saúde EM DEBATE

ORIGINAL ARTICLE

# Spatial correlation: heterogeneous pattern of COVID-19 mortality in Brazil

## *Correlação espacial: padrão heterogêneo de mortalidade por covid-19 no Brasil*

Adriani Isabel de Souza Moraes[1], Ana Paula Vechi Corrêa[1], Helena Nayara Santos Pereira[1], Sílvia Carla da Silva André Uehara[1]

DOI: 10.1590/2358-289820241429255I

**ABSTRACT** This ecological study analyzed the spatial correlation between socioeconomic and demographic indicators and deaths due to COVID-19 in Brazil. The independent variables covered population, sex, age, race, literacy, and Gini index, while the dependent variable was COVID-19 mortality. Socioeconomic and demographic data were obtained from the Continuous National Household Sample Survey, and data on COVID-19 cases and deaths were obtained from the Ministry of Health website. The analysis included the calculation of univariate and bivariate Global Moran's Indices. The results revealed a significant spatial correlation of the independent variables with COVID-19 mortality. A moderate positive correlation stands out for literate individuals aged 20 to 59 years. Therefore, there is an association between socioeconomic factors and COVID-19 mortality, with variations between Brazilian states. This conclusion highlights the need to implement intersectoral measures to ensure universal access to health and allocate resources equitably across states.

**KEYWORDS** COVID-19. SARS-CoV-2. Social indicators. Economic indexes. Mortality.

**RESUMO** *Este estudo ecológico analisou a correlação espacial entre indicadores socioeconômicos, demográficos e óbitos por covid-19 no Brasil. As variáveis independentes abrangeram população, sexo, idade, raça, alfabetização e índice de Gini, enquanto a variável dependente foi a mortalidade por covid-19. Os dados socioeconômicos e demográficos foram obtidos da Pesquisa Nacional por Amostra de Domicílios Contínua, e os dados de casos e óbitos de covid-19 foram obtidos do site do Ministério da Saúde. A análise incluiu o cálculo dos Índices de Moran Global de forma uni e bivariada. Os resultados revelaram correlação espacial significativa das variáveis independentes com mortalidade por covid-19. Destaca-se correlação positiva moderada para os indivíduos alfabetizados e de 20 a 59 anos. Portanto, existe associação entre fatores socioeconômicos e mortalidade por covid-19, com variações entre os estados brasileiros. Essa conclusão ressalta a necessidade de implementar medidas intersetoriais para assegurar o acesso universal à saúde e alocar recursos de maneira equitativa entre os estados.*

**PALAVRAS-CHAVE** *Covid-19. Sars-CoV-2. Indicadores sociais. Indicadores econômicos. Mortalidade.*

[1] Universidade Federal de São Carlos (UFSCar) – São Carlos (SP), Brasil.
*helena.n.btu@gmail.com*

## Introduction

The COVID-19 pandemic has heterogeneously affected the population, especially in Brazil, which is among the ten countries with the highest inequality in the world[1]. The occurrence of COVID-19 is not uniform, but its worsening and death from the disease are associated with sociodemographic characteristics and the pre-existence of comorbidities. In addition, individuals with a higher degree of social vulnerability are susceptible to a greater impact by COVID-19, and it is essential to consider the social determinants of health to identify vulnerability to the disease[1]. A study carried out in Mexico highlighted that the COVID-19 lethality coefficient was also higher in municipalities with lower Human Development Index (HDI), which allows us to establish that the disease has more serious effects on the most unprotected layers of the population[2].

Socioeconomic factors, such as low income, affect living conditions, such as residence in poorer neighborhoods and housing conditions, especially tight or overcrowded housing, besides low educational level, which is indirectly associated with a higher risk of developing severe forms of the disease[3].

The analysis of the association between socioeconomic factors and the mortality rate due to COVID-19 showed that per capita income, unemployment rate, comorbidities, and difficulty in accessing health services are risk factors associated with a higher mortality rate due to COVID-19[4]. Likewise, some analyses also point to a relationship between COVID-19 mortality and socioeconomic factors, such as low income, unemployment, comorbidities, black ethnicity, low level of education, and older individuals[3].

Thus, studies on COVID-19 involving socioeconomic factors and patient profiles address the association in specific periods of the pandemic[1-4], with small and specific time frames. To minimize this knowledge gap, this study aimed to analyze the spatial correlation between socioeconomic and demographic indicators and deaths from COVID-19 in Brazilian states, from March 2020 to June 2022.

## Material and methods

This is an analytical ecological study. Data on the population, sex, age, race, literacy, and Gini index were obtained through the National Household Sample Survey (PNAD), referring to 2015, as it corresponds to the last update of these data; and data on mortality from the disease in the period from March 2020 to June 2022 were obtained from the electronic platform of the Ministry of Health, entitled 'COVID-19 in Brazil'.

