

# The epidemiology of emergency department crowding and boarding in Brazil: a nationwide multicenter study

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## Research Article

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# Abstract

## Background

Emergency department (ED) crowding is associated with adverse patient outcomes, yet its epidemiology remains poorly characterized in low- and middle-income countries. We aimed to characterize ED crowding and boarding across Brazil, including their geographic distribution, temporal trends, hospital characteristics, and association with municipal socioeconomic indicators.

## Methods

We conducted a multicenter observational study using operational data from 160 Brazilian EDs participating in a national quality improvement program between 2019 and 2025. Two ED strain indicators were evaluated: occupancy ratio (ED census divided by designated ED beds) and boarding proportion (admitted patients remaining in the ED divided by total ED census). Descriptive analyses examined temporal trends and geographic variation. Multivariable linear regression assessed associations between municipal Human Development Index (MHDI) and ED strain, with prespecified sensitivity analyses.

## Results

The final cohort comprised 160 hospitals contributing 351 hospital-years and 2,443 hospital-month observations. Median occupancy ratio was 1.03 (IQR, 0.74–1.39), indicating that EDs routinely operated beyond formal capacity. Median boarding proportion was 0.45 (IQR, 0.29–0.63), meaning that nearly half of ED patients were awaiting inpatient beds. Occupancy declined transiently during the COVID-19 pandemic but subsequently returned to pre-pandemic levels, whereas boarding remained consistently elevated throughout the study period. Regional variation was observed, although high ED strain was widespread nationwide. MHDI was not independently associated with either occupancy or boarding in adjusted analyses.

## Conclusions

ED crowding and boarding are pervasive across Brazilian emergency departments, with occupancy routinely exceeding formal capacity and boarding representing a substantial proportion of ED census. These findings suggest that impaired hospital output is a nationwide structural challenge requiring hospital- and system-level strategies to improve patient flow and inpatient capacity.

## Introduction

The concept of emergency department (ED) crowding refers to situations in which the demand for emergency care exceeds the available capacity to provide timely and appropriate care. Crowding not only

results in prolonged waiting times and a poorer patient experience but also compromises the quality of care delivered, creating an environment that is more susceptible to medical errors and adverse events<sup>1</sup>. ED crowding can be better understood using the input-throughput-output model proposed by Asplin et al. (2003)<sup>2</sup>, in which each component is interdependent and contributes to the development of crowding. Input encompasses all conditions, events, and system characteristics that increase the demand for emergency care. Throughput refers to processes within the ED that influence patient length of stay and may contribute to crowding. Output relates to factors affecting patient disposition from the ED, particularly delays in transferring patients to appropriate inpatient settings. Among the most important factors affecting ED output and therefore ED crowding are access block and ED boarding.

ED boarding refers to the practice of keeping patients in the ED after the decision to admit has been made because they cannot be transferred to an appropriate inpatient bed<sup>3</sup>. Access block (or exit block) is the underlying systems-level condition that causes boarding, occurring when admitted patients experience prolonged delays in leaving the ED due to insufficient inpatient capacity or impaired hospital flow. Although the specific operational definition varies across health systems, the Australasian College for Emergency Medicine (ACEM) defines access block as an ED length of stay exceeding 8 hours for patients requiring hospital admission<sup>4</sup>. Thus, ED boarding is the patient-level manifestation of access block, while access block describes the hospital-wide failure of patient flow that results in boarding. Access block and prolonged ED boarding are associated with ED overcrowding, treatment delays, increased hospital length of stay, adverse events such as delirium, higher rates of medical errors, diagnostic failures, clinical deterioration and higher mortality<sup>5–12</sup>. Beyond its impact on patients, ED crowding has important system-level consequences. From an operational perspective, boarding is considered a clinically less productive period and has been associated with longer hospital stays and increased healthcare costs. In parallel, healthcare professionals working in EDs are exposed to substantial occupational stress, with higher rates of burnout and more frequent episodes of workplace violence and aggression<sup>9,13</sup>.

In Brazil, unlike high-income countries where boarding is typically measured in hours, hospitals report mean boarding times of up to 1.8 days, with durations exceeding 5 days among patients experiencing the longest delays<sup>14</sup>. National evidence from a regional quaternary referral hospital has shown that each additional day of boarding is associated with a 6% increase in the odds of in-hospital mortality, reinforcing that access blockage is the principal determinant of adverse outcomes associated with ED crowding<sup>14</sup>. A large Brazilian multicenter cohort also showed that boarding, and not occupancy, was associated with early mortality, with each 0.1 increase in boarding proportion of total ED census being associated with an IRR of 1.14<sup>15</sup>. Evidence from high-income countries also show that prolonged boarding is associated with adverse outcomes regardless of the healthcare setting and overcrowding. Among patients who deteriorated while still in the ED, the effect was the greatest, with each additional hour of boarding associated with a 2.4% increase in the relative risk of deterioration occurring within the ED<sup>12</sup>.

These findings underscore the need for institutional- and system-level strategies aimed at mitigating ED crowding, optimizing hospital patient flow, and advancing the understanding of this phenomenon.

Although the adverse effects of ED boarding on patient outcomes have been consistently demonstrated, fundamental epidemiological aspects of ED crowding in Brazil remain poorly characterized. In particular, there is limited information regarding the magnitude of crowding and boarding across different regions of the country, hospital characteristics, and local socioeconomic contexts. Healthcare infrastructure, hospital capacity, and access to inpatient care vary substantially across Brazil, and differences in ED crowding may therefore reflect broader contextual characteristics. Emergency care is delivered through geographically organized healthcare networks, making the geographic distribution of ED crowding a useful indicator of structural inequalities in healthcare access, hospital capacity, and patient flow that may not be apparent from hospital-level operational indicators alone. The Municipal Human Development Index (MHDI)<sup>16</sup> and the Social Progress Index (SPI)<sup>17</sup> are composite indicators that summarize important dimensions of social development and could therefore provide useful proxies for contextual factors associated with emergency care performance. Accordingly, the present study aimed to characterize emergency department crowding and boarding across Brazil, including geographic distribution, temporal trends, hospital characteristics, and their association with municipal socioeconomic indicators.

## Methodology

### Study Design and Setting

We conducted a multi-year, multicenter observational study using operational data from EDs participating in a national emergency care quality improvement program (Projeto Lean nas Emergências) between 2019 and 2025.

The Brazilian healthcare system comprises a mixed public-private model anchored by the Unified Health System (Sistema Único de Saúde, SUS), a publicly funded system that ensures universal access to healthcare. The “Lean in Emergency Departments” (Projeto Lean nas Emergências) is a federal initiative designed to improve ED performance by reducing crowding and optimizing patient flow using Lean-based management principles<sup>18</sup>. Hospitals enrolled in the program include both publicly and privately governed institutions; however, all provide care within the SUS and therefore serve a predominantly publicly funded patient population, rather than operating as exclusively private hospitals. Emergency Medicine was formally recognized as a medical specialty in Brazil in 2015, and the emergency care workforce remains heterogeneous, with most physicians working in EDs not formally trained as emergency medicine specialists<sup>19</sup>.

Hospitals were selected through a structured, multi-step process coordinated with regional and local health authorities. Initially, institutions that had formally expressed interest in participating in the program were identified, and additional hospitals could be nominated by state and municipal health managers. Eligible hospitals were then selected based on predefined criteria encompassing structural capacity, governance, and ED organization.

