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A geospatial analysis of inequality indicators related to COVID-19 in Brazil

Guilherme Pasqual Fogaça [1], Arlene Leite dos Santos Spengler [1], Leonardo Pedro Salesse [1], Anita Maria da Rocha Fernandes [2], Rodrigo Lyra [2], Ricardo Heffel Farias [4] and Graziela Liebel [3,*]

[1] *Degree in Medicine, University of Vale do Itajaí, Itajaí, SC, Brazil.*
[2] *Master in Applied Computing, University of Vale do Itajaí, Itajaí, SC, Brazil.*
[3] *Professional Master's Program in Health and Work Management, University of Vale do Itajaí, Itajaí, SC, Brazil.*
[4] *Computer Science, University of Vale do Itajaí, Itajaí, SC, Brazil.*

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Abstract

Background: This study aims at analyzing through the usage of computer models the relationship of variables such as the supply infrastructure, and socioeconomic and demographic contexts with the contagion and mortality rate by COVID-19 in Brazilian microregions.

Methods: It's an analytical ecological study that covers the 5570 municipalities aggregated in the 558 microregions of the IBGE, Brazilian Institute of Geography and Statistics, in the year 2020, based on the mean and standard deviation. Geospatial computer models were applied for data visualization.

Results: Demonstrate that inequality and concentration of supply in some Brazilian regions, mainly in relation to the average household income per capita, Gross Domestic Product per capita, rate of Community Health Agents, Intensive Care Unit beds, Toilets, X-ray equipment and coverage by the Family Health Strategy, contributed to the fragility with which the country received COVID-19.

Conclusion: It was possible to identify how housing conditions, and income and service provision infrastructure are related to indicators of infection and mortality by COVID-19 in Brazil, as well as the spatial behavior of health and inequality indicators. It is important to consider that the pandemic was still ongoing by the time this study was conducted and that other values can be found.

Keywords: Health information systems; Coronavirus infections; Family health strategy; Social differences; Mortality

1. Introduction

This research aims at verifying if data analysis and processing through computational models may help improving resource allocation for reducing the contagium and mortality rates by COVID-19, and other diseases with pandemic potential, in Brazilian microregions. For attaining this aim the research takes into consideration data obtained from Family Health Strategy and socio-economic aspects of the analyzed microregions. Since the first reported cases in late 2019 until the time this study was conducted COVID-19 contamination has exceeded 219 million recorded cases and over 4.55 million deaths worldwide. Brazil alone has over 21 million registered cases and over 586 thousand deaths[1].

COVID-19 high contagiousness and rapid spread caused an overload in the hospital system. A previous North American study[2], with a sample of 5,700 infected people, showed that 14.2% of patients required ICU care during hospitalization, 12.2% of mechanical ventilation and 21% died. Among patients requiring mechanical ventilation, mortality quadrupled

* Corresponding author: Graziela Liebel

to 88.1%. The incidence of death was higher among people over 60 years of age, men, and people with hypertension and/or diabetes. This pattern was also observed the data reported in China[3] and in Brazil, with slight variations[4]. The data demonstrates the fragility of the current health system when fighting a pandemic.

Changes in the epidemiological profile due to the emergence of new mutant variants is of major concern since they can impact viral fitness and transmissibility[5]. The P.1 variant has become emerging and dominant in Brazil. This variant occurred in the Brazilian state of Amazonas and was first identified in January 2021 by the National Institute of Infectious Diseases of Japan. Its rapid rise as the dominant variant in Brazil is of particular concern since it increases the threat of reinfection and diminishes protection from previous vaccines[6], increasing risk of secondary waves of contamination. Together with new overloads, it may result in a possible collapse of health services increasing mortality rates with serious socioeconomic consequences.

Pedrosa and Albuquerque[7] developed indicators to estimate contingency planning requirements, such as the need for hospital beds in wards and ICUs with ventilatory assistance. Results of a different study conducted with 8,616 patients verified the importance of the associated infrastructure, since patients with COVID-19 hospitalized in the ICU during periods of high demand had an increased risk of mortality, when compared to ones hospitalized in periods of low demand[8]. Considering that the shortage of specialized hospital beds in Brazil is historically determined by the economy, regional inequality in health has been intensified by the pandemic[9].