In this study, the independent variables were population, sex, age, race, literacy and Gini index, considering the absolute numbers. The dependent variable was COVID-19 mortality in Brazil. It is noteworthy that the variable race was divided into two categories (white and non-white), due to the underreporting of the data, which generated a low n value. Thus, to enable the statistical analysis, it was necessary to group the black, brown, yellow, and indigenous races in the non-white category.

Descriptive analyses of independent variables and mortality (dependent variable) were performed. To evaluate the spatial autocorrelations of the variables of interest, the Global Moran Indexes (GMI) were calculated according to a bivariate analysis. To estimate the spatial autocorrelation, the GMI was used, which varies between -1 and +1 and provides its statistical significance (p). All analyses adopted a significance level of 5%.

GeoDa 1.20.0.10 software was used for index calculations[5], and the QGIS 3.26.0 software was used to prepare the maps and frequency distributions[6]. Bivariate analysis was performed to evaluate the spatial correlation between the dependent variable COVID-19 mortality and the independent variables (sex, age, race, literacy, Gini index). This analysis

generated the Local Moran Index (LMI) and spatial correlation maps. For the bivariate spatial correlation, clusters were interpreted in one of the five types: Not significant: regions that did not enter any cluster; High-High: regions with high frequency of the variable of interest and high frequency of mortality; Low-Low: regions with low frequency of the variable of interest and low frequency of mortality; Low-High: regions with low frequency of the variable of interest and high frequency of mortality; High-Low: regions with high frequency of the variable of interest and low frequency of mortality[7].

The correlation values generated by the GMI and LMI could be evaluated as positive or negative and as weak (< 0.3), moderate (0.3-0.7), or strong (> 0.7), as used in the evaluation of Pearson's correlation.

As this research uses secondary data, without personal identification and in the public domain, and according to Resolution No. 510/2016, of the National Health Council[8], it was not necessary to be considered by the Ethics Committee on Research with Human Beings.

## Results

In the period studied, the state of Rio de Janeiro stands out, where the highest mortality rate (428.92 deaths/100,000 inhabitants) was recorded, followed by Mato Grosso (421.6 deaths/100,000 inhabitants), Roraima (407.10 deaths/100,000 inhabitants), and Rondônia (407.10 deaths/100,000 inhabitants) (*table 1*).

Table 1. Deaths/100,000 inhabitants by Federative Units and Brazilian regions from 03/27/2020 to 06/24/2022. Brasil, 2022

| Federative Unit/Region | Deaths/100.000 inhabitants |
|---|---|
| **North Region** | |
| Pará | 214.5 |
| Acre | 227.0 |
| Amapá | 253.0 |
| Tocantins | 264.4 |
| Amazonas | 342.1 |
| Roraima | 407.1 |
| Rondônia | 407.1 |
| **Northeast Region** | |
| Maranhão | 154.0 |
| Bahia | 201.8 |
| Alagoas | 208.0 |
| Pernambuco | 228.5 |
| Rio Grande do Norte | 235.0 |
| Piauí | 237.0 |
| Paraíba | 254.9 |
| Sergipe | 276.5 |
| Ceará | 297.5 |

Table 1. Deaths/100,000 inhabitants by Federative Units and Brazilian regions from 03/27/2020 to 06/24/2022. Brasil, 2022

| Federative Unit/Region | Deaths/100.000 inhabitants |
|---|---|
| **Southeast Region** | |
| Minas Gerais | 293.0 |
| Espírito Santo | 359.9 |
| São Paulo | 371.4 |
| Rio de Janeiro | 428.9 |
| **South Region** | |
| Santa Catarina | 306.6 |
| Rio Grande do Sul | 351.1 |
| Paraná | 381.6 |
| **Central West Region** | |
| Mato Grosso do Sul | 381.8 |
| Goiás | 382.1 |
| Distrito Federal | 389.6 |
| Mato Grosso | 421.6 |

Source: Prepared by the authors.

During the period of the study, it was possible to verify a moderate positive spatial correlation in relation to COVID-19 mortality and individuals aged 20 to 59 years (IMl = 0.31; p < 0.01), mortality from the disease and literate (IMl = 0.48; p < 0.01), that is, states with higher mortality had a higher population of individuals aged 20 to 59 years and literate individuals (*table 2*).

Regarding ethnicity, a weak positive spatial correlation can be observed regarding COVID-19 mortality and white individuals (IMl = 0.26; p < 0.01). A moderate negative spatial correlation was also found in relation to mortality and the Gini index, that is, states with higher mortality had a lower Gini index (IMl = -0.310; p < 0.01). Although the relationship between spatial distribution of mortality and sex was not significant, a positive correlation between COVID-19 mortality and male sex can be observed (*table 2*).

