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ARTICLE

Spatial Analysis of COVID-19 cases and intensive care beds in the State of Ceará, Brazil

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Abstract *The geographical distribution of COVID-19 through Geographic Information Systems resources is hardly explored. We aimed to analyze the distribution of COVID-19 cases and the exclusive intensive care beds in the state of Ceará, Brazil. This is an ecological study with the geographic distribution of the case detection coefficient in 184 municipalities. Maps of crude and estimated values (global and local Bayesian method) were developed, calculating the Moran index and using BoxMap and MoranMap. Intensive care beds were distributed through geolocalized points. In total, 3,000 cases and 459 beds were studied. The highest rates were found in the capital Fortaleza, the Metropolitan Region (MR), and the south of this region. A positive spatial autocorrelation has been identified in the local Bayesian rate (I = 0.66). The distribution of beds superimposed on the BoxMap shows clusters with a High-High pattern of number of beds (capital, MR, northwestern part). However, a similar pattern is found in the far east or transition areas with insufficient beds. The MoranMap shows clusters statistically significant in the state. COVID-19 interiorization in Ceará requires contingency measures geared to the distribution of specific intensive care beds for COVID-19 cases in order to meet the demand.*

Key words *COVID-19, Spatial analysis, Ecological studies*

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Introduction

First identified in Wuhan (Hubei province) in December 2019, a rapidly evolving viral infection became a pandemic. Its etiological agent is a new coronavirus of zoonotic origin, similar to the viruses responsible for Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS). Currently called COVID-19, this disease with predominantly respiratory symptomatic characteristics can develop in a portion of those infected, to acute respiratory distress/diffuse alveolar damage, requiring intensive care[1].

The COVID-19 pandemic has already had devastating consequences for humanity. Besides the number of people killed by the disease, the economic and social impacts are still incalculable. The speed at which the virus spreads, the existence along with the source of infection, and the difficulty of completely blocking transmission in a large, susceptible population make it reasonable to think about the presence of the disease for a long period[2].

In a retrospective study, about 25% of the people diagnosed with COVID-19 became serious, and, of these, 80% had to be admitted to the Intensive Care Unit (ICU)[3] beds. Thus, it is essential to have some ICU beds to meet the growing demand.

Some research has been developed to estimate the need for planning contingencies, such as requirements for hospital beds in wards, in the ICU, and probable deaths per population[4].

In Latin America, Brazil was the first country to report COVID-19, on February 25, 2020. Since then, as of April 14, 65,000 cases have been detected in Latin America, with discrepant performance among government officials of countries[5].

In Brazil, up to April 17, 33,962 COVID-19 cases and 2,141 deaths from the disease had been confirmed (6.4% lethality). In Ceará, in turn, 2,684 cases and 149 deaths were recorded in the same period (5.5% lethality)[6].

However, the distribution of COVID-19 is not homogeneous in the regions. With the first cases identified in the Brazilian capitals, new cases were gradually detected in more distant regions, to the detriment of community transmission.

Knowing how the disease is spreading in a region allows an understanding of the spread of the disease and how it is internalized, from large urban centers to less developed areas. Moreover, observing the geographical dispersion of the disease, together with the expansion of UTI-COVID-19 beds, allows understanding the accessibility to this type of care, which can be crucial for critically ill patients. Thus, this study aimed to analyze the distribution of COVID-19 and ICU beds in the state of Ceará.

Methods

This is an ecological study, which performed an exploratory analysis of the spatial distribution of COVID-19 in the state of Ceará from cases registered between March 15, 2020 (first registration in the state), and April 18, 2020. The municipalities were adopted as units of analysis, and disease data distributed by area and specific ICU beds to receive people with COVID-19 distributed by points were used.

Ceará is located in the Northeast Region of Brazil. It is divided into 184 municipalities, with an area of around 148,895 km². It has approximately 9,178,363 inhabitants[7]. Currently, it is one of the states with the highest incidence of COVID-19[6].

Data concerning the number of confirmed cases in each municipality in the state were extracted from the IntegraSUS platform (https://indicadores.integrasus.saude.ce.gov.br). The search was carried out on April 18, 2020, at 2 pm. It should be noted that data is constantly updated. The number of cases per municipality, from the individual's place of residence, can be retrieved on the portal.