Key eligibility criteria included being a hospital with intensive care capacity, serving as a regional referral center, and integrated within the public emergency care network. Both public and nonprofit (philanthropic) institutions were eligible. Additional requirements included the presence of an operational ED with standardized triage protocols, dedicated medical staffing, and established bed management processes. Institutional commitment was ensured through formal agreements signed by hospital leadership and regional health authorities. Following selection, participating hospitals were enrolled into the program and integrated into a coordinated implementation structure involving local, regional, and national stakeholders.

## Data Sources

This study used routinely collected operational data from hospitals participating in the Lean nas Emergências project. Data was entered locally by trained personnel through a standardized web-based platform, which was actively monitored by project personnel to ensure data completeness.

Participating hospitals collected indicators for the quality improvement program on a monthly basis and twice daily (at 10:00 and 16:00).

Daily variables included ED census, number of designated ED beds, number of boarded patients, and date of observation.

ED census was defined as the total number of patients receiving care in the ED, excluding those in the waiting room. The number of designated ED beds refers to formally assigned care spaces only, excluding temporary overflow areas, as the use of additional chairs or stretchers to accommodate excess patients is common practice.

Institutional characteristics, including governance type (public vs private), academic status (teaching vs non-teaching), and hospital size, were obtained from the Brazilian National Registry of Health Facilities (CNES)<sup>20</sup>.

Municipality-level socioeconomic indicators were included to characterize the social and economic context surrounding participating hospitals. The Municipal Human Development Index (MHDI) is a composite measure of health, education, and income ranging from 0 to 1, adapted from the United Nations Human Development Index for Brazilian municipalities<sup>16</sup>. The Social Progress Index (SPI) is a multidimensional measure of social and environmental performance that assesses the extent to which populations' basic human needs, foundations of well-being, and opportunity are met, independently of economic output<sup>17</sup>. The MHDI primarily reflects long-term human development through income, education, and longevity, whereas the SPI captures broader social and environmental conditions independently of economic indicators. Municipal Human Development Index (MHDI; 2010 Census), gross domestic product per capita (2016), population and population density (2017), and hospital bed indicators

were obtained from the Atlas of Human Development in Brazil<sup>16</sup>. The Social Progress Index (SPI; 2024 edition) was obtained from the IPS Brasil platform<sup>17</sup>.

## Cohort Structure and Units of Analysis

Hospitals entered the dataset in successive implementation cycles, resulting in a dynamic cohort in which institutions contributed data over different calendar periods.

For data quality assurance, hospitals were included in a given year only if at least 180 valid daily observations were available. Monthly observations were then derived from these data and used as the unit of analysis for both descriptive and regression analyses. Bi-daily operational measures were aggregated to match the level of analysis (i.e., monthly for regression analyses and annually for descriptive analyses). Associations should therefore be interpreted at the hospital or system level rather than as individual patient-level effects.

## Data Preprocessing and Completeness

Daily data were reported at standardized time points (10:00 and 16:00), reflecting typical operational conditions across participating EDs. When both measurements were available for a given day, values were averaged to obtain a single daily estimate.

To ensure temporal representativeness, hospitals were included in a given year only if at least 180 valid daily observations were available. The number of hospitals contributing data varied across years due to the progressive inclusion of new institutions into the program, rather than loss to follow-up of a fixed cohort. Applying these criteria, the number of hospitals per year ranged from 28 to 95, with higher numbers in later years.

Within periods of active data availability, missing days accounted for approximately 0.9% of expected observations. Days with missing values in any key variable (ED census, ED bed capacity, or number of boarded patients) were rare (< 0.01%). Data were recorded at two standardized time points (10:00 and 16:00); both were available in ~ 99% of days and averaged, while a single measurement was available in the remaining 0.001%.

Hospitals were categorized according to teaching status, ownership (public vs private), location (capital vs non-capital), and size based on operational bed counts.

## ED Strain Indicators

Two point-prevalence indicators were derived from measurements collected at 10:00 and 16:00:

- ED occupancy ratio: defined as the number of patients physically present in the ED at the time of measurement divided by the number of designated ED beds available at that same time point. This

metric reflects a cross-sectional snapshot of ED load relative to formal treatment capacity. Only formally designated care spaces were included, excluding temporary overflow areas or improvised extra chairs and stretchers. Patients in the waiting room were not captured in the dataset and were therefore not included.

- ED boarding proportion: defined as the number of admitted patients remaining in the ED at the time of measurement divided by the total ED census at that same time point. This metric represents the proportion of ED patients who have already been admitted but remain physically in the ED due to lack of inpatient bed availability. It does not represent total daily admissions or cumulative flow.

## Descriptive Analyses

Descriptive statistics were calculated at the hospital-month level and summarized as medians with interquartile ranges.

To illustrate the distribution and heterogeneity of ED strain across hospitals, hospitals were ordered according to their median occupancy ratio or boarding proportion of ED census during the study period. Caterpillar plots display each hospital's median value with interquartile ranges derived from monthly observations.

Monthly national trends were summarized by calculating the median value across participating hospitals for each month from January 2019 to June 2025. Variability between hospitals was represented by the interquartile range (IQR). Occupancy ratio and boarding proportion were analyzed separately and displayed as monthly time series.

Geographic variation was illustrated using municipality-level choropleth maps. For each municipality, the median ED boarding proportion and the proportion of monthly observations with an occupancy ratio greater than 1.0 were calculated across the study period. Municipalities were categorized into predefined intervals and displayed using sequential color scales.

## Regression analyses

The primary exposure was municipal Human Development Index (MHDI, 2010)<sup>16</sup>, modeled per 0.1-point increase. Two separate multivariable linear regression models were fitted: one for occupancy ratio and one for boarding proportion. Both models were adjusted a priori for geographic region, state capital versus non-capital municipality, log-transformed municipal population in 2022, hospital size, teaching status, legal status, calendar year, and calendar month. Hospital size was classified according to the modal number of operational hospital beds during the study period as small ( $\leq 50$  beds), medium (51–150 beds), or large ( $\geq 151$  beds). Legal status was categorized as public versus philanthropic, with private legal entities classified as philanthropic because all hospitals in the cohort provided care to SUS patients.

Sensitivity analyses were performed by additionally adjusting for municipal SUS beds per 1,000 inhabitants and for the proportion of SUS beds among all municipal hospital beds; replacing MHDI with

municipal gross domestic product per capita; replacing MHDl with the 2024 Social Progress Index<sup>17</sup>; and replacing log-transformed population with log-transformed population density. Standard errors were clustered at the municipality level to account for correlation among hospitals and repeated observations within the same municipality. Results are reported as regression coefficients ( $\beta$ ), 95% confidence intervals (95% CI), and p-values.

After observing that adjustment for the proportion of SUS beds among all hospital beds increased the MHDl coefficient in the occupancy model, we performed a post hoc exploratory assessment of the relationship between MHDl and municipal bed supply composition. Pearson correlations were estimated between MHDl, SUS beds per 1,000 inhabitants, and the proportion of SUS beds among all hospital beds, both in the analytic dataset and after aggregation at the municipality level.

## Software

Data management, visualization, and statistical analyses were performed using Python with the following packages: *pandas* for data manipulation, *numpy* for numerical operations, *statsmodels* for regression modelling and correlation analyses, and *matplotlib* for data visualization. Spatial data validation, regional filtering, and final mapping were executed using QGIS v. 4.0<sup>21</sup>.