Table 2. Bivariate Moran index of the independent variables sex, age, ethnicity, and literacy in relation to mortality from covid-19 in Brazil. Brasil, 2022

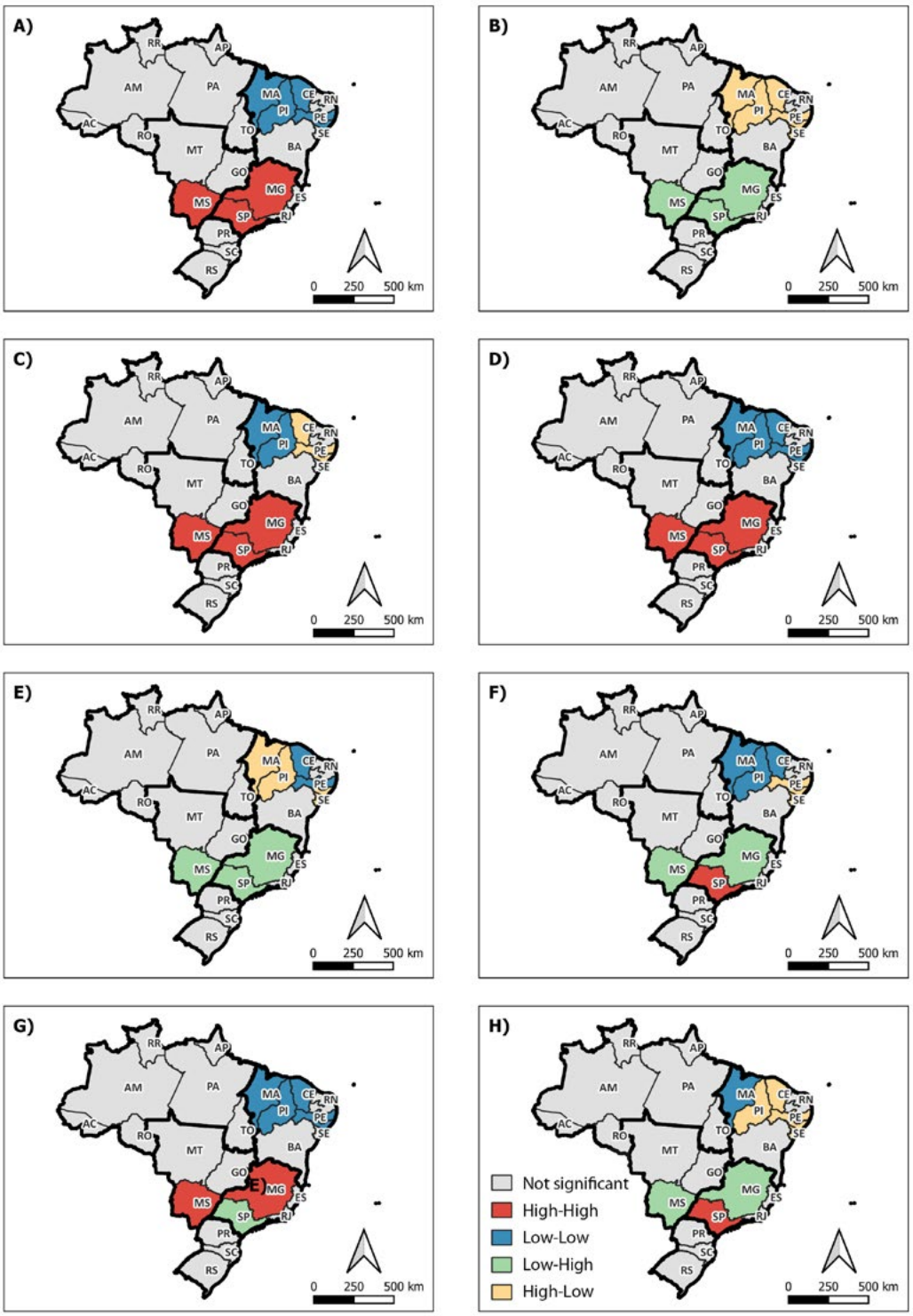
| **Mortality (/100 thousand) vs** | **Bivariate Moran index** | **p-value** |
|---|---|---|
| **Gini index** | **-0.310** | **< 0.010** |
| **Sex** | | |
| Female | -0.099 | 0.180 |
| Male | 0.099 | 0.180 |
| **Age (years)** | | |
| 0 to 19 | -0.251 | 0.020 |
| 20 to 59 | 0.317 | < 0.010 |
| ≥ 60 | 0.127 | 0.110 |
| **Race** | | |
| White | 0.265 | < 0.010 |
| Non-white | -0.265 | < 0.010 |
| **Education** | | |
| Literate | 0.483 | < 0.010 |
| Illiterate | -0.483 | < 0.010 |

Source: Prepared by the authors.

