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THEMATIC ARTICLE

Ethnic-racial composition of the population in COVID-19 mortality: A spatial ecological approach to Brazilian health inequalities

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Abstract *The COVID-19 pandemic has unevenly affected regions, countries, and ethnic-racial segments. Socioenvironmental factors were associated with worse disease evolution, with a greater likelihood of mortality in vulnerable people. This study aimed to investigate the association between the proportion of vulnerable populations (Black, brown, and Indigenous people) and mortality from COVID-19 in Brazil from March 2020 to February 2021. Mortality rate ratios and respective 95% Confidence Intervals (95%CI) were estimated using negative binomial regression models. Statistically significant associations were found between the proportion of these populations and mortality rates, emphasizing Blacks in the first four-month period, mixed race in the second four-month period, and Indigenous people in the third four-month period, in which an increase of 54%, 16% and 27% in mortality rates was observed, respectively, for every 10% increase in the proportion of these populations. We highlight the existence of ethnic-racial inequalities in COVID-19 mortality in Brazil and that efforts must be made to mitigate health inequalities, an expression of the perpetuated structural racism and social exclusion of historically vulnerable groups.*
Key words *Racial groups, Health inequality, COVID-19, Ethnicity*

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Introduction

The COVID-19 pandemic was declared by the World Health Organization (WHO) in March 2020, becoming one of the largest and most important health and humanitarian crises in History[1]. The first cases of illness and death from COVID-19 in Brazil were reported in February and March 2020[2], respectively. It is a disease caused by the new coronavirus, SARS-CoV-2, which can manifest as severe acute respiratory syndrome (SARS). In many cases, SARS requires intensive and prolonged medical and hospital care, overloading health systems[3].

In Brazil, the COVID-19 pandemic was an event that unequally and more severely affected the population segments most vulnerable due to adverse geographic, environmental, socioeconomic, and ethnic-racial conditions and healthcare access, resulting in a higher risk of death from the disease in these groups[4-6]. Individual factors, such as age over 60, pregnancy, and comorbidities, which include hypertension, obesity, and diabetes, were also associated with a worse prognosis for COVID-19[5,6].

A vast scientific production on health inequalities was produced during the pandemic, evidencing that the pandemic effects on people's health resulted from the mutual enhancement of social determinants of health, such as ethnic-racial, socioeconomic, and geographic aspects and health patterns, which was considered a syndemic[7]. For example, ethnic-racial inequalities were shown by Pontes *et al.*[8] when they reported age-group-specific mortality rates in Indigenous people higher than those in the general population, with higher rate ratios in the 0-9-year groups (RR: 7.1) and 80 or older (RR: 2.1). The cumulative lethality by COVID-19 rate had reached 41.8% among Indigenous people and 35.1% among non-Indigenous people in the country up to August 2020, with heterogeneity by region. The most significant inequalities were identified in the North and Midwest. Santos *et al.*[9] found maternal mortality rates approximately twice as high in Black women than in white women. Baqui *et al.*[10] found a significantly higher risk of death in brown people (RR: 1.45; 95%CI: 1.33-1.58) and Black people (RR: 1.32; 95% CI: 1.15-1.52) than white people.

In the Epi-Covid study, seroepidemiological surveys were conducted in all 27 federative units of Brazil, in three different waves and 133 sentinel cities, using a sampling method, estimating the seroprevalence of COVID-19 and its respective confidence intervals in these locations, showing a seroprevalence five times higher in Indigenous people than white people, and three times higher in mixed race people than white people in the three waves. Furthermore, seroprevalence was inversely proportional to wealth, where the poorest quintile was about twice as likely to have antibodies than the most affluent quintile in all three study waves. Regarding the regions of the country, 10% of the population in the North, on average, had or had already contracted the coronavirus. In contrast, this percentage was 1% in the South in the third wave. In the first wave, none of the cities analyzed had positive seroprevalence results in the Midwest, in contrast to the North, where only 32% of the cities analyzed had no positive results[11,12].

Given this evidence, the present study aimed to investigate the association between the proportion of vulnerable populations (Black, brown, and Indigenous people) and mortality from SARS by COVID-19 (COVID-19) in the first year of the pandemic and its interaction with socioeconomic inequality and healthcare access per the Brazilian mesoregions.

Methods

Study design and area

This ecological space-time study assessed the association between the proportion of vulnerable people (Black, brown, and Indigenous) and COVID-19 mortality in the first year of the pandemic, from March 2020 (month of the first death from COVID-19 in the country) to February 2021 (month of the start of vaccination against COVID-19 in the country), considering 137 Brazilian mesoregions as units of spatial analysis and three four-month periods (March to June 2020, July to October 2020, and November 2020 to February 2021) as units of temporal analysis.

