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Spatial disparities of COVID-19 pandemic in cerebrovascular diseases in Brazil

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Abstract

Background The Covid-19 pandemic emphasized healthcare inequalities. This study aimed to estimate the spatial effects of socioeconomic factors and healthcare coverage on hospitalizations and hospital mortality rates due to cerebrovascular diseases (CD) according to skin color self-identification before and during the Covid-19 pandemic in São Paulo, Brazil.

Methods This ecological study evaluated CD hospitalizations and hospital deaths (2019-2021) by skin color self-identification in the 63 microregions of the state of São Paulo. To determine spatial autocorrelation, we used the global and local Moran index. We also evaluated the local effects of wealth level (IPRS), the number of hospital beds, health coverage (ESF), and proportions of Black, Brown, Yellow, and Indigenous (BBYI) populations using Geographically Weighted Poisson Regression.

Results We observe significant global and local spatial autocorrelation in CD hospitalizations and mortality in the BBYI group before and during the pandemic, particularly in the metropolitan region. In 2020, we identify differences in hospitalization and mortality rates among BBYI individuals, with a higher risk of hospital death. For hospitalizations, IPRS, the number of beds, and ESF show significant associations, contributing to a decreased risk in the north, east, south, and west. For mortality, IPRS is associated with decreased risk, while ESF and BBYI proportions are associated with increased risk in the south, southeast, and metropolitan regions.

Conclusion The Covid-19 pandemic impacts CD hospitalizations and hospital deaths, particularly among the BBYI population. The presence of spatial autocorrelation in BBYI and the local effects of IPRS, ESF, and BBYI proportions underscore persistent inequalities related to skin color self-identification, geographic microregion, and socioeconomic level in access to healthcare resources during the pandemic.

Plain language summary

The COVID-19 pandemic has highlighted challenges in accessing healthcare, affecting the treatment of chronic diseases like cerebrovascular disease (CD). This study examines how these challenges impacted different racial and ethnic groups in São Paulo, Brazil. They analyzed hospital data from 2019 to 2021 to understand hospitalization and mortality rates due to CD. They find an increased risk of hospitalization and mortality among the minority ethnic groups and regions with more economic deprivation. The study suggests that addressing healthcare disparities can help reduce CVD rates, especially during health crises. Future research should explore travel patterns to healthcare facilities to better understand these disparities.

The Coronavirus Disease 2019 (COVID-19) pandemic exposed and increased barriers related to access to healthcare, leading to a reduction in elective procedures and disruptions in the care of chronic diseases. These challenges may have impacted morbidity and mortality from cerebrovascular diseases (CD), as COVID-19, the disease caused by the SARS-CoV-2 virus, strained healthcare systems and affected the management of other health conditions[1–3].

In Brazil, differences in the spatial and temporal distribution of hospital mortality rates from COVID-19 were primarily associated with geographic inequalities and a shortage of medical care capacity[4–6].

Although the literature indicates a reduction in hospitalizations and an increase in the severity of CD cases during the pandemic[3,7], there is limited knowledge about whether this increase is concentrated in racially and ethnically diverse populations[8–10]. The high burden of CD, especially in regions with lower socioeconomic development, is distributed unevenly throughout society, with substantial disparities between racial and ethnic groups even before the COVID-19 pandemic. In particular, Black skin color is associated with an increased risk of stroke, with a threefold increase in risk in some age groups, even when adjusted for traditional CD risk factors[11–13].

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Table 1 | Ratio of hospitalization and mortality rates due to cerebrovascular diseases (CD) 2019–2021. São Paulo, Brazil

CD hospitalizations	Rate/100,000 inh.	*N* admissions	Population	RR (%)	CD mortality rates	Rate/*N* admissions	*N* deaths	*N* admissions	RR (%)
W 2019	186.05	29,838	16,037,326.15		W 2019	157.18	4690	29,838	
BBYI 2019	314.02	28,431	9,053,774.48	0.59 (41%)	BBYI 2019	91.70	2607	28,431	1.71 (71%)
W 2020	169.55	28,512	16,815,296.19		W 2020	165.40	4716	28,512	
BBYI 2020	168.91	16,035	9,492,972.72	1.00	BBYI 2020	170.00	2726	16,035	0.97 (3%)
W 2021	95.08	16,482	17,333,339.79		W 2021	295.78	4875	16,482	
BBYI 2021	173.94	17,021	9,785,431.06	0.55 (45%)	BBYI 2021	173.02	2945	17,021	1.71 (71%)

CD cerebrovascular diseases, *W* White group, *BBYI* Black, Brown, Yellow and Indigenous groups, *inh* inhabitants, *N* absolute number, *Population* population estimated according to ethnic–racial proportion, *RR* rate ratio (group W/BBYI group), %: percentage (RT−1*100).

Studies by Johnson and Buford[14], Goes, and collaborators[15] show that Black and Hispanic communities worldwide suffered pronounced disparities from the burden of COVID-19 due to greater social and economic vulnerability, in addition to a higher prevalence of chronic diseases in the Black population.

In Brazil, studies reveal socioeconomic factors and access to health services as the main determinants of health inequities in the country, impacting the incidence of several diseases, including CD[16,17]. Recent studies have identified the lack of control of chronic non-communicable diseases (NCDs), such as hypertension, low education, lack of private health insurance and skin color/Black and Brown self-identification as facilitators for the occurrence of CD in the country[18–20].

Among Brazilian states, the state of São Paulo has the largest volume of records of CD cases and deaths in Latin America[21]. Considering regional variations during the pandemic, the state of São Paulo had the highest number of cases and deaths from COVID-19 infection in Brazil[22].

Understanding potential ethnic-racial differences, as well as the relevance of the geographic context of CD, would allow identifying and developing public health strategies to mitigate the short- and long-term adverse effects of the COVID-19 pandemic on CD. Therefore, this study aimed to analyze the spatial distribution of hospitalization and hospital mortality rates due to CD before and during the COVID-19 pandemic in the state of São Paulo, according to skin color self-identification, as well as to estimate the local effects of socioeconomic factors and healthcare coverage.

