

## Inequalities in COVID-19 Surveillance Performance across Health Mesoregions in Pará, Brazil

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### Abstract

The COVID-19 outbreak has triggered widespread and serious effects on healthcare systems, economic stability, educational processes, and daily living conditions globally. Strong pandemic management efforts are closely linked to the overall effectiveness of the response, which plays a central role in enabling more precise strategies to promote health, provide treatment, and limit the spread of COVID-19. To examine key epidemiological and operational indicators of COVID-19 monitoring among hospitalized patients across the state of Pará in 2021, organized by health mesoregion. This research employed a cross-sectional, analytical, and ecological design in epidemiology. All information came from the national database for Severe Acute Respiratory Syndrome surveillance, accessed through the Influenza Epidemiological Surveillance System (SIVEP-Gripe). In total, 18,007 records of severe acute respiratory syndrome notifications were analyzed. Incidence levels differed significantly in the Lower Amazon, Southwest Pará, and Southeast Pará ( $P < 0.001$ ). The highest lethality figures appeared in the Lower Amazon and the Metropolitan Region of Belém ( $P < 0.001$ ). Mortality rates also showed significant differences in the Lower Amazon, the Metropolitan Region of Belém, and Southwest Pará ( $P < 0.001$ ). Regarding operational performance targets, no mesoregion met the required standards for timely notification (80%), timely sample collection (80%), recording the date of sample collection (100%), documenting the molecular test date (100%), or ICU admission recording (100%). Likewise, the fields for case confirmation, patient outcome, and date of outcome fell short of the 100% target in every mesoregion. In contrast, five mesoregions achieved the desired level for timely case closure (80%): Lower Amazon, Marajó, Metropolitan Region of Belém, Northeast Pará, and Southeast Pará. Clear variations were identified among the health mesoregions in both epidemiological and operational performance indicators. The areas experiencing the greatest burden were the Lower Amazon, Southwest Pará, and Southeast Pará. These territories stand out for their elevated levels of social vulnerability and their considerable distance from the Belém metropolitan zone, which concentrates superior hospital facilities and laboratory resources.

**Keywords:** COVID-19, Healthcare systems, Patients, Health mesoregion

### Introduction

The COVID-19 pandemic has inflicted and continues to inflict extensive damage on health services, economic activity, schooling, and living standards throughout the world. It has brought to light sharp contrasts between wealthier and less developed nations, because successful

containment relies heavily on high-quality epidemiological monitoring, above all, the ready availability of molecular testing. This must be supported by complementary actions including physical distancing, isolation of positive cases, and thorough contact tracing — all of which define active surveillance and remain vital for controlling the outbreak effectively [1–4].

By October 23, 2021, Brazil had accumulated 21,723,559 confirmed infections and 605,457 fatalities, producing a case fatality rate of 2.8% and a mortality rate of 288.1 deaths per 100,000 people. On that same date, the North region reported 1,859,549 cases along with 46,773 deaths. Inside this region, Pará stood out with the largest totals: 596,977 cases and 16,730 deaths [5].

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A breakdown by macroregion inside Pará revealed that macroregion III, covering the Lower Amazon and Tapajós, recorded a lethality rate of 2.2% but posted the state's highest mortality rate at 307.6 per 100,000 inhabitants. Macroregion I, which includes the metropolitan area and Marajó, showed a lethality rate of 2.9%, surpassing the national average of 2.0%. By comparison, macroregion IV (Araguaia, Lago de Tucuruí, and Carajás) had the lowest lethality at 1.4%. Across the entire state, incidence exceeded 7,000 cases per 100,000 inhabitants, though it remained below Brazil's national incidence of 16,535 per 100,000 [6].

Earlier work by Sardinha *et al.* [7], focusing on the initial months of the pandemic in Pará, demonstrated clear differences in incidence rates among health mesoregions, with the southern parts registering the highest values. At the same time, morbidity reached its peak in the Amazon and Tapajós areas, directly contributing to the highest lethality observed. Even with shortcomings in regional surveillance systems and challenges posed by vast distances, these locations also faced higher comorbidity burdens, resulting in greater overall mortality.

Consequently, the health emergency revealed serious shortcomings in the Unified Health System (SUS) and its surveillance framework, including unequal staffing, weak infrastructure, limited geographic reach, and insufficient testing capacity. Once the first signs of the new disease emerged, the Ministry of Health (MS) rolled out multiple initiatives and plans to tackle COVID-19, while accounting for the wide variations and challenges across Brazilian territory. Among these steps were the creation of contingency plans, transparent communication with citizens and media to curb false information, and the regular issuance of official epidemiological reports on cases and deaths [8].

All of these aspects, combined with the distinct traits of each mesoregion, make it essential to study and evaluate mesoregion-specific data to properly assess health service delivery. While past research has already mapped social inequalities in the Amazon, there remains a lack of studies that compare epidemiological and operational indicators side by side across mesoregions.

The present work intends to close this gap through an ecological analysis that describes and contrasts COVID-19 surveillance indicators across the different health mesoregions of Pará. It includes sensitivity testing, evaluation of data completeness, and age-adjusted rates — features that are frequently overlooked in similar investigations. This research holds particular value

because it emphasizes the importance of reliable data collection, which helps health authorities and frontline teams better understand local challenges and develop targeted actions to improve health, patient care, and disease control. The main question it addresses is: How do the epidemiological and operational indicators of COVID-19 vary across the state of Pará's health mesoregions?

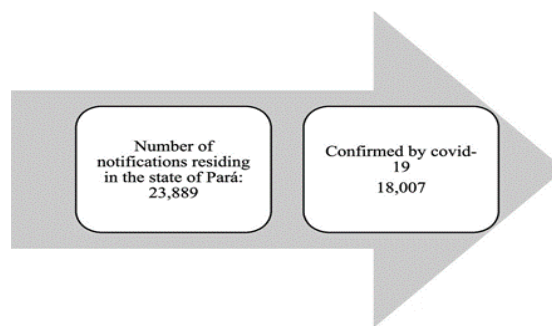
## Materials and Methods

### *Design of the study*

This investigation employed a cross-sectional, analytical, and ecological epidemiological design that relied on secondary data. All information was retrieved from the national severe acute respiratory syndrome surveillance database through the influenza epidemiological surveillance system (SIVEP-Gripe). The study was conducted in accordance with the recommendations of The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies [9].

