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Social vulnerability and COVID-19 incidence in a Brazilian metropolis

Virna Ribeiro Feitosa Cestari (http://orcid.org/0000-0002-7955-0894) [1]
Raquel Sampaio Florêncio (https://orcid.org/0000-0003-3119-7187) [1]
George Jó Bezerra Sousa (https://orcid.org/0000-0003-0291-6613) [1]
Thiago Santos Garces (https://orcid.org/0000-0002-1670-725X) [1]
Thatiana Araújo Maranhão (https://orcid.org/0000-0003-4003-1365) [2]
Révia Ribeiro Castro (https://orcid.org/0000-0002-9260-4148) [1]
Luana Ibiapina Cordeiro (https://orcid.org/0000-0002-3128-6000) [1]
Lara Lídia Ventura Damasceno (https://orcid.org/0000-0002-0496-5622) [1]
Vera Lucia Mendes de Paula Pessoa (https://orcid.org/0000-0002-8158-7071) [1]
Maria Lúcia Duarte Pereira (http://orcid.org/0000-0002-7685-6169) [1]
Thereza Maria Magalhães Moreira (https://orcid.org/0000-0003-1424-0649) [1]

Abstract *Vulnerability is a crucial factor in addressing COVID-19 as it can aggravate the disease. Thus, it should be considered in COVID-19 control and health prevention and promotion. This ecological study aimed to analyze the spatial distribution of the incidence of COVID-19 cases in a Brazilian metropolis and its association with social vulnerability indicators. Spatial scan analysis was used to identify COVID-19 clusters. The variables for identifying the vulnerability were inserted in a Geographically Weighted Regression (GWR) model to identify their spatial relationship with COVID-19 cases. The incidence of COVID-19 in Fortaleza was 74.52/10,000 inhabitants, with 3,554 reported cases and at least one case registered in each neighborhood. The spatial GWR showed a negative relationship between the incidence of COVID-19 and demographic density (β=-0,0002) and a positive relationship between the incidence of COVID-19 and the percentage of self-employed >18 years (β=1.40), and maximum per capita household income of the poorest fifth (β=0.04). The influence of vulnerability indicators on incidence showed areas that can be the target of public policies to impact the incidence of COVID-19.*

Key words *Coronavirus, Social Vulnerability, Ecological Studies*

[1] Universidade Estadual do Ceará. Av. Dr. Silas Muguba 1700, Itaperi. 60714-903 Fortaleza CE Brasil. virna.ribeiro@hotmail.com
[2] Departamento de Enfermagem, Universidade Estadual do Piauí. Parnaíba PI Brasil.

Introduction

The Coronavirus Disease 2019 (COVID-19) etiological agent is the new Beta Coronavirus 2, which causes Severe Acute Respiratory Syndrome (SARS-CoV-2). In 2020, a Public Health Emergency of International Importance was declared by the World Health Organization (WHO), thus pandemic, with high transmissibility and rapid lethality on all continents[1].

A total of 7,283,289 cases and 431,541 deaths had been confirmed globally from the first case revealed in Wuhan, China, at the end of 2019, to June 15, 2020. In the same period, the U.S. ranked first, with 3,841,609 cases and 203,574 deaths[2]. In the meantime, the American countries with the most cases by August 13, 2020, were the United States (North America), with 5,217,094 cases, and Brazil (South America), with 3,180,758 cases[3].

The Ministry of Health has worked with the Emergency Operations Center (COE) in the planning, organization, and monitoring of actions in this epidemiological setting since the onset of the disease's spread in Brazil. Among the most affected Brazilian states are São Paulo and Rio de Janeiro in the Southeast of Brazil, and Ceará, in the Northeast. The latter, in turn, had confirmed 195,298 thousand cases until August 13, 2020[4]. Among these, 66.3% were residents of Fortaleza, the state capital[5,6].

With a population of 2.7 million, Fortaleza had the first recorded cases of COVID-19 in the state in March 2020, located in the wealthiest neighborhoods and with the best Human Development Index (HDI). The virus entered the city through infected residents returning from foreign trips and is currently spreading through the suburban zone, which hosts the poorest population[7,8].

Besides the epidemiological aggravation, Fortaleza is marked by social inequality regarding housing conditions, income, and demographic structure[9], implying the need for the government's urgent surveillance to identify more significant social vulnerability spaces to streamline spread control prevention of COVID-19. In this sense, studies point to the involvement of highly-vulnerable population groups, depending on their living conditions and health situation[10-12].