Our findings reveal significant spatial clustering of cerebrovascular disease hospitalizations and hospital mortality, particularly among Black, Brown, Yellow, and Indigenous populations, both before and during the COVID-19 pandemic. We observe that socioeconomic development, healthcare coverage, and hospital bed availability exert distinct local effects on hospitalization and mortality rates across microregions of São Paulo. The study demonstrates that inequalities related to skin color self-identification and geographic context persist, underscoring the crucial role of equitable healthcare access and socioeconomic improvement in reducing the burden of cerebrovascular diseases during and beyond public health crises.

Methods

This is an ecological study of hospital admissions and deaths due to cerebrovascular disease (CD) stratified by skin color self-identification, as reported in the Hospital Information System of Unified Health System (SIH-SUS) of the state of São Paulo from January 1, 2019 to December 31, 2021.

The SIH-SUS data source collects information on admissions and deaths in 7161 public or SUS-affiliated hospitals in the state of São Paulo. Sistema Único de Saúde (SUS) is the Brazilian public healthcare system, designed to provide free access to health services for all Brazilian citizens, regardless of income, social status, or employment. It is estimated that SUS accounts for ~85% of hospital admissions in the state[23]. Therefore, admissions to private hospitals, paid directly by patients or health insurance plans, were not considered, as their data is not registered in the SIH/SUS.

Eligible CD admissions and deaths were those coded as I60–I69 according to the International Statistical Classification of Diseases and Related Health Problems, 10th revision (ICD-10). Anonymous data is publicly available on the website https://tabnet.datasus.gov.br/, accessed on 08/15/2023.

For this study, the 63 geographic microregions of the state of São Paulo were considered, according to the territorial characterization proposed in 1995 by the Brazilian Institute of Geography and Statistics (IBGE). The digital file representing these microregions was retrieved in shapefile format with a reference scale of 1:50,000[23].

The 42 municipalities that make up the metropolitan region constitute seven micro-regions in the southeast of the state, namely São Paulo, Santos, Guarulhos, Mogi das Cruzes, Itapecerica da Serra, Franco da Rocha and Osasco (Geographic and Cartographic Institute of the state of São Paulo —IGC).

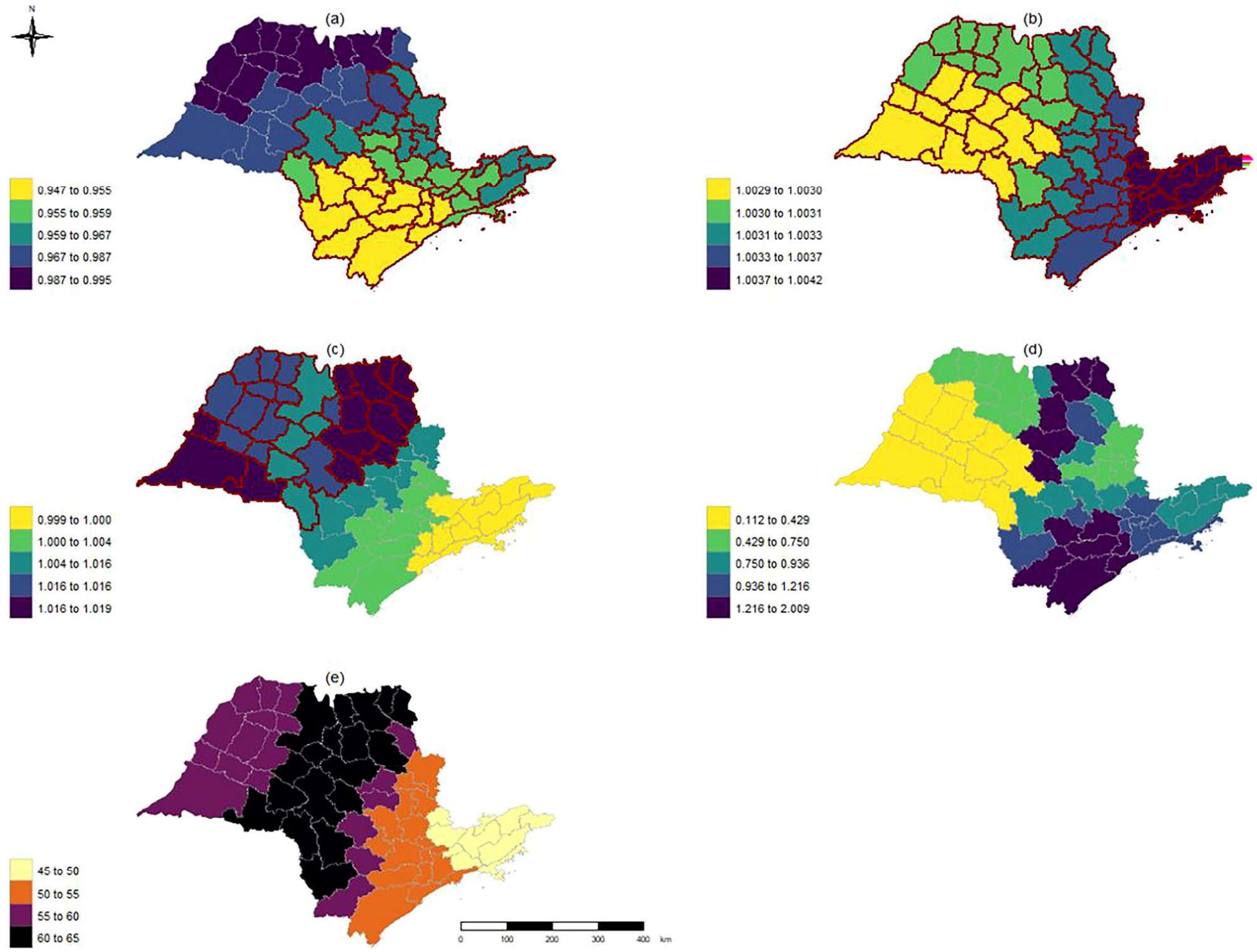

Fig. 1 | Coefficient maps of the São Paulo social responsibility index coefficients, bed rate, coverage of the family health strategy and proportion of Black, Brown, Yellow and Indigenous people in hospitalizations for CD, in the state of São Paulo, 2019, Brazil. **a** Social responsibility index (IPRS wealth). **b** Bed rate (/1000 inhabitants). **c** Coverage of the family health strategy (ESF (%)). **d** Proportion of Black + Brown + Yellow + Indigenous. **e** Deviance. Red lines indicate $p < 0.05$. Values on maps **a**–**d** indicate the relative risk.

