenza and less than one year for RSV), more often had a reported comorbidity (77.8% vs. 47.1% and 13.1%), and had higher crude in-hospital mortality (23.5% vs. 6.7% and 1.7%). After adjustment for age group, sex, and comorbidity, in-hospital death was more likely with COVID-19 than with influenza (aOR 2.14; 95% CI 1.32-3.47), whereas ICU admission was not significantly different (aOR 0.79; 0.55-1.15). During the same years, the number of hospitalized SARI cases without an identified etiology exceeded the number classified as COVID-19 (e.g., 1,383 vs. 137 in 2025).

Characteristic	COVID-19	Influenza	RSV
Hospitalizations, n	679	357	229
Median age, years	72	14	0
Aged ≥60 years, %	68.0	31.1	4.8
Aged ≥80 years, %	34.0	12.3	3.1
Aged <5 years, %	11.9	35.6	90.8
Any comorbidity/risk factor, %	77.8	47.1	13.1
ICU admission, %	21.9	17.4	15.3
In-hospital deaths, n	159	24	4
In-hospital mortality, % (all ages)	23.5	6.7	1.7
In-hospital mortality, % (≥60 years)	28.9	11.7	18.2

TABLE 4: SARI hospitalizations by etiology among residents of Uberlândia, endemic period (2023–2025)

SARI: severe acute respiratory infection; RSV: respiratory syncytial virus; ICU: intensive care unit. In-hospital mortality among notifications with a known outcome.

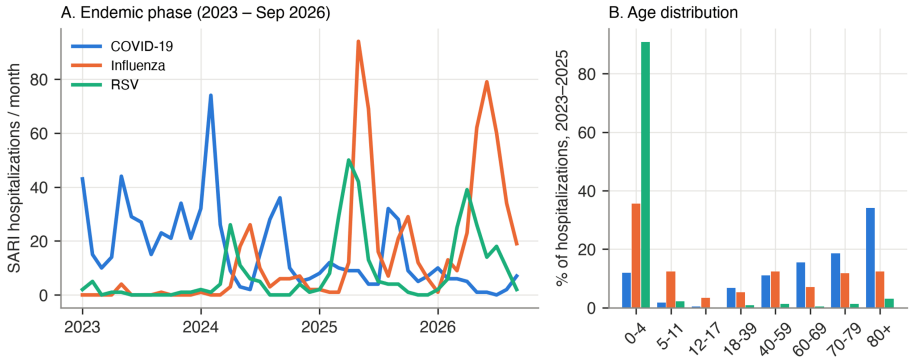


FIGURE 9: Monthly SARI hospitalizations by etiology (A) and age distribution (B) in the endemic period

SARI: severe acute respiratory infection; RSV: respiratory syncytial virus.

Data completeness and sensitivity analyses

Among the 13,883 COVID-19 SARI hospitalizations, age and sex were complete, the outcome was known for 99.9% (10 notifications were excluded from mortality analyses), and ICU and ventilatory-support information was missing for 0.3% and 0.7%, respectively (Appendix 3). Race/skin color was missing for 0.2%, whereas schooling was missing for 42.5%. The risk-factor field was blank for 34.4% of notifications (19.9-39.2% across periods), and the COVID-19 vaccination field was blank or unknown for 94.8% of notifications in P1 (before the field existed) and 26.5% in P2, and for none in P3-P4. In SIM, age was missing for 18 of 47,795 deaths registered in 2015-2025 and for none of the COVID-19 deaths; in the SI-PNI campaign database, no record of a resident lacked the person identifier, age, date, or dose type, and 0.18% of records were removed as duplicates. The proportion of hospitalized SARI notifications without an identified etiology was 48.1% in 2020, 33.4% in 2021, and 48.4% in 2022, and it rose to 68.6-71.3% in 2023-2025.

The period estimates for in-hospital death changed little in the sensitivity analyses (Appendix 4). After the addition of race/skin color to the model, the aORs relative to P1 were 1.81 (95% CI 1.64-1.99) for P2, 0.62 (0.53-0.73) for P3, and 0.67 (0.54-0.83) for P4; among patients with at least one reported risk factor, they were 1.56 (1.41-1.73), 0.63 (0.54-0.74), and 0.68 (0.55-0.84), respectively. With year-specific population estimates instead of the fixed census denominator, crude COVID-19 mortality rates differed by -4.2% to +1.9% across periods, and the reduction from P2 to P4 was 98.0% instead of 97.9%. With the alternative baselines, the all-cause P-score for 2021 ranged from 57.6% to 67.6% (main analysis 58.3%). Excess mortality in 2023-2024 remained positive under all baselines, but its magnitude varied (618 to 1,619 excess deaths, compared with 852 in the main analysis).