Brazil was divided into mesoregions in 1989 to compose geographic units capable of integrating the organization, planning, and implementation of public functions of common interest. Each mesoregion includes a set of geographically articulated municipalities with economic, geographic, and social similarities, which respect the limits of the state to which it belongs (Brazilian Institute of Geography and Statistics, IBGE, 2017). The Northeast is the Brazilian region with the most significant number of mesoregions (42), followed by the Southeast (37), South (23), North (20), and Midwest (15) (Figure 1).

Study variables, indicators, and data sources

The number of COVID-19 deaths was considered the study's outcome. The primary exposure in this study was the proportion of vulnerable populations, defined as the proportion of Black, brown, and Indigenous populations in each mesoregion. The analysis also considered these ethnicity/skin color categories as secondary exposures. The mean Socioeconomic Index of the Geographic Context for Health Studies (GeoSES), as an indicator of socioeconomic status, the ratio of ICU beds per inhabitant as an indicator of healthcare access, and the aging index, as an indicator of the age structure of the population, were included as the study's covariates. All study indicators were aggregated by mesoregion and four-month periods for analysis. Data on COVID-19 deaths by municipality of residence were retrieved from the Influenza Epidemiological Surveillance System (SIVEP-Gripe) and comprised the numerators of COVID-19 mortality rates and the study outcome. The population by ethnicity/skin color category and municipality, later aggregated by mesoregion, derived from