As pointed by studies, the numerical results of the indices suggest the spatial distribution of the structure of the health system in Brazil is clearly not homogeneous[10]. In this context the presence of the Family Health Strategy (ESF) has proved to play a major role in providing access to health services to the population, directly impacting the contagion rate of COVID-19[11]. Considering the ESFs' complex functioning along with the potentiality of their actions, direct and indirect effects attributed to their actions on COVID-19 strategy is a vast factor and still little explored. Knowing the impacts of its coverage, processing its sociodemographic, infrastructure and economic variables, through computer models, can provide better evidence for health policy makers with a hierarchical basis for decisions on the allocation of health equipment during the current global emergency.

The use of dashboards in this research has potential utility in public health emergencies, allowing to monitor the direction and rate of spread of infectious diseases. Consequently, the data-derived control strategy and the rational allocation of resources can be planned from reliable information. In order to achieve maximum utilization of the health services involved in the governance process, the balance between costs and the provision of equipment and services must be carefully considered[11,12].

2. Material and methods

The present study is an analytical ecological study, which covers the 5570 municipalities aggregated in the 558 microregions of the IBGE, Brazilian Institute of Geography and Statistics. The data collection took place in December 2020. The related variables of the study were characterized based on the infrastructure, being further subdivided into physical resources (hospital beds, ICU beds, X-ray, CT and respirators) and human resources (Community Health Agent or *ACS*, Family Health Strategy or *ESF*, nurses, physiotherapists and doctors); sociodemographic (population, illiteracy, sanitation facilities, water supply and garbage collection) and economic (GDP and average household income).

Data regarding the care network, physical and human resources were obtained and tabulated via DATASUS[13], the Information Technology Department of the Unified Health System. Data related to COVID-19 were extracted from the website Brasil.IO[14] and population density, territorial networks and socioeconomic indicators were obtained from IBGE[15]. As the data used in this study came from different repositories, there is no uniform standard regarding their format. Most IBGE data were requested through the Application Programming Interface - API and received in Java Script Object Notation (JSON) or JSON geographic data (GeoJSON). The Pandas library (pandas.pydata.org) was used to compile the data and generate tables with key variables from data grouped by in each municipality IBGE.

The rates of each variable associated with the COVID-19 infection and mortality rate were calculated from the raw data. The contagion rate of COVID-19 and the mortality rate of a given region was determined by the quotient of the sum of the number of confirmed cases of the disease in each municipality in the region, and the sum of the number of inhabitants of each municipality in the same region. As a result, a value ranging from 0 to 1 (0% to 100%) indicates the percentage of inhabitants infected by COVID-19. The indicators were descriptively analyzed with mean and standard deviation (SD). Geospatial computational models were also applied for data visualization.

3. Results

Processed data was structures on table 1, found below. The table presents the sociodemographic, economic, and structural profile of Brazil, together with the epidemiological indicators of infection and mortality of COVID-19. Resulting data is grouped in the 558 microregions of the IBGE.

Regarding the sociodemographic characteristics, the population size had an average of 379,490.49 (SD = 964,396.47), ranging from 3,101 to 15,132,944 inhabitants. The illiteracy rate averaged 3.53 (SD = 3.33), ranging from 0.40 to 20.65. The rate of sanitary facilities had an average of 320.22 (SD = 267.40), with a minimum of 1.33 and a maximum of 872.16. The water supply rate had an average of 0.20 (SD = 0.06), ranging from 0.04 to 0.33. For garbage collection, the average value was 0.18 (SD = 0.07), with a minimum of 0.01 and a maximum of 0.31.

Regarding the economic variables, the Gross Domestic Product per capita had an average of 19,524.06 (SD = 6,324.35), with a minimum value of 4,268.69 and a maximum of 229,246.30. The average household income per capita had an average value of 542.17 (SD = 250.68), ranging between minimum and maximum of 162.15 and 1,665.42, respectively.