Discussion

Principal findings

In this population-based ecological study of a Brazilian regional hub city, COVID-19 mortality was concentrated in 2021 and declined by approximately 98% between the vaccine-rollout period and the endemic period. The decline coincided with high primary-series coverage, a transient shift of deaths away from the first-vaccinated oldest age groups, and lower adjusted in-hospital mortality after 2021. It also coincided with the replacement of the Gamma and Delta variants by Omicron, the accumulation of infection-acquired immunity, changes in clinical management, and the relief of hospital strain; the contribution of each factor cannot be separated in these data. Uberlândia's mortality in 2021 was among the highest in Minas Gerais and among Brazilian regional capitals, without evidence that federal COVID-19 funding or municipal spending growth was lower than in comparable cities. In the endemic period, COVID-19 remained the respiratory virus with the highest adjusted in-hospital mortality among hospitalized patients, affected mainly older adults with comorbidities, and annual vaccine uptake among older adults declined substantially.

Interpretation in the context of existing evidence

The age-specific pattern observed in 2021, a fall in the share of deaths among the oldest residents as their coverage rose, followed by a rebound when younger groups were vaccinated and Omicron spread, mirrors that described for Brazil as a whole using the same type of data [5] and is consistent with test-negative estimates of vaccine effectiveness against severe outcomes in older Brazilians during Gamma circulation [6]. However, this pattern can also arise from differences in exposure, infection-acquired immunity, and variant-specific age profiles; in our data it cannot be attributed to vaccination alone.

The higher adjusted in-hospital mortality in 2021 than in 2020 is consistent with reports of greater severity and mortality during the Gamma-dominated second wave in Brazil, when hospital and ICU capacity were strained [3,28]. In Uberlândia, the monthly number of COVID-19 ICU admissions of residents in February and March 2021 reached or exceeded the total registered adult ICU capacity, and non-residents accounted for up to one in five ICU admissions in local hospitals, which may have compounded pressure on a regional referral system. These observations support, but do not demonstrate, a contribution of health-system saturation to 2021 mortality.

The comparison with other municipalities suggests that Uberlândia's 2021 mortality was unusually high and unlikely to reflect chance alone, since it exceeded control limits that account for population size and overdispersion. At the same time, the city's position was less extreme for all-cause excess mortality than for certified COVID-19 mortality, and in 2023-2024 its COVID-19 mortality ratio remained high while all-cause mortality was within expected limits. One plausible explanation is differential ascertainment: municipalities with greater testing capacity or more complete death certification will attribute a larger share of deaths to COVID-19 [29]. Excess all-cause mortality, which does not depend on cause attribution, is therefore the more robust indicator for between-municipality comparisons [24,25].

We found no correlation between federal COVID-19 transfers or municipal spending growth and excess mortality among regional capitals. This null ecological association should not be interpreted as evidence that funding was ineffective or that resources were allocated inefficiently. Resources were allocated partly in response to need, creating reverse causation; transfers were measured as amounts received rather than how and when they were spent; and state transfers, private-sector capacity, and the timing of epidemic waves were not considered. Ecological associations are additionally susceptible to the ecological fallacy and to confounding by area-level factors [30].

The persistence of all-cause excess mortality in 2023-2024, without a corresponding number of certified COVID-19 deaths, deserves cautious interpretation: the prediction interval for 2023 included zero, and the magnitude of the excess depended on the baseline. It may reflect under-ascertainment of COVID-19, indirect effects of the pandemic on other conditions, or a mis-specified baseline (for example, population ageing not captured by a linear 2015-2019 trend) [24,25]. The concurrent increase in deaths with ill-defined underlying causes indicates a deterioration in cause-of-death certification and precludes reliable cause-specific excess analyses [29].