Population data was obtained by consulting the TabNet (https://datasus.saude.gov.br/informacoes-de-saude-tabnet/), on April 18, 2020. The total population of Ceará used was the one estimated by Federative Unit until 2030. The population of each municipality was reached, maintaining the population proportion of the estimate of the Federal Court of Accounts for 2019. For this study, we considered no change in the proportion between municipalities compared to the total value of the population of the State in 2019.

The number of UTI-COVID-19 beds was obtained on the platform of the National Register of Health Establishments (CNES) (http://cnes2.datasus.gov.br/), on April 19, 2020. The cartographic base of Ceará was obtained on the website of the Brazilian Institute of Geography and Statistics.

A total of 3,034 cases were evaluated. Of these, 34 cases were excluded because they did not con-

Ciência & Saúde Coletiva, 25(Supl.1):2461-2468, 2020

tain information on the place of residence. Of the 3,000 cases, the distribution of absolute and relative frequency (number of cases divided by the total population, multiplied by 100,000) by municipality was carried out.

The global and local Bayesian rates were also calculated to smooth out the proportion of cases detected by municipality. The first (Global Empirical Bayesian Estimator) smooths out the value of the municipality's detection coefficient compared to the mean of all others. The second (Local Bayesian Estimator) calculates this value also based on the mean of their proximities[8].

Thematic maps were created to visualize the distribution of the gross detection coefficients by municipality, smoothed by the global and local Bayesian estimator. The grading of values was due to natural breaks (jerks).

A Proximity Matrix was created by contiguity. The Moran Index was calculated to verify the spatial dependence of the distribution of the gross detection coefficient and global and local Bayesian rates. The level of significance was set at 5%. The index ranges from -1 to +1: values close to +1 show positive autocorrelation; values close to -1 indicate negative spatial correlation; values close to 0 indicate the absence of spatial autocorrelation[9].

The Moran scatter plot of the detection coefficient calculated by the Local Bayesian Estimator was used, and was viewed through BoxMap to identify areas with high values and proximal values in the same condition (Q1- High-High Pattern), areas with low values and with proximities also in the same condition (Q2- Low-Low Pattern), or areas in transition (Q3- High-Low Pattern and Q4- Low-High Pattern). The visualization of these clusters with statistically significant positive spatial autocorrelation was demonstrated through the MoranMap.

The UTI-COVID-19 beds were distributed through the creation of a vector layer of points superimposed on the BoxMap, with the location of beds in the municipalities, and the number of beds was its attribute. Categorization by point size was performed in ascending order to the number of beds.

Excel 2013, Terraview 4.2.2, and Qgis 2.18.0 programs were employed. The study observed policies involving human research. The study was not submitted to a research ethics committee because it used public domain data.

Results

Concerning COVID-19, the state of Ceará currently has 33 cases/100,000 inhabitants. Most of the cases of the disease included in the study are concentrated in the metropolitan region of Fortaleza (Figure 1). The capital of Ceará has the highest number of cases (2,540 people detected with COVID-19), representing approximately 85% of all cases. Most municipalities had up to seven cases.

The illustration below (Figure 2) shows the distribution of the crude coefficient of detection of COVID-19 cases (Figure 2A), smoothed by the global Bayesian (Figure 2B) and local Bayesian (Figure 2C) estimators. The Moran indices and the respective p-values are shown below. The Moran index with positive spatial autocorrelation was calculated based on the local Bayesian estimator, with a value of 0.66 (p = 0.001).