Table 1 Characterization of sociodemographic, economic, and structural variables of IBGE microregions – Brazil 2020

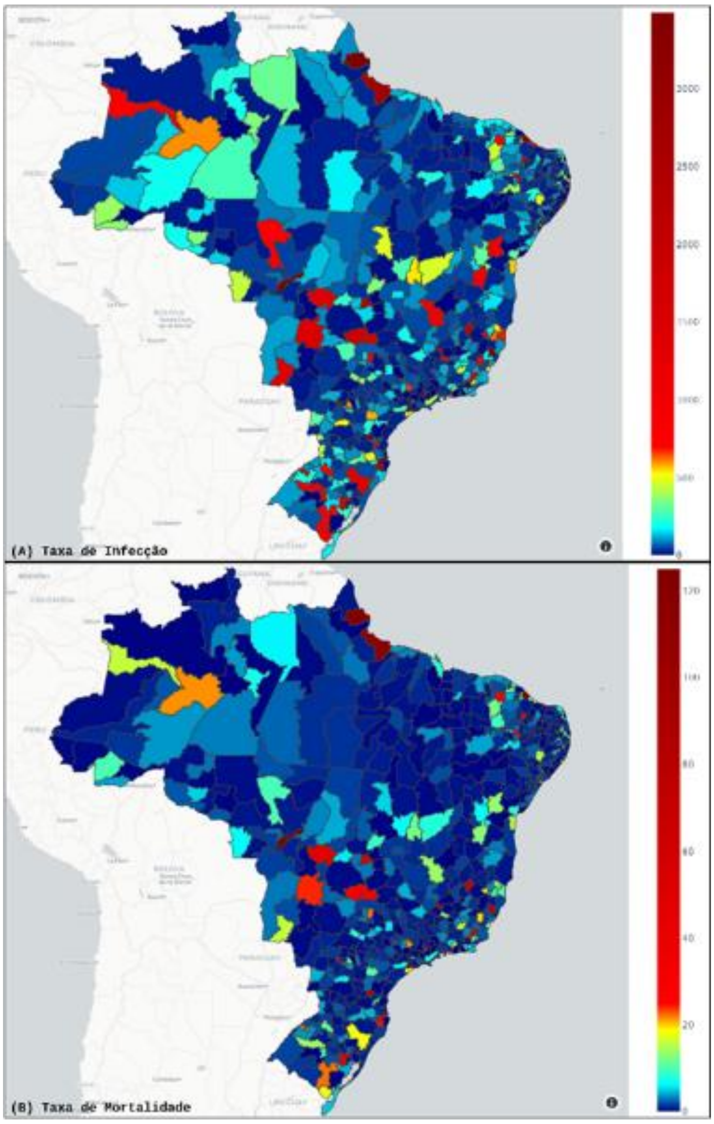
Variables	**Average ± SD[1]**	**Minimum**	**Maximum**
Sociodemographic			
Population Size (n)	379 490.49 ± 964 396.47	3 101	15 132 944
Illiteracy *	3.53 ± 3.33	0.40	20.65
Sanitary facilities *	320.22 ± 267.40	1.33	872.16
Water supply*	0.20 ± 0.06	0.04	0.33
Garbage Collection*	0.18 ± 0.07	0.01	0.31
Economic variables			
Gross Domestic Product *per capita*	19 524.06 ± 16 324.35	4 268.69	229 246.30
Average Household Income *per capita*	542.17 ± 250.68	162.15	1 665.42
Structural variables			
Physical Resources			
Inpatient beds*	1.96 ± 0.83	0.03	5.48
ICU beds*	1.12 ± 4.86	0.00	61.30
X Ray Equipment*	0.11 ± 0.06	0.00	0.47
C*omputerized tomography* scan*	0.02 ± 0.02	0.00	0.10
Mechanical Ventilators*	0.24 ± 0.19	0.00	1.01
Human Resources			
Community Health Agents*	1.90 ± 0.65	0.31	4.29
Family Health Strategy Coverage *	0.93 ± 0.28	0.20	1.90
Nurses*	1.21 ± 0.40	0.38	3.86
Physical Therapists *	0.37 ± 0.18	0.04	1.12
Physician *	1.30 ± 0.85	0.19	7.37
COVID-19 epidemiological indicators			
Infection*	318.48 ± 1 584.79	0.43	32 161.53
Mortality*	8.35 ± 58.34	0.00	1 270.36