Study variables

The socioeconomic condition was assessed using the São Paulo Social Responsibility Index (IPRS), constructed based on parameters that support the Human Development Index (HDI), which includes factors related to longevity, wealth, and education. This index aims to evaluate the development stage of each region while considering the diversity among municipalities and is publicly available on the Legislative Assembly of the State of São Paulo website[24].

The IPRS wealth was quantitatively used for the analyses. This dimension seeks to capture both the municipality's wealth production and the residents' family income. It is expressed by factors such as residential electrical energy consumption, electrical energy consumption in agriculture, commerce and services, average employee remuneration with a formal contract, and fiscal value added per capita. The values can range from 0 to 60, with higher values indicating a better socioeconomic condition.

Healthcare coverage was composed of the number of hospital beds and coverage of the family health strategy (ESF).

Population coverage data estimated by the ESF of the Unified Health System (SUS) in 2020 were extracted from the monitoring system for access to primary care services of the primary health care secretariat[25]. The percentage of the population served by the ESF varies from 0% to 100%, with higher values indicating greater ESF coverage.

The number of beds was retrieved from the National Registry of Health Establishments (CNES) for the years 2019, 2020, and 2021, and the data were freely available on the website of the IT department of the Unified Health System[26]. Bed rates per year were calculated based on the population value and expressed per 1000 inhabitants.

Population estimates for the years 2019, 2020, and 2021 were obtained from projections for the state of São Paulo available by the State Data Analysis System Foundation[27] (SEADE, 2016). The distribution of the population by skin color was obtained from the 2010 Demographic Census of the Brazilian Institute of Geography and Statistics[28]. Skin color self-identification was used in accordance with Brazil's legal and ethical standards (Racial Equality Statute and National Health Council Resolution 510/2016) and follows IBGE's five self-declared categories: White, Black, Brown (Parda), Yellow (Asian), and Indigenous, which are considered the most ethical and reliable for research purposes.

Data analysis

The descriptive analysis of the data was carried out using rate ratios and thematic maps of hospitalization rates and hospital lethality (hospital deaths/hospitalizations) due to CD stratified by skin color self-identification in the pre-pandemic period (January–December 2019) and during the pandemic (February 2020–December 2021). The unit of analysis was the microregion with standardized population rates per 1000 inhabitants.

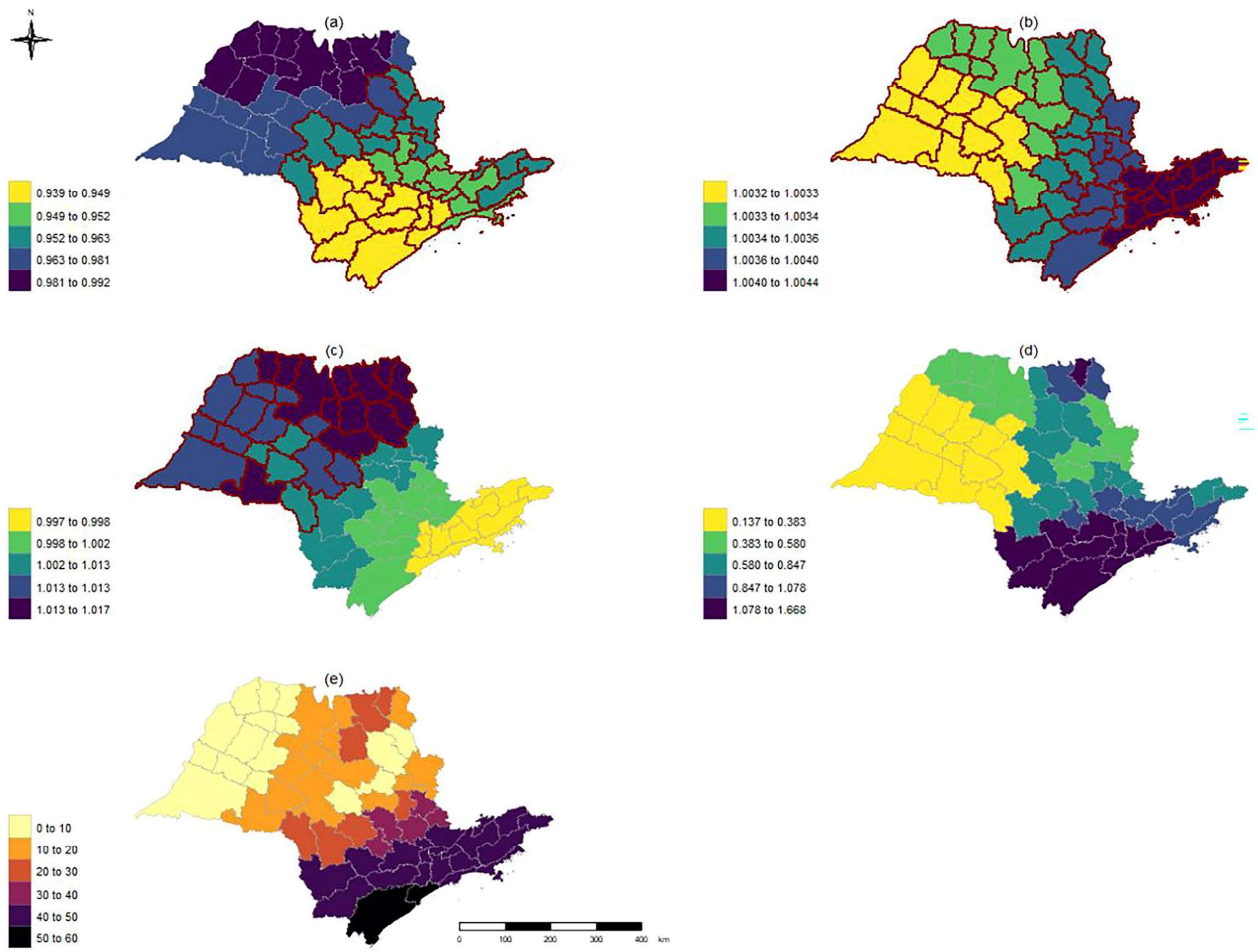

Fig. 2 | Coefficient maps of the São Paulo social responsibility index coefficients, bed rate, coverage of the family health strategy and proportion of Black, Brown, Yellow and Indigenous people in hospitalizations for CD, in the state of São Paulo, 2020, Brazil. **a** Social responsibility index (IPRS wealth). **b** Bed rate (/1000 inhabitants). **c** Coverage of the family health strategy (ESF (%)). **d** Proportion of Black + Brown + Yellow + Indigenous. **e** Deviance. Red lines indicate $p < 0.05$. Values on maps **a–d** indicate the relative risk.