### *Study location and population*

The research focused on the state of Pará, situated in Brazil's northern region. Ranking as the second-largest state in the country by territory, Pará covers an area of 1,245,870.798 km<sup>2</sup>. It is organized into six mesoregions, which together include 22 microregions and 144 municipalities, with Belém as the capital (**Figure 1**). Much of the state lies within the Amazon Forest, recognized as the largest tropical rainforest on Earth. The landscape is mainly low and flat, with 58% of the land at elevations below 200 m. Higher elevations above 500 m are found only in the Serra dos Carajás, Serra do Cachimbo, and Serra do Acari regions. In 2020, the population was estimated at 8,690,745 inhabitants, and the human development index (HDI) stood at 0.646 [10].



**Figure 1.** Hospitalized cases reported in the SIVEP-Gripe system in the state of Pará during the second year of the COVID-19 pandemic (2021) (Source: SIVEP-GRIPPE, Ministry of Health, 2023).

The study population consisted of all hospitalized cases of severe acute respiratory infection (SARI) associated with COVID-19 among residents of Pará, whose investigations were finalized between January 1, 2021, and December 31, 2021. Any duplicate entries were removed, and only the first notification was kept.

For comparisons of epidemiological and operational indicators, as well as for analyses of death, Intensive Care Unit (ICU) admission, and risk factors, only cases involving Pará residents who met the diagnostic criteria and had a complete final classification with a recorded disease outcome were retained. These represented fully investigated and closed cases. Cases were excluded if they were duplicates, with the earliest notification given preference.

All investigated and closed COVID-19 cases were included, as detailed in the flowchart describing participant selection.

#### *Data collection and analysis*

The variables collected for this study encompassed: mesoregion of residence, risk factors, ICU admission, date of notification, date of sample collection, date of result, case closure criterion, patient evolution (recovery or death), date of evolution, date of hospitalization, date of investigation, and date of closure, following the fields defined in the SIVEP-Gripe investigation form [11].

$$\frac{\text{Number of new cases of COVID – 19 cases in the mesoregion}}{\text{Population of the mesoregion}} \times 100.000 \quad (1)$$

Divided into the following quartile classes: quartile 1 (72.0–143.7), quartile 2 (143.7–225.2), quartile 3 (225.2–304.4), and quartile 4 (304.4–342.1). The mesoregions corresponding to the four quartiles were labeled on the map.

$$\frac{\text{Number of COVID – 19 deaths in the mesoregion}}{\text{Number of COVID – 19 patients in the mesoregion}} \times 100 \quad (2)$$

Divided into the following quartile classes: quartile 1 (23.8–28.2), quartile 2 (28.2–31.1), quartile 3 (31.1–33.4), and quartile 4 (33.4–45.7). The mesoregions

The dataset was provided by the State Secretariat for Public Health (SESPA) in August 2023. This timing was considered suitable to allow sufficient opportunity for the completion of investigations from earlier years. Data were supplied in Excel format.

The information was organized in a Microsoft Excel spreadsheet, and all statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS version 20; <https://www.ibm.com/analytics/spss-statistics-software>). Epidemiological indicators, specifically incidence, lethality, and mortality, were computed. Adherence tests were applied to examine variations in the expected proportions of these indicators across the different health mesoregions. Thematic maps were created to illustrate the distribution of the indicators by mesoregion. To allow fairer comparisons across mesoregions with different age profiles, direct age standardization was performed using the IBGE standard population.

Cartographic data layers were acquired from the Brazilian Institute of Geography and Statistics.<sup>1</sup> The geographic area and the spatial pattern of cases by mesoregion in Pará were processed and mapped using QGIS software. The results were grouped into quartiles based on three core indicators: incidence, lethality, and mortality.

Incidence is a measure of how frequently a disease appears in a population and indicates the rate of newly diagnosed cases over a defined time frame. It is determined by dividing the number of new cases by the population at risk and then multiplying by 100,000 [12].

Lethality is the proportion of deaths among individuals diagnosed with a disease within a specific period. It is obtained by dividing the number of deaths from the disease by the total number of diagnosed cases in the same period and multiplying by 100 [12].

corresponding to the four quartiles were labeled on the map.

Mortality reflects the overall impact of death on a population and is often regarded as the crude death rate. It is computed by dividing the total number of deaths

$$\frac{\text{Number of COVID – 19 deaths in the mesoregion}}{\text{Population of the mesoregion}} \times 1.000 \quad (3)$$

Divided into the following quartile classes: quartile 1 (22.7–46.1), quartile 2 (46.1–73.5), quartile 3 (73.5–91.1), and quartile 4 (91.1–107.8). The mesoregions corresponding to the four quartiles were labeled on the map.

To assess the operational performance of COVID-19 surveillance across health mesoregions, the following indicators were examined: timely notification, defined as reporting a confirmed case within 24 hours (target: 80%); sample collection (target: 100%); completion of the sample collection date (target: 100%); completion of the real-time polymerase chain reaction (RT-PCR) result date (target: 100%); completion of the PCR test date (target: 100%); completion of ICU admission (target: 100%); completion of confirmation criteria (target: 100%); completion of case evolution (target: 100%); completion of the date of evolution (target: 100%); and timely case closure, defined as closure within 60 days from the date of notification (target: 80%) [13, 14].

#### *Statistical analysis*

Epidemiological indicators were evaluated after age-standardizing incidence and mortality rates using the 2020 IBGE population as the reference. The case fatality rate was computed as the percentage of deaths among all confirmed cases.

Factors related to the main outcomes (death, ICU admission, and presence of risk factors) were examined using multilevel logistic regression models with mixed effects. This method properly handled the hierarchical data structure, with individuals grouped within their respective mesoregions. Variables were selected based on their conceptual importance and their presence in the SIVEP-Gripe records.

When analyzing operational indicators, any incomplete fields were recorded as “not filled in.” A sensitivity analysis was conducted after removing cases with more than 50% missing values in the key operational fields, and the outcomes remained unchanged. Multiple imputation was not applied because the missing data followed a non-random pattern; this limitation is noted elsewhere in the study.

occurring in a given period by the total population size [12].

Three different multivariate binary logistic regression models were constructed: one with death serving as the outcome, another with ICU admission as the outcome, and the third with the presence of risk factors as the outcome. In every model, the health mesoregion served as the central independent variable to examine how outcomes related to mesoregional patterns. Statistical significance was determined using an alpha threshold of  $< 0.05$  across all tests. The purpose was not to establish cause-and-effect at the individual level, but to identify associations at the mesoregional scale, given that the mesoregion was the main unit of analysis.

#### *Ethical aspects*

This research was carried out in full accordance with Resolution No. 466, dated December 12, 2012, which defines core bioethical principles. These include respect for human dignity, individual freedom and autonomy, as well as the duties of non-maleficence, beneficence, justice, and equity. The goal was to protect the rights and obligations of all people connected to the research. Approval was granted on November 16, 2020, by the Research Ethics Committee of the Marco School Health Center, State University of Pará (UEPA), under protocol number 4.399.970. The present work constitutes one component of a larger umbrella project named “Socio-epidemiological and spatial analysis of COVID-19 in the state of Pará during the pandemic.” It was developed jointly with the graduate program in Parasite Biology in the Amazon at the State University of Pará and the Evandro Chagas Institute (UEPA-IEC), the bodies responsible for the overarching project.