* Per capita; [1] Standard Deviation; Source: Datasus[13] and Brasil.IO[14]

Regarding the structural variables, these were further subdivided into physical resources and human resources. Among the physical resources, the rate of hospital beds had an average of 1.96 (SD = 0.83), with 0.03 for the minimum value and 5.48 for the maximum value. As for the rate for ICU beds, the mean was 1.12 (SD = 4.86), ranging from 0.00 to 61.30. The rate of X-ray equipment had an average of 0.11 (SD = 0.06), ranging from 0.00 to 0.47. Regarding the rate of computed tomography scanners, the mean was 0.02 (SD = 0.02), ranging from 0.00 to 0.10. The rate of respirators had a mean value of 0.24 (SD = 0.19), with a minimum of 0.00 and a maximum of 1.01. As for human resources, the rate of community health workers had an average of 1.90 (SD = 0.65), with values ranging from 0.31 to 4.29. The family health strategy coverage rate had a mean of 0.93 (SD = 0.28), with minimum values of 0.20 and maximum of 1.90. The nurse rate had a mean value of 1.21 (SD = 0.40), ranging from 0.38 to 3.86. The rate of physical therapists had a mean of 0.37 (SD = 0.18), ranging from 0.04 to 1.12. Finally, the physician rate had a mean of 1.30 (SD = 0.85), with values ranging from 0.19 to 7.37.

Regarding the last COVID-19 data collection in Brazil, the infection rate had an average of 318.48 (SD = 1,584.79), ranging from 0.43 to 32,161.53, and the average mortality rate of 8 .35 (SD = 58.34), ranging from 0.00 to 1270.36.

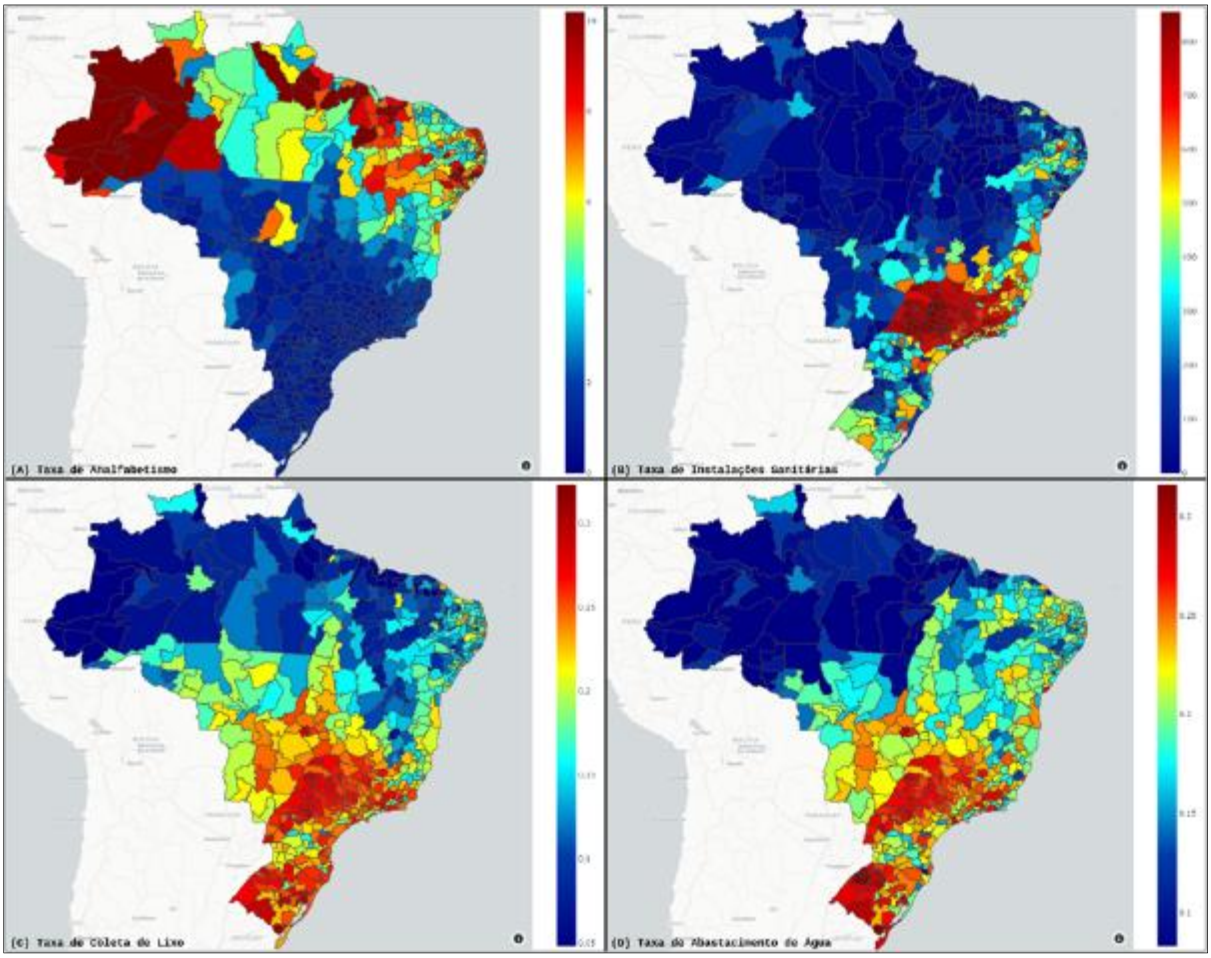
The collected data allowed the creation of heat maps subdivided by microregions. These maps illustrate the comparisons of other addressed variables and indicators of infection and mortality. For these maps warm colors represent higher values while cooler colors represent lower values of each presented variable.