Initially, we proposed the rate ratio (RR) to describe the probability or susceptibility of hospitalization or hospital mortality due to CD according to stratification by skin color self-identification (White versus Black, Brown, Yellow and Indigenous—BBYI). Hospitalization rates were determined based on the population data for the respective year, and hospital fatality rates were calculated using the total hospitalizations for each group in the same year. Subsequently, we calculated the ratio between the rates, using the White group in the numerator and the BBYI group in the denominator. The results of these calculations should be interpreted as follows: RR < 1 indicates a lower occurrence in the numerator group (Whites), while RR > 1 indicates a higher occurrence in the numerator group (Whites) compared to the denominator group (BBYI).

To explore the presence of spatial autocorrelation in CD hospitalization and hospital mortality rates, we used the global and local Moran Index (I). To determine the neighborhood, the first-order queen contiguity matrix was used. It is represented with the spatial correlation coefficient, where $I > 0$ demonstrates positive spatial autocorrelation, $I < 0$ negative spatial autocorrelation and $I = 0$ absence of spatial autocorrelation[29,30].

To estimate the combined local impact of the IPRS variables, including wealth, beds, family health coverage, and the proportion of the BBYI population on the outcomes of hospitalization rates and hospital mortality due to CD, we used the geographically weighted Poisson regression model, also known as geographically weighted Poisson regression—GWPR[31].

The analysis was conducted separately for each outcome and year. We used the population as the offset term in the model for the hospitalization outcomes, and for the hospital lethality outcomes, the number of hospitalizations was used as the offset term. The estimation of coefficients (effects) was performed using a quasi-similarity approach.

The results of the models were presented through coefficient maps, which illustrate the local effects and p-values of each variable on hospitalization rates and hospital mortality due to CD in micro-regions. The effects were transformed into relative risk using the exponential function of the coefficients, where values <1 indicate a reduction in rates and values > 1 indicate an increase in rates. The explanatory power of the model was verified by calculating the percentage Deviance for each area, where higher values indicate greater explanatory power of the model.

We performed the analyses using the libraries 'lctools' of the free software R, version 4.0.2[32,33].

Ethical aspects

This study utilized publicly available anonymous data and did not require ethical approval. The research was registered under number 1698 in the Institutional Research Management System of the Evandro Chagas Itapecerica da Serra, Franco da Rocha and OsascoNational Institute of Infectious Diseases at the Oswaldo Cruz Foundation.