#### **Results and Discussion**

The investigation concentrated on hospitalized patients with reported and laboratory-confirmed COVID-19. In total, 18,007 notifications from the SARS surveillance system were incorporated into the analysis. Comparison of epidemiological indicators using the adherence test revealed clear differences from the expected proportions among the health mesoregions. Incidence displayed

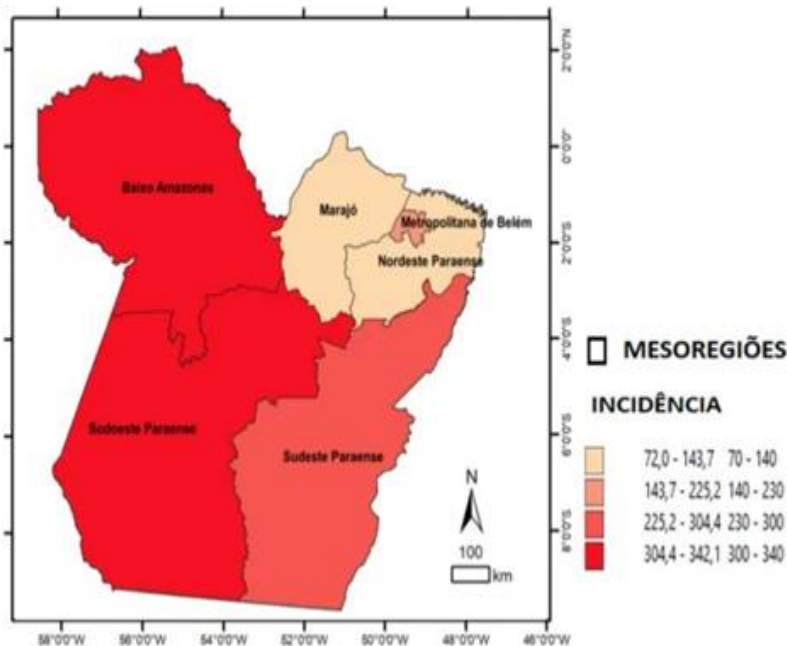
statistically significant variation, specifically in the Lower Amazon, Southwest Pará, and Southeast Pará ( $P < 0.001$ ). Lethality attained its highest values in the Lower Amazon and the Metropolitan Region of Belém ( $P < 0.001$ ). Mortality showed significant differences in the Lower Amazon, the Metropolitan Region of Belém, and Southwest Pará ( $P < 0.001$ ). Maps showing the

geographic distribution of these indicators by mesoregion effectively highlight areas with meaningful statistical differences. Taken together, the mesoregions that experienced the heaviest burden from COVID-19, measured by new cases and deaths per 100,000 inhabitants, were Baixo Amazonas, Metropolitana de Belém, and Southwest do Pará (**Table 1; Figures 2–4**).

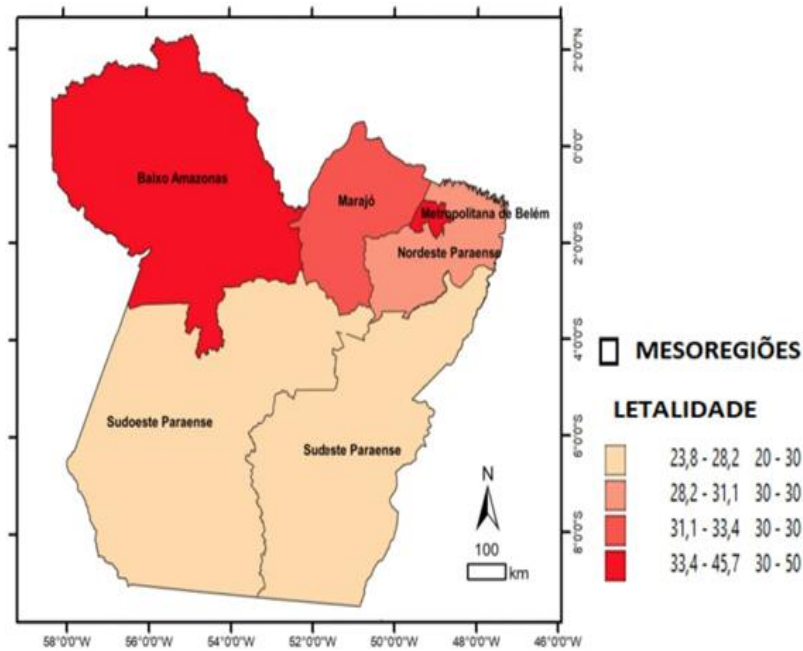
**Table 1.** Epidemiological indicators of COVID-19 among hospitalized patients by health mesoregion in the state of Pará, 2021.

Mesoregion	Mortality	P-value	Lethality (%)	P-value	Incidence	P-value
Lower Amazon	107.8		34.0		316.5	
Marajó	22.7		31.5		72.0	
Metropolitan Region of Belém	83.1	< 0.001*	45.7	< 0.001*	182.0	< 0.001*
Northeast Pará	40.2		30.7		130.9	
Southwest Pará	93.8		27.4		342.1	
Southeast Pará	63.9		23.8		268.3	

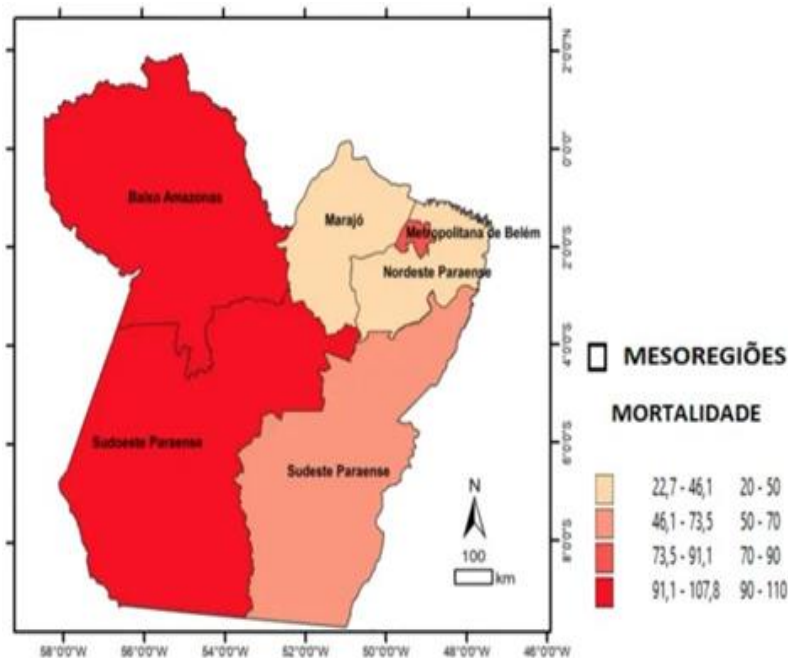
Source: SIVEP-Gripe, SESPA, 2021. \*Adhesion test.