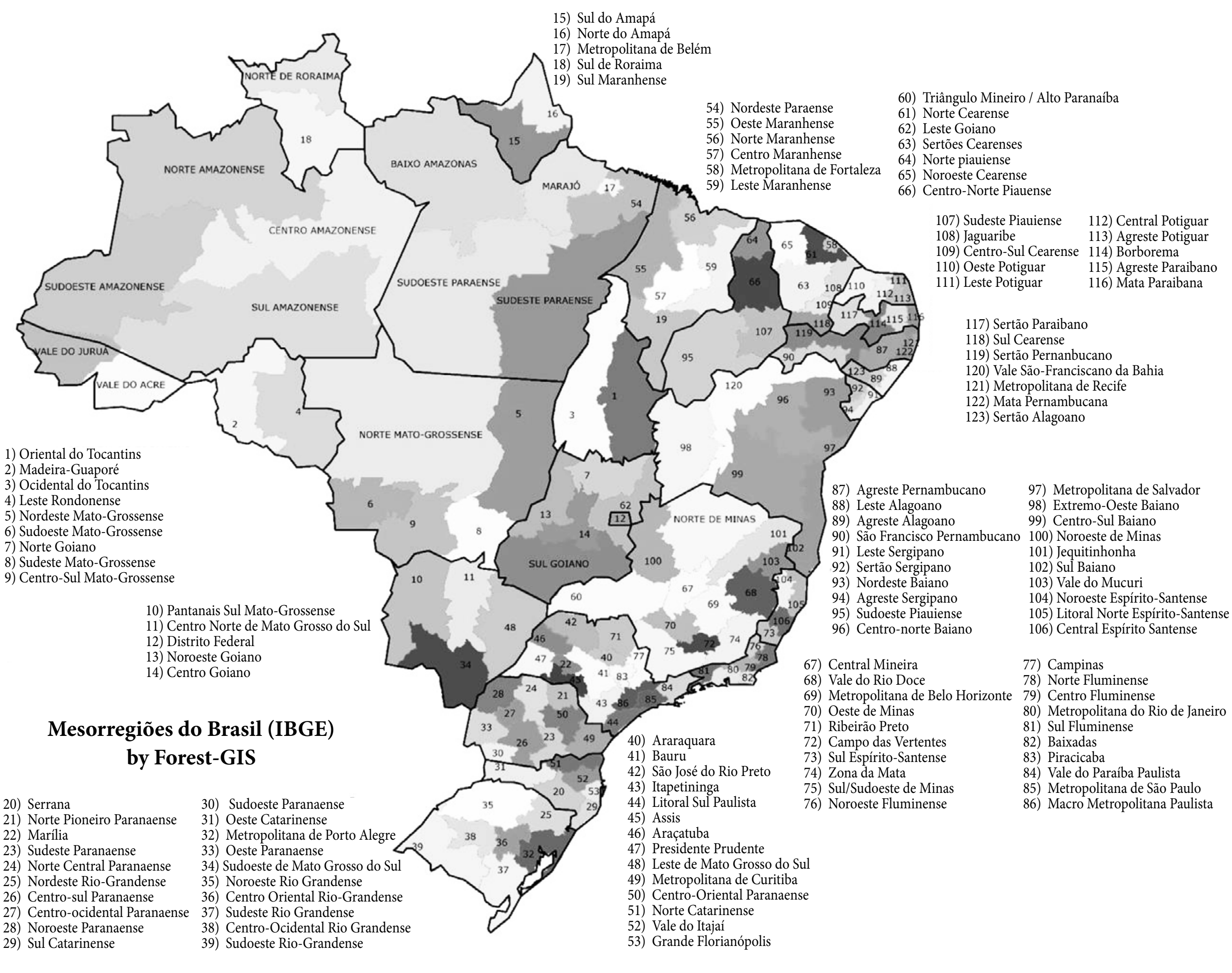

Figure 1. Brazilian Mesoregions by the IBGE.

Source: IBGE, 2005.

the 2010 Brazilian Demographic Census (IBGE, 2010), since there was a delay in conducting the 2020 Demographic Census. The sum of the Black, brown, and Indigenous populations was divided by the total population of each mesoregion to obtain the proportion of vulnerable populations, per the proportions of the 2010 Census. The calculation was made for the three populations together and for each separately. The estimate of the Brazilian population by municipality, used to calculate the mortality rates by SARS-COVID-19 in the pandemic year, was obtained from the IBGE's population projections for 2020. The "Socioeconomic Index of the Geographic Context for Health Studies" (GeoSES) was generated by principal component analysis based on data from the 2010 Demographic Census;. It is composed of the dimensions education, mobility, poverty (absolute poverty, defined as the lack of minimum survival capacity and access to material resources), and wealth (proxy for all economic resources accumulated throughout life), income, segregation (which refers to a broad concept related to separate housing of different population groups in different parts of a city and affects health by escalating psychosocial effects involving insecurity, anxiety, social isolation, socially dangerous environments, bullying, and depression), and deprived access to services and resources[13]. The GeoSES index ranges from -1 to +1, with a lower index indicating worse socioeconomic conditions. The calculated index is available for all Brazilian municipalities on the IBGE website ((https://www.ibge.gov.br/estatisticas/downloads-estatisticas.html). For our study, we calculated the mean index by mesoregion.

The ratio of ICU beds per inhabitant was calculated by dividing the number of available ICU beds by the population per mesoregion. Data on the number of ICU beds were retrieved from DATASUS through the National Registry of Health Establishments (CNES) (CnesWeb - Cadastro Nacional de Estabelecimentos de Saúde (datasus.gov.br)).

We adopted the Aging Index to represent the population's age structure. The index is calculated by dividing the number of individuals over 60 by those under 15. The population in these age groups was obtained from the population estimate projected by the IBGE for 2020.

Statistical analysis

We created thematic maps showing the spatial distribution of mortality rates per four-month period, the proportion of vulnerable populations, the ratio of ICU beds per inhabitant, mean GeoSES, and the Aging Index.

A negative binomial regression model assessed the association between the proportion of vulnerable populations and COVID-19 mortality. The outcome variable was the number of deaths by COVID-19 per mesoregion. The primary exposure was the proportion of vulnerable populations, and the general population was considered an offset in the model. Moreover, we separately assessed the proportion of Black, brown, and Indigenous populations as secondary exposures. The ratio of ICU beds per inhabitant, mean GeoSES, and Aging Index were considered the model's adjustment variables.

Initially, we created the model with only the raw exposure variable (Model 1). Then, each of the following adjustment variables was progressively and cumulatively added to the raw model, in this order: Aging Index (Model 2), simple GeoSES mean (Model 3), and ratio of ICU beds per inhabitant (Model 4). Finally, we investigated socioeconomic and healthcare access indicators as possible effect modifiers on the association in question, adopting a multiplicative scale by introducing an interaction term in the model. The non-significance of the interaction term indicates no effect modification. The mortality rate ratios estimated from the adjusted models considered a 10% increase in the proportion of the vulnerable population. All analyses were performed for the accumulated period of one year and per four-month periods using R software (R core team, 2022).

Results

A total of 224,430 deaths by COVID-19 were recorded in Brazil from March 2020 to February 2021, 224,405 of which were in people residing in the country. Of this total, 83,125, 85,332, and 55,948 occurred in the first, second, and third four-month periods.