Regarding the spatial distribution, the results show a heterogeneous pattern of COVID-19 mortality in Brazil, highlighting the correlation of mortality with the Gini index, age between 20 and 59 years old, white and literate individuals, reflecting the complexity and challenges in coping with the pandemic in a continental country (*figure 1*).

The maps demonstrate the formation of clusters when the spatial correlation of COVID-19 mortality with the independent variables, sex, age, race, literacy, and Gini index is verified (*figure 1*).

Figure 1. Spatial correlation of mortality by COVID-19 with the variables: sex, age, race, literacy, and Gini index. Brasil, 2022




Source: Prepared by the authors.

Spatial autocorrelation maps of COVID-19 mortality in Brazil: A – BiLisamap, proportion of literate individuals in Brazil; B – BiLisamap, proportion of non-white individuals in Brazil; C – BiLisamap, proportion of individuals aged 60 or older in Brazil; D – BiLisamap, proportion of individuals aged 20 to 59 years in Brazil; E – BiLisamap, proportion of individuals aged 0 to 19 years in Brazil; F – BiLisamap, proportion of men in Brazil; G – BiLisamap, incidence of COVID-19 in Brazil from 03/27/2020 to 06/24/2022; and H – BiLisamap, Gini index.

In general, in the spatial autocorrelation regarding mortality and literacy, most individuals were 60 years or more, and men. As for the incidence, there was formation of a high-high cluster, covering states in the Southeast and Central West, mainly Mato Grosso do Sul and Minas Gerais. Low-low mortality clusters and age from 20 to 59 years and literate people were more concentrated in the Northeast region, involving the states of Maranhão, Piauí, Ceará, and Pernambuco.

Regarding the Gini index and mortality, a high-high cluster was formed in an isolated state, São Paulo. It is also worth mentioning the formation of inverse clusters in the Northeast and Southeast regions, concerning non-white individuals and mortality, with the high-low and low-high types being verified, respectively.

## Discussion

The spatial distribution of COVID-19 mortality in the period studied and the independent variables showed a spatial correlation and the formation of several clusters for each region, a fact associated with regional diversity. Thus, there was a positive correlation between mortality and individuals aged 20 to 59 years and literate; a weak positive correlation between mortality and white people; and a moderate negative correlation between mortality and the Gini index, confirming a spatial correlation of COVID-19 mortality with socioeconomic and demographic indicators.

These correlations may be associated with the scope of the period studied, as it went through the various waves of the COVID-19 pandemic, in which different measures were adopted by managers to minimize the impact of the disease, in addition to the beginning and evolution of vaccination.

The heterogeneous distribution of cases and COVID-19 mortality can be related to the arrival of new virus variants at different times in each region, the adoption, and adherence of the population to non-pharmacological measures to prevent the disease, initiation, and adherence of the population to vaccination, in addition to existing social vulnerabilities and health structure[9]. During the pandemic, several variants were identified, causing epidemic waves of COVID-19, such as Alpha, Beta, Gamma, Delta, and Omicron (+). The variants Alpha and Delta were associated with a higher mortality rate, which may be related to the ability of both to generate many infections in a short time, overburdening health services[10].

It was also found that the risk of hospitalization, due to the more severe forms of the disease, was related to the Alpha and Beta[11] variants. In January 2021, Brazil was notified by Japan's health authorities that a new variant had been identified in four Japanese who had returned from Manaus[12]. Therefore, the new variant, called P.1, lineage B.1.1.28.1, Gama, was found out to have been circulating in the state of Amazonas since October 2020[13]. In Paraná, mortality rates tripled in young people aged between 20 and 29 years and doubled in adults aged 30 to 59 years after the emergence and spread of the Gamma variant[14].

Unlike the previous variants, infection by the Omicron variant does not cause loss of smell or taste, with more recurrent symptoms being tiredness, muscle pain, fever, dry cough, sore throat, headache, and tachycardia[15]. A study carried out at the National Middle Center, in South Korea, with 40 patients infected with the Omicron variant, found that

47.5% were asymptomatic cases[16]. In Brazil, on the other hand, it was found that the mortality of patients hospitalized with Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) increased during the wave of COVID-19 caused by the Omicron variant. People over 60 years of age, the presence of comorbidities, and males had a higher risk of death from the disease caused by this variant. On the other hand, the booster dose of the COVID-19 vaccine contributed to a decrease in the probability of death[17].

In this context, the pandemic went through several phases. In Brazil, in the first phase, from February to May 2020, there was an internalization of cases, causing difficulty in accessing beds in the Intensive Care Unit (ICU) and increasing the occurrence of death. From June to August 2020, COVID-19 had already spread throughout the country, with an average of 1,000 deaths per day, in addition to regions such as the Central West and South, which experienced critical situations of occupation of ICU beds. In the third phase, from September to November 2020, there was a reduction in cases and deaths from the disease, so isolation measures were relaxed to different degrees and times by the states; however, there was no vaccine, which favored the development of new variants[18].