**Figure 2.** Spatial distribution of COVID-19 incidence among hospitalized patients by health mesoregion in the state of Pará, 2021. Source: IBGE, 2021. Software: QGIS. ([www.qgis.org](http://www.qgis.org)), OpenDataSUS, Ministry of Health.



**Figure 3.** Spatial distribution of COVID-19 lethality among hospitalized patients by health mesoregion in the state of Pará, 2021. Source: IBGE, 2021. Software: QGIS. ([www.qgis.org](http://www.qgis.org)), OpenDataSUS, Ministry of Health.



**Figure 4.** Spatial distribution of COVID-19 mortality among hospitalized patients by health mesoregion in the state of Pará, 2021. Source: IBGE, 2021. Software: QGIS. ([www.qgis.org](http://www.qgis.org)), OpenDataSUS, Ministry of Health.

Operational indicators serve as a gauge for the effectiveness of epidemiological surveillance activities. When it came to timely notification (target: 80%), every single mesoregion missed the mark: Lower Amazon registered 69.9%, Marajó 43.8%, Metropolitan Region of

Belém 50.7%, Northeast Pará 60.9%, Southeast Pará 67.9%, Southwest Pará 71.6%, and the statewide total stood at 62.2%. In the case of sample collection (target: 100%), no mesoregion met the full standard. Southeast Pará led with 92.4%, followed by the Metropolitan

Region of Belém at 80.1%, Southwest Pará at 77.3%, Lower Amazon at 74.5%, Northeast Pará at 73.7%, Marajó at 68.5%, and the overall state figure at 81.5%. Looking at the recording of the sample collection date (target: 100%), results stayed below the required level in all areas: Lower Amazon 74.5%, Marajó 68.5%, Metropolitan Region of Belém 80.1%, Northeast Pará

73.7%, Southeast Pará 92.4%, Southwest Pará 77.3%, and the state average 81.5%. For entering the PCR result date (target: 100%), compliance remained low throughout: Lower Amazon 35.1%, Marajó 24.0%, Metropolitan Region of Belém 54.5%, Northeast Pará 21.6%, Southeast Pará 30.4%, Southwest Pará 14.3%, and the state total 34.7% (**Table 2**).

**Table 2.** Operational indicators for epidemiological surveillance of patients hospitalized with COVID-19 in the state of Pará, by health mesoregion, in 2021, the second year of the pandemic.

Indicator	Category	Southwest Pará	Southeast Pará	Northeast Pará	Metropolitan Region of Belém	Marajó	Lower Amazon	P-value	Total
Timely notification	No	439 (23.9%)	1,631 (30.0%)	940 (34.9%)	2,146 (42.9%)	180 (43.3%)	661 (25.3%)	< 0.001	5,997 (33.3%)
	Missing	83 (4.5%)	115 (2.1%)	114 (4.2%)	324 (6.5%)	54 (13.0%)	125 (4.8%)		815 (4.5%)
	Yes	1,317 (71.6%)	3,693 (67.9%)	1,641 (60.9%)	2,537 (50.7%)	182 (43.8%)	1,825 (69.9%)		11,195 (62.2%)
Sample collection performed	No	211 (11.5%)	205 (3.8%)	427 (15.8%)	672 (13.4%)	50 (12.0%)	427 (16.4%)	< 0.001	1,992 (11.1%)
	Missing	207 (11.3%)	210 (3.9%)	281 (10.4%)	324 (6.5%)	81 (19.5%)	239 (9.2%)		1,342 (7.5%)
	Yes	1,421 (77.3%)	5,024 (92.4%)	1,987 (73.7%)	4,011 (80.1%)	285 (68.5%)	1,945 (74.5%)		14,673 (81.5%)
Collection date recorded	Missing	418 (22.7%)	415 (7.6%)	708 (26.3%)	996 (19.9%)	131 (31.5%)	666 (25.5%)	< 0.001	3,334 (18.5%)
	Yes	1,421 (77.3%)	5,024 (92.4%)	1,987 (73.7%)	4,011 (80.1%)	285 (68.5%)	1,945 (74.5%)		14,673 (81.5%)
	Missing	540 (29.4%)	1,462 (26.9%)	764 (28.3%)	1,045 (20.9%)	143 (34.4%)	963 (36.9%)	< 0.001	4,917 (27.3%)
PCR result recorded	Yes	1,299 (70.6%)	3,977 (73.1%)	1,931 (71.7%)	3,962 (79.1%)	273 (65.6%)	1,648 (63.1%)		13,090 (72.7%)
	Missing	1,576 (85.7%)	3,787 (69.6%)	2,113 (78.4%)	2,280 (45.5%)	316 (76.0%)	1,694 (64.9%)	< 0.001	11,766 (65.3%)
	Yes	263 (14.3%)	1,652 (30.4%)	582 (21.6%)	2,727 (54.5%)	100 (24.0%)	917 (35.1%)		6,241 (34.7%)
ICU admission recorded	Missing	258 (14.0%)	304 (5.6%)	282 (10.5%)	446 (8.9%)	82 (19.7%)	634 (24.3%)	< 0.001	2,006 (11.1%)
	Yes	1,581 (86.0%)	5,135 (94.4%)	2,413 (89.5%)	4,561 (91.1%)	334 (80.3%)	1,977 (75.7%)		16,001 (88.9%)
Confirmation criteria completed	No	84 (4.6%)	133 (2.4%)	88 (3.3%)	81 (1.6%)	24 (5.8%)	242 (9.3%)	< 0.001	652 (3.6%)
	Yes	1,755 (95.4%)	5,306 (97.6%)	2,607 (96.7%)	4,926 (98.4%)	392 (94.2%)	2,369 (90.7%)		17,355 (96.4%)
Outcome (evolution) completed	No	151 (8.2%)	461 (8.5%)	118 (4.4%)	142 (2.8%)	39 (9.4%)	136 (5.2%)	< 0.001	1,047 (5.8%)
	Yes	1,688 (91.8%)	4,978 (91.5%)	2,577 (95.6%)	4,865 (97.2%)	377 (90.6%)	2,475 (94.8%)		16,960 (94.2%)
	No	263 (14.3%)	882 (16.2%)	373 (13.8%)	551 (11.0%)	68 (16.3%)	514 (19.7%)	< 0.001	2,651 (14.7%)

<b>Outcome date recorded</b>	Yes	1,576 (85.7%)	4,557 (83.8%)	2,322 (86.2%)	4,456 (89.0%)	348 (83.7%)	2,097 (80.3%)	15,356 (85.3%)
<b>Timely case closure (<math>\leq</math> 60 days)</b>	No	372 (20.2%)	1,060 (19.5%)	298 (11.1%)	993 (19.8%)	76 (18.3%)	308 (11.8%)	< 3,107 (17.3%)
	Yes	1,467 (79.8%)	4,379 (80.5%)	2,397 (88.9%)	4,014 (80.2%)	340 (81.7%)	2,303 (88.2%)	14,900 (82.7%)

Source: OpenDataSUS, Ministry of Health.