COVID-19 mortality rates were higher in the North of the country and some Southeast and Midwest regions in the accumulated period of one year (Figure 2). The first four-month period's rates were higher in the North and a small area of the Southeast. In the second four-month period, rates declined in the North and hiked in the Midwest, with a new increase in the North and a decrease in the Midwest in the third four-month period.

Figure 3 shows the spatial distribution of the proportions of vulnerable populations by mesoregion. We observed a more significant proportion of these populations in the North and Northeast of the country, besides the northernmost Midwest, and a more significant proportion of the Indigenous population in mesoregions to the northwest of the North and the west of the Midwest region.

Figure 4 shows the spatial distribution of the covariates. The mean GeoSES Index increases gradually from the North to the South of the country, as does the Aging Index. We observed a few mesoregions in the North and Northeast with a ratio of ICU beds per inhabitant comparable to those in the central-southern region of the country, which has the highest ratio of ICU beds per inhabitant in Brazil.

No statistically significant association was observed in the crude model (Model 1) for any of the categories of vulnerable populations analyzed (Table 1). After adjusting for the variables Aging Index, Mean GeoSES Index, and ratio of ICU beds per population, we identified statistically significant associations between proportions of vulnerable population (RR: 1.12, 95%CI: 1.04-1.21), brown people (RR: 1.09, 95%CI: 1.01-1.17), and COVID-19 mortality. An increase of 12% and 9% in the COVID-19 mortality rate is observed for each 10% increase in the proportions of vulnerable populations or Brown people.

In the first four-month period, we observed statistically significant associations between COVID-19 mortality rates and the increase in the proportions of vulnerable populations (RR: 1.44, 95%CI: 1.23-1.67), brown (RT: 1.36, 95%CI: 1.17-1.58) and Black people (RR: 1.54, 95%CI: 1.01-2.42), after adjustment for socioeconomic indicators, healthcare access, and Aging Index (Model 4) (Table 1). The proportion of the Black people lost statistical significance in the second four-month period, with only the proportions of the vulnerable population (RR: 1.17, 95%CI: 1.07-1.28) and Brown people (RR: 1.16, 95%CI: 1.05-1.27) remaining associated. In the third four-month period, only the proportion of the Indigenous population (RR: 1.27; 95%CI 1.03-1.64) remained associated with higher COVID-19 mortality. We observed a 27% increase in the COVID-19 mortality rate (Table 1) for each 10% increase in the proportion of the Indigenous population.

In the multiplicative interaction analysis, socioeconomic and healthcare access indicators were not effect modifiers in the association between the proportion of the vulnerable population and SARS-COVID-19 mortality (p-value>0.05).

Discussion

In our study, we observed higher mortality rates in mesoregions with higher proportions of vulnerable populations in the first year of the COVID-19 pandemic in Brazil, particularly in the first and second four-month periods, even after adjusting for variables of healthcare access, socioeconomic index, and aging index. Also, in the analysis stratified by four-month periods, we observed that the behavior of mortality rates suffered different effects depending on the ethnic-racial composition of the mesoregions, with the proportion of Black people having a more significant effect on the increased mortality in the first four-month period. In comparison, the proportion of brown people had a more significant effect in the second, and the Indigenous people in the third. No interaction was observed between the socioeconomic index or access to healthcare and the proportion of vulnerable populations associated with COVID-19 mortality.

Higher proportions of brown and Indigenous people were found in the North and of Black people in the Northeast and Southeast. Furthermore, the map of the vulnerable population's spatial distribution resembles the spatial distribution of the brown population since the brown population represents the most significant proportion of the total population and corresponds spatially to the most unfavorable distribution of socioeconomic and healthcare access indices and aging rate. All these indicators showed an upward trend in a North-South direction, consistent with the historical social and economic inequality and demographic patterns that distinguish the regions of the country, in which the South and Southeast are socioeconomically more developed than the Midwest, Northeast, and North[14-18].

Regarding age structure, the southernmost areas have older populations than the northernmost areas[19] due to demographic dynamics that reflect higher fertility and early mortality and lower life expectancy at birth in the North and Northeast[20]. Besides the inequalities already shown, the ratio of ICU beds/inhabitants is higher in the central-southern regions of the country, revealing fewer barriers to healthcare access[16-18].

