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ARTICLE

Distribution of COVID-19 cases and health resources in Brazil's Amazon region: a spatial analysis

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Abstract *Spatial analysis can help measure the spatial accessibility of health services with a view to improving the allocation of health care resources. The objective of this study was to analyze the spatial distribution of COVID-19 detection rates and health care resources in Brazil's Amazon region. We conducted an ecological study using data on COVID-19 cases and the availability of health care resources in 772 municipalities during two waves of the pandemic. Local and global Bayesian estimation were used to construct choropleth maps. Moran's I was calculated to detect the presence of spatial dependence and Moran maps were used to identify disease clusters. In both periods, Moran's I values indicate the presence of positive spatial autocorrelation in distributions and spatial dependence between municipalities, with only a slight difference between the two estimators. The findings also reveal that case rates were highest in the states of Amapá, Amazonas, and Roraima. The data suggest that health care resources were inefficiently allocated, with higher concentrations of ventilators and ICU beds being found in state capitals.*
Key words *COVID-19, Spatial analysis, Ecological studies, Mechanical ventilators, Intensive care units*

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Introduction

Brazil is the only country in the world with a population of over 100 million with a universal health care system[1]. This system, which for decades has helped reduce inequalities in access to health care, was overwhelmed during the pandemic as Brazil was among the countries hardest hit by COVID-19, leading Latin America to be declared the epicenter of the pandemic in May and June 2020[2].

Despite having an extensive primary care network, Brazil faced the largest health and hospital system collapse in the country's history during the pandemic. Adult COVID-19 intensive care unit (ICU) bed occupancy rates in the country's public health system, the *Sistema* Único *de Saúde* (SUS) or Unified Health System, in March 2021 were greater than or equal to 80% in 24 states and the Federal District, with 15 states having rates of at least 90%[3].

Between 17% and 35% of non-vaccinated patients hospitalized with COVID-19 need to be admitted to an ICU, mainly due to hypoxemic respiratory failure. In addition, between 29% and 91% of COVID-19 patients who have hypoxemic respiratory failure need invasive ventilatory support[4-6].

The SARS-CoV-2 virus is highly transmissible and most individuals are susceptible to infection[7]. The spread of the virus is a complex process influenced by demographic characteristics, population mobility, and the environment, meaning that transmissibility varies greatly between countries and regions and over time[5].

Despite having a low population density, Brazil's Amazon region in the North of the country had a high concentration of COVID-19 cases[8]. The Amazon is a multifaceted and socially and environmentally diverse region with populous cities intermingled with sparsely populated areas isolated from large urban centers. The region also has a large concentration of traditional and indigenous peoples living in remote rural areas, including riverine, fishing, and Quilombola communities. The Amazon is also characterized by social, economic, and health disparities, combined with rapid population and economic growth and high-income concentration, and a large proportion of the population suffer from poor living conditions[9].

Manaus, capital of the state of Amazonas, was surprised by a sharp rise in the number of cases and deaths in April 2020[10], putting considerable pressure on the city's health services. Geographical barriers have been used as a justification for difficulties in developing interiorized actions and providing access to the three tiers of health care across the Amazon[11].

Mapping patterns in the distribution of the disease and physical health care resources can therefore help to understand the current dynamics of access to care and identify areas that are most vulnerable to the pandemic. This understanding can help support the implementation of measures to control the spread of the virus, prevent local outbreaks, and guide resource allocation, improving the accessibility of intensive care for critically ill patients. In light of the above, the aim of the present study was to analyze the spatial distribution of COVID-19 detection rates and the availability of health care resources in Brazil's Amazon region.

Materials and methods

We conducted an ecological study using data on the distribution of COVID-19 detection rates and health care resources (COVID-19 ICU beds and mechanical ventilators) in Brazil's Amazon region.

The units of analysis were the 772 municipalities in the Amazon region, which is made up of the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, Tocantins and part of Maranhão. The Amazon covers an area of 5,015,067.75 km² (58.9% of the country) and population density is low across most of the region[12].

We used data on cases of COVID-19 detected during the period 25 February 2020 (date of the first recorded case) to 31 March 2021, considering the cumulative total of cases up to July 2020 and up to March 2021. These periods were chosen because they include two peaks of the pandemic in Brazil, as can be seen on the graph of cases per epidemiological week on the World Health Organisation's website[13].

The number of COVID-19 cases per municipality of residence was extracted from the Ministry of Health coronavirus platform on 10 April 2021[14]. These data are constantly updated and corrected. In this regard, the municipality where the cases is notified is not always the same as the municipality of residence, with the latter being corrected after the completion of the investigation process. A total of 1,860,217 cases were recorded during the study period, including 559,349 up to the first peak in July 2020.

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To calculate the municipal case detection rates, we used 2020 population estimates published by the Brazilian Institute of Geography and Statistics[15].

We calculated cumulative crude municipal case detection rates (number of cases divided by total population multiplied by 100,000) and smoothed rates using the global Bayesian estimator, which calculates the weighted average between the local and regional rate, and local Bayesian estimator, which considers the spatial effects of estimates in neighboring municipalities[16].