## Results

### Hospital selection and characteristics

Figure 1 shows the selection of hospitals included in the study. Among hospitals participating in the *Lean nas Emergências* project with available occupancy monitoring, those that met the predefined eligibility criteria were included. After excluding hospitals and hospital-years that did not satisfy the minimum data completeness requirements, 160 hospitals remained for analysis, contributing 351 hospital-years (Table 1). ED crowding was consistently high throughout the study period. The median occupancy ratio was 1.03 (IQR 0.74–1.39), indicating that EDs were operating above their nominal capacity. The median boarding proportion was 0.45 (IQR 0.29–0.63), meaning that nearly half of ED patients had already been admitted but remained in the ED awaiting inpatient beds (Fig. 2).

Table 1

Hospital characteristics: Annual columns are expressed as hospital-years. The Total column reflects unique hospitals contributing data during the study period. Percentages are calculated within each column. Occupancy rate and boarding proportion are summarized as monthly medians across hospital-months, with interquartile ranges (IQRs).

| Characteristic                    | 2019                | 2020                | 2021                | 2022                | 2023                | 2024                | 2025                | Total               |
|-----------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Unique hospitals                  | 28                  | 38                  | 36                  | 47                  | 95                  | 72                  | 35                  | 160                 |
| Public hospitals                  | 17<br>(60.7%)       | 23<br>(60.5%)       | 23<br>(63.9%)       | 31<br>(66.0%)       | 58<br>(61.1%)       | 45<br>(62.5%)       | 23<br>(65.7%)       | 100<br>(62.5%)      |
| Private hospitals                 | 11<br>(39.3%)       | 15<br>(39.5%)       | 13<br>(36.1%)       | 16<br>(34.0%)       | 37<br>(38.9%)       | 27<br>(37.5%)       | 12<br>(34.3%)       | 60<br>(37.5%)       |
| Teaching hospitals                | 12<br>(42.9%)       | 16<br>(42.1%)       | 15<br>(41.7%)       | 16<br>(34.0%)       | 29<br>(30.5%)       | 18<br>(25.0%)       | 8<br>(22.9%)        | 50<br>(31.3%)       |
| Non-teaching hospitals            | 16<br>(57.1%)       | 22<br>(57.9%)       | 21<br>(58.3%)       | 31<br>(66.0%)       | 66<br>(69.5%)       | 54<br>(75.0%)       | 27<br>(77.1%)       | 110<br>(68.7%)      |
| Hospitals in state capitals       | 19<br>(67.9%)       | 26<br>(68.4%)       | 25<br>(69.4%)       | 32<br>(68.1%)       | 66<br>(69.5%)       | 49<br>(68.1%)       | 25<br>(71.4%)       | 112<br>(70.0%)      |
| Hospitals outside state capitals  | 9<br>(32.1%)        | 12<br>(31.6%)       | 11<br>(30.6%)       | 15<br>(31.9%)       | 29<br>(30.5%)       | 23<br>(31.9%)       | 10<br>(28.6%)       | 48<br>(30.0%)       |
| Small hospitals (5–50 beds)       | 0<br>(0.0%)         | 2<br>(5.3%)         | 2<br>(5.6%)         | 2<br>(4.3%)         | 2<br>(2.1%)         | 3<br>(4.2%)         | 1<br>(2.9%)         | 7<br>(4.4%)         |
| Medium hospitals (51–150 beds)    | 11<br>(39.3%)       | 17<br>(44.7%)       | 18<br>(50.0%)       | 19<br>(40.4%)       | 50<br>(52.6%)       | 47<br>(65.3%)       | 19<br>(54.3%)       | 81<br>(50.6%)       |
| Large hospitals (> 150 beds)      | 17<br>(60.7%)       | 19<br>(50.0%)       | 16<br>(44.4%)       | 26<br>(55.3%)       | 43<br>(45.3%)       | 22<br>(30.6%)       | 15<br>(42.9%)       | 72<br>(45.0%)       |
| Occupancy rate, median (IQR)      | 1.22<br>(0.90–1.63) | 0.94<br>(0.64–1.41) | 1.04<br>(0.72–1.41) | 1.05<br>(0.79–1.61) | 1.06<br>(0.74–1.36) | 0.95<br>(0.76–1.27) | 1.09<br>(0.77–1.63) | 1.03<br>(0.74–1.39) |
| Boarding proportion, median (IQR) | 0.51<br>(0.40–0.69) | 0.53<br>(0.34–0.74) | 0.47<br>(0.30–0.67) | 0.40<br>(0.23–0.60) | 0.43<br>(0.28–0.62) | 0.44<br>(0.31–0.63) | 0.47<br>(0.24–0.65) | 0.45<br>(0.29–0.63) |

## Temporal trends

Figure 3 shows the national monthly evolution of ED occupancy ratio and the boarding proportion of total ED census. Occupancy remained consistently close to or above 1.0 for most of the study period, with a marked but transient decline during the early COVID-19 pandemic in 2020, followed by recovery to pre-pandemic levels. In contrast, the boarding proportion remained relatively stable throughout the study

period, with median values generally ranging between approximately 0.4 and 0.6. Both indicators exhibited substantial between-hospital variability, as reflected by the wide interquartile ranges.

## Geographic distribution of emergency department strain

To facilitate the visualization of geographic heterogeneity in emergency department strain across participating municipalities, hospital-level median occupancy rates and boarding proportions were displayed on choropleth maps (Figs. 4 and 5). Regional variation in ED strain was observed throughout the study period. Median occupancy rates exceeded 100% in most macroregions during most study years, although substantial between-region variability was present (Table 2, Fig. 4). The South and Southeast generally showed persistently elevated occupancy, whereas the Central-West exhibited particularly high values in 2019. Estimates from the North and Central-West should be interpreted cautiously because relatively few hospitals contributed data in several years.

Table 2  
ED occupancy ratios per macroregion and year, summarized as monthly medians across hospital-months, with interquartile ranges (IQRs).

| Year | Central-West     | North            | Northeast        | South            | Southeast        |
|------|------------------|------------------|------------------|------------------|------------------|
| 2019 | 2.29 [1.58–2.83] | 1.75 [1.75–1.75] | 1.09 [0.79–1.24] | 1.13 [1.05–1.27] | 1.44 [1.22–1.78] |
| n    | 3                | 1                | 6                | 10               | 8                |
| 2020 | 0.85 [0.73–0.94] | 1.16 [1.16–1.16] | 0.82 [0.67–0.95] | 0.82 [0.63–1.59] | 0.92 [0.79–1.05] |
| n    | 4                | 1                | 10               | 10               | 13               |
| 2021 | 0.67 [0.60–0.88] | 1.66 [1.61–1.70] | 0.87 [0.72–1.23] | 0.81 [0.67–0.99] | 1.11 [0.74–1.35] |
| n    | 3                | 2                | 9                | 8                | 14               |
| 2022 | 1.41 [1.14–1.64] | 1.38 [1.09–1.81] | 1.28 [0.90–1.73] | 1.01 [0.89–1.38] | 0.93 [0.68–1.43] |
| n    | 4                | 4                | 13               | 11               | 15               |
| 2023 | 1.22 [0.94–1.39] | 1.11 [0.63–1.91] | 1.14 [0.83–1.53] | 1.00 [0.55–1.17] | 0.92 [0.70–1.33] |
| n    | 6                | 11               | 24               | 16               | 38               |
| 2024 | 1.31 [1.11–1.45] | 1.21 [0.68–1.94] | 1.16 [0.82–1.67] | 1.06 [0.66–1.45] | 0.98 [0.83–1.55] |
| n    | 3                | 4                | 16               | 14               | 35               |
| 2025 | 1.42 [1.42–1.42] | 0.89 [0.89–0.89] | 1.43 [1.19–2.12] | 0.86 [0.71–1.22] | 1.17 [0.76–1.50] |
| n    | 1                | 1                | 6                | 6                | 21               |

Boarding proportion also varied across macroregions, although no consistent geographic gradient was evident (Table 3, Fig. 5). Higher median boarding proportions were observed in the South and Southeast during the early study period, whereas the Northeast showed comparatively higher values in 2022 and 2025. Considerable year-to-year fluctuations were observed in macroregions with fewer participating hospitals.