The level of variable completeness is a crucial indicator of how reliably surveillance systems perform. Rates for documenting ICU admission fluctuated between 75.7% in the Lower Amazon and 94.4% in Southeast Pará. The breakdown for the rest included: Marajó at 80.3%; Metropolitan Region of Belém at 91.1%; Northeast Pará at 89.5%; Southeast Pará at 94.4%; Southwest Pará at 86.0%; and the statewide rate at 88.9%. Confirmation criteria achieved notably high completion levels in every mesoregion: Lower Amazon (90.7%), Marajó (94.2%), Metropolitan Region of Belém (98.4%), Northeast Pará (96.7%), Southeast Pará (97.6%), Southwest Pará (95.4%), and the state overall (96.4%). Documentation of case evolution surpassed 90% across all mesoregions: Lower Amazon 94.8%, Marajó 90.6%, Metropolitan Region of Belém 97.2%, Northeast Pará 95.6%, Southeast Pará 91.5%, Southwest Pará 91.8%, and the state total 94.2%. Recording the exact date of evolution ranged from 80.3% in the Lower Amazon to 89.0% in the Metropolitan Region of Belém, with the state figure at 85.3% (**Table 2**).

Achieving timely case closure (within 60 days of notification; target: 80%) was successful in five mesoregions: Lower Amazon reached 88.2%, Marajó 81.7%, Metropolitan Region of Belém 80.2%, Northeast Pará 88.9%, and Southeast Pará 80.5%. Southwest Pará came close but did not quite reach the goal at 79.8%, while the state as a whole managed 82.7% (**Table 2**).

When odds ratios were calculated by health mesoregion with death as the main outcome, the Metropolitan Region of Belém stood out with the strongest association ( $P < 0.000$ ; OR = 1.896; 95% CI: 1.717–2.093), ahead of the Lower Amazon ( $p < 0.010$ ; OR 1.164; 95% CI: 1.038–1.306). On the other hand, Southeast Pará ( $P < 0.000$ ; OR = 0.705; 95% CI: 0.636–0.782) and Southwest Pará ( $P < 0.016$ ; OR = 0.851; 95% CI: 0.747–0.971) showed associations with improved survival. Results for Marajó did not attain statistical significance ( $P < 0.753$ ) (**Table 3**). For the likelihood of ICU admission, the Metropolitan Region of Belém was the only area associated with elevated risk ( $P < 0.000$ ; OR = 1.990; 95% CI: 1.795–2.207). All remaining mesoregions correlated with lower chances of ICU admission: Southeast Pará ( $P < 0.000$ ; OR = 0.682; 95% CI: 0.611–0.761), Southwest Pará ( $P < 0.000$ ; OR = 0.424; 95% CI: 0.361–0.499), and Baixo Amazonas ( $P < 0.000$ ; OR = 0.702; 95% CI: 0.616–0.799). Once again, Marajó showed no statistical significance ( $P < 0.160$ ) (**Table 3**). As for the occurrence of risk factors (encompassing comorbidities, puerperal condition, immunodeficiency, or immunosuppression), the Metropolitan Region of Belém exhibited higher odds ( $P < 0.000$ ; OR = 1.489; 95% CI: 1.355–1.636), with Southwest Pará next ( $P < 0.030$ ; OR = 1.141; 95% CI: 1.013–1.286). The other mesoregions produced no meaningful statistical links: Southeast Pará ( $P < 0.725$ ), Marajó ( $P < 0.899$ ), and Lower Amazon ( $P < 0.707$ ) (**Table 3**).

**Table 3.** Binary logistic regression for risk of death, ICU admission, and presence of risk factors by health mesoregion among patients hospitalized with COVID-19 in Pará, 2021.

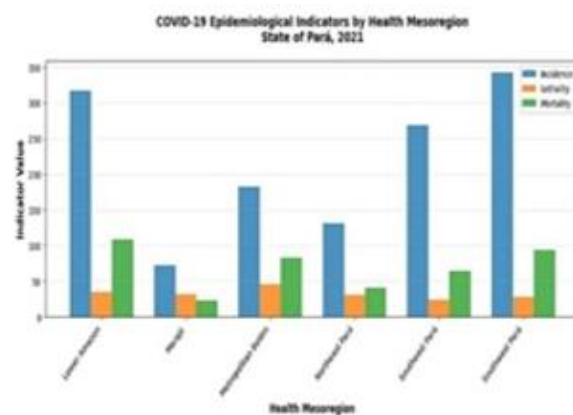
Outcome	Health mesoregion	95% CI (Upper)	95% CI (Lower)	OR	P-value
Risk of death	Southeast Pará	0.782	0.636	0.705	< 0.001
	Southwest Pará	0.971	0.747	0.851	0.016
	Lower Amazon	1.306	1.038	1.164	0.010
	Metropolitan Region of Belém	2.093	1.717	1.896	< 0.001
	Marajó	1.295	0.830	1.036	0.753
	Constant	—	—	0.443	< 0.001
	Southeast Pará	0.761	0.611	0.682	< 0.001

<b>Risk of ICU admission</b>	Southwest Pará	0.499	0.361	0.424	< 0.001
	Lower Amazon	0.799	0.616	0.702	< 0.001
	Metropolitan Region of Belém	2.207	1.795	1.990	< 0.001
	Marajó	1.072	0.655	0.838	0.160
	Constant	—	—	0.343	< 0.001
<b>Risk associated with the presence of risk factors</b>	Southeast Pará	1.079	0.896	0.983	0.725
	Southwest Pará	1.286	1.013	1.141	0.030
	Lower Amazon	1.092	0.879	0.979	0.707
	Metropolitan Region of Belém	1.636	1.355	1.489	< 0.001
	Marajó	1.215	0.801	0.987	0.899
Constant	—	—	0.773	< 0.001	

Source: OpenDataSUS, Ministry of Health.