The estimators reduce random rate fluctuations and can indicate priority areas for health actions (where rates are more pronounced even after smoothing) and, in the case of the local Bayesian estimator, take into account trends in neighboring areas. For the local Bayesian estimator, we considered first-order neighbors, i.e. only immediate neighbors. Choropleth maps were created to visualize the distribution of rates, graduating values using natural breaks.

Moran's I was calculated to determine the spatial dependence in the distribution of the global and local Bayesian rates. The index ranges between -1 and +1, with positive values indicating spatial dependence and negative values indicating negative spatial correlation. Values close to 0 indicate no spatial autocorrelation. A neighborhood contiguity matrix was created adopting a 5% significance level.

A Moran scatter plot of the detection coefficient calculated using the local Bayesian estimator was used to determine spatial patterns. A Moran map was used to identify statistically significant clusters of areas with high values with neighbors with high values (Q1 – high-high pattern), areas with low values with neighbors with low values (Q2 – low-low pattern), and transition areas (Q3 – high-low pattern and Q4 – low-high pattern).

The data on mechanical ventilators and COVID-19 ICU beds were collected from the National Register of Health Establishments (CNES)[17]. The number of beds and mechanical ventilators was represented using proportional circles placed over the municipality's administrative center. This information was superimposed over the Moran map to compare numbers with case clusters.

Data processing, georeferencing, spatial analysis, and mapping were performed using Excel 2013, GeoDa 1.18.0, and QGIS 3.18.1. Pearson's chi-squared test was used to determine the correlation between variables in the two waves adopting a 95% confidence level. Pearson's chi-squared test and the descriptive analyses were performed using SPSS.

The study did not require ethical approval as it was conducted using secondary data available in the public domain.

Results

The total number of COVID-19 cases/100,000 population rose from 1.99 during the first wave (up to 31 July 2020) to 6.62 cases/100,000 population in the second wave (up to 31 March 2021). Table 1 shows the data for the first and second wave.

Local and global Moran's I were 0.44 ($p = 0.001$) and 0.43 ($p = 0.001$) during the first wave and 0.46 ($p = 0.001$) and 0.45 ($p = 0.001$) in the second. The values indicate that the distribution displays positive spatial autocorrelation and spatial dependence between municipalities in both periods, with only a slight difference between the two estimators.

Figures 1 and 2 present the distribution of the cumulative crude COVID-19 detection rates and smoothed rates for both periods. The maps show that there was only a slight variation between crude and smoothed rates in both waves.

In the first wave, the municipalities with a detection coefficient of more than 3,000 cases/100,000 population were concentrated in the state of Amapá, the northwest and mid-south of Amazonas, and the east and south and sparsely populated areas of Pará. The lowest detection rates (less than 1,000 cases/100,000 population) occurred mainly in Mato Grosso, Tocantins, the west of Rondônia, and the north and southeast of Pará (Figure 1). The only municipality not to have recorded cases of the disease was Mateiros in Tocantins.

The cumulative detection rate rose sharply in the second wave. The highest crude detection rates (more than 8,000 cases/100,000 population) were concentrated in Amapá, the south and northeast of Pará, and the north and southeast of Amazonas, while the lowest detection rates (less than 4,000 cases/100,000 population) were found in Maranhão and the northeast of Pará. All municipalities recorded cases of the disease in this period (Figure 2).

Figure 3 shows the distribution of mechanical ventilators superimposed over the Moran map of the smoothed rates in the first and second waves,

Table 1. COVID-19 cases and availability of physical health care resources in the Amazon region during the pandemic up to July 2020 and up to March 2021.

Variables	Minimum	Maximum	Mean	Median	Standard deviation
Population	946	2,219,580	36,416.04	16.212	116,588.12
Cases up to July 2020	0	35,592	724.55	219	2,339.83
ICU beds up to July 2020	0	196	2.50	0	14.57
Ventilators up to July 2020	0	1,040	9.84	0	65.4
Cases up to March 2021	14	159,948	2,409.61	747,5	8,524.81
ICU beds up to March 2021	0	360	3.84	0	22.93
Ventilators up to March 2021	0	1,179	11.51	0	73.49
Municipal cumulative incidence in the "first wave"	0	17,061.92	1,721.11	1.282,16	1,726.49
Municipal cumulative incidence in the "second wave"	167,02	34,473.57	6,244.91	5.554,73	4,068.64

Source: Authors.

revealing that ventilators were concentrated in state capitals in both periods.

In the first wave, although some state capitals such as Manaus (1,040), Cuiabá (847), and Belém (829) show a high concentration of ventilators, the findings show regions with statistically significant high-high patterns and a low number of ventilators. An example of this pattern is Pará, where the number of ventilators was greater in regions without high detection rates and high-high clusters (Novo Progresso/Itaituba and Parauapebas/Canaã dos Carajás) had a small number of ventilators. Various critical regions therefore had a shortage of ventilators (Figure 3) and none of the regions with a high-high pattern had a high number of available ICU beds (Figure 4).