Table 3  
Proportion of boarded patients per macroregion and year, summarized as monthly medians across hospital-months, with interquartile ranges (IQRs).

| Year | Central-West     | North            | Northeast        | South            | Southeast        |
|------|------------------|------------------|------------------|------------------|------------------|
| 2019 | 0.36 [0.33–0.47] | 0.40 [0.40–0.40] | 0.47 [0.45–0.48] | 0.60 [0.46–0.69] | 0.59 [0.49–0.73] |
| n    | 3                | 1                | 6                | 10               | 8                |
| 2020 | 0.63 [0.50–0.71] | 0.30 [0.30–0.30] | 0.51 [0.42–0.69] | 0.45 [0.39–0.70] | 0.62 [0.36–0.74] |
| n    | 4                | 1                | 10               | 10               | 13               |
| 2021 | 0.89 [0.78–0.92] | 0.26 [0.23–0.29] | 0.60 [0.43–0.70] | 0.42 [0.36–0.49] | 0.48 [0.32–0.65] |
| n    | 3                | 2                | 9                | 8                | 14               |
| 2022 | 0.41 [0.34–0.49] | 0.45 [0.37–0.51] | 0.68 [0.57–0.75] | 0.41 [0.20–0.47] | 0.27 [0.17–0.57] |
| n    | 4                | 4                | 13               | 11               | 15               |
| 2023 | 0.37 [0.17–0.56] | 0.47 [0.37–0.71] | 0.49 [0.28–0.69] | 0.41 [0.32–0.48] | 0.50 [0.33–0.64] |
| n    | 6                | 11               | 24               | 16               | 38               |
| 2024 | 0.48 [0.33–0.70] | 0.16 [0.06–0.36] | 0.48 [0.29–0.72] | 0.43 [0.29–0.52] | 0.39 [0.25–0.56] |
| n    | 3                | 4                | 16               | 14               | 35               |
| 2025 | 0.46 [0.46–0.46] | 0.05 [0.05–0.05] | 0.62 [0.53–0.84] | 0.44 [0.29–0.68] | 0.31 [0.24–0.61] |
| n    | 1                | 1                | 6                | 6                | 21               |

Table 4

Summary of primary and sensitivity multivariable regression analyses: The table summarizes adjusted associations of municipal sociodemographic characteristics with emergency department occupancy rate and boarding proportion.  $\beta$  coefficients are reported for the present multivariable linear regression analyses. Analyses were adjusted for geographic region, state capital versus non-capital municipality, hospital size, teaching status, legal status (public versus philanthropic), calendar year, and calendar month. Primary models included log-transformed municipal population; the final sensitivity analysis replaced population with log-transformed population density. Standard errors were clustered at the municipality level.

| Outcome             | Model                                                | $\beta$ (95% CI)          | p value |
|---------------------|------------------------------------------------------|---------------------------|---------|
| ED occupancy rate   | Primary (MHDI)                                       | 0.255 (-0.114 to 0.624)   | 0.176   |
|                     | Adjusted for SUS beds/1,000 inhabitants (MHDI)       | 0.250 (-0.124 to 0.624)   | 0.190   |
|                     | Adjusted for SUS/total hospital beds (MHDI)          | 0.453 (-0.038 to 0.944)   | 0.071   |
|                     | GDP per capita substituted for MHDI                  | 4.798 (-27.999 to 37.594) | 0.774   |
|                     | Social Progress Index substituted for MHDI           | 0.111 (-0.280 to 0.502)   | 0.579   |
|                     | Population density substituted for population (MHDI) | 0.270 (-0.107 to 0.646)   | 0.160   |
| Boarding proportion | Primary (MHDI)                                       | 0.075 (-0.055 to 0.205)   | 0.258   |
|                     | Adjusted for SUS beds/1,000 inhabitants (MHDI)       | 0.069 (-0.052 to 0.191)   | 0.265   |
|                     | Adjusted for SUS/total hospital beds (MHDI)          | 0.090 (-0.044 to 0.223)   | 0.188   |
|                     | GDP per capita substituted for MHDI                  | 0.547 (-11.125 to 12.220) | 0.927   |
|                     | Social Progress Index substituted for MHDI           | 0.096 (-0.023 to 0.214)   | 0.113   |
|                     | Population density substituted for population (MHDI) | 0.081 (-0.064 to 0.225)   | 0.275   |

## Social indicators and ED strain

The hospital-month analytic dataset included 2,443 observations from 160 hospitals located in 112 municipalities. The median number of repeated measurements contributing to each hospital-month estimate was 61 (IQR, 60–62).

In the primary occupancy model, MHDI was not significantly associated with ED occupancy rate ( $\beta = 0.255$ ; 95% CI, -0.114 to 0.624;  $p = 0.175$ ). Exploratory analyses were broadly consistent with the primary

model. Additional adjustment for SUS beds per 1,000 inhabitants yielded a similar estimate for MHDl ( $\beta = 0.250$ ; 95% CI, -0.124 to 0.624;  $p = 0.190$ ). When the proportion of SUS beds among all municipal hospital beds was added to the model, the MHDl coefficient increased to 0.453 (95% CI, -0.038 to 0.944;  $p = 0.071$ ). In this model, the coefficient for the SUS-to-total bed ratio was positive but not statistically significant ( $\beta = 1.668$ ; 95% CI, -0.903 to 4.239;  $p = 0.204$ ). Replacing MHDl with GDP per capita or the SPI did not show significant associations with occupancy. Replacing population with population density produced similar results for MHDl ( $\beta = 0.270$ ; 95% CI, -0.107 to 0.646;  $p = 0.160$ ).

For boarding proportion, MHDl was also not significantly associated with the outcome ( $\beta = 0.075$ ; 95% CI, -0.055 to 0.205;  $p = 0.258$ ). Results were similar across sensitivity analyses. The largest estimated effect among the alternative socioeconomic indicators was observed for the SPI ( $\beta = 0.096$  per 10-point increase; 95% CI, -0.023 to 0.214;  $p = 0.113$ ). In the model additionally adjusted for the proportion of SUS beds among all municipal hospital beds, the MHDl coefficient was 0.090 (95% CI, -0.044 to 0.223;  $p = 0.188$ ), and the coefficient for the SUS-to-total bed ratio was 0.152 (95% CI, -0.188 to 0.491;  $p = 0.381$ ).