Considering the raw data, 98 municipal-

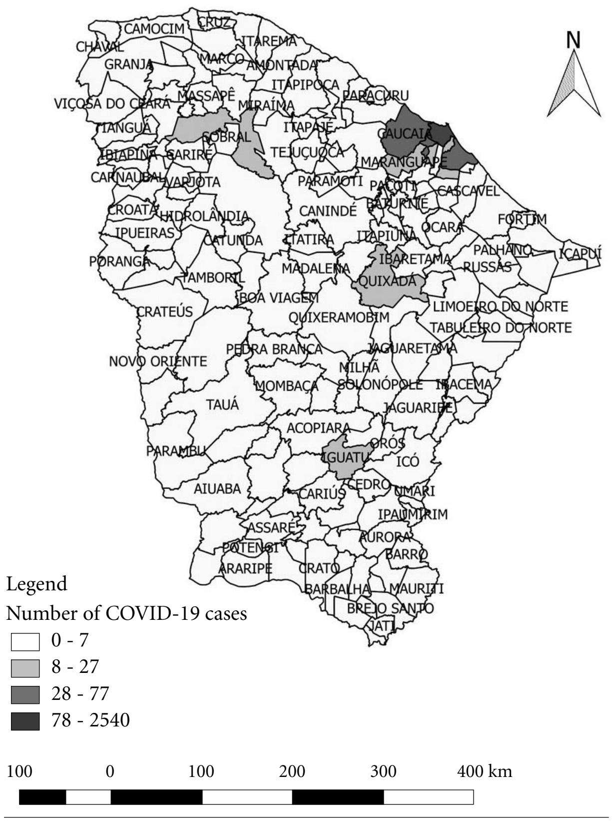

Figure 1. Distribution of the number of COVID-19 cases detected in Ceará by municipality, Ceará, Brazil, 2020.

Source: IntegraSUS (2020).

ities did not report COVID-19 cases. The local Bayesian detection coefficient reveals that the highest detection coefficients are concentrated in the capital (94.6 cases/100,000 inhabi-