In the endemic period, the higher adjusted in-hospital mortality of COVID-19 compared with influenza is consistent with cohort studies from the United States Veterans Health Administration [9,10]. Because SARI testing practices differ by pathogen and most SARI hospitalizations had no identified etiology, the absolute number of COVID-19 hospitalizations in this period is likely underestimated, and comparisons between pathogens may be affected by selective testing. The decline in annual vaccine uptake among older adults, to approximately one in six residents aged ⩾60 years in 2025, with an even lower dose rate in the state as a whole, is a potentially modifiable gap, because this group accounted for most endemic hospitalizations and deaths and is a priority group in the current routine schedule [8]. Our data cannot determine the reasons for low uptake, which may include reduced risk perception, vaccine hesitancy, supply, or access, nor whether higher uptake would have reduced the residual burden.

Finally, the expansion of ICU capacity during the pandemic relied almost entirely on temporary COVID-19-exclusive beds. By September 2026, registered adult ICU capacity (169 beds) was below its December 2019 level (181 beds), although above that of January 2019 (147 beds), suggesting that the surge capacity was temporary and was not retained as critical care infrastructure.

Strengths and limitations

Strengths include the use of population-based national information systems covering more than five years; person-level vaccination records linked across two databases to estimate coverage and annual uptake; adjustment for age, sex, and comorbidity in in-hospital analyses; age standardization; and comparison sets defined by external criteria, analyzed with funnel plots that account for random variation and overdispersion.

This study has important limitations. First, the ecological design does not allow causal inference about vaccination, variants, health-system capacity, or funding: individual vaccination status could not be linked to hospitalization or death records, so vaccine effectiveness was not estimated, and the regression models adjusted only for age, sex, and reported comorbidity. Socioeconomic position, access to care, variant, and treatment were unmeasured or incompletely recorded, so residual confounding of the comparisons between periods and between pathogens cannot be excluded, although the period estimates were robust in sensitivity analyses. Second, selection and reporting biases are likely. SIVEP-Gripe captures only hospitalized cases that met the SARI definition and were notified; case definitions, testing, and notification practices changed over time; the large and growing number of SARI cases without an identified etiology implies under-ascertainment of COVID-19, particularly after 2022; the risk-factor field was blank for about one-third of notifications and may under-record comorbidities; and the vaccination field of the notification form, whose quality has been questioned [31], was not used. Third, mortality data have limits: SIM records for 2025 were

available only through August, so endemic-period mortality rates refer to 2023-2024, and changes in the quality of cause-of-death certification affect cause-specific estimates. Fourth, population denominators were fixed at the 2022 census, and age at vaccination may differ from age at the census, which can bias coverage estimates for some age groups; in a sensitivity analysis with year-specific population estimates, crude mortality rates changed by less than 5%, and the relative decline between periods was virtually unchanged. Fifth, the expected mortality baseline assumed a linear pre-pandemic trend; with alternative baselines, the 2021 excess was stable, whereas the magnitude of the 2023-2024 excess varied more than twofold, and the prediction intervals for 2022 and 2023 included zero. Sixth, pandemic periods were defined by calendar milestones rather than local genomic surveillance, variant circulation overlapped between periods, and registered bed counts in CNES reflect authorized capacity rather than operational beds or occupancy. Seventh, the findings come from a single large urban municipality that functions as a regional referral center and may not be generalizable to smaller municipalities or to regions with different age structures, socioeconomic conditions, or health-system organization; the comparisons with other municipalities place Uberlândia in context but do not make its results transferable. Finally, multiple comparisons were performed without adjustment, and all p-values should be regarded as exploratory.

Implications

These results are descriptive and hypothesis-generating. They suggest that (i) local surveillance should monitor COVID-19 mortality among older adults and ensure etiological testing of SARI cases to avoid underestimating the residual burden; (ii) strategies to sustain annual vaccine uptake among older adults warrant evaluation; (iii) comparisons of municipal pandemic performance should rely on all-cause excess mortality and on comparator sets defined by external criteria; (iv) preparedness planning for regional referral centers should consider the demand from non-residents and the temporary nature of the surge ICU capacity observed here; and (v) the reasons for Uberlândia's high 2021 mortality, including hospital saturation, regional patient flows, and the timing of the Gamma wave, merit investigation with individual-level data. None of these implications presupposes a causal effect of vaccination, funding, or hospital capacity on mortality, which this study was not designed to estimate.

Conclusions

In Uberlândia, a Brazilian regional hub city, COVID-19 mortality declined by about 98% from the 2021 vaccine-rollout period to the endemic period, in temporal association with high vaccine coverage and with changes in circulating variants and population immunity. The city experienced one of the highest mortality burdens among comparable municipalities in 2021, without receiving less federal COVID-19 funding per capita than the median of these cities. In the endemic period, COVID-19 continued to cause hospitalizations with higher in-hospital mortality than influenza, predominantly among older adults, while their annual vaccine uptake declined to 16% in 2025.