Also with regard to the first wave, regions with a statistically significant low-low pattern were concentrated mainly in Tocantins, which had a medium number of ventilators and ICU beds, and the northwest and northeast of Mato Grosso, which had low numbers of ventilators and ICU beds (figure 3 and 4).

In the second wave, Amazonas continued to experience high-high patterns in the north and southeast, with these patterns expanding to the southeast and northeast of the state. Case patterns and the availability of ventilators remained the same in Amapá, while the situation in Pará changed, with high-high patterns being concentrated in the southeast and northeast. In Roraima, a high-high pattern continued to be found in the south of the state and rates increased in the central region. In Acre, the municipalities Feijó, Assis Brasil and Sena Madureira showed a high-high pattern in the second wave, with only the latter having ventilators (two). In Rondônia, the region surrounding the capital Porto Velho, also showed the same pattern, but with a high concentration of ventilators and ICU (figure 3 and 4).

Low-low patterns were concentrated in the northeast of Pará and in Maranhão in the second wave, with both regions having a high concentration of ventilators and ICU beds (figures 3 and 4). It is important to highlight that ventilators and ICU beds are made available to patients living in the municipalities and in adjacent municipalities located in the same health region.

The results of Pearson's chi-squared test showed a significant correlation between variations in COVID-19 detection rates and number of ventilators (0.267) and ICU beds (0.359) across health regions, showing a positive correlation between allocation of mechanical ventilators and ICU beds and a rise in detection rates between the two periods ($p < 0.05$).

Discussion

The findings show that detection rates and the number of ventilators and ICU beds increased by 332%, 14.54%, and 35%, respectively, between the two periods and the presence of spatial dependence in the distribution in both periods. Municipalities in the bordering states of Amapá, Amazonas, and Roraima had high-high patterns of detection in both periods.

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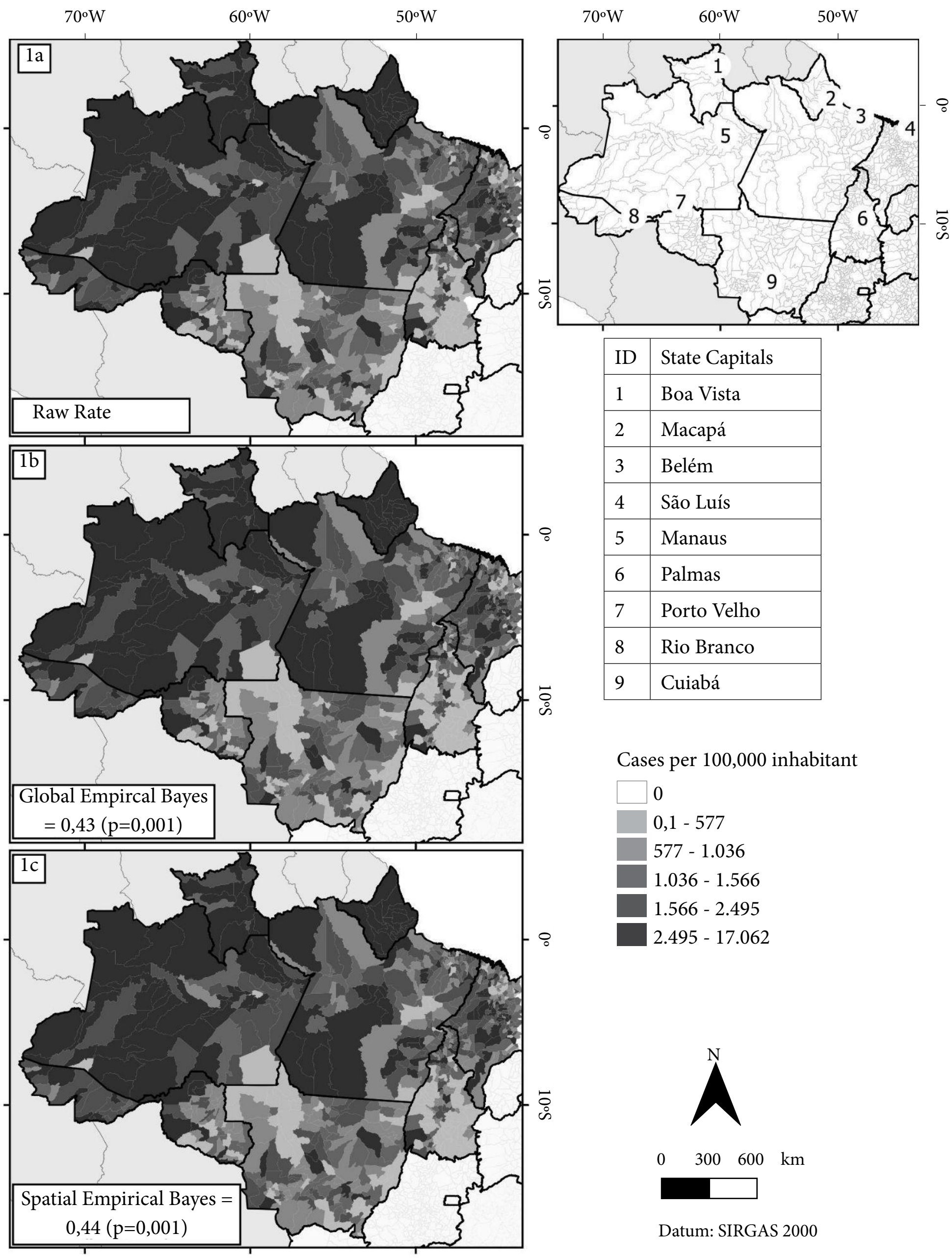