The visual displays of the findings appear in **Figure 5**. Marked geographic variation stands out, with the Lower Amazon and Southeast Pará recording the highest incidence levels, whereas death rates and lethality showed irregular patterns across the mesoregions. The heatmap depicts the degree of adherence to operational targets for COVID-19 monitoring, covering timely notification, sample collection, entry of PCR results, recording of ICU admissions, and prompt case closure. Areas shaded in deeper green represent stronger achievement. Clear contrasts emerge: the Metropolitan Region of Belém and Lower Amazon demonstrated relatively better adherence, whereas Marajó and portions of Northeast Pará performed more poorly, especially in the entry of PCR data. The Metropolitan Region of Belém had the highest likelihood of fatal outcomes (OR = 1.866;  $P < 0.001$ ), followed by the Lower Amazon (OR = 1.164;  $P = 0.010$ ).

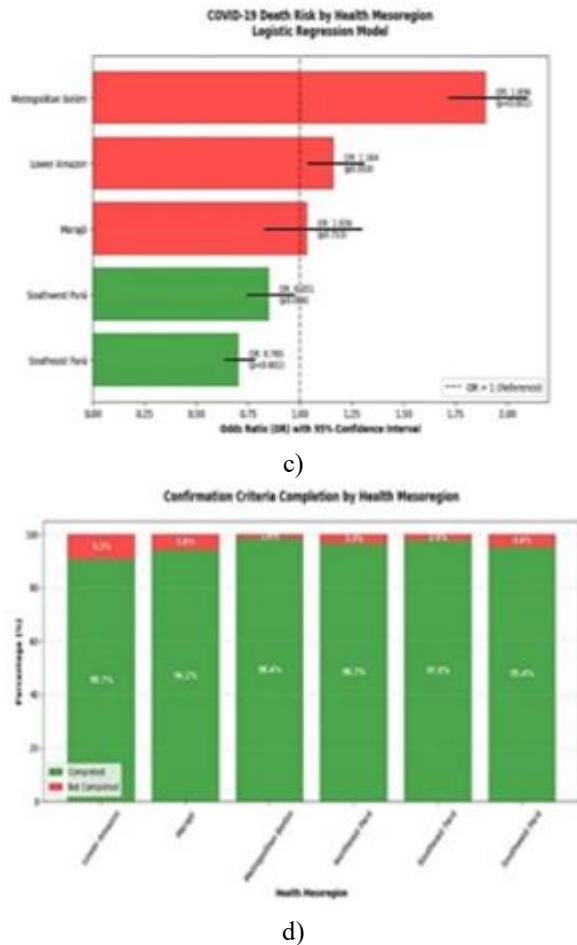
Meanwhile, Southeast Pará and Southwest Pará exhibited notably reduced risk (OR < 1). Taken as a whole, the analysis underscores significant geographic disparities in COVID-19 severity. Every mesoregion displayed strong completion rates for disease confirmation standards (exceeding 90%), though modest differences existed, with the Metropolitan Region of Belém and Southeast Pará achieving the strongest mandatory recording levels.



a)



b)



**Figure 5.** Epidemiological and operational performance of COVID-19 by health mesoregion of the state of Pará, 2021: (a) epidemiological indicators of COVID-19 by health mesoregion (bar graph comparing incidence, lethality, and mortality across the seven mesoregions of Pará), (b) heatmap of the performance of operational indicators by mesoregion (percentage of goal achievement), (c) risk of death from COVID-19 by mesoregion—logistic regression model, and (d) proportion of completion of COVID-19 confirmation criteria by mesoregion.

This research is the first to examine both epidemiological and operational indicators of COVID-19 across the state of Pará throughout the pandemic. The enormous size of the state's territory, combined with varying social determinants between health mesoregions, emerged as the key drivers of poorer COVID-19 outcomes. Effective surveillance depends on rapid case investigation and early diagnosis, which, in turn, enable timely interventions to limit viral spread and improve patient recovery.

Mesoregions farther from the state capital experienced the worst results. These areas lacked adequate healthcare infrastructure to support every stage of clinical care and high-quality surveillance for COVID-19 patients. As a result, mortality rose, and clear gaps appeared in both the quality of medical attention and diagnostic testing. The underlying cause is the high concentration of advanced hospital services and surveillance capabilities — including access to gold-standard COVID-19 tests — within the metropolitan region.

An earlier investigation in Pará during 2020 reviewed 100,819 confirmed cases. The municipalities with the highest incidence were Parauapebas, Canaã dos Carajás, and Jacareacanga. Elevated morbidity levels were similarly observed in the Lower Amazon, Marajó, and Southwest Pará mesoregions. The majority of cases involved young adult women who presented with typical influenza-like symptoms and underlying chronic illnesses. Importantly, the highest incidence rates had shifted away from the metropolitan area. Lethality in the state exceeded national figures for Brazil, potentially reflecting either a greater disease burden on the local Amazonian population or shortcomings in epidemiological surveillance, particularly under-reporting of recovered cases [7].

A separate study examined how COVID-19 incidence was associated with social inequalities in the cities of Ananindeua and Marituba in Pará. Using maps of income, race, and sex indicators, the researchers assessed the spatial alignment between health monitoring and hospitalization facilities and areas with subnormal clusters. The findings revealed persistent spatial patterns in which the most disadvantaged zones overlapped with poor indicator values, while better conditions were found in neighboring sectors. This exposed pronounced socio-spatial inequalities within the urban conurbation, inequalities that public policies supporting social distancing have largely failed to address. The authors also observed that the public healthcare network — including basic health units (UBS) and SUS hospitals designated for COVID-19 treatment — did not align with the locations of the poorest communities, which are characterized by overcrowded households, low income, and a high share of female-headed families [15].

In the current analysis, incidence rates were particularly high in the Lower Amazon and Southwest Pará mesoregions. These territories lie even farther from the metropolitan center and face more severe social vulnerabilities. Consistent with this, research conducted

in Belém, PA, found that COVID-19 spread more rapidly in economically disadvantaged neighborhoods. Social determinants were important risk factors for adverse outcomes, yet control measures rarely accounted for local realities. When such determinants are ignored, efforts to manage the disease become significantly more challenging [16]. The same underlying pattern extends to the remaining mesoregions of Pará, which are even more vulnerable than the metropolitan area.

One additional survey on COVID-19 in the state of Pará highlighted how the pandemic worsened existing social problems and unequal access to healthcare services. It emphasized the importance of evaluating both official government responses and community-level actions to design and implement more effective public policies to bring the pandemic under control [17].