Given the loosening of restriction measures, at the end of 2020, the fatigue of the population from restrictive measures and the holiday parties led to an increase in cases and deaths, from the end of 2020, starting the fourth phase, which lasted until June 2021. In this period, considered the most dramatic of the pandemic, the Gamma variant was circulating, and the unpreparedness of the health system contributed to an increase in mortality, reaching an average of 3,000 deaths per day from COVID-19. This phase of the pandemic led to the collapse of health systems in several states, which had a lack of equipment, ICU supplies, and depletion of the workforce of healthcare providers. The collapse of the health and funeral system in the North region stands out, with a lack of ICU beds and supplies, and equipment[19].

In this scenario, in Brazil, vaccination began in the second half of January, concomitantly with the rapid transmission of the Gamma variant, identified in Manaus, which experienced explosive peaks in mortality. The situation in Manaus forced the Ministry of Health to allocate extra quotas of COVID-19 vaccines to Amazonas, aimed at individuals over 70 years old and health collaborators, to halt the advance of the pandemic. COVID-19 Mortality in Amazonas, between April and May 2020 and January 2021, showed a change in the death profile by sex and age group when comparing the first with the second wave of the pandemic in the state. There was an increase in the proportion of deaths from COVID-19 among women and in the age group from 20 to 59 years of both sexes. In addition, there was a relative increase in mortality and lethality coefficients in different age groups and sexes[20].

The age group with the highest risk of death is associated with the elderly and may be justified by immunosenescence, a situation in which the immune system weakens because of increased production of cytokines and weakening of T and B cells, in addition to the presence of comorbidities, which increase with age, influencing the increase in mortality in the elderly[21]. Thus, age is one of the demographic risks related to the development of the severe form of COVID-19.

Regarding COVID-19 mortality and sex, studies have shown that higher numbers of deaths occurred in males[21,22]. This may be associated with higher prevalence of diabetes, cancer, and heart disease among men, in addition to lower levels of male immune resistance associated with testosterone immunosuppressive behavior[20]. A similar fact was identified in a study carried out in 63 countries, with a higher mortality rate in males due to COVID-19, related to the greater presence of comorbidities such as diabetes and heart disease, in addition to biological factors, such

as a higher expression of the angiotensin-converting enzyme receptor 2, used by the SARS-CoV-2, to enter the host cell [23].

Regarding non-white ethnicity, the study identified a negative spatial correlation, that is, the formation of high-low clusters in the Northeast region, with a high number of non-white individuals and low mortality, and low-high in the Southeast region, with a small number of non-white individuals and high COVID-19 mortality, which may be associated with a higher mortality rate in non-white individuals in the period studied.

On the other hand, in Rondônia, among the notifications with the information of race/color, the highest lethality was identified among black people [24]. This relationship between COVID-19 mortality and the black population may be associated with both a higher incidence of associated diseases and socioeconomic inequality [25].

The South and Southeast regions had the highest hospitalization rates per 100,000 inhabitants; however, in-hospital mortality was higher in the Northern and Northeastern states. When checking for racial differences, it was observed that white individuals were the most hospitalized, but black people had higher mortality rates. These data may be associated with disadvantages related to housing conditions, income distribution, education, and less access to health services [26].

In this context, the income and employment occupied by the black population also stand out, which often develops activities that favor contamination by COVID-19. A considerable part of this population occupies jobs that cannot be performed online; thus, race and ethnicity profile were directly correlated with exposure to SARS-CoV-2 [27].

In England, hesitation regarding the COVID-19 vaccine was identified among black and Asian individuals, one of the concerns being insecurity about side effects. Thus, for better adherence to the vaccine, a broader look at communities is necessary, trying to involve them, asking for help from community leaders, social workers, local councils, as well as greater dissemination of publicly available and qualified information and transparency about possible side effects [28].

From July to November 2021, the incidence of COVID-19 in the country was reduced, accompanied by a drop in the number of serious cases and deaths, resulting in a reduction in ICU occupancy rates. In the aforementioned period, the effectiveness of ongoing vaccination was evidenced, by reducing the transmission and severity of the disease, and 60% of the Brazilian adult population was vaccinated; however, about 250 daily deaths were still recorded [18].

After vaccination with BioNTech vaccine, Pfizer, 33 individuals among 3,720 healthcare providers were infected with the Alpha variant; however, they were asymptomatic or had mild symptoms of the disease [11]. In the United States, the overall efficacy of Pfizer's vaccine against infection of the Delta variant of the SARS-CoV-2 virus decreased from 93% at one month after complete vaccination to 53% after four months [29].

In addition to vaccination, the structural capacity of health systems was important in the pandemic. A study created and mapped the Health Infrastructure Index (IIS) in Brazilian states, noting that there are regional disparities in the spatial distribution of health system infrastructure, with the lowest rates recorded in the North region, in states such as Amapá and Roraima, places where the health system was severely affected by the pandemic [30].