Patterns of socioeconomic, demographic, and health access inequalities overlap with the ethnic-racial distribution of the population,

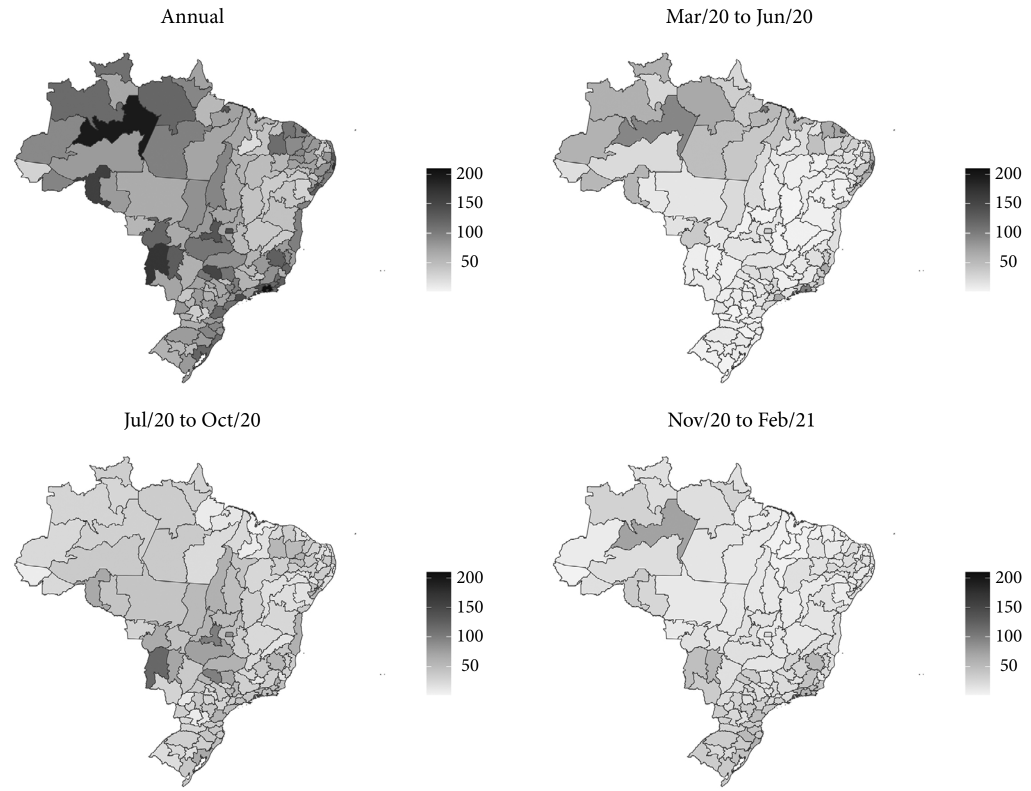

Figure 2. Spatial distribution of cumulative and four-month specific mortality rates due to SARS-COVID-19 by Brazilian mesoregions from March 2020 to February 2021.

Source: Authors.

characterizing a syndemic condition, resulting in worse control of COVID-19 and its unfavorable outcomes in locations with a higher proportion of these populations[7]. Several authors have shown through descriptive studies at the individual level that morbidity and COVID-19 mortality and lethality were higher in Black[9,21-23], mixed-race[10,22], and Indigenous[8,10,22] people in the country. Our study also confirms this vulnerability from an ecological perspective, showing the ethnic-racial inequalities that exceed socioeconomic, demographic, and healthcare access inequalities. Estrela *et al.*[24] emphasize that structural racism in the country and worldwide generates health inequalities, which lead to a deteriorated health situation in minority populations. The inequalities highlighted may likely reflect a broader outlook of historically rooted social exclusion, which is an expression of structural racism[24-26].

The association between age over 60 and the risk of death from COVID-19 has been widely demonstrated at the individual level, nationally and internationally[6,27]. In contrast, our study showed that specific SARS-COVID-19 mortality in the accumulated period was lower in the mesoregions with the highest aging rate in the Center-South of the country and higher in the North, which indicates that social determinants and individual factors operated to increase the risk of death from COVID-19 in Brazilian mesoregions[4,28]. Corroborating this hypothesis, we highlight the higher mortality rates in mesoregions with lower socioeconomic index and less access to healthcare, evidencing the prognostic relevance of these determinants in the pandemic, besides Ranzani *et al.*'s study[22], which revealed that approximately half of the first 250,000 hospitalizations for COVID-19 in the country occurred in patients under 60 (47%), and mortality in this age group was higher in the North and Northeast, reaching 31% in the Northeast.