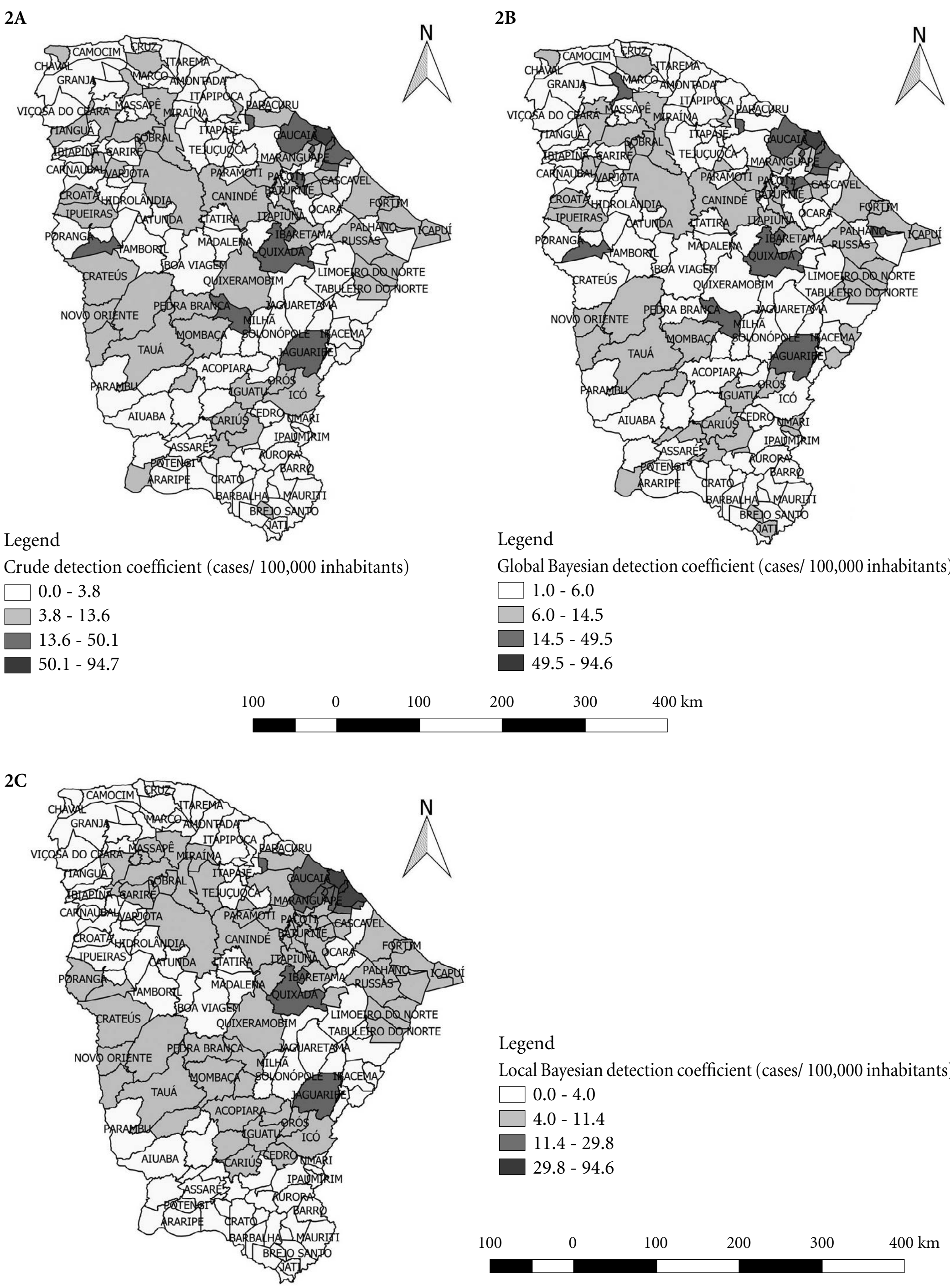

Figure 2. Coefficient of detection of COVID-19 cases in the state of Ceará, Brazil – crude, smoothed by the global and local Bayesian estimator, 2020.

Source: IntegraSUS; TabNet.
Moran Index. Crude detection coefficient = 0.45 (p = 00.1). Smoothed by the Global Bayesian Estimator = 0.43 (p = 00.1). Smoothed by the Local Bayesian Estimator = 0.66 (p = 00.1).

tants) and the municipalities of the Metropolitan Region, such as Eusébio (70.9/100,000), Aquiraz (54.3/100,000), Itaitinga (29.8/100,000), Maracanaú (29.1/100,000), and Caucaia (22.4/100,000). Moreover, municipalities in the central part of the state, such as Quixadá and Jaguaribe, also have higher values (both with 14.8 cases/100,000 inhabitants). Some municipalities of the west coast and southern part of Ceará have no recorded cases or a lower detection coefficient.

Regarding the BoxMap of the COVID-19 case detection coefficient smoothed by the local Bayesian method (Figure 3), both the metropolitan region of Fortaleza and municipalities further south of the same region show a High-High pattern, that is, high detection rates with proximities also showing high values. The same pattern is also seen in the region of the municipality of Sobral and its surroundings (west), Aracati, and its surroundings. It is worth noting areas in the state with a transition pattern (High-Low or Low-High) in the central part (municipalities of Quixadá, Quixeramobim, and Canindé). Areas with a Low-Low pattern can be seen in the extreme south, extreme west, and the central part.

It appears from the superimposition of the distribution of UTI-COVID-19 beds that most of the beds are concentrated near the municipalities with the highest rates in the capital and the Metropolitan Region (Fortaleza had 307 disease beds), in part of the western part (Sobral had 47 beds). Municipalities in transition, such as Quixeramobim and Icó (both with a Low-High pattern), have 20 and 10 beds, respectively. Although Iguatu (center-south of the state) is a municipality with a Low-Low pattern and has 29 specific beds for COVID-19, it has nearby municipalities with High-High (Orós), Low-High (Icó) and High-Low (Cariús and Cedro) patterns.

The southern portion of the state has 35 ICU beds located in Juazeiro do Norte. However, the region has a Low-Low pattern in almost its entire extension. It is noteworthy that the extreme northwest of the state has municipalities with a High-High pattern (for example, Aracati and Fortim), and there are no nearby municipalities with ICU beds. Furthermore, the midwest part with municipalities with a transition pattern (Novo Oriente, Quiterianópolis, Tauá, Mombaça, and Pedra Branca) are equipped with only one UTI-COVID-19 bed located in Tauá. It is important to emphasize that the ICU beds serve not only the bed-holding municipalities but bordering municipalities within the same health region.