The territory encompasses a rich array of indigenous and traditional communities spread across a vast landmass, making it difficult for many residents to access medical services or stay informed. To address this challenge, an initiative in the Xingu area focused on supporting the local population, particularly indigenous groups and rural residents. The effort included spreading messages via social media and sharing practical advice on protective measures, vulnerable populations, and the benefits of staying apart from others. In areas without internet connectivity, a nearby radio station delivered essential updates to remote rural and indigenous settlements. The project further developed a bilingual guide written in Portuguese and the Kayapó language, providing clear instructions on how to avoid COVID-19 infection for indigenous residents living in the Middle Xingu [18]. Efforts of this nature are crucial for raising health awareness and encouraging protective behaviors in places where social disadvantages heighten the risk of disease spread.

Matos *et al.* [19] examined the trajectory and impacts of COVID-19 in Pará after a full year of the pandemic. Their review identified 420,372 confirmed infections, the majority affecting women (53.4%), while men represented the largest share of fatalities (60.1%). A substantial portion of infections clustered in Belém (20.45%). When broken down by age, young adults formed 23.5% of all cases, but the 70–79 age bracket accounted for the highest death proportion (26.7%). Heart disease stood out as the leading comorbidity (43%), followed by diabetes (33%), especially among those who needed critical care (87.63%).

Geha *et al.* [20] analyzed the epidemiological traits of both influenza A(H1N1) pdm09 and COVID-19 in Pará, highlighting parallels and key distinctions. During the period studied, Pará recorded 124,934 COVID-19 infections, compared with only 783 cases of the pandemic influenza strain. The 30–39 years age range contributed 24.95% of COVID-19 infections, with death rates peaking among elderly individuals (74.00%). By comparison, the H1N1 virus mainly struck children and teenagers between 10 and 19 years old (31.42%), and mortality was greatest in the 20–29 years age group (26.83%). Unlike the more localized pattern seen with influenza, COVID-19 infections spread more widely throughout the state. These contrasts suggest that planners must adapt their approaches to the specific population segments and clinical realities of COVID-19 rather than relying on strategies developed for the earlier influenza outbreak.

One extensive review of 16,000 hospital admissions linked to COVID-19 across California, Colorado, Connecticut, Georgia, Iowa, Maryland, Michigan, Minnesota, New Mexico, New York, Ohio, Oregon, Tennessee, and Utah found that 34.8% involved non-Hispanic white patients, 36.3% involved non-Hispanic black patients, and 18.2% involved Hispanic or Latino patients. After adjusting for age, the hospitalization rate reached 151.6 (95% CI: 147.1–156.1) in neighborhoods where 15.2%–83.2% of residents lived below the poverty threshold, versus 75.5 (95% CI: 72.9–78.1) in areas with just 0–4.9% in poverty. Within high-poverty zones, the adjusted rates were 120.3 (95% CI: 112.3–128.2) for white individuals, 252.2 (95% CI: 241.4–263.0) for black individuals, and 341.1 (95% CI: 317.3–365.0) for Hispanic individuals. In low-poverty zones, those figures were 58.2 (95% CI: 55.4–61.1), 304.0 (95% CI: 282.4–325.6), and 540.3 (95% CI: 477.0–603.6), respectively. Although overall hospitalization rates peaked in poorer neighborhoods, black and Hispanic groups continued to show high rates even in wealthier settings. Health officials, therefore, need to tailor prevention programs and immunization drives to serve better ethnic minorities and residents of economically disadvantaged districts [21].

These patterns align closely with our own observations, where the Lower Amazon and Southwest Pará mesoregions — known for their elevated social disadvantages relative to the rest of the state — experienced notably higher infection and death rates, according to the yearly overview issued by the Amazon

Foundation for the Support of Studies and Research (FAPESPA) [22].

Broader social conditions strongly shape the extent to which COVID-19 affects different populations. Lower-income districts frequently encounter obstacles when seeking medical care, and these barriers are associated with worse outcomes from the illness [23]. Past analyses have linked low earnings and racial background to increased overcrowding at work and at home, which raises the chances of the virus passing between people [24].

Researchers who studied social influences on COVID-19 in Brazilian municipalities during 2020 reported that 44.8% of all municipalities had recorded cases and 14.7% had recorded deaths. Of the municipalities reporting cases, 56.2% ranked as having very low human development, with an incidence of 59.00 per 100,000 residents and a mortality rate of 36.75 per 100,000 residents. Meanwhile, 52.8% showed very high social vulnerability, recording an incidence of 41.68 per 100,000 and mortality of 27.46 per 100,000. The data emphasize that control efforts must consider the unique social context of each locality to effectively manage the pandemic [25].

Work conducted in the United States revealed that communities facing higher levels of social disadvantage were more than twice as likely to see their intensive care units reach full capacity as less disadvantaged areas (OR = 2.15, 95% CI: 1.41–3.29). This connection between vulnerability and ICU strain reveals long-standing inequities in healthcare availability. It gives decision-makers a window to act before overloaded critical care services widen existing gaps in COVID-19 outcomes [26]. Supporting this view, our data showed that 94.4% of all ICU admissions originated from the southeastern part of Pará, an area recognized for its substantial social challenges.

A separate examination in Spain reviewed records from 10,110 hospitalized individuals across 18 facilities (average age 68 years, IQR = 54–80; 44.5% women; 14.8% born abroad). Among them, 779 patients (7.7%) entered intensive care, and 1,678 (16.6%) passed away while in hospital. Factors independently linked to ICU admission included advancing age, male gender, immigrant background, and reduced hospital workload. Predictors of death during hospitalization included advancing age, male gender, immigrant background, lower income ranking, and the hospital's level of experience. Living in poorer districts or coming from

Latin American countries raised the odds of both ICU entry and fatal outcomes. Outcomes varied noticeably from one Spanish hospital to another [27].

Karmakar *et al.* [28] observed in the United States that the emergence of SARS-CoV-2 did not generate new health inequalities or uncover hidden social problems. Rather, the pandemic intensified long-standing racial, ethnic, social, political, and economic divides. As a result, the most disadvantaged and poorly supported communities suffered the heaviest burden. Numerous social elements — such as socioeconomic position, belonging to racial or ethnic minorities, family structure, and surrounding environmental conditions — showed strong links to both the spread and the death toll of COVID-19. These elements were major contributors to the racial, ethnic, and social gaps observed throughout the pandemic in the United States.

To successfully narrow these gaps in COVID-19 and in future outbreaks or pandemics, it is essential to address the underlying social risk factors and their deeper origins through targeted government policies and increased social spending [28]. In a similar vein, research conducted in Brazil in 2020 found that territories in the North and Northeast faced a higher risk of COVID-19 surges, exhibited very high social vulnerability, and ultimately endured the most serious consequences as the pandemic unfolded [29].