The results obtained from the adjusted models in the cumulative period and the four-month periods analyzed indicate that vulnerable popu-

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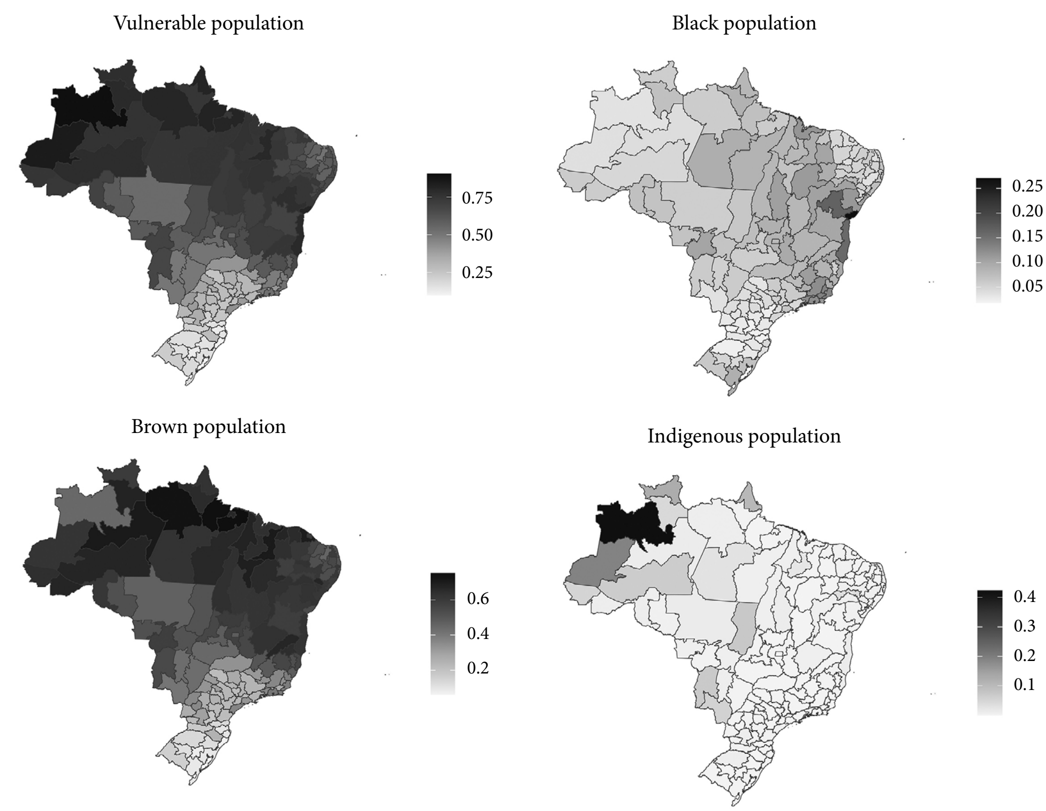

Figure 3. Spatial distribution of the proportions of vulnerable populations (Black, brown, and Indigenous) and the proportion of Black, brown, and Indigenous people separately by Brazilian mesoregions.

Source: Authors.

lations were exposed to COVID-19 and experienced a higher risk of death from the disease at different stages during the pandemic, which can be explained by the dynamics of the geographic spread of the pandemic in the country, the introduction of different SARS-CoV-2 variants and their respective virulence, and the geographic distribution of vulnerable populations.

When analyzing the association between the proportion of vulnerable populations and SARS-COVID-19 mortality per four-month period, we realized that these populations suffered the effects of the pandemic early, particularly in the first four-month period, possibly as a reflection of their vulnerabilities and barriers in access to healthcare, the dynamics of viral circulation in the regions of the country, and the ethnic-racial composition of the population. In the first COVID-19 wave in the country, when the possibility of social distancing did not exist for informal workers, who account for a large portion of Brazilians in the worst socioeconomic conditions in the country, we found statistically significant associations even after adjusting for the aging index, socioeconomic index, and proxy for access to healthcare. This result confirms the findings of other studies already published, which showed a higher risk of mortality in vulnerable populations, such as Black and brown people[29,30].