In this sense, it is known that the socioeconomic context is decisive in the greater vulnerability to the disease, as it fuels the expansion of the new coronavirus[13,14]. Thus, the socially vulnerable population is the most impacted by its effects, given the lack of or scarce resources and disease prevention or treatment strategies in their daily lives, associated with the difficulties of achieving social distancing, keeping employment and income, and lower access to health and basic sanitation[15-17]. Therefore, this social vulnerability setting must be considered in the actions of health promotion, prevention, and control of COVID-19[9].

This study considered social vulnerability as a poor condition produced by different and unequal ways of subjects to interact with other lives or institutions in health, referring to the socioeconomic situation, demographic identity, culture, family context, networks and social support, gender, violence, social control, and ecosystem[18]. This perspective brings a broader understanding of health policy actions on the multiple factors affecting individuals' daily lives in their territories[19].

Thus, this study aimed to analyze the spatial distribution of the incidence of COVID-19 cases in this Brazilian metropolis and its association with social vulnerability indicators. Our work analyzed data related to March and April that contained geographical case locations made available by the Government of the State of Ceará on a public database.

Methods

This is an ecological study employing the neighborhoods of Fortaleza as units of analysis. According to the Brazilian Institute of Geography and Statistics (IBGE), the city has 121 neighborhoods, 2,669,342 inhabitants, and an area of 312.353km², with a demographic density of 7,786.44 inhabitants/Km² based on data of 1991, 2000, and 2010 Demographic Censuses. It is the most populous city in the state and the fifth most populous in Brazil. It has the tenth largest GDP in the country, accumulating wealth and inequalities, as its income is concentrated in a few neighborhoods with a high HDI, while most of its neighborhoods have an HDI below 0.5, which is considered very low (Figure 1).

Furthermore, this investigation employed secondary data from the IntegraSUS website, which contains information regarding the number of COVID-19 cases and indicators in Ceará available in the public domain[20]. The data analyzed refer to March and April and were collected in May 2020, including only the cases whose notification contained the neighborhood of oc-

Figure 1. Figure 1A. Location of the State of Ceará in Brazil. Figure 1B: Location of Fortaleza in the State of Ceará. Figure 1C: Map of Fortaleza. Figure 1D: Map of Fortaleza with the HDI of its neighborhoods.

Codes: 1 Jacarecanga; 2 São Gerardo; 3 Monte Castelo; 4 Moura Brasil; 5 Barra do Ceará; 6 Vila Velha; 7 Jardim Guanabara; 8 Jardim Iracema; 9 Floresta; 10 Álvaro Weyne; 11 Cristo Redentor; 12 Pirambu; 13 Carlito Pamplona; 14 Ellery; 15 Praia de Iracema; 16 Meireles; 17 Cocó; 18 Cidade 2000; 19 Manuel Dias Branco; 20 Praia do Futuro I; 21 Praia do Futuro II; 22 Engenheiro Luciano Cavalcante; 23 Salinas; 24 Guararapes; 25 Dionísio Torres; 26 Mucuripe; 27 Varjota; 28 Papicu; 29 Cais do Porto; 30 Vicente Pinzón; 31 De Lourdes; 32 Aldeota; 33 Joaquim Távora; 34 Henrique Jorge; 35 João XXIII; 36 Bela Vista; 37 Amadeu Furtado; 38 Parquelândia; 39 Olavo Oliveira; 40 Autran Nunes; 41 Dom Lustosa; 42 Pici; 43 Bonsucesso; 44 Jóquei Clube; 45 Presidente Kennedy; 46 Antônio Bezerra; 47 Quintino Cunha; 48 Padre Andrade; 49 Demócrito Rocha; 50 Montese; 51 Vila União; 52 Aeroporto; 53 Panamericano; 54 Couto Fernandes; 55 Bom Futuro; 56 Jardim América; 57 Itaoca; 58 José Bonifácio; 59 Benfica; 60 Granja Lisboa; 61 Dendê; 62 Mondubim; 63 Jardim Cearense; 64 Vila Peri; 65 Manoel Sátiro; 66 Granja Portugal; 67 Parque São José; 68 Bom Jardim; 69 Prefeito José Walter; 70 Planalto Ayrton Senna; 71 Aracapé; 72 Parque Presidente Vargas; 73 Parque Santa Rosa; 74 Canindezinho; 75 Siqueira; 76 Novo Mondubim; 77 Conjunto Esperança; 78 Genibaú; 79 Passaré; 80 Parque Manibura; 81 Sabiaguaba; 82 Lagoa Redonda; 83 Coaçu; 84 São Bento; 85 Paupina; 86 Jardim das Oliveiras; 87 Edson Queiroz; 88 Alto da Balança; 89 Cajazeiras; 90 Barroso; 91 Serrinha; 92 Dias Macêdo; 93 Boa Vista/Castelão; 94 Cambeba; 95 José de Alencar; 96 Ancuri; 97 Parque Santa Maria; 98 Sapiranga/Coité; 99 Guajeru; 100 Messejana; 101 Curió; 102 Jangurussu; 103 Conjunto Palmeiras; 104 Parque Iracema; 105 Cidade dos Funcionários; 106 Parque Dois Irmãos; 107 Centro; 108 Farias Brito; 109 Fátima; 110 Conjunto Ceará II; 111 Parangaba; 112 Aerolândia; 113 Conjunto Ceará I; 114 Damas; 115 Tauape; 116 Rodolfo Teófilo; 117 Parreão; 118 Maraponga; 119 Itaperi; 120 Parque Araxá; 121 Pedras.