Source: BRASIL.IO14

Figure 1 Characterization of variables regarding Infection Rate (A) and Mortality Rate (B)

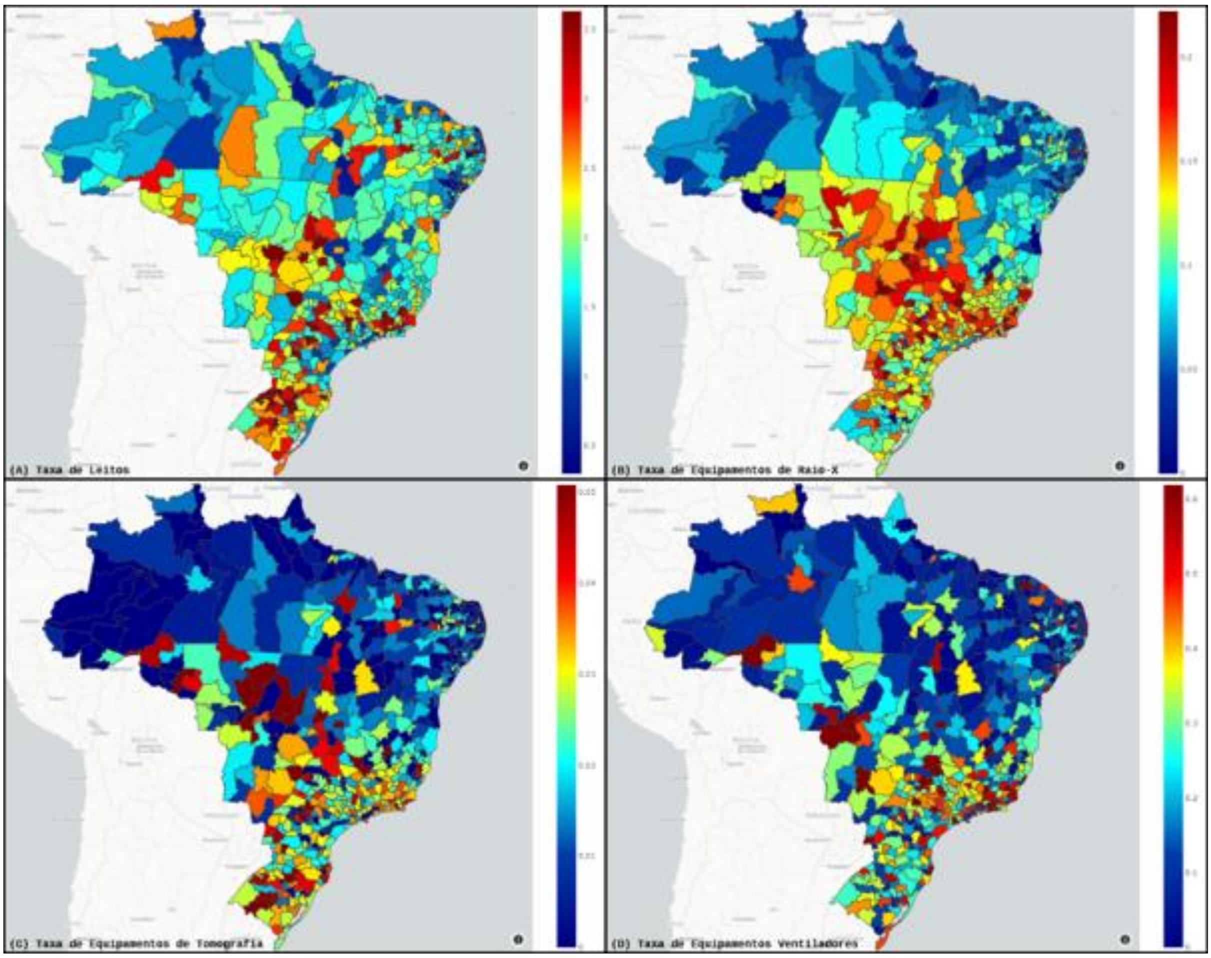
Figure 2 illustrates the heat map of regional inequalities in relation to the housing conditions of the Brazilian population. Data represented in figure two takes into consideration Illiteracy Rate (A), Sanitary Facilities Rate (B), Garbage Collection Rate (C) and Rate of Water Supply (D).