In post hoc analyses, MHDl was moderately and inversely correlated with the proportion of SUS beds among all hospital beds at the municipality level ( $r = -0.551$ ), whereas its correlation with SUS beds per 1,000 inhabitants was negligible ( $r = -0.072$ ). The corresponding correlation between SUS beds per 1,000 inhabitants and the SUS-to-total bed ratio was modestly positive ( $r = 0.341$ ). These findings suggest that municipalities with higher MHDl tended to have a lower relative share of SUS beds, and that adjustment for this bed supply composition may have acted as a suppressor in the occupancy model.

## Discussion

In this nationwide multicenter study of emergency departments participating in a large Brazilian quality improvement initiative, we found that ED crowding and boarding were pervasive across hospitals, geographic regions, and hospital characteristics. Median ED occupancy exceeded the number of designated treatment spaces (occupancy ratio, 1.03), indicating that, at any given measurement, Brazilian EDs were typically operating beyond their intended capacity. Even more strikingly, nearly one-half of all patients present in the ED had already been admitted but remained awaiting an inpatient bed (median boarding proportion, 0.45), highlighting that impaired hospital output, rather than excess demand alone, is a defining feature of emergency care delivery in Brazil. Although substantial heterogeneity was observed across institutions, persistently elevated values throughout the study period indicate that crowding and boarding are not episodic events but rather chronic characteristics of the Brazilian emergency care system.

The magnitude of these findings has important public health implications. An occupancy ratio persistently above 1.0 implies that the formal treatment capacity of participating EDs is routinely exceeded, requiring the continuous use of temporary stretchers, hallway care, and other improvised treatment spaces that are not reflected in official bed counts. Simultaneously, a boarding proportion approaching 50% indicates that a large share of ED resources is devoted not to the evaluation and stabilization of new emergency patients but to the ongoing care of patients whose admission has already been decided. Together, these

findings suggest that a substantial proportion of emergency care capacity is systematically diverted from its primary function, compromising access, efficiency, and quality of care. Rather than representing isolated operational failures, these indicators characterize a healthcare system functioning under sustained strain.

These observations are particularly concerning when interpreted in light of the growing body of evidence linking ED crowding and boarding to adverse clinical outcomes. Previous studies from both high-income countries and Brazil have consistently demonstrated associations between prolonged boarding, delayed treatment, clinical deterioration, increased in-hospital mortality, and higher healthcare costs. Within the same multicenter cohort analyzed here, boarding—but not occupancy—was independently associated with early in-hospital mortality, with each 0.10 increase in boarding proportion associated with a 14% increase in mortality risk, whereas occupancy showed no independent association after adjustment<sup>15</sup>. These findings reinforce the interpretation that ED crowding should not be viewed solely as an emergency department problem but rather as the downstream manifestation of hospital-wide patient flow dysfunction. Hospitals exhibiting persistently high boarding proportions are therefore likely to represent institutions where inpatient bed availability, discharge processes, or overall hospital capacity are insufficient to accommodate emergency admissions in a timely manner. Consequently, interventions focused exclusively on ED operations are unlikely to substantially reduce crowding unless accompanied by strategies addressing patient flow throughout the hospital.

Although ED crowding was widespread nationwide, important regional differences were observed. Occupancy ratios were consistently highest in the Central-West and Northeast regions, whereas boarding proportions tended to be greatest in the Northeast and, during some years, in the Southeast. These findings likely reflect broader territorial characteristics, including the unequal distribution of hospital resources, regional referral patterns, the concentration of specialized services, differences in inpatient bed availability, and variation in access to healthcare across municipalities, rather than differences in emergency care demand alone. Likewise, variation across hospital characteristics suggests that crowding is not restricted to a particular institutional profile but affects diverse hospital settings, including both teaching and non-teaching institutions, public and philanthropic hospitals, and hospitals of different sizes. The broad geographic distribution of elevated occupancy and boarding reinforces that ED crowding constitutes a nationwide structural challenge rather than a localized phenomenon affecting only selected healthcare systems.

Temporal analyses further support this interpretation. The transient decline in occupancy observed during the early phase of the COVID-19 pandemic probably reflects the well-described reduction in ED utilization during periods of social distancing and deferred healthcare seeking. However, occupancy rapidly returned to pre-pandemic levels thereafter, while boarding proportion remained remarkably stable throughout the study period despite fluctuations in patient demand. This relative stability of boarding suggests that hospital output constraints are persistent structural characteristics rather than temporary consequences of periods of increased ED utilization. The absence of sustained improvement despite ongoing participation in a national quality improvement initiative further emphasizes the complexity of the

problem and suggests that hospital-level interventions alone may be insufficient when broader health system constraints remain unchanged.

We hypothesized that municipalities with higher socioeconomic development would exhibit lower levels of ED strain. Contrary to this expectation, municipal socioeconomic development was not independently associated with either ED occupancy or boarding in the primary analyses. At first glance, these findings suggest that ED crowding is not simply a consequence of municipal wealth or human development but rather reflects structural characteristics of healthcare delivery that transcend socioeconomic context. Notably, however, adjustment for the proportion of publicly funded (SUS) beds among all hospital beds strengthened the association between the Municipal Human Development Index (MHDI) and occupancy, bringing the estimate close to statistical significance. Together with the observed inverse correlation between MHDI and the proportion of SUS beds, these findings suggest that healthcare infrastructure may partially mediate or mask the relationship between socioeconomic development and ED strain. In municipalities with higher human development, the lower relative availability of SUS beds may offset advantages typically associated with socioeconomic conditions, emphasizing that emergency department performance depends not only on broader social determinants but also on the organization and capacity of local healthcare systems. Consequently, strategies aimed at reducing ED crowding should prioritize strengthening healthcare infrastructure and improving hospital capacity rather than relying on socioeconomic development alone.

These findings have important implications for healthcare leaders and policymakers. Historically, many interventions targeting ED crowding have focused on processes internal to the emergency department, including triage optimization, fast-track pathways, staffing adjustments, and Lean-based operational improvements. Although these approaches may improve throughput, the consistently elevated boarding proportions observed in the present study reinforce growing international evidence that the principal bottleneck lies outside the ED itself. Policies addressing inpatient bed capacity, discharge efficiency, hospital-wide bed management, and regional coordination of patient flow are therefore likely to yield greater benefits than interventions restricted to emergency department operations. From a health system perspective, ED boarding should be considered a key performance indicator reflecting hospital-wide operational efficiency rather than solely emergency department performance.

The present findings also identify several priorities for future research. First, studies evaluating interventions to reduce boarding at the hospital and regional levels are needed to determine which organizational strategies most effectively improve patient flow within the Brazilian healthcare system. Second, future investigations should examine the relationship between ED strain and additional patient-centered outcomes, including morbidity, healthcare-associated complications, readmissions, patient experience, and healthcare expenditures.

This study has several limitations. Participating hospitals were not selected through probabilistic national sampling but were enrolled in a federal quality improvement initiative according to predefined eligibility criteria. Consequently, although the cohort included hospitals from all Brazilian macroregions and a broad range of institutional characteristics, the findings may not be fully generalizable to all emergency

departments nationwide, particularly smaller hospitals or institutions outside the public emergency care network. Besides that, operational indicators were derived from standardized point-prevalence measurements collected twice daily and therefore may not fully capture intraday fluctuations in ED crowding or boarding. Also, occupancy and boarding represent complementary but simplified measures of ED strain and do not encompass other important dimensions of emergency department performance, such as waiting room congestion, ambulance offload delays, or patient acuity. The ecological design precludes inference regarding individual patient-level risk, as associations were evaluated at the hospital-month level. Finally, although multiple hospital and municipality-level characteristics were included in adjusted analyses, residual confounding from unmeasured organizational or regional factors cannot be excluded.