A 2020 investigation in Minas Gerais (MG) examined the quality, timeliness, and representativeness of COVID-19 monitoring data within the Jequitinhonha health macroregion. The researchers reviewed information in the e-SUS Notifica and SIVEP-Gripe systems. In e-SUS Notifica, 38.38% of the reports contained inconsistencies, and 4.67% were duplicates. Around 40% of entries lacked complete information on case closure, disease progression, and final classification. In SIVEP-Gripe, the quality of notifications regarding inconsistencies and duplicates was rated as excellent, yet 14% of records were finalized after the recommended deadline, and 18% remained incomplete. Timeliness performed well overall, with 82% of cases reported inside seven days and 96% added to the system within 30 days. The authors stressed that surveillance systems need stronger consistency in e-SUS Notifica records and better completion of case-closure fields in both platforms [30]. A hospital-focused analysis in Rio Grande do Sul assessed the reliability of SARS notifications linked to COVID-19 in the SIVEP-Gripe database, aiming to identify strengths and weaknesses in local hospital-based

epidemiological monitoring. Only 21% of notifications were submitted promptly, although overall data completeness reached acceptable levels, except in the education field, which was missing in 58.6% of cases. Consistency across variables was weak due to frequent mismatches. The results underline the importance of strengthening the information system by linking databases, updating notification forms, and providing targeted training for clinical and administrative staff [31]. In Aracaju, Sergipe, researchers reviewed SIVEP-Gripe records of COVID-19 fatalities between March 2020 and June 30, 2021. The evaluation revealed an average completeness rate of 81% for required and essential fields. Timeliness fell short for initial notifications (44.35%) and for collecting nasopharyngeal samples (69.28%), but performed well for closing cases (96.75%). The authors recommended enhancing SIVEP-Gripe by strengthening contributions from sentinel sites through oversight by health department teams, and they identified professional training for healthcare workers and system users as an effective way to raise performance standards [32].

A United States-based investigation into monitoring hospitalized COVID-19 patients found that hospital admission rates, the proportion of positive test results, emergency department visits linked to COVID-19, and COVID-19 deaths all serve as reliable and timely indicators of changes in disease activity and severity [33].

A separate United States study on COVID-19 monitoring described updates made to the national surveillance approach and the COVID Data Tracker platform, which also oversees immunization tracking. These changes built upon notable advances across multiple monitoring systems. The primary markers selected for ongoing surveillance were weekly hospital admission rates and the proportion of all deaths associated with COVID-19. Additional useful signals included visits to emergency departments and the percentage of laboratory tests that returned positive for SARS-CoV-2, both of which help spot emerging trends at an early stage. Genomic monitoring was expected to remain important for detecting and following new variants of SARS-CoV-2 [34].

This research represents the initial effort to assess both epidemiological and operational aspects of COVID-19 surveillance across the various health mesoregions of Pará. The results reveal clear inequalities in both sets of indicators, with the most disadvantaged and isolated

areas — specifically the Lower Amazon, Southwest Pará, and Southeast Pará — recording the poorest performance. These mesoregions are farther from the metropolitan hub of Belém, where healthcare resources are primarily centralized. Nevertheless, we recognize that certain unmeasured variables, such as underlying health conditions and the overall capacity of local services, could partly account for the observed associations. The operational metrics reveal significant shortcomings in the surveillance framework, particularly in prompt reporting and the proper recording of laboratory information. These insights can guide the development of targeted actions to strengthen surveillance in the hardest-hit mesoregions. Studies emphasize that monitoring flu-like syndromes is critical for detecting rising case numbers and localized clusters, thereby supporting forecasts of increased hospital demand and contributing to fewer severe illnesses and fatalities from COVID-19 [35].

The study's constraints and potential sources of bias stem from its reliance on secondary data from routine epidemiological surveillance systems, where the completeness of recorded variables largely depends on healthcare staff. When professionals do not fully appreciate the importance of mandatory reporting, this directly weakens epidemiological understanding and leads to under-notification, since the gathered information guides decisions on social and public health matters. Because the study follows an ecological approach, it cannot support conclusions about direct cause-and-effect relationships. Furthermore, it was not possible to control for all potential confounding factors, including comorbidities, differences in diagnostic testing availability, and variations in healthcare infrastructure.

The dataset is vulnerable to underreporting and incomplete entries, issues that are likely more severe in the most socially fragile mesoregions. Although missing values were addressed through sensitivity testing, the nature of the missing data could still influence the findings. Employing multilevel modeling constitutes a methodological advantage, yet some residual confounding persists. Additionally, weaknesses in local surveillance capacity may conceal a more concerning reality in remote areas, as mesoregions that are more remote and socially disadvantaged often experience higher levels of underreporting due to shortages of personnel, equipment, and technological support.

## Conclusion

In this work, we analyzed variations in epidemiological and operational indicators of COVID-19 across the state of Pará. We draw attention to the marked differences observed across health mesoregions in both indicator categories. The mesoregions that suffered the most were the Lower Amazon, Southwest Pará, and Southeast Pará — precisely those characterized by elevated social vulnerabilities and located farthest from Belém's metropolitan zone, where superior hospital facilities and laboratory services are concentrated.

In this way, social disparities restrict access to medical care and create uneven COVID-19 results, affecting both disease patterns and the effectiveness of monitoring systems. The pandemic did not produce social inequality; instead, it intensified pre-existing vulnerabilities within these mesoregions. Consequently, efforts to manage and contain COVID-19 must take social conditions into account. Municipal, state, and federal authorities need to confront these underlying factors, since interventions that integrate social considerations tend to achieve better results in lowering infection rates, hospital admissions, and mortality, while also enhancing quality of life, advancing health education, and decreasing expenditures within the Unified Health System. Vaccination remains a key priority and is organized by health mesoregion; however, the state's immense geographic size, along with its sizable rural and indigenous populations, creates substantial obstacles to achieving adequate immunization levels. For this reason, the SUS should give special attention and ensure equitable vaccine distribution to all traditional communities and to populations facing socioeconomic hardship.

The COVID-19 pandemic has reinforced systems for tracking respiratory viruses across Brazil. The information gathered here can offer valuable guidance for enhancing SARS surveillance and improving data reliability through staff training and the supply of suitable infrastructure. This applies both to sentinel surveillance of influenza-like illness — which tracks the spread of respiratory pathogens — and to hospital-based monitoring, which relies on indicators such as bed occupancy rates and the use of gold-standard diagnostic tests to determine the cause of illness. Such improvements would support more timely and effective epidemiological responses, particularly in territories marked by high social vulnerability.

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