ID	State Capitals
1	Boa Vista
2	Macapá
3	Belém
4	São Luís
5	Manaus
6	Palmas
7	Porto Velho
8	Rio Branco
9	Cuiabá

Figure 1. Crude and smoothed COVID-19 detection rates up to July 2020 in the Amazon region, Brazil.

Source: Authors.

The overwhelming majority of countries have not carried out enough testing to provide good quality COVID-19-related health indicators[18]. In Brazil, access to tests is unequal, with poorer regions such as the Amazon having lower testing capacity[19].

The initial spread of COVID-19 and deaths in Brazil was not driven by population age structure and pre-existing health conditions but rather patterns of socioeconomic vulnerability[20-21]. The North of the country was the region with the highest vulnerability to COVID-19[22], which is

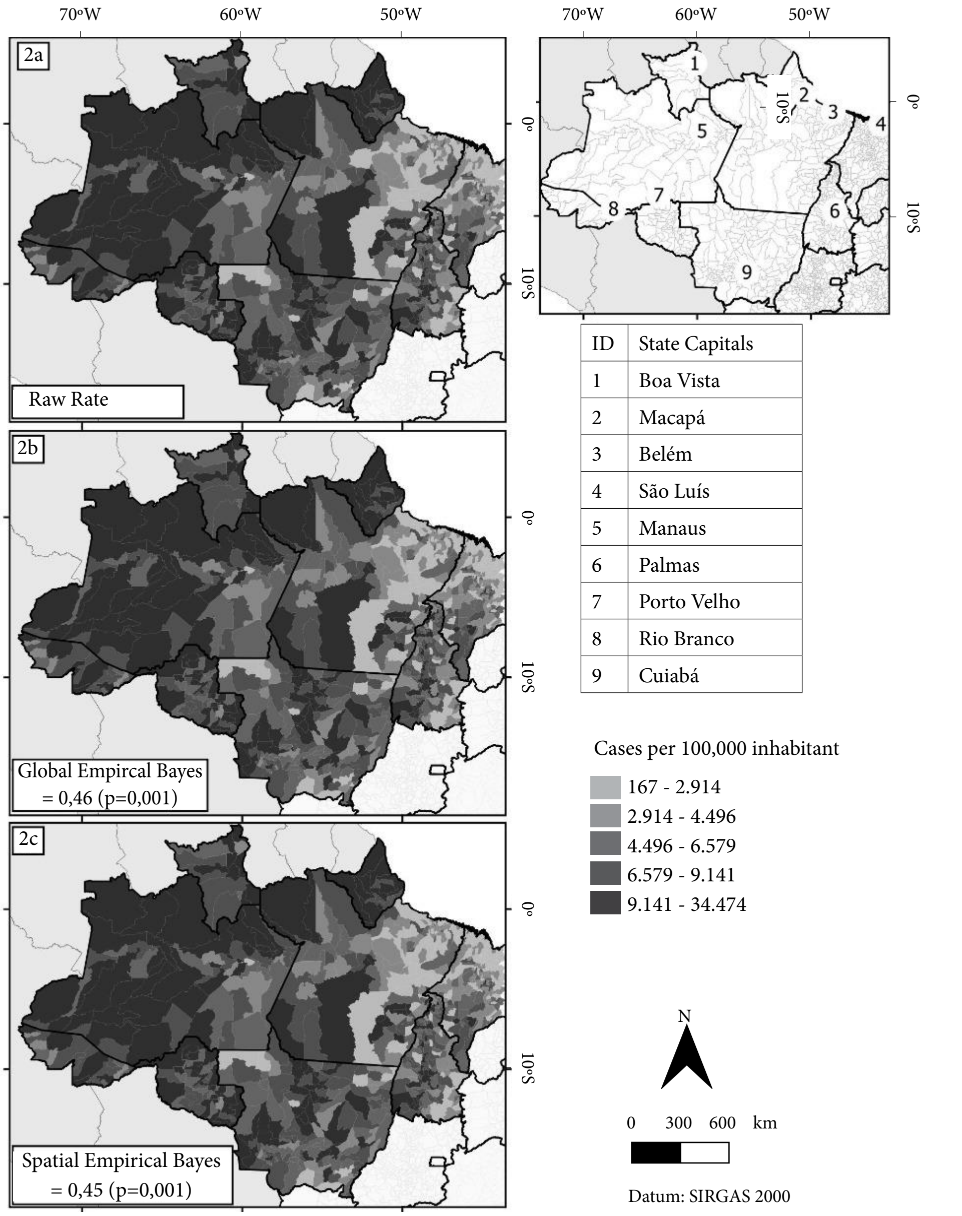

Figure 2. Crude and smoothed COVID-19 detection rates up to March 2021 in the Amazon region, Brazil.