In conclusion, ED crowding and boarding are widespread and persistent across Brazilian emergency departments, with occupancy routinely exceeding formal treatment capacity and nearly half of ED patients awaiting inpatient admission at any given time. Together with previous evidence linking boarding to increased mortality, these findings support the interpretation that impaired hospital output represents one of the principal operational challenges facing emergency care in Brazil. Addressing this problem will require coordinated hospital- and system-level strategies aimed at improving patient flow, expanding effective inpatient capacity, and strengthening health system organization beyond the boundaries of the emergency department itself.

## **Declarations**

The authors declare that they have no known financial or personal relationships that could have appeared to influence the work reported in this manuscript. All authors confirm that there are no conflicts of interest regarding the publication of this article.

Generative AI tools (ChatGPT, OpenAI) were used to assist with Python scripting for data processing and statistical analyses. All scientific decisions, data analyses, interpretation of results, and final manuscript content were performed and verified by the authors.

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## **CRedit statement**

Isabela Lopes Lima: writing - original draft; formal analysis

Eduarda Bordini Ferro: writing - review & editing

Marcelo A.D. Martinho: writing - review & editing

Welfane Cordeiro Júnior: writing - review & editing; validation

Rafael Nicolaidis: writing - original draft; visualization; methodology; formal analysis; conceptualization

Lucas Oliveira J. e Silva: writing - review & editing; validation; supervision

Arthur Felipe F.L. Ceraso: writing - review & editing; project administration; conceptualization; validation; supervision

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## Figures

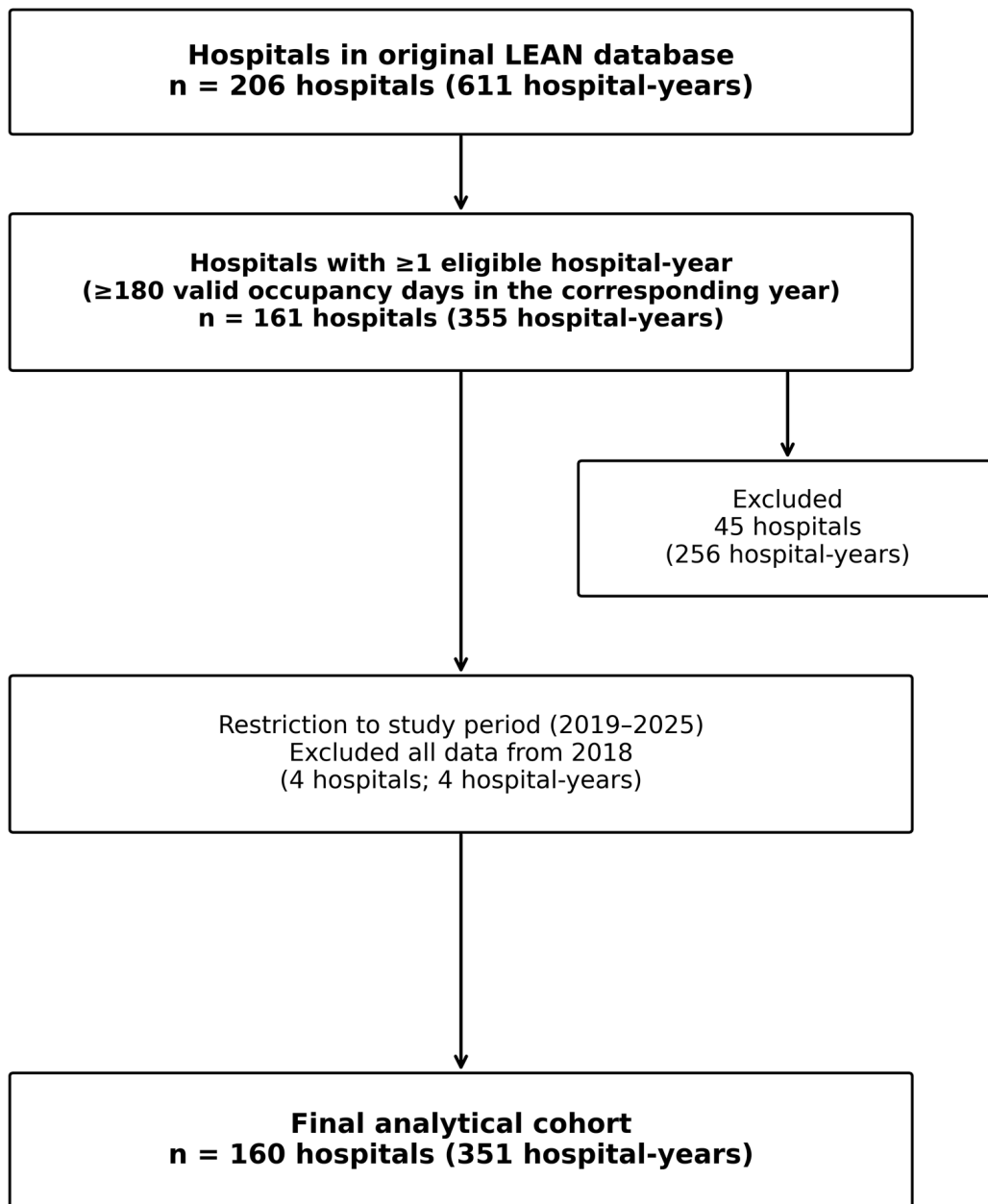


**Figure 1**

STROBE flow diagram of hospital selection.