Given the ecological, descriptive design, these findings cannot establish causality. They should inform hypotheses for analytical studies and surveillance priorities, particularly the monitoring of residual COVID-19 mortality among older adults and the evaluation of strategies to sustain their annual vaccination, rather than definitive policy conclusions.

Appendices

Appendix 1

Variable	In-hospital death, aOR (95% CI)	p	ICU admission, aOR (95% CI)	p
Period P2, rollout, Gamma/Delta (reference: P1, pre-vaccine)	1.77 (1.61–1.95)	<0.001	1.52 (1.37–1.68)	<0.001
Period P3, Omicron (reference: P1)	0.64 (0.55–0.75)	<0.001	1.33 (1.14–1.55)	<0.001
Period P4, endemic (reference: P1)	0.69 (0.56–0.85)	<0.001	1.32 (1.07–1.63)	0.009
Age 0–17 years (reference: 18–39)	0.40 (0.19–0.83)	0.014	1.22 (0.85–1.75)	0.272
Age 40–59 years (reference: 18–39)	1.91 (1.62–2.26)	<0.001	1.44 (1.24–1.67)	<0.001
Age 60–69 years (reference: 18–39)	3.10 (2.60–3.70)	<0.001	1.45 (1.22–1.71)	<0.001
Age 70–79 years (reference: 18–39)	4.79 (4.01–5.73)	<0.001	1.78 (1.50–2.11)	<0.001
Age ≥80 years (reference: 18–39)	7.33 (6.10–8.81)	<0.001	1.80 (1.51–2.15)	<0.001
Male sex (reference: female)	1.51 (1.39–1.64)	<0.001	1.41 (1.29–1.54)	<0.001
Any reported comorbidity or risk factor (reference: none)	4.10 (3.66–4.60)	<0.001	2.34 (2.10–2.61)	<0.001

TABLE 5: Adjusted logistic regression models for in-hospital death and ICU admission among residents hospitalized with COVID-19 SARI, Uberlândia, March 2020–December 2025

aOR: adjusted odds ratio; CI: confidence interval; ICU: intensive care unit; SARI: severe acute respiratory infection. Both models include all variables shown; outcomes restricted to notifications with a known outcome (death model) or known ICU status (ICU model). Data source: SIVEP-Gripe [15].

Appendix 2

Year	All-cause deaths, n	Ill-defined causes, n	Ill-defined causes, %
2015	3,806	142	3.7
2016	3,860	116	3.0
2017	3,883	78	2.0
2018	3,917	113	2.9
2019	4,065	97	2.4
2020	4,591	175	3.8
2021	6,554	404	6.2
2022	4,521	360	8.0
2023	4,624	262	5.7
2024	4,815	249	5.2

TABLE 6: All-cause deaths and deaths with ill-defined underlying causes (ICD-10 chapter R) among residents of Uberlândia, 2015-2024

ICD-10: International Classification of Diseases, 10th revision [22]. Data source: Mortality Information System (SIM) [16]; 2024 data may be subject to minor revision.

Appendix 3

Variable	P1 Pre-vaccine (Mar 2020–Jan 2021)	P2 Rollout, Gamma/Delta (Feb–Dec 2021)	P3 Omicron (2022)	P4 Endemic (2023–2025)	Total
Hospitalizations, n	4,000	7,770	1,434	679	13,883
Age missing, %	0.0	0.0	0.0	0.0	0.0
Sex missing, %	0.0	0.0	0.0	0.0	0.0
Race/skin color missing or unknown, %	0.2	0.3	0.1	0.1	0.2
Schooling missing or unknown, %	42.6	44.6	33.8	37.0	42.5
Risk-factor field blank, %	32.2	39.2	19.9	22.2	34.4
ICU admission missing or unknown, %	0.5	0.2	0.1	1.0	0.3
Ventilatory support missing or unknown, %	0.7	0.8	0.1	0.4	0.7
Outcome other than cure or death, n	0	8	1	1	10
COVID-19 vaccination field blank or unknown, %	94.8	26.5	0.0	0.0	42.2
Laboratory-confirmed cases, %	99.9	99.8	99.9	99.3	99.8

TABLE 7: Completeness of key variables among COVID-19 SARI hospitalizations of residents of Uberlândia in SIVEP-Gripe, by pandemic period, March 2020-December 2025

SARI: severe acute respiratory infection; SIVEP-Gripe: Influenza Epidemiological Surveillance Information System [15]; ICU: intensive care unit. A blank risk-factor field was classified as no reported risk factor or comorbidity; notifications with an outcome other than cure or death were excluded from in-hospital mortality analyses. Schooling and the COVID-19 vaccination field were not used in any analysis.