Source: Authors.

corroborated by the high COVID-19 detection rates in the Amazon Region and sharp increases between waves.

The spread of the virus in the state of Amazonas was driven by the proximity of regions and the macro-regional urban hierarchy, in conjunction with the presence of international ports, the Manaus Free Trade Zone, and a vast river network, which is the region's main means of passenger and freight transport. These elements contributed to the interiorization of the spread of COVID-19[23], which may explain the case distribution patterns observed in this study.

Another study reported high-high patterns in both reference periods in Amapá. At the end of May 2020, the state accounted for the third-high-

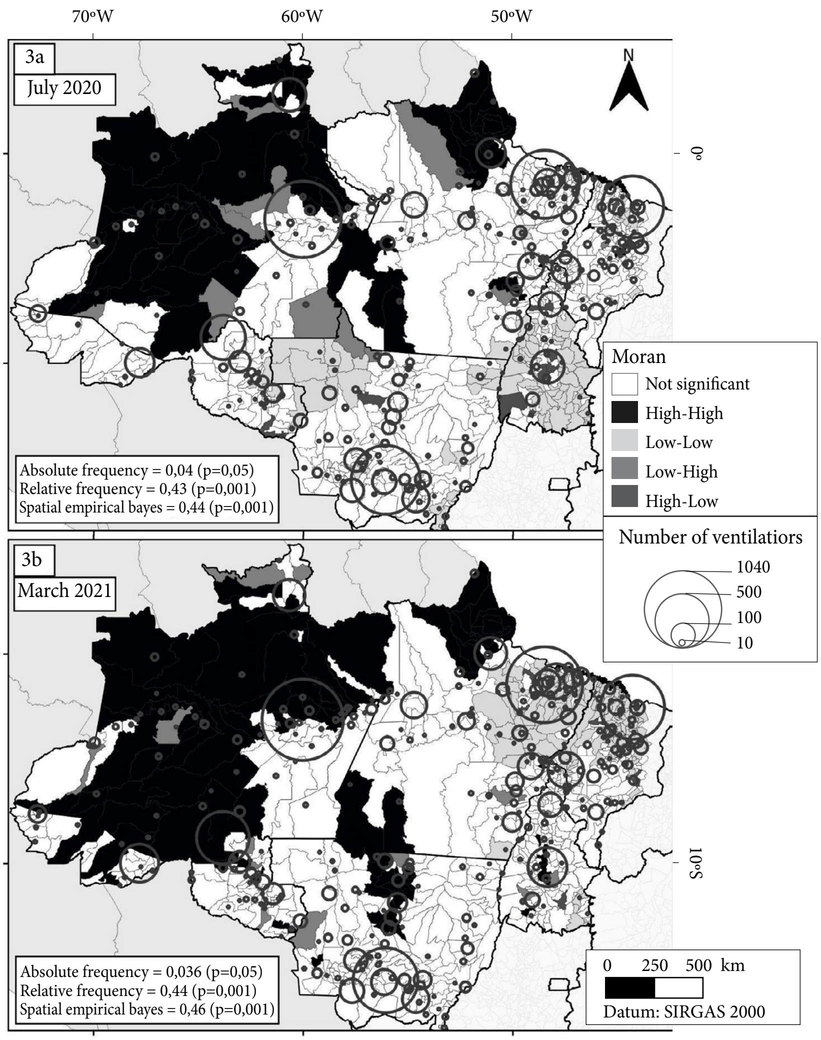

Figure 3. Moran map of municipal COVID-19 case detection coefficients and distribution of the number of mechanical ventilators in the Amazon region, Brazil, 2020 and 2021.

Source: Authors.

est percentage of overall COVID-19 cases in the North yet had the country's highest incidence rate[24]. These numbers may be explained by the fact that the state borders French Guiana, which had the highest cumulative incidence rate in Latin America in November 2021, with 14,941.98 cases/100,000 population[25]. The relationship between cases in French Guiana and Amapá could be an interesting topic for future research.

Regarding the availability of health care resources, the findings reveal several regions with high-high patterns and low numbers of ventilators and ICU beds. Although some of the health services in municipalities in the same health region are integrated, heavy demand combined with poor geographic accessibility can result in unequal access to complex care. Our findings are corroborated by a study conducted by Bezerra et al. (2020)[26], which revealed that access to healthcare across Brazil is uneven and unequal.