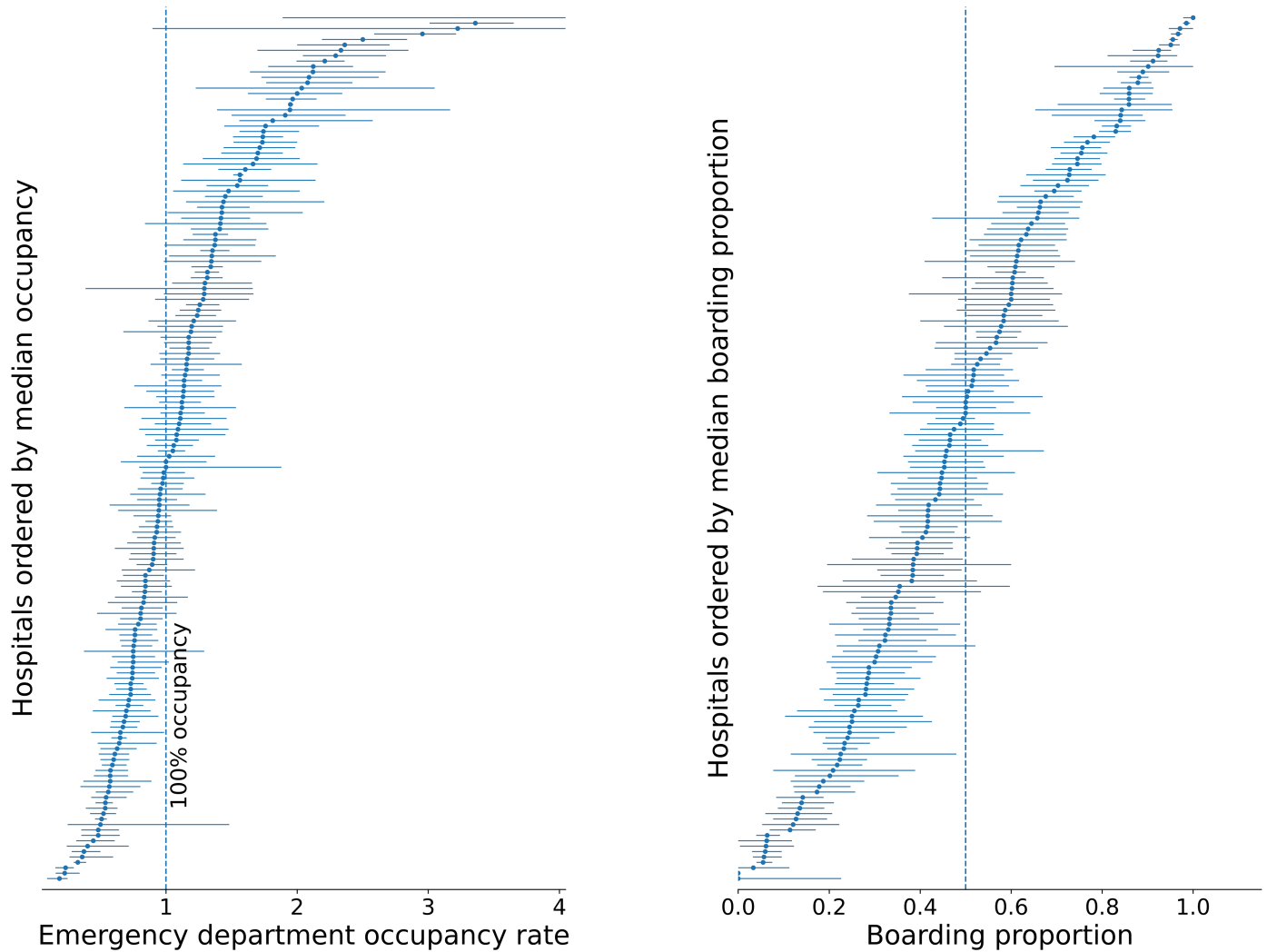


**Figure 2**

Distribution of hospital-level emergency department strain indicators across participating hospitals. (A) Median (IQR) emergency department occupancy rate and (B) median (IQR) boarding proportion (proportion of emergency department occupancy represented by boarded patients), calculated over the study period for each participating hospital. Hospitals are ordered from lowest to highest median value. Source: prepared by the authors.

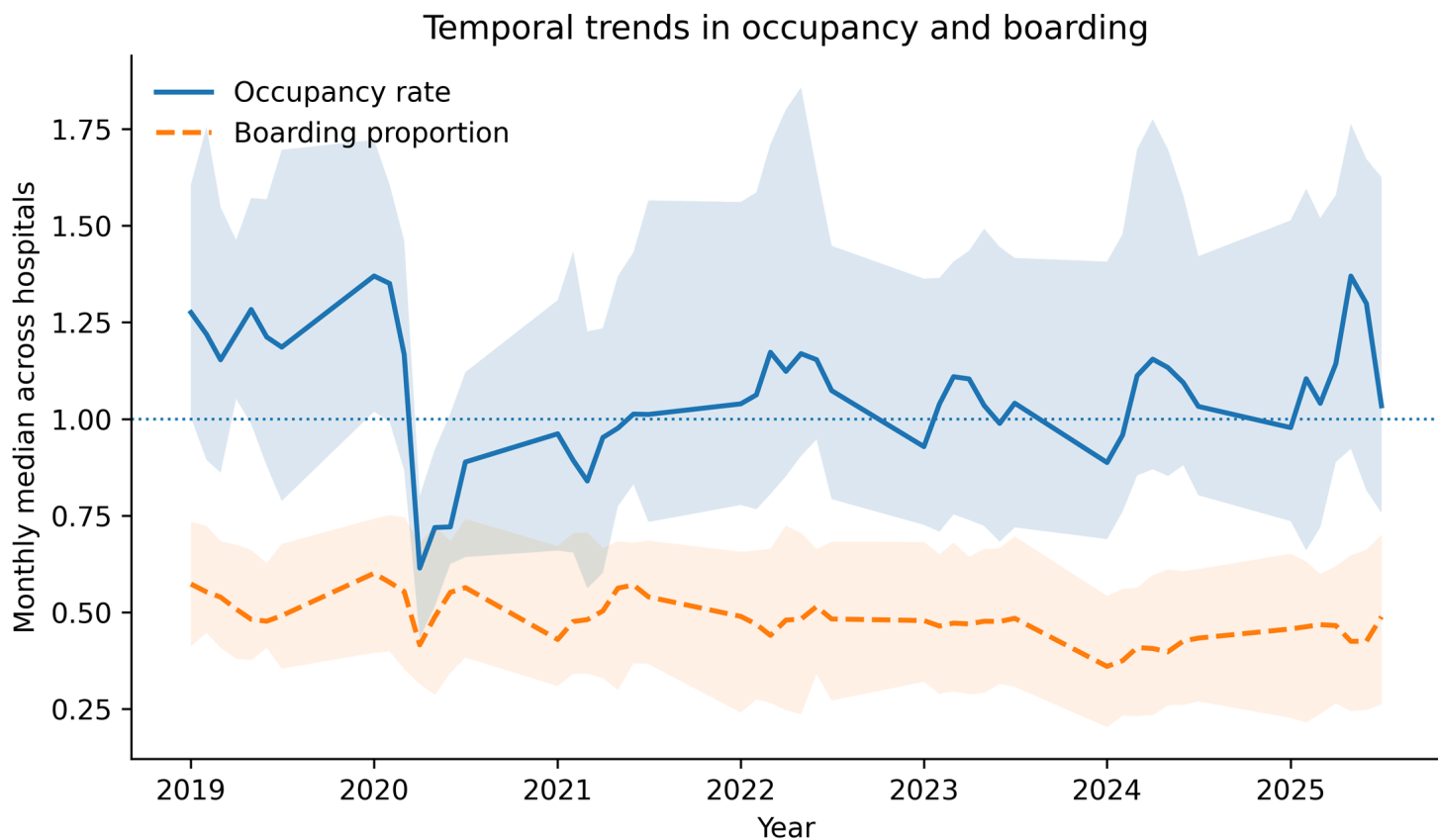


**Figure 3**

National trends in ED occupancy ratio and boarding proportion from 2019 to 2025. Data are based on monthly data contributed by 160 participating hospitals over the study period. Lines represent median monthly values, and shaded areas the interquartile range. Both indicators are expressed as proportions (unitless, scale 0–2). The marked decline in occupancy in 2020 corresponds to the COVID-19 pandemic period. Source: prepared by the authors.