For example, Lana *et al.*[31] demonstrated that COVID-19 transmission was initially concentrated in a few large urban centers, with a rapid internalization in some states, such as Amazonas, Rio de Janeiro, and São Paulo. The North has the most significant proportion of Indigenous people in the country, which had a significant impact on this segment, as observed in the seroepidemiological studies conducted, which showed a higher seroconversion in the North and this population group[11]. However, the most significant impact on mortality in this segment occurred later, as seen in our study in the third four-month period,

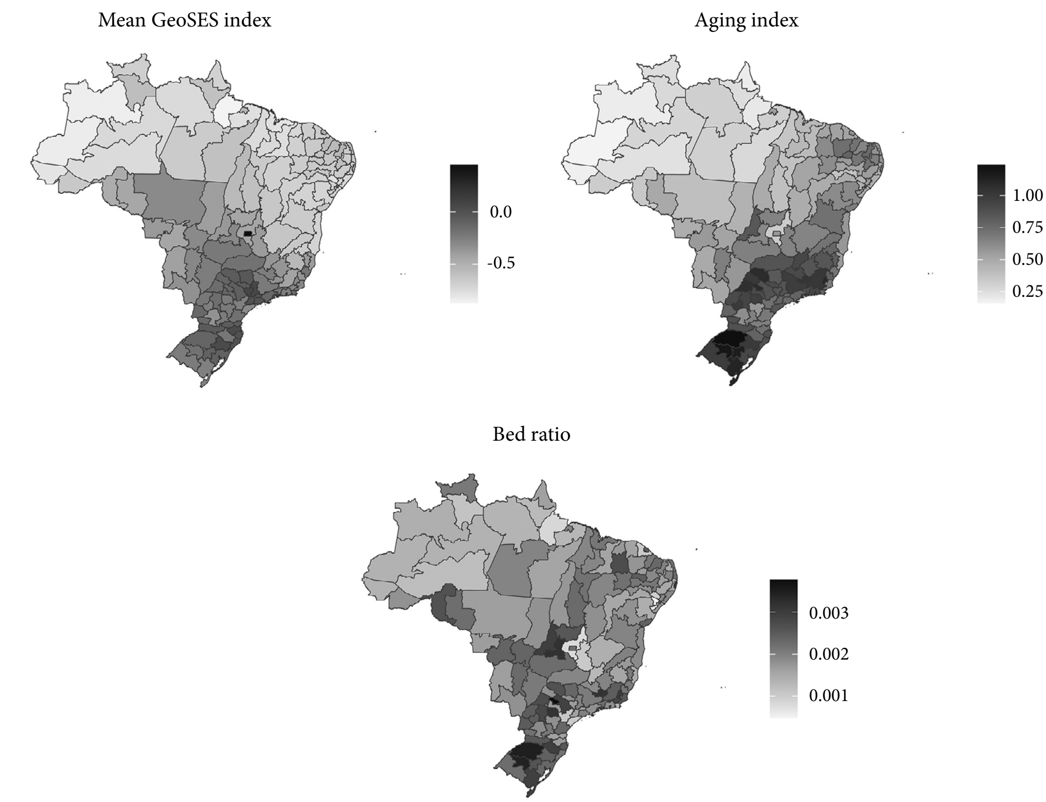

Figure 4. Spatial distribution of the socioeconomic index measured by the mean GeoSES index, Aging index, and Ratio of ICU beds per population by Brazilian mesoregions.

Source: Authors.

where the disease again increased its rates in the North, which can be explained by the presence of the P.1 variant in this region, which had greater transmissibility and a possible greater lethality than the variants previously circulating in our country[32,33].

Regarding mortality rates related to the Indigenous people in the third four-month period, our study revealed a 27% increase in the COVID-19 mortality rate in the mesoregion for each 10% increase in the proportion of the Indigenous population, corroborating the findings of other studies, which also showed higher mortality and lethality[8] in this specific population. Significant mortality differentials were observed in the study by Pontes *et al.*[8], for example, where the mortality rate ratio between the Indigenous population and the general population was 7.1 for the 0-9 years group, 3.6 for the 10-19 years group, 2.3 for the 50-59 years group, and 2.1 in the 80 years and older group. These findings confirm that the Indigenous population in our country has unfavorable health indicators compared to other population groups[34,35] and that this population was particularly affected by the COVID-19 pandemic[8,21,22].

The main limitation of our study is the lack of an updated demographic census, which challenges the more accurate calculation of the proportion of population by ethnicity/skin color required for calculating the proportion of vulnerable population. Population growth is not merely a demographic event associated with the demographic growth of the general Brazilian population. Self-designation of one's ethnicity/skin color is influenced by the people's environment, economic characteristics, and political situation, which has occurred significantly in the country's Indigenous populations in recent decades[34-36]. Thus, populations may experience variations in their growth, which are not explained solely by demographics and may influence the magnitude

Table 1. Mortality rate ratios and respective 95% confidence intervals for crude and adjusted associations between the proportion of vulnerable population and mortality from SARS-COVID-19 in the accumulated period of one year and by four-month period.