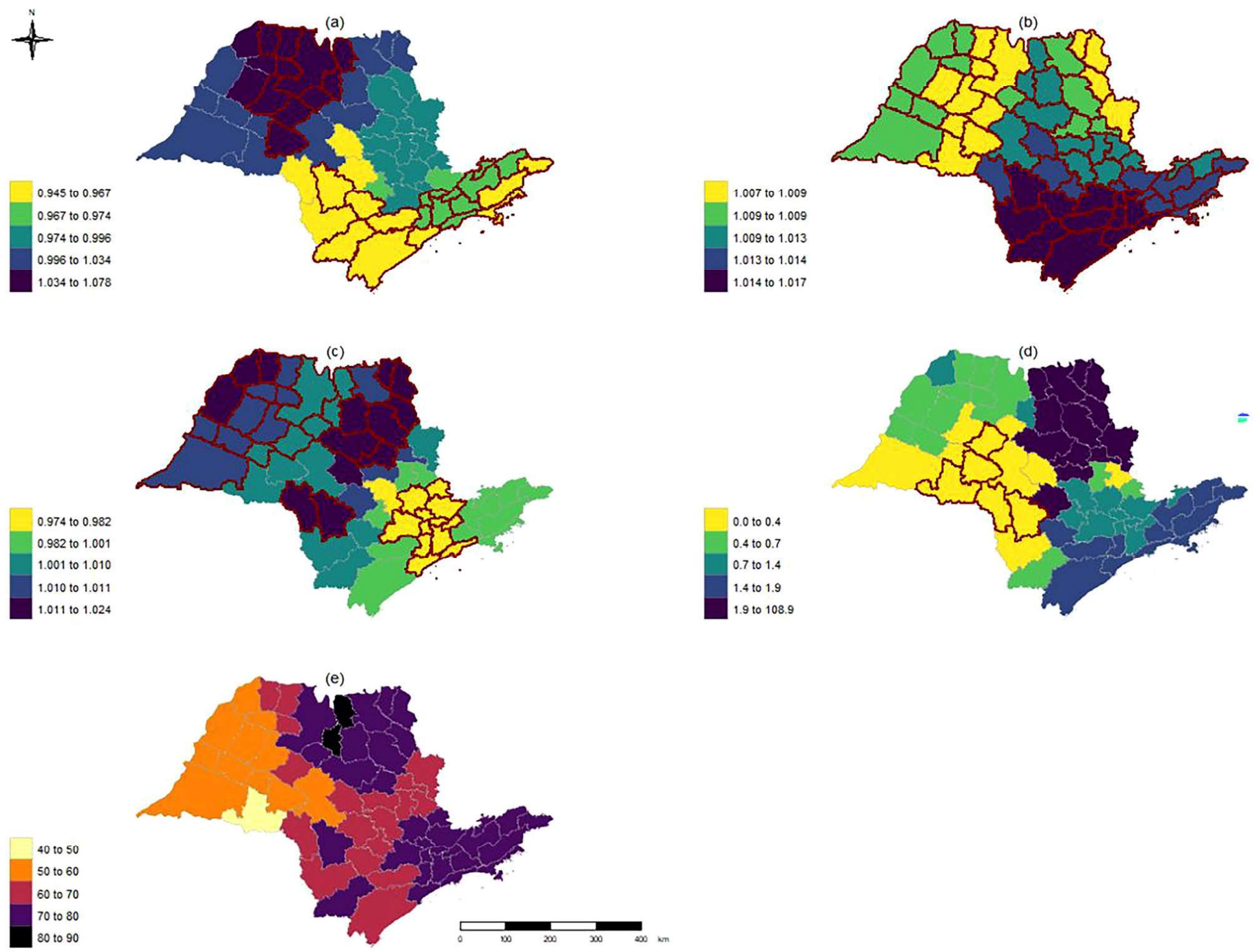

Fig. 3 | Coefficient maps of the São Paulo social responsibility index coefficients, bed rate, coverage of the family health strategy and proportion of Black, Brown, Yellow and Indigenous people in hospitalizations for CD, in the state of São Paulo, 2021, Brazil. **a** Social responsibility index (IPRS wealth), **b** Bed rate (/1000 inhabitants), **c** Coverage of the family health strategy (ESF (%)), **d** Proportion of Black + Brown + Yellow + Indigenous. **e** Deviance. Red lines indicate $p < 0.05$. Values on maps **a–d** indicate the relative risk.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Results

A total of 50,927 CD hospitalizations were included in 2019, 41,901 in 2020 and 44,829 in 2021. Hospital deaths included in 2019, 2020, and 2021 were 7916, 7354, and 8051, respectively. In total, 86,781 hospitalizations were analyzed among White individuals, and 49,538 were among Black, Brown, Yellow, and Indigenous individuals (BBYI). Additionally, there were 14,281 hospital deaths among White individuals and 8278 among BBYI.

Table 1 illustrates the rate ratio between hospitalizations and hospital mortality due to CD according to skin color self-identification before and during the pandemic.

Through the rate ratio, we can observe similarities regarding the values referring to hospitalization and hospital lethality between the groups in 2019 and 2021. In which there are 41% and 45% fewer hospitalizations in White people in 2019 and 2021, respectively, and 71% higher hospital lethality in Whites in 2019 and 2021.

Regarding the year 2020, we observed a difference in the pattern observed in 2019 and 2021, with no increase or reduction in hospitalizations for White people compared to Black, Brown, Yellow and Indigenous people and 3% less hospital mortality.

Significant global and local spatial autocorrelation was observed for hospitalization and lethality rates among Black, Brown, Yellow, and Indigenous people in all the years analyzed in the Southeast, which comprises the metropolitan region (Moran Index $p < 0.001$). Thematic and spatial autocorrelation maps of CD hospitalization and hospital mortality rates for Whites and BBYI before and during the pandemic are illustrated in Supplementary Fig. 1 (Hospitalizations of cerebrovascular disease in Black, Brown, Yellow and Indigenous), Supplementary Fig. 2 (Hospitalizations of cerebrovascular disease in Whites), Supplementary Fig. 3 (Hospital deaths of cerebrovascular disease in Black, Brown, Yellow and Indigenous), and Supplementary Fig. 4 (Hospital deaths of cerebrovascular disease in Whites).

The local effects of the variables, including wealth level (IPRS), bed rate, family health strategy coverage (ESF), and the population proportion of Black, Brown, Yellow, and Indigenous people in the GPWR models of CD hospitalization rates, can be seen in Figs. 1–3.

Regarding the socioeconomic index IPRS and hospitalizations for CD (Figs. 1a, 2a, and 3a), we observed a reduction in the risk in the south before and during the pandemic. In other words, with each increase in the index, the risk of hospitalization for CD is reduced. However, in 2021, we observed an increased risk in the northern regions.

In terms of the number of beds (Figs. 1b, 2b, and 3b), there is a higher risk of hospitalization with an increase in the bed rate in all micro-regions