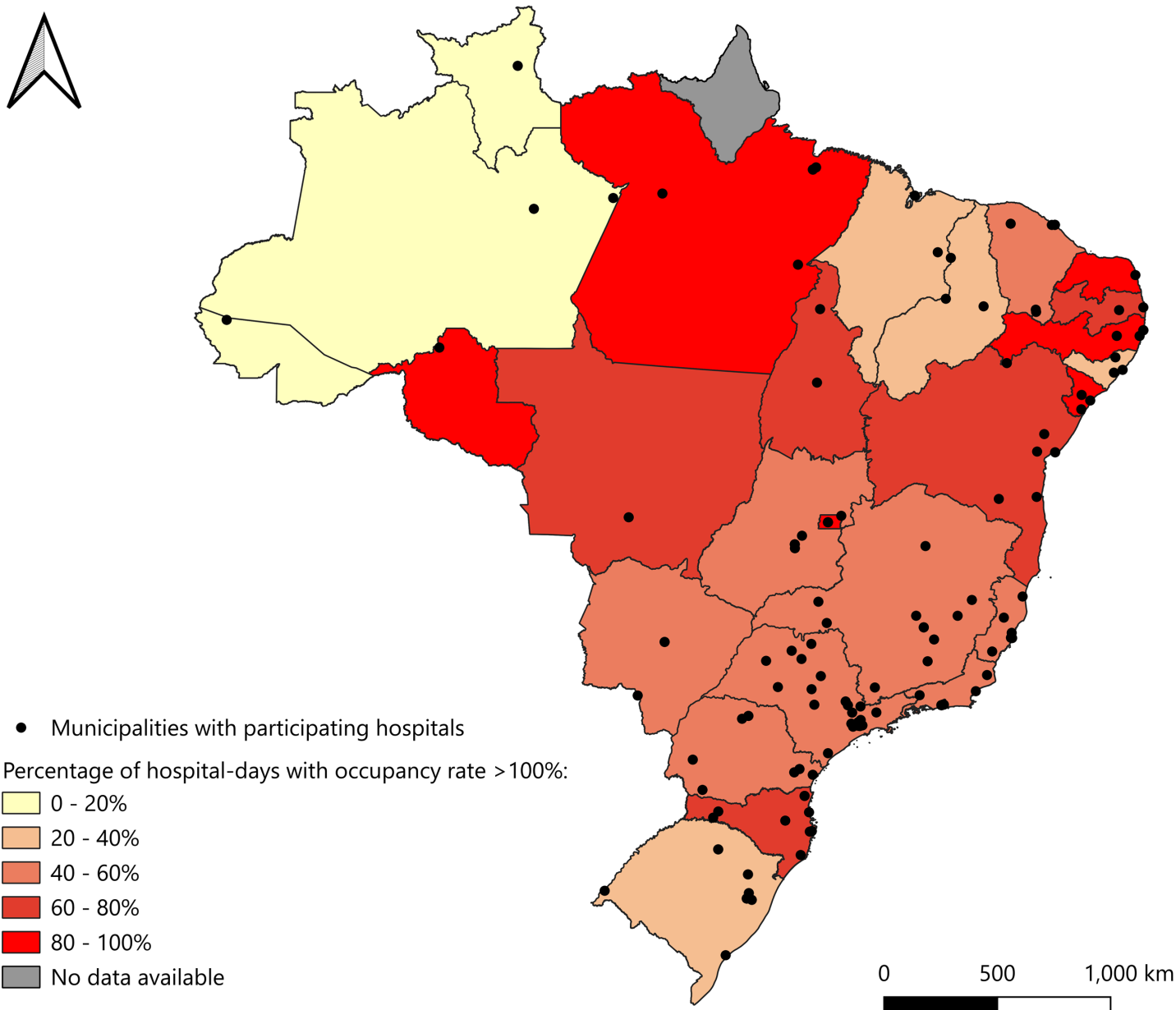


**Figure 4**

Geographic distribution of emergency department occupancy across participating hospitals: choropleth map showing the percentage of study days with an emergency department occupancy rate >100% for each participating hospital over the study period (February 2019 to June 2025). Source: prepared by the authors.

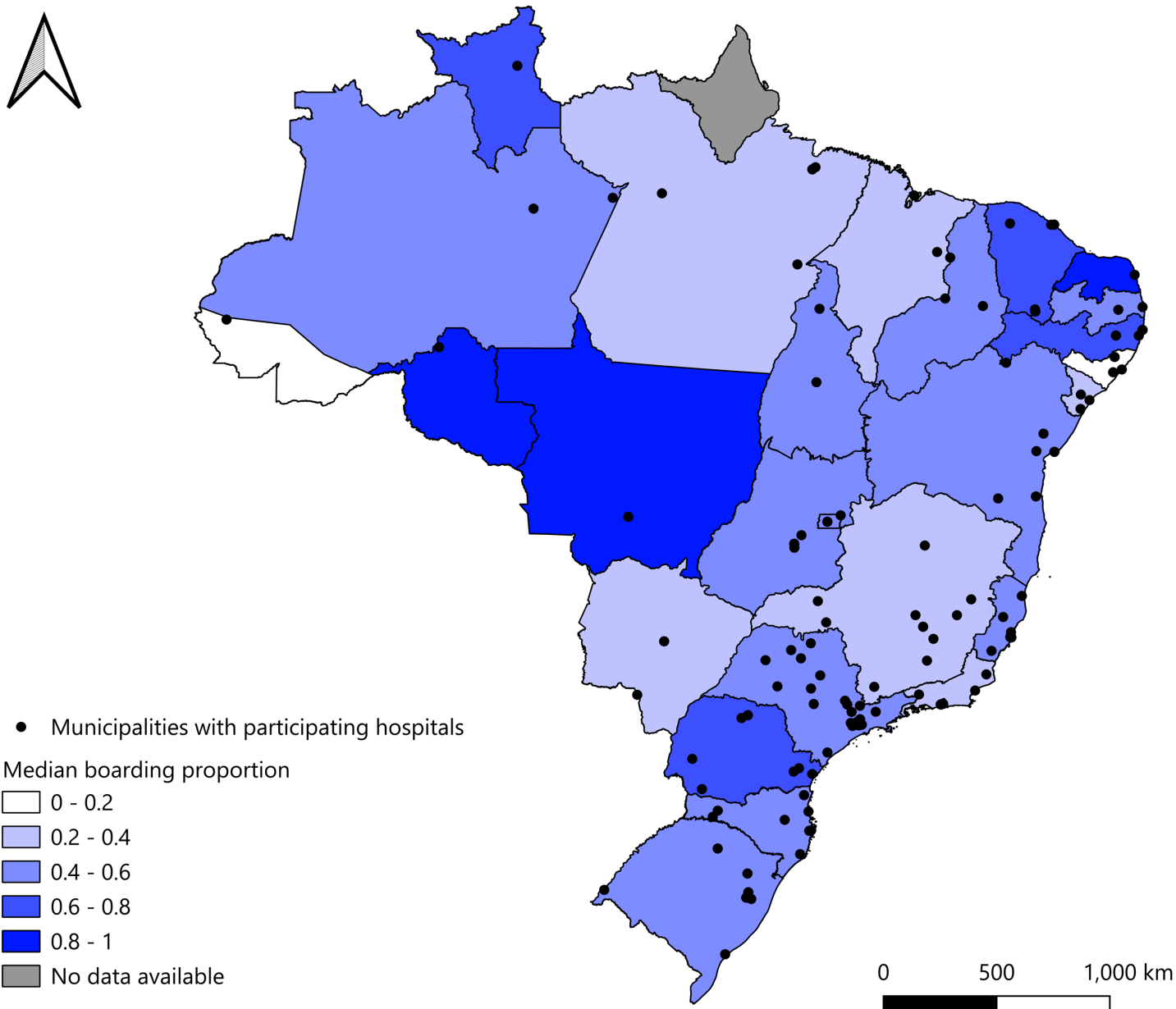


**Figure 5**

Geographic distribution of boarding proportion across participating hospitals: choropleth map showing the median boarding proportion for each participating hospital over the study period (February 2019 to June 2025). Source: prepared by the authors.