Source: IBGE15

Figure 2 Characterization of variables regarding Illiteracy Rate (A), Sanitary Facilities Rate (B), Garbage Collection Rate (C) and Water Supply Rate (D)

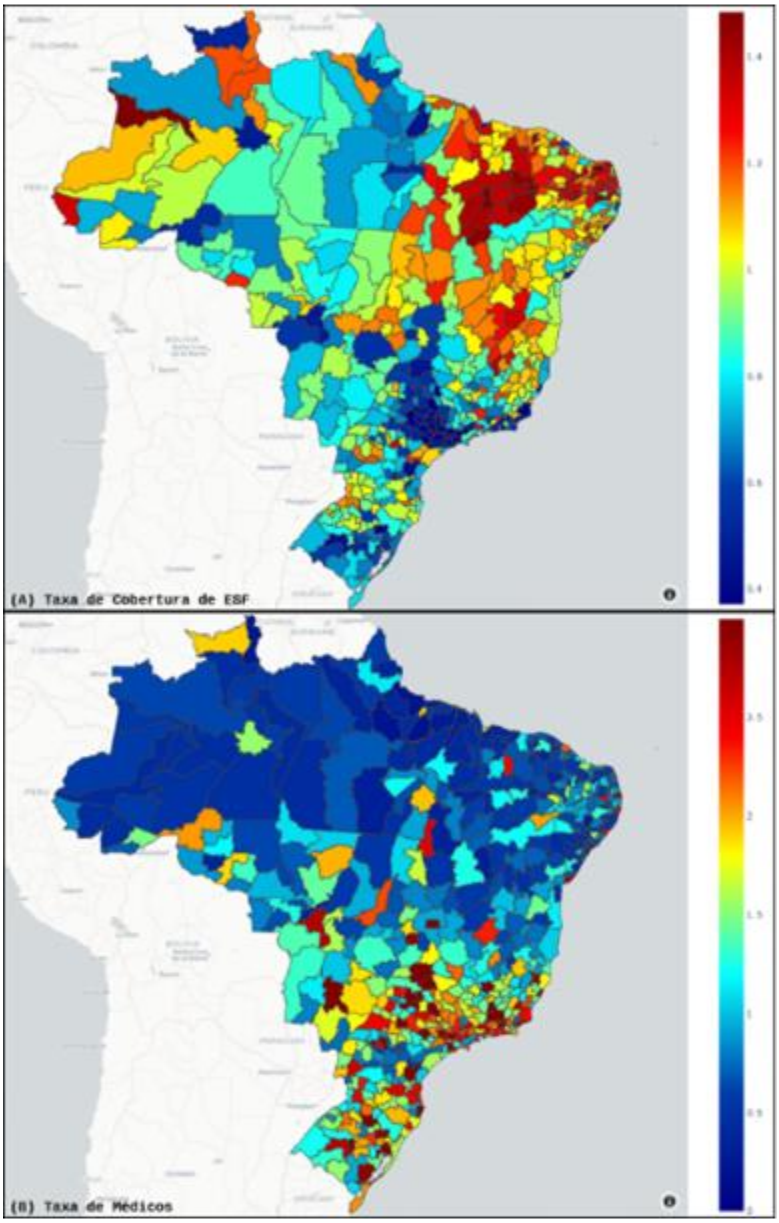
The heat map in Figure 3 presents regional inequalities and income concentration in large metropolitan regions through the analysis of the average household income per capita. It is also possible to observe the infrastructure of health services offered to the Brazilian population is unevenly concentrated through the microregions. As it is displayed on north and northeast micro-regions.