Source: Elaborated by the author.

currence. It is worth mentioning that the state database contains all the cases tested for the disease since the first suspected case. The inclusion criterion was the availability of information on the geographical location of the cases.

Regarding the variables associated with the outcome, the Atlas of Human Development in Brazil addresses more than 200 social vulnerability indicators in demography, education, income, work, and housing, with data from the 1991, 2000, and 2010 Demographic Censuses.

The following indicators were considered for analysis: demographic density, illiteracy, elementary and secondary education in the population

>18 years of age, percentage of the population >25 years of age with a college degree, Gini index, average per capita income, Theil-L index, percentage (%) of self-employed >18 years of age, self-employed and unemployed, percentage (%) of the population with running water, with bathroom and running water, living in households with >2 people per bedroom, percentage (%) of the population living in urban households with garbage collection service, with inadequate water supply and sewage, percentage (%) of people in households with walls that are not masonry or fitted wood, percentage (%) of people in households vulnerable to poverty and who spend more than one hour to commute to work in total employed persons, percentage (%) of people in households without electricity, percentage (%) of vulnerable people and elderly dependents, in the total of people in vulnerable households and with older adults, population of female heads of household with at least one child <15 years of age, population in vulnerable households and with older adults, poverty-vulnerable working population returning daily from work to home, Human Development Index, and maximum per capita household income of the poorest fifth. All of these indicators were taken from the 2010 census.

Initially, a descriptive analysis of the data was carried out, considering the simple and relative or median frequency and interquartile range (IQR), to describe the epidemiological profile of the COVID-19 cases in Fortaleza. Then, we calculated the incidence of the disease in the city, using the number of cases accumulated in each neighborhood in the numerator and the neighborhoods' population in 2010 as the denominator, multiplied by 10,000 inhabitants. The constant 10,000 was selected to compare neighborhoods since some are populous, and others are not.

Concerning spatial analysis, we established the thematic map of COVID-19 incidence in each neighborhood and smoothed the rates by the Bayesian method to reduce the instability caused by the differences between them. This method considers the neighborhood's value, but weighs it against border neighborhoods by a spatial proximity matrix, considering the contiguity criterion, in which a value of "1" is assigned to those with common borders and "0" to those without common borders.

Then, we performed a spatial scan to identify clusters and COVID-19 risk areas. The Relative Risk (RR) of each neighborhood was calculated for the incidence of the disease, and the presence of spatial clusters was identified. We employed the Poisson discrete model to identify spatial clusters, requiring no geographic overlap of clusters, maximum cluster size equal to 50% of the exposed population, circular clusters, and 999 replications.

Finally, the indicators were inserted in an Ordinary Least Square (OLS) step forward non-spatial regression model with an input value of 0.1 to identify the disease incidence-related factors. Those who remained in the final model were also included in a spatial Geographically Weighted Regression (GWR) model because it uses values from the specific neighborhood indicators and considers values from neighboring neighborhoods, adopting a spatial proximity matrix by the contiguity criterion. Finally, the result of the GWR regression was presented on thematic maps.

The local empirical Bayesian rate was calculated by TerraView 4.2.2, the purely spatial scanning analysis was performed by SaTScan 9.6, the non-spatial OLS regression was performed by Stata 12, and the spatial GWR by GWR4.0.9. All maps were produced using QGIS 2.4.17.