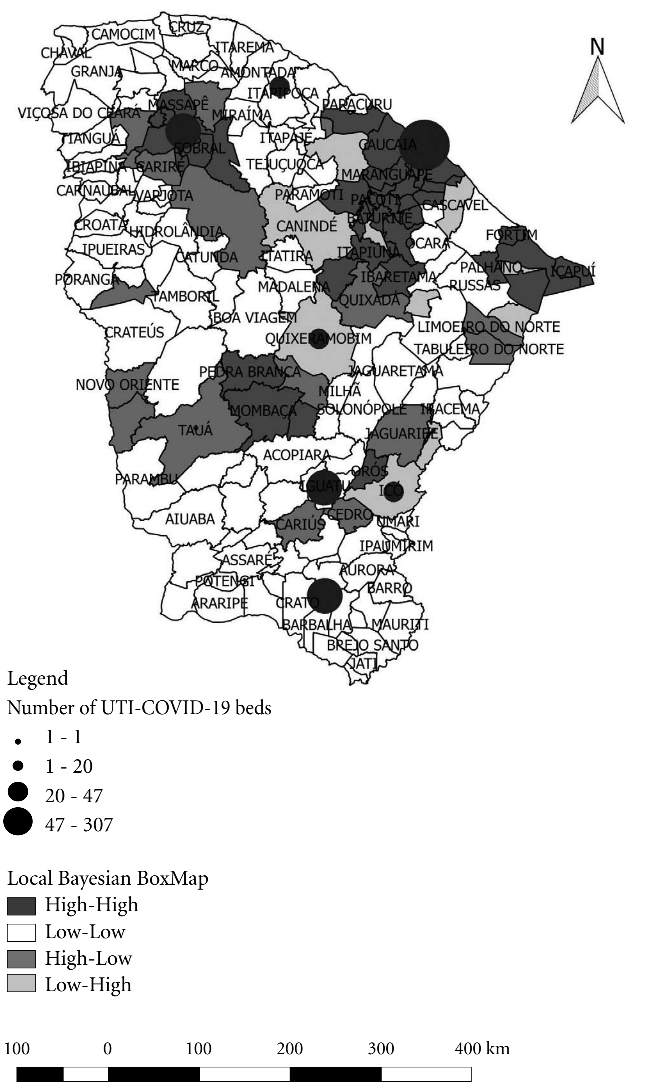

Figure 3. BoxMap of the COVID-19 case detection coefficient by municipality and distribution of the number of UTI-COVID-19 beds, Ceará, Brazil, 2020.

Source: IntegraSUS, TabNet, CNES (2020).

Regarding the MoranMap of the local Bayesian rate (Figure 4), we can observe a statistically significant cluster with a High-High pattern in the capital and almost all municipalities in the metropolitan region, and with a Low-Low pattern in the extreme northwest and extreme south of the state.

Discussion

As of the data collection date, this study showed a positive spatial autocorrelation of local Bayesian rates (I = 0.66), observing a spatial dependence on the distribution of the disease. The distribution of the UTI-COVID-19 beds superimposed on the BoxMap showed clusters with a High-High pattern in the capital and Metropolitan Region, and part of the western part with some UTI-COVID-19 beds. In the south of the state, with a Low-Low pattern, we find 29 ICU beds. However, the extreme (coastal) east has a High-High pattern and has a transition area with probable insufficient beds in the central-western portion. The MoranMap showed statistically significant clusters with a High-High pattern in the metropolitan region (including the capital), and a Low-Low pattern in the south and far east of Ceará.

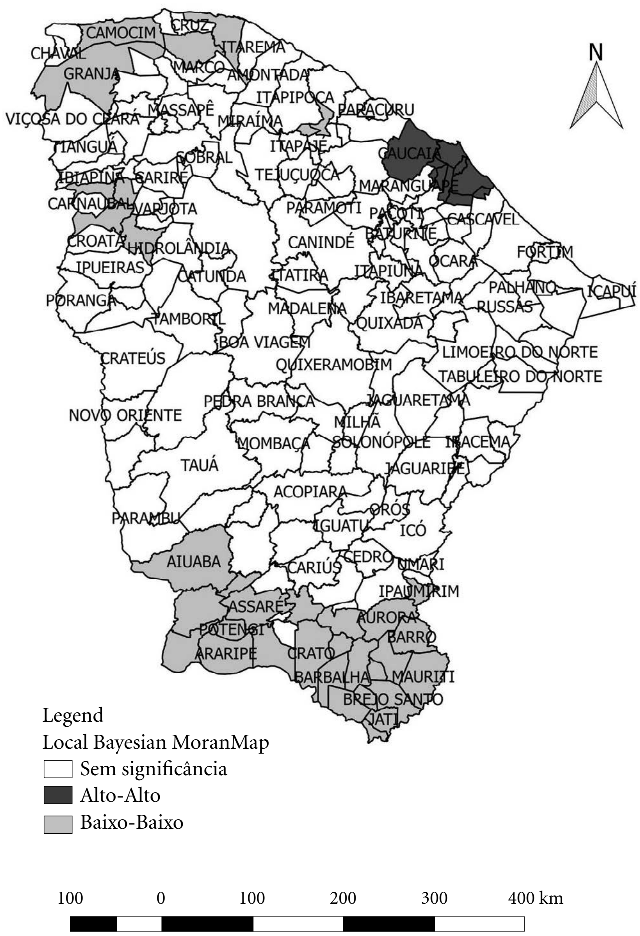

Figure 4. MoranMap of the COVID-19 case detection coefficient by municipality, Ceará, Brazil, 2020.