Another point to be considered is the misalignment and lack of coordination between the Union, states, and municipalities in coping with the pandemic in Brazil, from the initial phase to the execution of the National COVID-19 Immunization Plan. At the beginning of vaccination, there was a shortage of vaccine doses, in addition to the divergence of vaccination schedules and criteria for prioritizing groups between states and municipalities, and especially due to the delays

in the purchase of vaccines by the federal government, as well as the anti-vaccines manifestations at this level of management[31-33].

In Brazil, with the advancement of COVID-19 vaccination, there was a reduction in the number of serious cases and clinical and ICU admissions, in addition to the number of deaths[21]. In Manaus, there were changes in hospitalization patterns and deaths from COVID-19 after the start of vaccination, with reduced rates of hospitalization and death from the disease, especially in the age group from 60 to 69 years[20].

From July to November 2021, the fifth phase of the pandemic, there was a reduction in serious cases and deaths from COVID-19, even in the face of the high spread of the Delta variant, with the effectiveness of vaccination being noticeable. It is noteworthy that, in the face of 40% of the eligible vaccinated population, an average of 500 deaths were reported per day; and with 60% being vaccinated, an average of 250 deaths per day were recorded. In the sixth phase of the pandemic, from December 2021 to January 2022, a new wave with the Omicron variant was verified, increasing the number of cases and the occupancy rate of ICU beds; however, this increase occurred in a smaller proportion when comparing this phase with the others of the pandemic[18].

Despite the therapeutic measures, and contrary to what was found in this study, analyses show that socioeconomic and political contexts are determining factors for the number of cases and deaths from the disease; thus, demographic density and the Gini index are associated with COVID-19 mortality[34,35]. Social inequality impacts the adoption of preventive measures, as the population belonging to the most vulnerable strata of society represents the majority of people with informal jobs, domestic workers, commercial service providers, transportation workers and post office workers, who remained active even during the most critical phases of the pandemic. In addition, the scarcity of income influences the availability of resources due to the absence of investments in community infrastructure, such as education, transportation, sanitation, housing, and health services[22].

### Study Limitations

The study presents limiting factors related to underreporting and the use of retroactive Censuses of the National Household Sample Survey (PNAD), referring to 2015. However, these factors did not interfere with the quality of the results, since the data used showed spatial correlations between the independent variables and COVID-19 mortality, verifying the heterogeneity of the states with their particularities and forms of coping, being crucial for the direction of government projects and actions at the municipal, state, or federal levels, according to their profile.

### Contributions to the Practice between Socioeconomic and Demographic Indicators and Deaths from COVID-19 in Brazilian States

This study covers the identification of the association between socioeconomic and demographic indicators and deaths from COVID-19, offering relevant information for clinical practice and health resource management. Still, for healthcare providers, the results show the importance of considering the influence of local socioeconomic indicators on the dynamics of an infectious disease, and their inclusion in the preparation of contingency plans for outbreaks and epidemics is essential.

## Conclusions

A spatial correlation was observed between socioeconomic and demographic indicators and deaths from COVID-19 in Brazilian states, with clusters in the mortality coefficient and the categories described, verifying the significance between mortality and age, ethnicity, literacy, and Gini index. Thus, there is a need

to adopt intersectoral measures to ensure universal access to health and equitable allocation of resources to minimize social inequalities.

## Collaborators

Moraes AIS (0000-0001-6619-8791)* and Uehara SCSA (0000-0002-0236-5025)* contributed to the design of the project, analysis, and interpretation of the data, writing and relevant critical review of the intellectual content and final approval of the manuscript. Corrêa APV (0000-0002-9098-3594)* and Pereira HNS (0000-0002-6766-4907)* contributed to the writing, relevant critical review of the intellectual content, and final approval of the manuscript.■

## References


1. Albuquerque MV, Ribeiro LHL. Inequality, geographic situation, and meanings of action in the COVID-19 pandemic in Brazil. Cad Saúde Pública. 2021;36(12):e00208720. DOI: https://doi.org/10.1590/0102-311x00208720

2. Chávez-Almazán LA, Díaz-González L, Rosales-Rivera M. Socioeconomic determinants of health and COVID-19 in Mexico. Gac Med Mex. 2023;158(1). DOI: https://doi.org/10.24875/GMM.M22000633

3. Khalatbari-Soltani S, Cumming RC, Delpierre C, et al. Importance of collecting data on socioeconomic determinants from the early stage of the COVID-19 outbreak onwards. J Epidemiol Community Health. 2020;74(8):620-623. DOI: https://doi.org/10.1136/jech-2020-214297

4. Cajachagua-Torres KN, Quezada-Pinedo HG, Huayanay-Espinoza CA, et al. COVID-19 and drivers of excess death rate in Peru: A longitudinal ecological study. Heliyon. 2022;8(12):e11948. DOI: https://doi.org/10.1016/j.heliyon.2022.e11948

5. Anselin L, Syabri I, Kho Y. GeoDa: an introduction to spatial data analysis. In: Fischer M, Getis A. Handbook of applied spatial analysis: Software tools, methods and applications. Berlin, Heidelberg: Springer Berlin Heidelberg; 2010. p. 73-89. DOI: https://doi.org/10.1007/978-3-642-03647-75.