	Vulnerable population	Black population	Brown population	Indigenous Population
	RR (95%CI)	RR (95%CI)	RR (95%CI)	RR (95%CI)
One-year accumulation				
Model 1: Vulnerable population	1.00 (0.97-1.04)	1.09 (0.89-1.35)	1.00 (0.96-1.04)	1.08 (0.92-1.29)
Model 2: Model 1 + Aging index	1.01(0.96-1.06)	1.09 (0.89-1.35)	0.99 (0.94-1.05)	1.09 (0.93-1.33)
Model 3: Model 2 + Mean GeoSES	1.12 (1.04-1.21)*	1.18 (0.96-1.46)	1.09(1.00-1.17)	1.10 (0.93-1.32)
Model 4: Model 3 + Bed to population ratio	1.12 (1.04-1.21)*	1.16 (0.95-1.44)	1.09 (1.01-1.17)*	1.09 (0.93-1.31)
Four-month period 1				
Model 1: Vulnerable population	1.26 (1.17-1.34)*	1.42 (0.90-2.34)	1.27 (1.18-1.37)*	1.29 (0.96-1.96)
Model 2: Model 1 + Aging index	1.26 (1.13-1.41)*	1.60 (1.06-2.50)*	1.25 (1.11-1.41)*	0.98 (0.74-1.41)
Model 3: Model 2 + Mean GeoSES	1.44 (1.23-1.67)*	1.57 (1.03-2.47)*	1.36 (1.16-1.58)*	0.98 (0.74-1.41)
Model 4: Model 3 + Bed to population ratio	1.44 (1.23-1.67)*	1.54 (1.01-2.42)*	1.36 (1.17-1.58)*	0.97 (0.74-1.40)
Four-month period 2				
Model 1: Vulnerable population	0.71 (0.46-1.08)	1.08 (0.84-1.40)	0.96 (0.91-1.00)	0.95 (0.78-1.19)
Model 2: Model 1 + Aging index	0.99 (0.93-1.06)	1.10 (0.86-1.43)	0.98 (0.91-1.05)	1.03 (0.15-17.56)
Model 3: Model 2 + Mean GeoSES	1.18 (1.08-1.28)*	1.27 (0.99-1.64)	1.15 (1.05-1.27)*	1.03 (0.84-1.31)
Model 4: Model 3 + Bed to population ratio	1.17 (1.07-1.28)*	1.24 (0.97-1.61)	1.16 (1.05-1.27)*	1.03 (0.84-1.30)
Four-month period 3				
Model 1: Vulnerable population	0.87 (0.84-0.91)*	0.88 (0.68-1.16)	0.85 (0.81-0.89)*	0.98 (0.80-1.26)
Model 2: Model 1 + Aging index	0.90 (0.84-0.96)*	0.86 (0.67-1.12)	0.86 (0.80-0.92)*	1.26 (1.00-1.67)
Model 3: Model 2 + Mean GeoSES	0.97 (0.88-1.07)	1.03 (0.80-1.35)	0.90 (0.82-1.00)	1.27 (1.02-1.64)*
Model 4: Model 3 + Bed to population ratio	0.97 (0.88-1.07)	1.04 (0.80-1.36)	0.90 (0.82-1.00)	1.27 (1.03-1.64)*

Source: Authors.

of specific mortality rates by ethnicity/skin color and the proportions of vulnerable populations. However, the data sources used were the only ones available and employed in all other studies on the subject.

Our study shows a consistent pattern of higher SARS-CoV-2 mortality in mesoregions with higher proportions of Black, brown, and Indigenous people, with more significant increases related to brown and Indigenous people in the North and Midwest and Black people in the Southeast. These results powerfully demonstrate that the pandemic was an event that affected, to a greater degree, the regions with higher proportions of vulnerable populations. Some overlapping distinct vulnerabilities are reflected in ethnic-racial health inequalities, an event that can be characterized as a syndemic. Despite this, no synergistic effect was confirmed between socioeconomic index and access to healthcare and ethnicity on mortality levels. This fact shows that other aspects not controlled in the multiple analysis affect mortality through the condition related to skin color in Brazil, and structural racism can be mentioned. This study brings significant results regarding the health inequalities in our country and becomes an essential instrument in the fight for their mitigation.

Collaborations

JMD Cajazeiro drafted the manuscript. JMD Cajazeiro, AA Nobre, and AM Cardoso participated in the work design, data analysis, and interpretation of results; conducted the review and approved the article's final version.

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