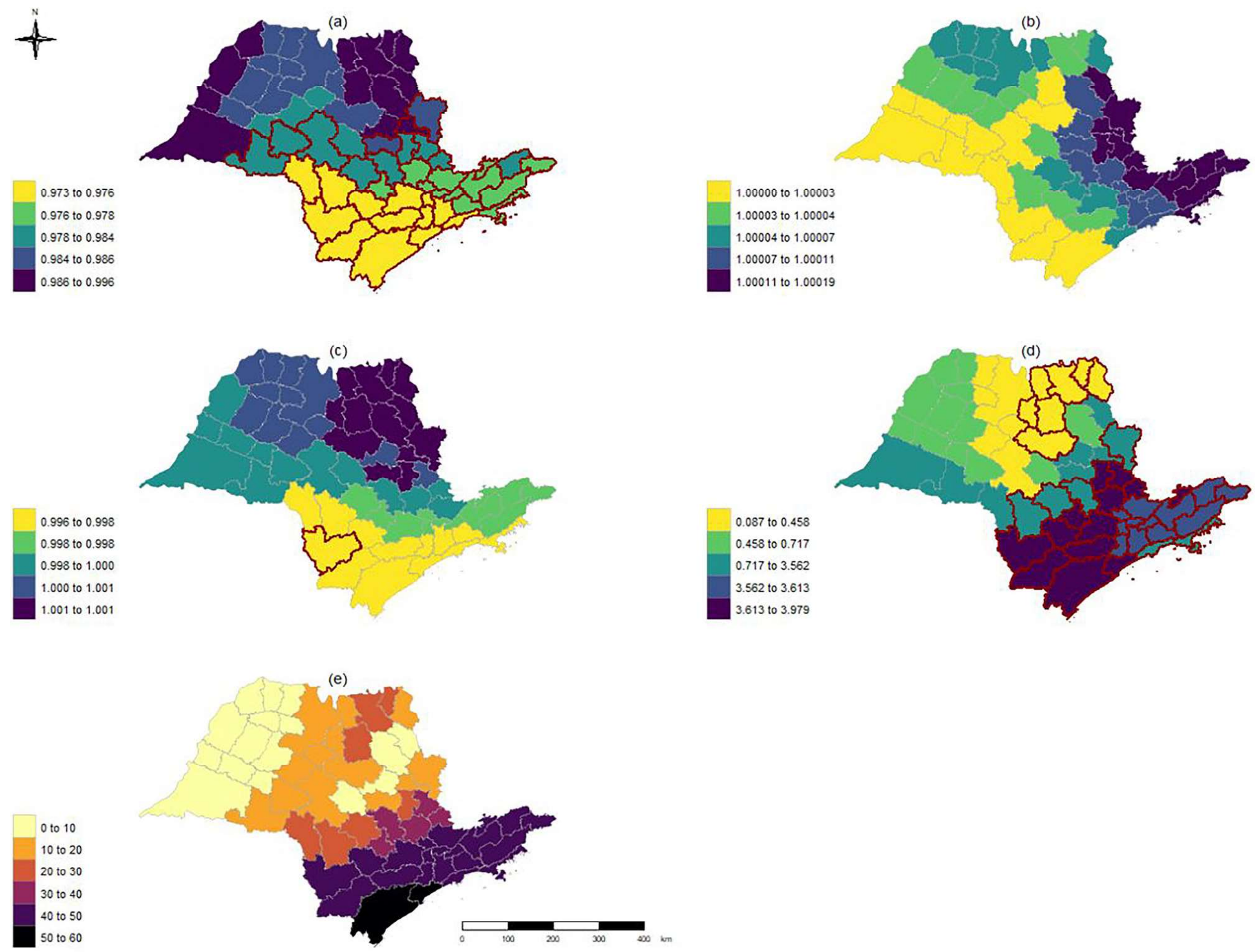

Fig. 4 | Coefficient maps of the São Paulo social responsibility index coefficients, bed rate, family health strategy coverage and proportion of Black, Brown, Yellow and Indigenous people in hospital mortality due to CD, in the state of São Paulo, 2019, Brazil. **a** Social responsibility index (IPRS wealth). **b** Bed rate (/1000 inhabitants). **c** Coverage of the family health strategy (ESF (%)). **d** Proportion of Black + Brown + Yellow + Indigenous. **e** Deviance. Red lines indicate $p < 0.05$. Values on maps **a–d** indicate the relative risk.

across all years. With an increase in the percentage of ESF coverage (Figs. 1c, 2c, and 3c), the risk of hospitalization increases in several northern micro-regions every year. Furthermore, in 2021, we observed risk reduction effects with an increase in ESF coverage in micro-regions of the metropolitan area.

The proportion of BBYI showed no significant effects in 2019 and 2020, but in 2021, we observed effects that reduced the risk of hospitalizations in a group of western micro-regions (Figs. 1d, 2d, and 3d).

Regarding the model's adjustments, we observed an explanation of at least 50% in all micro-regions in 2019. However, similar values were observed only in the southern micro-regions in 2020. In 2021, the best adjustments were observed throughout the state, with areas having up to 90% explanation (Figs. 1e, 2e, and 3e). Coefficient maps of the São Paulo social responsibility index (IPRS wealth), bed rate, coverage of the family health strategy and proportion of Black, Brown, Yellow and Indigenous people in hospitalizations for CD, in the state of São Paulo, 2019, Brazil.

In the GPWR multiple models for CD mortality rates (Figs. 4–6), an increase in IPRS wealth is associated with a reduced risk of hospital mortality in microregions located to the south in 2019, 2020, and 2021, and in some areas to the north in 2020 (Figs. 4a, 5a, and 6a). The effect of the number of beds was not statistically significant in all microregions (Figs. 4b, 5b, and 6b).

With an increase in the percentage of ESF coverage, the risk of hospital fatality was reduced in a microregion in the southwest in 2019, while the risk of hospital lethality increased in four micro-regions in the center-north in 2020, with no significant effects observed in 2021 (Figs. 4c, 5c, and 6c). An increased risk of hospital fatality was found in the proportion of BBYI in the years 2019 and 2020 in micro-regions to the south and southeast of the metropolitan region, and in 2021, five micro-regions showed risk reduction effects to the west (Figs. 4d, 5d, and 6d).

Regarding the model's adjustments, greater explanatory power was observed in the southern and southeastern microregions of the metropolitan region (Figs. 4e, 5e, and 6e).

Discussion

This study explored the spatial distribution of hospitalization and hospital mortality rates due to cerebrovascular diseases (CD) in the context of the COVID-19 pandemic in the most populous state in Brazil. It also investigated the impact of socioeconomic factors and healthcare access on different ethnic-racial groups, revealing disparities in rate distribution and spatial effects related to skin color self-identification, socioeconomic factors, and healthcare coverage.

In our findings, we observed similarities in hospitalization and hospital mortality rates due to CD between ethnic groups in 2019 and 2021, with higher rates among White people. However, in 2020, there was a notable change in the direction of these rates, with an increase in hospital mortality among Black, Brown, Yellow, and Indigenous people. The differences