Another study in Brazil reported that the smoothed COVID-19 mortality rate was higher in the North region, where a greater shortage of hospital resources was observed[21]. In the same study, COVID-19 deaths were positively correlated with socioeconomic vulnerabilities and negatively associated with hospital resources[21]. Moreira (2020)[27] concluded that health regions

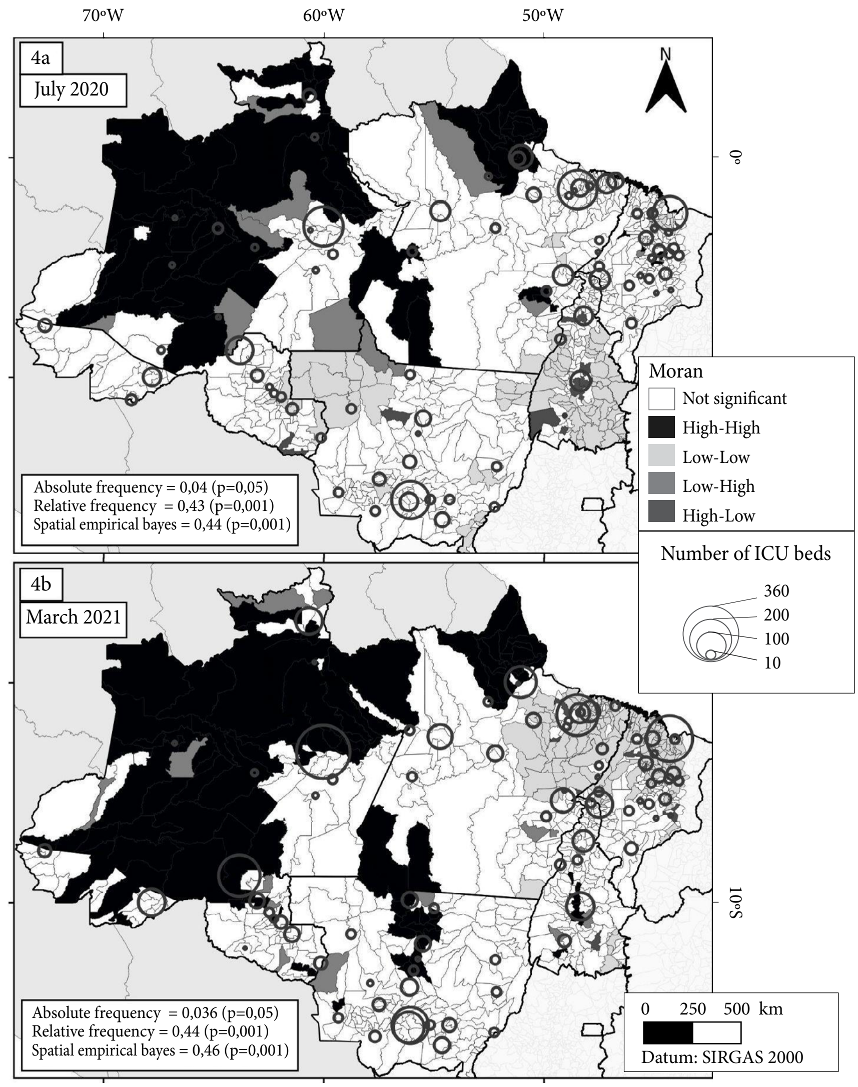

Figure 4. Moran map of municipal COVID-19 case detection coefficients and distribution of number of ICU beds in the Amazon region, Brazil, 2020 and 2021.

Source: Authors.

with the highest mean mortality rates were located in regions with shortages of ICU beds and mechanical ventilators.

A survey conducted in April 2020 showed that Amapá and Roraima had the lowest health care infrastructure indices. The same study reported a concentration of low-low clusters in Amazonas and Pará, suggesting weak health system capacity, especially in critical situations with heavy demand[26].

Despite its size, the overwhelming majority of the state of Amazonas' ICUs are located in the capital, Manaus, meaning that a collapse in this city's health system reverberates across the entire state. The same can be said of Amapá and Roraima, meaning that municipalities in the region are directly dependent on the capital's health care infrastructure.

Inequalities in access to health care in Amazonas are driven by low population densities and the state's vast size, with huge river basins covered with tropical forest and a precarious transport network[28]. As a result, COVID-19 patients from remote areas experience major difficulties

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in getting to regional centers that provide medium- and high-complexity care services[23]. In addition, the increase in the number of mechanical ventilators (14.54%) and adult COVID-19 ICU beds (35%) between the first and second wave found by this study was not proportional to the rise in detection rates (332%).

The prospect of recurring COVID-19 outbreaks in Brazil is real. It is recommended that countries adjust and coordinate their COVID-19 response based on increasingly detailed data (PAHO, 2020)[29]. The use of georeferenced data and geographic information systems can help inform decision-making, speeding up response and improving the effectiveness of public health actions. It is therefore hoped that this study can contribute to more effective health care resource allocation that takes into account more vulnerable areas.