6. QGIS.org. QGIS Geographic Information System [Internet]. [local desconhecido]: QGIS Association; 2022 [acesso em 2023 set 13]. Disponível em: http://www.qgis.org

7. Anselin L. Local Indicators of Spatial Association – LISA. Geogr Analysis. 1995;27(2):93-115. DOI: https://doi.org/10.1111/j.1538-4632.1995.tb00338.x

8. Ministério da Saúde (BR); Conselho Nacional de Saúde. Resolução nº 510, de 7 de abril de 2016. Dispõe sobre as normas aplicáveis a pesquisas em Ciências Humanas e Sociais cujos procedimentos metodológicos envolvam a utilização de dados diretamente obtidos com os participantes ou de informações identificáveis ou que possam acarretar riscos maiores do que os existentes na vida cotidiana. Diário Oficial da União, Brasília, DF. 2016 maio 24; Seção I:44.

9. Spinella C, Mio AM. Simulation of the impact of people mobility, vaccination rate, and virus variants on the evolution of Covid-19 outbreak in Italy. Sci Rep. 2021;11(1):23225. DOI: https://doi.org/10.1038/s41598-021-02546-y


*Orcid (Open Researcher and Contributor ID).

10. Bedoya-Sommerkamp M, Medina-Ranilla J, Chau--Rodríguez V, et al. Variantes del SARS-CoV-2: epidemiología, fisiopatología y la importancia de las vacunas. Rev. Peru Med. Exp. Salud Publica. 2021;38(3):442-451. DOI: https://doi.org/10.17843/rpmesp.2021.383.8734

11. Rovida F, Cassaniti I, Paolucci S, et al. SARS-CoV-2 vaccine breakthrough infections with the alpha variant are asymptomatic or mildly symptomatic among health care workers. Nat Commun. 2021;12(1). DOI: https://doi.org/10.1038/s41467-021-26154-6

12. Fujino T, Nomoto H, Kutsuna S, et al. Novel SARS-CoV-2 Variant in Travelers from Brazil to Japan. Emerg. Infect. Dis. 2021;27(4). DOI: https://doi.org/10.3201/eid2704.210138

13. Ministério da Saúde (BR), Secretaria de Vigilância em Saúde. Plano nacional de operacionalização da vacinação contra a COVID-19 [Internet]. Brasília, DF: Ministério da Saúde; 2021 [acesso em 2023 set 13]. Disponível em: https://sbim.org.br/images/files/notas-tecnicas/plano-vacinao-covid19-ed5-17mar21-cgpni.pdf

14. Oliveira MHS, Lippi G, Henry BM. Sudden rise in COVID-19 case fatality among young and middle-aged adults in the south of Brazil after identification of the novel B.1.1.28.1 (P.1) SARS-CoV-2 strain: analysis of data from the state of Parana. medRxiv. 2021. DOI: https://doi.org/10.1101/2021.03.24.21254046

15. Orellana-Centeno JE, Guerrero Sotelo RN. La variante SARS-CoV-2 ómicron. Rev. ADM. 2022;79(1):28-31. DOI: https://doi.org/10.35366/103815

16. Kim MK, Lee B, Choi YY, et al. Clinical Characteristics of 40 Patients Infected With the SARS--CoV-2 Omicron Variant in Korea. J Korean Med. Sci. 2022;37(3):e31. DOI: https://doi.org/10.3346/jkms.2022.37.e31

17. Colnago M, Benvenuto GA, Casaca W, et al. Risk Factors Associated with mortality in hospitalized patients with COVID-19 during the omicron wave in Brazil. Bioengineering (Basel). 2022;9(10):584. DOI: https://doi.org/10.3390/bioengineering9100584

18. Fundação Osvaldo Cruz (BR). Boletim Observatório Fiocruz COVID-19: Boletim especial: balanço de dois anos da pandemia Covid-19: janeiro de 2020 a janeiro de 2022 [Internet]. Rio de Janeiro: Fiocruz; 2022 [acesso em 2023 set 13]. Disponível em: https://www.arca.fiocruz.br/handle/icict/55828

19. Carvalho R. Amazonas apresenta colapso no sistema de saúde por causa do coronavírus. Estadão [Internet]. 2020 abr 15 [acesso em 2023 set 13]. Disponível em: https://saude.estadao.com.br/noticias/geral,amazonas-apresenta-colapso-no-sistema-de-saude-por--causa-do-coronavirus,70003272136