Source: DATASUS13

Figure 3 Characterization of variables regarding Bed Rate (A), X-Ray Equipment Rate (B), Tomography Equipment Rate (C) and Mechanical Ventilator Rate (D)

As shown in Figure 4, we can observe a homogeneity in the coverage of ESF with a predominant concentration in the North and Northeast regions. This pattern is opposite to the other analyzed variables. It is also possible to observe an unequal distribution of doctors through the microregions, where south and southeast regions present greater concentrations of them.



Source: DATASUS13

Figure 4 Characterization of variables regarding Family Health Strategy Coverage Rate (A) and Physicians Rate (B)

4. Discussion

The analysis of the socioeconomic scenario carried out by this study, and based on numbers raised by previous research, allows a correlation between it and indicators related to COVID-19. As demonstrated in the study by Dedecca[16] and with data from the IPEA 2015 on social inequality and the political challenges to overcome it, Brazil started the 2010s with a high level of inequality despite having managed to improve its GINI index of 0 .60 to 0.53, values corresponding to the years 1999 and 2011, respectively. The results here presented demonstrate that housing conditions, income and service provision infrastructure are related to indicators of infection and mortality by COVID-19 in Brazil.

For the study author, the improvement in the previously presented indicator reflects the adopted policy of valuing the minimum wage plus social benefits and keeping low inflation rates. These factors during 2000 to 2010, contributed to the increase in the purchasing power of the less favored parts of the population. However, this reduction of social inequality is restricted to current income, having no direct impact on the precariousness of access to public service goods. Also, according to the study, the *status-quo* of socioeconomic inequality in the country could not undergo major structural changes starting with a growth of limited duration and intensity known to have been experienced in the past decade.

Figueiredo et al.[17] also discuss the probable relationship between social determination and the risk of infection, morbidity and mortality associated with COVID-19. It is possible to verify in their study heterogenic rates of infection by SARS-COV-2. However, the authors suggest that the pandemic started in Federation Units with better socioeconomic conditions and expanded to more vulnerable areas. Furthermore, the authors conclude that socioeconomic factors and inequities influenced both the incidence and mortality from COVID-19 and that the data may still be underreported, since regions with better infrastructure also have a greater supply of tests and access to treatment.

In this context, data presented in this work also show the concentration of the best infrastructure is in the micro-regions with development of the secondary and tertiary sectors. In addition, the areas with the worst infrastructure reflect the country's historical socioeconomic inequality, therefore, the IBGE microregions that present the worst indicators of mortality and infection by COVID-19, certainly, are the same with precarious infrastructure. In the same way as previous studies, Dedecca[16] and Castro et al[18]. the analysis of sociodemographic, economic, structural variables and the epidemiological indicators of COVID-19 show heterogeneity between the territories of the IBGE microregions.