This study has some limitations that are inherent to ecological studies, including the fact that it is not possible to determine the relationship between exposure and outcome at individual level. In addition, testing in Brazil is performed mainly on symptomatic people, meaning that underreporting is possible, especially given low testing rates in remote areas and among vulnerable communities where access to health services and information is poor. Case incidence data should therefore be treated with caution. Although data are updated daily, gaps in information may occur as local and state health departments have the autonomy to correct information on the place of residence after the investigation of the notification. In addition, created for epidemiological surveillance purposes, the federal government information system was updated on various occasions during the pandemic and the information was inputted by people who were not involved in the study, meaning that the data are subject to error. Despite the above, our findings provide important insights into the distribution of COVID-19 cases during the two waves.

Conclusion

Our findings indicate the presence of positive spatial autocorrelation in the distributions of COVID-19 cases and spatial dependence between municipalities in both periods. The results also reveal that case rates were highest in the states of Amapá, Amazonas, and Roraima. In addition, the data indicate that health care resources were inefficiently allocated, with higher concentrations of ventilators and ICU beds being found in state capitals.

Spatial analysis allowed us to measure the spatial accessibility of health services, providing important inputs to inform public policies and help promote the efficient and effective allocation of health care resources.

Collaborations

AAB Rede: project design, data collection, interpretation of findings, writing and review of the final version of the manuscript. NL Pedrosa: interpretation of findings and writing. RA Luz: data analysis, map making and writing review. AR Campos, W Rodrigues and AN Paixão: data tabulation, statistical analysis and manuscript writing. MAR Silva and RP da Silva: review of the writing and the final version.

References

1. Castro MC, Massuda A, Almeida G, Menezes-Filho NA, Andrade MV, Souza Noronha KVM, Rocha R, Macinko J, Hone T, Tasca R, Giovanella L, Malik AM, Werneck H, Fachini LA, Atun R. Brazil's Unified Health System: the first 30 years and prospects for the future. *Lancet* 2019; 394(10195):345-356.
2. Castro MC, Kim S, Barberia L, Ribeiro AF, Gurzenda S, Ribeiro KB, Abbott E, Blossom J, Rache B, Singer BH. Spatiotemporal pattern of COVID-19 spread in Brazil. *Science* 2021; 372(6544):821.
3. Brasil. Ministério da Saúde (MS). Fundação Oswaldo Cruz (Fiocruz). *Boletim Observatório COVID-19* 2021; 16 mar. [acessado 2021 set 21]. Disponível em: https://portal.fiocruz.br/sites/portal.fiocruz.br/files/documentos/boletim_extraordinario_2021-marco-16-red-red-red.pdf.
4. Myers LC, Parodi SM, Escobar GJ, Liu VX. Characteristics of hospitalized adults with COVID-19 in an integrated health care system in California. *JAMA* 2020; 323(21):2195-2198.
5. Yang X, Yu Y, Xu J, Shu H, Xia J, Liu H, Wu Y, Zhang L, Yu Z, Fang M, Yu T, Wang Y, Pan S, Zou X, Yuan S, Shang Y. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. *Lancet Respir Med* 2020; 8(5):475-481.
6. Grasselli G, Zangrillo A, Zanella A, Antonelli M, Cabrini L, Castelli A, Cereda D, Coluccello A, Foti G, Fumagalli R, Iotti G, Latronico N, Lorini L, Merler S, Natalini G, Piatti A, Ranieri MV, Scandroglio AM, Storti E, Cecconi M, Pesenti A, COVID-19 Lombardy ICU Network. Baseline characteristics and outcomes of 1,591 patients infected with SARS-CoV-2 admitted to ICUs of the Lombardy Region, Italy. *JAMA* 2020; 323(16):1574-1581.
7. Shi Y, Wang G, Cai XP, Deng JW, Zheng L, Zhu HH, Zheng M, Yang B, Chen Z. An overview of COVID-19. *J Zhejiang Univ Sci B* 2020; 21(5):343-360.
8. Mascarenhas ALS, Vidal MR. Estimativa da prevalência de infecção por COVID-19 na Amazônia Legal a partir da teoria corológica e da ciência da informação geográfica. *Rev Ensaios Geografia* 2020; 9(5):16-21.
9. Santos D, Mosaner M, Celentano D, Mouta R, Veríssimo A. *Índice de progresso social na Amazônia brasileira: IPS Amazônia 2018*. Belém: Imazon/Social Progress Imperative; 2018.
10. Orellana JDY, Cunha GMD, Marrero L, Horta BL, Leite IDC. Explosion in mortality in the Amazonian epicenter of the COVID-19 epidemic 19. *Cad Saude Publica* 2020; 36(7):e00120020.
11. Garnelo L, Sousa ABL, Silva COD. Health regionalization in Amazonas: progress and challenges. *Cien Saude Colet* 2017; 22(4):1225-1234.
12. Instituto Brasileiro de Geografia e Estatística (IBGE). IBGE atualiza mapa da Amazônia Legal [Internet]. 2020. [acessado 2021 jun 21]. Disponível em: https://agenciadenoticias.ibge.gov.br/agencia-sala-de-imprensa/2013-agencia-de-noticias/releases/28089-ibge-atualiza-mapa-da-amazonia-legal