20. Orellana JDY, Cunha GM, Marrero L, et al. Changes in the pattern of COVID-19 hospitalizations and deaths after substantial vaccination of the elderly in Manaus, Amazonas State, Brazil. Cad Saúde Pública. 2022;38(5). DOI: https://doi.org/10.1590/0102-311XPT192321

21. Ejaz R, Ashraf MT, Qadeer S, et al. Gender-based incidence, recovery period, and mortality rate of COVID-19 among the population of district Attock, Pakistan. Braz J Biol. 2023;83:e249125. DOI: https://doi.org/10.1590/1519-6984.249125

22. Silva VVA. A covid-19 enquanto questão social: classe, escolaridade e cor da pandemia no Pará. Holos. 2021;1:1-14. DOI: https://doi.org/10.15628/holos.2021.11519

23. Geldsetzer P, Mukama T, Jawad NK, et al. Sex differences in the mortality rate for coronavirus disease 2019 compared to other causes of death: an analysis of population-wide data from 63 countries. Eur. J. Epidemiol. 2022;37(8):797-806. DOI: https://doi.org/10.1007/s10654-022-00866-5

24. Escobar AL, Rodriguez TDM, Monteiro JC. Lethality and characteristics of deaths due to COVID-19 in Rondônia: an observational study. Epidemiol. Serv. Saúde. 2021;30(1):e2020763. DOI: https://doi.org/10.1590/S1679-49742021000100019

25. Magesh S, John D, Li WT, et al. Disparities in COVID-19 Outcomes by Race, Ethnicity, and Socioeconomic Sta-

tus. JAMA Netw Open. 2021;4(11):e2134147. DOI: https://doi.org/10.1001/jamanetworkopen.2021.34147

26. Zeiser FA, Donida B, Costa CA, et al. First and second COVID-19 waves in Brazil: A cross-sectional study of patients' characteristics related to hospitalization and in-hospital mortality. Lancet Reg Health Am. 2022;6:100107. DOI: https://doi.org/10.1016/j.lana.2021.100107

27. Gemelas J, Davison J, Keltner C, et al. Inequities in Employment by Race, Ethnicity, and Sector During COVID-19. J Racial Ethn Health Disparities. 2021;9(1):350-355. DOI: https://doi.org/10.1007/s40615-021-00963-3

28. Eberhardt J, Ling J, Horsley L, et al. Exploring COVID-19 Vaccine Confidence with People from Black and Asian Backgrounds in England. J Racial Ethn Health Disparities. 2022;10(4):1899-1909. DOI: https://doi.org/10.1007/s40615-022-01372-w

29. Tartof SY, Slezak JM, Fischer H, et al. Effectiveness of mRNA BNT162b2 COVID-19 vaccine up to 6 months in a large integrated health system in the USA: a retrospective cohort study. Lancet. 2021;398(10309):1407-1416. DOI: https://doi.org/10.1016/S0140-6736(21)02183-8

30. Vivanco VE, Morais TC, Daboin BG, et al. Evolution of mortality and lethality due to covid-19 in the state of Roraima, Brazil, from march 2020 to july 2021. J Hum Growth Dev. 2021;31(3):447-457. DOI: https://doi.org/10.36311/jhgd.v31.12184

31. Maciel E, Fernandez M, Calife K, et al. The SARS--CoV-2 vaccination campaign in Brazil and the invisibility of science evidences. Ciênc saúde coletiva. 2022;27(3):951-956. DOI: https://doi.org/10.1590/1413-81232022273.21822021

32. Brandão CC, Mendonça AVM, Sousa MF. O Ministério da Saúde e a gestão do enfrentamento à pandemia de Covid-19 no Brasil. Saúde debate. 2023. 47(137):58-75. DOI: https://doi.org/10.1590/0103-1104202313704

33. Fleury S, Fava VMD. Vacina contra Covid-19: arena da disputa federativa brasileira. Saúde debate. 2022;46(esp1):248-264. DOI: https://doi.org/10.1590/0103-11042022E117

34. Cestari VRF, Florêncio RS, Sousa GJB, et al. Social vulnerability and COVID-19 incidence in a Brazilian metropolis. Ciênc saúde coletiva. 2021;26(3):1023-1033. DOI: https://doi.org/10.1590/1413-81232021263.42372020

35. Poiatti ND, Pedroso NC. Desigualdade internacional no combate à Covid-19 e os seus impactos nos gastos públicos. Saúde debate. 2022;46(esp8):21-34. DOI: https://doi.org/10.1590/0103-11042022E802

Received on 01/23/2024
Approved on 06/10/2024
Conflict of interests: non-existent
Financial support: Coordination for the Improvement of Higher Education Personnel (CAPES)

**Editor in charge:** Jamilli Silva Santos