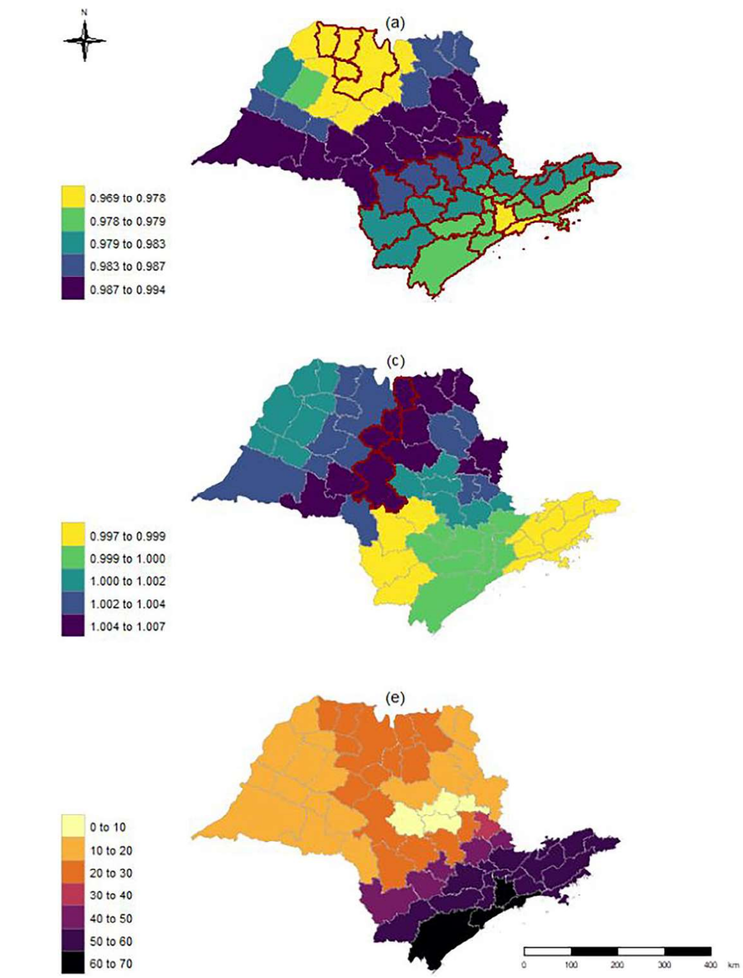

Fig. 5 | Coefficient maps of the São Paulo social responsibility index coefficients, bed rate, family health strategy coverage and proportion of Black, Brown, Yellow and Indigenous people in hospital mortality due to CD, in the state of São Paulo, 2020, Brazil. **a** Social responsibility index (IPRS wealth). **b** Bed rate (/1000 inhabitants), **c** Coverage of the family health strategy (ESF (%)), **d** Proportion Black + Brown + Yellow + Indigenous, **e** Deviance, Red lines indicate $p < 0.05$, Values on maps **a–d** indicate the relative risk.

observed among these groups in 2020 may be related to factors associated with the pandemic, which disproportionately affected different population groups in relation to CD[1,34–36]. Brizzi and collaborators[6] also discuss the role of inequalities in a study of 14 Brazilian capitals and estimate that half of the deaths from COVID-19 could have been avoided if there were no geographic inequalities prior to the pandemic.

In this context, we observed a tendency for the geographic clustering of hospitalization rates and hospital mortality due to CD with positive autocorrelation in the group of Black, Brown, Yellow, and Indigenous people (BBYI), both before and during the COVID-19 pandemic. This clustering was particularly prominent in the metropolitan region of the state (RMSP). RMSP is the largest urban agglomeration in the Americas, accounting for 50.2% of the state's GDP[37]. Despite being economically important, the region still struggles with social challenges, inadequate urban infrastructure, limited public services, and a shortage of proper housing. As a result, many residents live in precarious settlements and areas at high risk[37].

Positive spatial autocorrelation within ethnic groups indicates that similar values tend to cluster together in close proximity, underscoring the spatial influence of this variable. This spatial clustering can be attributed to various factors, including historical, social, economic, and cultural influences that lead to the concentration of people from a specific ethnic group in particular areas[13].

In the context of the pandemic, this finding may reflect health inequities among ethnic-racial groups, resulting in geographic disparities in disease rates and other health indicators. Similar disparities were observed in the early stages of the pandemic among Black, Hispanic, and Asian populations in the United States of America[34–36].

Brazil is one of the few countries in the Americas with a universal and free healthcare system[38]. The Unified Health System (SUS) provides healthcare and medication distribution to approximately 75% of the Brazilian population[39]. Despite its universal coverage, the system faced challenges during the pandemic, revealing deficiencies in access, particularly in regions with high population density[40].

Considering this scenario, when we analyze the local effects on hospitalization and hospital mortality rates due to CD in relation to socioeconomic and healthcare coverage variables, we can identify a situation that preexisted before the pandemic. The social and health determinants revealing regional inequalities with the best multiple model adjustments are predominantly located in the south and southeast regions of the RMSP. These regions boast better socioeconomic conditions and higher population density[6,40,41].

Additionally, the unexpected direction observed in the impact of the ESF coverage indicator on the outcomes, where higher coverage is associated with increased hospitalization and hospital mortality rates due to CD, can be attributed to two factors. Firstly, related to the resource allocation method, which does not align with the distribution criteria for the coverage areas defined by the indicator. Secondly, the interruption of primary care monitoring in the country, especially in 2020, may have affected regions