Some of the highlighted analyzed variables of this study are sanitary facilities, GPD, average household income, ICU beds, X-ray equipment, community health agents, coverage of the Family Health Strategy, nurses, and doctors. The analysis of these variables makes possible noticing different realities in resources distribution in Brazil for treatment of severe cases of COVID-19. While about 80% of the Brazilian population depends exclusively on the health services offered by the SUS, the supply of these same services is uneven. This creates different challenges for coping with the pandemic at the local level. Geographically, the distribution of beds in the regions North and Southeast was uneven, with 9 and 21 beds per 100,000 people, respectively[18].

Results also demonstrate that the health policy followed regional development proposals, aiming to improve the integration of health services, the distribution of resources and expansion of access to health. Despite the changes that have taken place in the Northeast region, characterized by an improvement in the profile of socioeconomic development and the supply of services, these have remained concentrated in a few regions, as it follows the historical trend of concentration in capitals and traditional regional centers. In addition, a few areas of this macro-region are inserted in the recent process of agribusiness expansion. In contrast it is possible to observe development and supply of services inland in the Southeast and South, to a greater extent in the state of São Paulo. This trend can be partially explained by the industries concentration, services, and urban population of large centers[19].

The analysis of the results along with the epidemiological indicators, made it possible to observe the different realities, in different aspects, of the micro-regional territories evaluated. The different commitments around sociodemographic, educational, structural and health services in general, show great inequalities present in the country. In this light, it is worth noting that universality is one of the fundamental principles of the SUS and determines that access to health actions and services must be guaranteed to all people, without discrimination[20]. It is necessary having local media and health teams themselves implementing and reinforcing public policies that promote greater and continuously population adherence to containment measures, such as the practice of social distancing, use of masks, hand hygiene. In addition, it is extremely important for the correct contingency that local surveillance system is constantly updated with notifications and quality of data.

5. Conclusion

This study presented the chronic situation of socioeconomic inequality and the infrastructure for the provision of health services in Brazil. Relevant variables in the context of health emergencies were also exposed, such as average household income per capita, GDP per capita, rate of Community Health Agents, ICU beds, coverage by the Family Health Strategy, sanitary installation, and X-ray equipment, with the variables COVID-19 infection and mortality rate. The examination of these aspects imposes the need for greater attention and investments on the part of the public management to the places with the worst infrastructure, promoting equity.

The relationship between aspects of housing conditions, income and service provision infrastructure, and indicators of infection and mortality by COVID-19 in Brazil was also demonstrated. The study highlighted the use of health information systems as a tool for direct application in epidemiology, which can be strategically used in future studies, to boost the sensitivity of surveillance systems. Health and inequality indicators were also mapped through the innovative methodology of spatial behavior. As geospatial modeling can influence decision-making in broad aspects, it may become a determining factor for a correct contingency of emergency situations or with future pandemic potential.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no financial or other conflicts of interest.

Author's contribution

All listed authors effectively participated in the elaboration of the manuscript "A geospatial analysis of inequality indicators related to COVID-19 in Brazil". Following a description of the specifics in each stage of the research is presented.

- Data collection and conceptualization

Guilherme Pasqual Fogaça, Arlene Leite dos Santos Spengler, Leonardo Pedro Salesse, Anita Maria da Rocha Fernandes, Rodrigo Lyra, Graziela Liebel

- Tabulation, data statistical analysis and creation of tables and figures

Guilherme Pasqual Fogaça, Anita Maria da Rocha Fernandes, Rodrigo Lyra, Graziela Liebel

- Text elaboration and norms standardization according to the journal

Guilherme Pasqual Fogaça, Arlene Leite dos Santos Spengler, Leonardo Pedro Salesse, Anita Maria da Rocha Fernandes, Rodrigo Lyra, Ricardo Heffel Farias, Graziela Liebel

- Text revision and significant contributions

Anita Maria da Rocha Fernandes, Rodrigo Lyra, Ricardo Heffel Farias, Graziela Liebel

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