Appendix 4

Analysis	Notifications, n	P2 vs. P1, aOR (95% CI)	P3 vs. P1, aOR (95% CI)	P4 vs. P1, aOR (95% CI)
Main analysis (known outcome of cure or death)	13,873	1.77 (1.61-1.95)	0.64 (0.55-0.75)	0.69 (0.56-0.85)
Additionally adjusted for race/skin color	13,873	1.81 (1.64-1.99)	0.62 (0.53-0.73)	0.67 (0.54-0.83)
Laboratory-confirmed cases only	13,849	1.77 (1.61-1.95)	0.64 (0.55-0.75)	0.69 (0.56-0.85)
Patients with at least one reported risk factor only	9,107	1.56 (1.41-1.73)	0.63 (0.54-0.74)	0.68 (0.55-0.84)
Notifications without a known outcome counted as survivors	13,883	1.77 (1.60-1.95)	0.64 (0.55-0.75)	0.69 (0.56-0.85)
Notifications without a known outcome counted as deaths	13,883	1.77 (1.61-1.95)	0.64 (0.55-0.75)	0.70 (0.57-0.86)

TABLE 8: Sensitivity analyses of the adjusted odds of in-hospital death by pandemic period among residents hospitalized with COVID-19 SARI, Uberlândia, March 2020-December 2025

aOR: adjusted odds ratio; CI: confidence interval; SARI: severe acute respiratory infection. P1: pre-vaccine period (reference); P2: vaccine rollout with Gamma and Delta circulation; P3: Omicron period; P4: endemic period. All models were adjusted for age group, sex, and any reported comorbidity or risk factor, except the model restricted to patients with at least one reported risk factor, which was adjusted for age group and sex. Data source: SIVEP-Gripe [15].

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Lucas Riquieri Nunes

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **AI use statement:** The authors used Claude (Anthropic, San Francisco, CA, USA), Claude 4.x and 5.x models via Claude Code, 2026 as follows: Programming support: writing the Python code used for data download, extraction, and statistical analysis of the public databases, language polishing, translation in the analysis code (data extraction and statistics), Tables 1-8, Figures 1-9, and all text sections (Abstract, Introduction, Materials and Methods, Results, Discussion, Conclusions). The authors defined the research question, study design, periods, and comparison criteria. All code outputs and numerical results were verified by the authors against the source data (record counts and summary statistics recomputed from the downloaded files), and all tables and figures were checked against the analysis outputs. Every reference was verified against the original source (DOI records in Crossref or the official document), and all interpretations and conclusions were written and approved by the authors, who take full responsibility for the content. The authors confirm that they have reviewed and verified all AI-assisted content and take full responsibility for the work. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** Lucas Riquieri Nunes received an undergraduate research scholarship from the Brazilian National Council for Scientific and Technological Development (CNPq) through the Institutional Program for Scientific Initiation Scholarships (PIBIC-CNPq) of the Universidade Federal de Uberlândia (Call 03/2021; 1 September 2021 to 31 August 2022) for the project from which the present study originated. The funder had no role in the design of the study, in the collection, analysis, or interpretation of the data, in the writing of the manuscript, or in the decision to submit it for publication. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

The authors thank Prof. Adriana Castro de Carvalho (Universidade Federal de Uberlândia) for supervising the undergraduate research project from which this study originated. That project was supported by an undergraduate research scholarship from the Brazilian National Council for Scientific and Technological Development (CNPq) through the Institutional Program for Scientific Initiation Scholarships (PIBIC-CNPq) of the Universidade Federal de Uberlândia (Call 03/2021). Data availability: all source data are publicly available from the official repositories listed in Table 1 (SIVEP-Gripe, SIM, SI-PNI, CNES, Portal da Transparência, Siconfi, and IBGE). The analysis code is available from the corresponding author (riquierilucas@gmail.com) upon reasonable request.

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