Source: IntegraSUS; TabNet (2020).

On the date of data collection, Ceará had a detection rate of 33 cases per 100,000 inhabitants. The highest rates are found in the state capital, its Metropolitan Region, extending further south to this region. We can observe that other regions of Ceará also show a High-High pattern of the disease, confirming the interiorization of the pandemic in the state. In this sense, understanding social and economic networks, commercial patterns, and travel flow can be important in understanding the territorial expansion of the disease[10]. These other regions, such as the municipalities of Sobral and Aracati and their respective surroundings, are important economic and tourist centers for the region, which may explain greater contact with the capital, where the first case of the disease was identified, or others large urban centers.

In a study carried out in the United States, the geographical differences in the number of COVID-19 cases were reflected from the date of the introduction of the disease at the site, population density, age distribution, underlying medical conditions, measures applied in the community, diagnostic capacity and notification practices[11].

In China, a study of its case distribution and population emigration from Wuhan has shown that the population that emigrated from Wuhan was the source of primary infection for other cities in the country. Furthermore, cities with low initial case detection showed a rapid increase in the disease burden[12]. Some locations of Ceará are still without detection of cases and clusters with a Low-Low pattern, which must be protected to avoid the introduction of cases due to patients traveling to these places.

Another Chinese study indicated that public transport had become a vehicle for the dissemination of imported COVID-19 cases to regions where there were still no indigenous cases. The distance between the epicenter and the destination, as well as the connectivity between these two spaces, determined the transmission risks[13]. In the BoxMap of the distribution of disease rates in Ceará, the central strip of municipalities with a High-High pattern and in transition is crossed by an important highway (BR-122) that connects the capital to other regions of the country. However, other methods should be used to analyze this relationship.

The use of resources for exploratory analysis of geographic data allowed the visualization

Ciência & Saúde Coletiva, 25(Supl.1):2461-2468, 2020

of the expansion of the state pandemic and the distribution of resources available for intensive care. In previous epidemics, such as the original SARS-CoV epidemic in 2002-03, and Influenza, Geographic Information Systems (GIS), such as real-time mapping of disease cases, social media reaction to disease spread, predictive mapping from population travels, and tracing paths and "spreading" contacts were already used in various application forms, and are an important apparatus in monitoring the development of COVID-19 and the response to preventive actions[14].

A time-geographic analysis of the growth in the number of COVID-19 cases outside China found that the geographical distribution shifted from a single center between the period January 13 to February 20, 2020, to a multicenter distribution from February 22, including China, South Korea, Italy, and Iran as epidemic centers[15]. Likewise, within the state of Ceará, the disease is not concentrated only in the capital of Ceará, as evidenced by BoxMap.

The study has some limitations. Brazil currently performs testing only on symptomatic people, and the detection coefficient values may be underestimated, considering that there may be an important proportion of asymptomatic people with the virus. However, currently, these data are widely used in epidemiological research and to support management decisions. The lack of similar studies aimed at the geographical distribution of COVID-19 restricts the comparability of disease internalization in other locations. There is also no consistency in the number of ICU beds needed to meet the necessary demand.

The study showed a higher concentration of disease rates in the capital of Ceará and the Metropolitan Region, however, with COVID-19 interiorization marks. Despite a greater number in regions with a High-High pattern, the distribution of UTI-COVID-19 beds may be scarce in some regions with a high concentration of the disease or in places that are in transition. Such municipalities that already have ICU beds can benefit from using the structure to face the pandemic.

The methodological resource used in this analysis through the elaboration of maps allows understanding the spatialization of the disease and resources, and can be used as a management tool and basis for decisions regarding the allocation of health equipment.

Collaborations

Corresponding author NL Pedrosa was responsible for designing the project, extracting and analyzing data, producing maps, interpreting the findings, drafting, and reviewing the final version of the manuscript. Co-author NLS Albuquerque contributed to the stages of data extraction and analysis, drafting, and reviewing the final version of the manuscript.

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