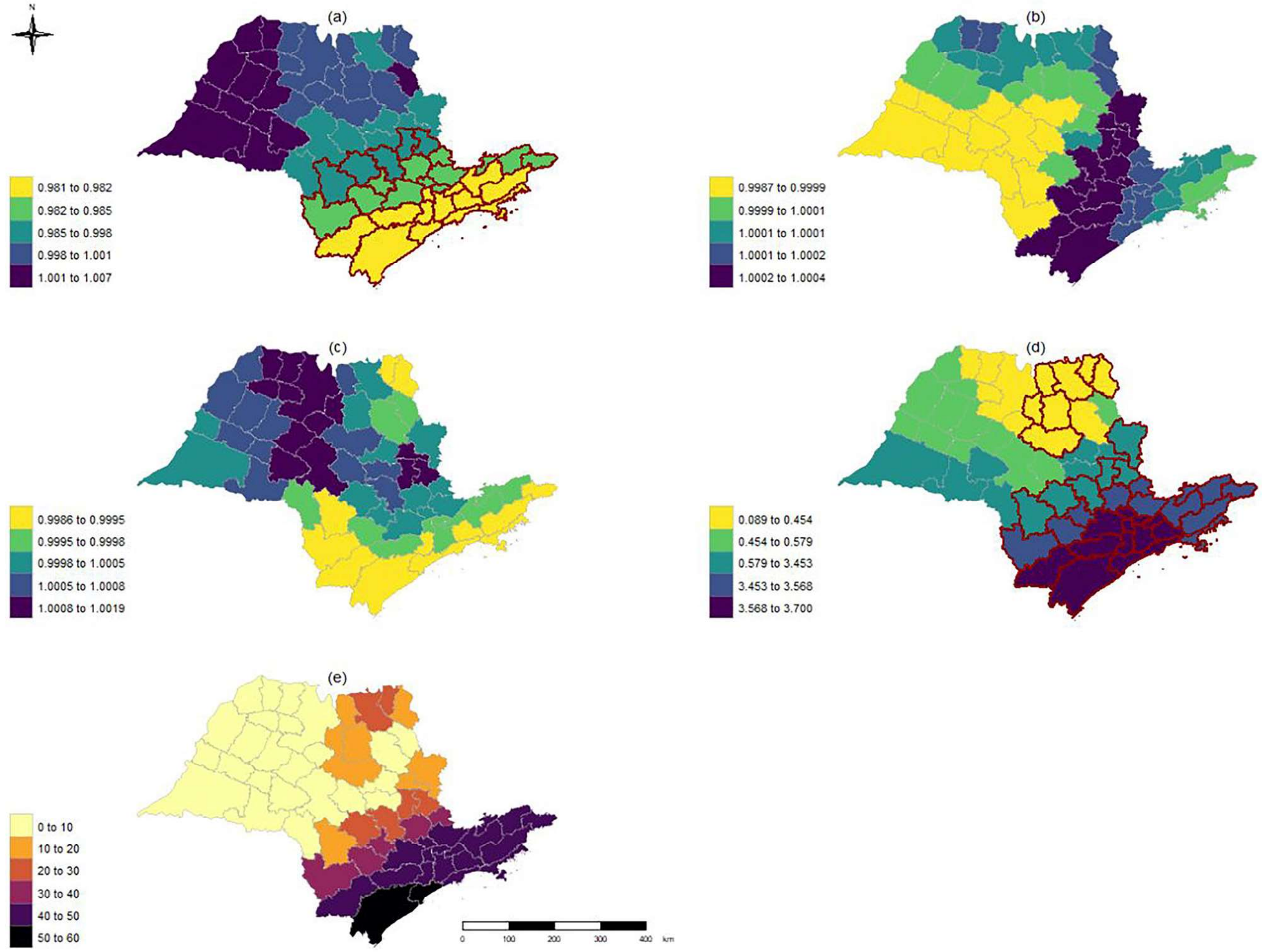

Fig. 6 | Coefficient maps of the São Paulo social responsibility index coefficients, bed rate, family health strategy coverage and proportion of Black, Brown, Yellow and Indigenous people in hospital mortality due to CD, in the state of São Paulo, 2021, Brazil. a Social responsibility Index (IPRS wealth). **b** Bed rate (/1000 inhabitants). **c** Coverage of the family health strategy (ESF (%)). **d** Proportion Black + Brown + Yellow + Indigenous. **e** Deviance. Red lines indicate $p < 0.05$. Values on maps **a–d** indicate the relative risk.

with sufficient ESF coverage, as they also faced challenges in restructuring and monitoring during the pandemic[42].

Our findings should be interpreted in light of certain limitations. These limitations include the use of qualitative socioeconomic indicators and the challenges related to IT health services during the pandemic. The data on skin color self-identification in the population are not as up-to-date as they should be (with the last record in 2010), and it was not further disaggregated for other social or healthcare indicators. Furthermore, the quality and standardization of filling out secondary data during the pandemic years may have been compromised due to the enormous volume of data being processed simultaneously and influenced by political factors. This, in turn, could have affected the quality of surveys and, consequently, the indicators derived from them[43]. Additionally, a limitation to consider is the underestimation of associations due to reporting errors in the causes of death within this area and the potential ecological fallacy inherent in studies that rely on aggregated data.

The use of raw data stratified by age, rather than age-standardized rates, in the descriptive analyses can be a limitation, particularly when the populations being analyzed have distinct age structures. This can distort comparisons between different regions. From 2015 to 2020, population estimates and censuses in the state of São Paulo showed a proportional increase in the population aged 60 years and older, from 13.2% to 15.3%, respectively (ref). Although the results were not presented using standardized rates, we observed a proportional reduction in the raw values of hospitalizations and hospital deaths across all age groups. Furthermore, the use of the geographically weighted Poisson regression model (GWPR) helps mitigate this limitation by modeling local spatial variations and adjusting disease rates more flexibly for different regional contexts, as demonstrated in this study.

It is important to note that, despite the Brown and Black population comprising 56.1% of the Brazilian population[28], and the well-documented ethnic-racial disparities in healthcare access, no studies were found that assess the spatial distribution of CD by skin color self-identification. Furthermore, this research was conducted in the most populous Brazilian state, known for its high-quality secondary data recording[44].

This characteristic can help mitigate potential impacts stemming from data collection and processing during the pandemic. Moreover, in the national literature, there is a recognized need to explore socioeconomic factors linked to adverse outcomes in COVID-19. Nevertheless, existing studies have primarily focused on the early stages of the pandemic[45,46]or on regions with lower population density compared to the state of São Paulo[47].

Therefore, we believe that this study enables the identification of areas within the state of São Paulo that require ongoing monitoring for the effects of health inequities and ethnic-racial differences. This, in turn, can contribute to reducing the rates of hospital admissions and deaths due to CD, especially in the context of emerging epidemics.

It is essential that public health policies and intervention strategies consider these ethnic and geographic disparities to promote health equity and ensure that all population groups have equal access to high-quality healthcare. Furthermore, to gain a more detailed understanding of healthcare inequities, we recommend that future studies investigate the travel patterns from residents' homes to healthcare facilities.

Data availability

All analyses, including those presented in figures, tables, and supplementary materials, were conducted using the same publicly available datasets obtained from https://tabnet.datasus.gov.br/. The datasets are available in CSV format, and the analysis scripts can be provided by the corresponding author upon reasonable request.

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Author contributions
Raiene Telassin Abbas and Raquel de Vasconcellos Carvalhaes de Oliveira: contributed to the conception and design of the study, acquisition and analysis of data, drafting the text, and preparing the figures. Yara Hahr Marques Hökerberg: contributed to the conception and design of the study, analysis of data, and drafting the text.

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The authors declare no competing interests.

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