Ciência & Saúde Coletiva, 28(1):131-141, 2023

13. Organização Mundial de Saúde (OMS). Painel de emergência de saúde da OMS [Internet]. [acessado 2021 jun 18]. Disponível em: https://covid19.who.int/region/amro/country/br
14. Brasil. Secretarias Estaduais de Saúde. COVID-19. Painel de controle, 2020. [acessado 2021 maio 10]. Disponível em: https://covid.saude.gov.br/
15. Brasil. Ministério da Saúde (MS). Banco de dados do Sistema Único de Saúde-DATASUS. População Residente. *Estudo de Estimativas Populacionais por Município, Idade, Sexo 2000-2020*. [acessado 2021 jun 20]. Disponível em: http://tabnet.datasus.gov.br/cgi/deftohtm.exe?ibge/cnv/popbr.def
16. Becker JN, Nero MA. Avaliação da aplicação dos estimadores bayesianos empíricos na determinação das áreas de risco de transmissão da malária. In: *Simpósio Brasileiro de Ciências Geodésicas e Tecnologias da Geoinformação*. Recife; 2012. p. 1-10.
17. Brasil. Ministério da Saúde (MS). Banco de dados do Sistema Único de Saúde. Recursos físicos-equipamentos-Tocantins. [acessado 2021 jun 10]. Disponível em: http://tabnet.datasus.gov.br/cgi/deftohtm.exe?cnes/cnv/equipobr.def
18. Pileca FB, Coelho CG, Fernandes QHRF, Silveira IH, Pescarini JM, Ortelan N, Gabrielli L, Aquino EML, Barreto ML. O efeito da testagem laboratorial nos indicadores de acompanhamento da COVID-19: uma análise dos 50 países com maior número de casos. *Epidemiol Serv Saude* 2021; 30(2):e2020722.
19. Rafael RMR, Neto M, Depret DG, Gil AC, Fonseca MHS, Souza-Santos R. Efeito da renda sobre a incidência cumulativa do COVID-19: estudo ecológico. *Rev Lat Am Enfermagem* 2020; 26;28:e3344.
20. Raymundo CE, Oliveira MC, Eleuterio TA, André SR, da Silva MG, Queiroz ERDS, Medronho RA. Spatial analysis of COVID-19 incidence and the sociodemographic context in Brazil. *PLoS One* 2021; 16(3):e0247794.
21. Rocha R, Atun R, Massuda A, Rache B, Spinola P, Nunes L, Lago M, Castro MC. Effect of socioeconomic inequalities and vulnerabilities on health-system preparedness and response to COVID-19 in Brazil: a comprehensive analysis. *Lancet Glob Health* 2021; 9(6):e782-e792.
22. Tavares FF, Betti G. The pandemic of poverty, vulnerability, and COVID-19: evidence from a fuzzy multidimensional analysis of deprivations in Brazil. *World Dev* 2021; 139:105307.
23. Nunes MA. O papel das estruturas territoriais na propagação da COVID-19 na fronteira Amazônica. *Nota Técnica* 2021; 25:1-34. [acessado 2021 jul 29]. Disponível em: http://repositorio.ipea.gov.br/bitstream/11058/10597/1/NT_25_Dirur_OPapel.pdf
24. Brasil. Ministério da Saúde (MS). Superintendência de Vigilância em Saúde. Doença pelo novo coronavírus 2019 – COVID-19. *Boletim Epidemiológico, nº 6.* Amapá; 2020.
25. Brasil. Ministério da Saúde (MS). Secretaria de Vigilância em Saúde. Avaliação de risco no cenário da COVID-19 N44 SE 44. 2021. [acessado 2021 ago 1]. Disponível em: https://www.gov.br/saude/pt-br/coronavirus/avaliacao-de-risco-para-covid-19/avaliacao-de-risco-no-cenario-da-covid-19
26. Bezerra ECD, Santos PSD, Lisbinski FC, Dias LC. Spatial analysis of Brazil's COVID-19 response capacity: a proposal for a Healthcare Infrastructure Index. *Cien Saude Colet* 2020; 25(12):4957-4967.
27. Moreira RDS. COVID-19: intensive care units, mechanical ventilators, and latent mortality profiles associated with case-fatality in Brazil. *Cad Saude Publica* 2020; 36(5):e00080020.
28. Gama ASM, Fernandes TG, Parente RCP, Secoli SR. Inquérito de saúde em comunidades ribeirinhas do Amazonas, Brasil. *Cad Saude Publica* 2018; 34(2):e00002817.
29. Organização Pan-Americana da Saúde (OPAS). Países devem se preparar para enfrentar surtos recorrentes de COVID-19 pelos próximos 2 anos. 2020. [acessado 21 dez 11]. Disponível em: https://www.paho.org/pt/noticias/24-6-2020-paises-devem-se-preparar-para-enfrentar-surtos-recorrentes-covid-19-pelos

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