This study did not require prior approval from the Research Ethics Committee, given that the COVID-19 database and the Atlas of Human Development in Brazil are public domain information available on the websites of the Government of the State of Ceará and the Institute of Applied Economic Research (IPEA), respectively. The impossibility of identifying the patient is also highlighted since information such as name or address has not been made available. We reiterate researchers' ethical commitment in the management, analysis, and publication of data, as recommended by Resolution No. 510/2016 of the National Research Council.

Results

As of April 28, 2020, Fortaleza had reported 3,554 COVID-19 cases. The patients had a median age of 47 years (IQR: 35-61) and were mostly female (52.9%; n=1,880). Also, the most commonly reported comorbidities were cardiovascular disease (6.5%; n=232) and diabetes (4.9%; n=175). A total of 14.2% (n=505) of the total number of cases were hospitalized, and 3.4% (n=122) of these were in the ICU (Table 1).

Regarding the spatial distribution of COVID-19, Figure 2A shows that all Fortaleza neighborhoods registered at least one case of the disease, and some neighborhoods had a crude incidence of up to 74.52/10,000 inhabitants, and these were located on the urban outskirts (Pedras and Mondubim). When smoothed, we identified that the wealthier neighborhoods (Meireles, Aldeota, Mucuripe, Papicu, and Cocó) still had an essential role in the disease's incidence, as they concentrated the cases for weeks (Figure 2B).

The scan identified that the risk of illness by COVID-19 in the city varied up to 5.26 times in suburban neighborhoods (Pedras and Mondubim) and that affluent neighborhoods, such as Meireles and Aldeota, have a risk 2-4 times greater than the rest of the municipality (Figure 2). Eight statistically significant clusters for the disease were also identified in the municipality (Figure 2D). The most likely cluster, in the small circle, has six neighborhoods (Meireles, Aldeota, Varjota, Mucuripe, Papicu, and Cocó) and a RR 3.06 times higher of illness than the other neighborhoods ($p<0.001$).

Table 2 presents the final model of the OLS regression, which evidenced the influence of vulnerability indicators on the incidence of COVID-19, which, in turn, indicated four statistically significant variables for the outcome: maximum per capita household income of the poorest fifth ($p<0.001$), percentage of self-employed ≥18 years ($p=0.03$), percentage of the population aged ≥18 years with complete elementary school ($p=0.04$), and demographic density ($p=0.04$).

We identified the spatial influence of these variables when entered in the GWR model. The model showed a negative relationship between the incidence of COVID-19 and the population ≥18 years with complete elementary education ($\beta=-0.26$) and demographic density ($\beta=-0.0002$). On the other hand, a positive relationship was observed between the incidence of COVID-19 and the percentage of self-employed ≥18 years ($\beta=1.40$), and the maximum per capita household income of the poorest fifth ($\beta=0.04$) (Table 2). It is noteworthy that the poorest fifth coefficients' demographic density and maximum per capita household income are very close to zero and should therefore be interpreted with caution.

Furthermore, the thematic maps of the results can be seen in Figure 3, except for the association between the incidence of COVID-19 and the percentage of the population ≥18 years with complete elementary school, since the GWR model did not identify a statistically significant relationship in any neighborhood.

Discussion

The COVID-19 pandemic requires reorganizing contemporary societies and has a significant impact, especially in countries and regions with greater social and economic inequalities. From this perspective, addressing the pandemic per-

Table 1. Characterization of COVID-19 reported cases in Fortaleza.

Variables	n (%)	n (%)
Age (median/interquartile range)	47 (35-61)	
Gender	Female	Male
	1880 (52.9)	1674 (47.1)
Diseases and hospitalization	Yes	No
Asthma	12 (0.4)	3542 (99.6)
Cardiovascular diseases	232 (6.5)	3322 (93.5)
Diabetes	175 (5.0)	3379 (95.0)
Immunodeficiencies	12 (0.3)	3542 (99.7)
Neurological diseases	28 (0.8)	3526 (99.2)
Obesity	9 (0.2)	3545 (99.8)
Pneumopathies	27 (0.8)	3527 (99.2)
Kidney diseases	29 (0.8)	3525 (99.2)
Hospitalization	505 (14.2)	3049 (85.8)
ICU admission	122 (3.4)	3432 (96.6)
Total	3554 (100.0)	

n = Sample size; %: Percentage.
Source: Elaborated by the author.

meates the biological field and health sectors, affecting the economy, politics, and society, which shows the need to pay attention to conditions that increase the population's health vulnerability.

Globally, the spread of the virus is significant in the suburbs. This population segment overly suffers from the high population density per household, the use of public transport, and the

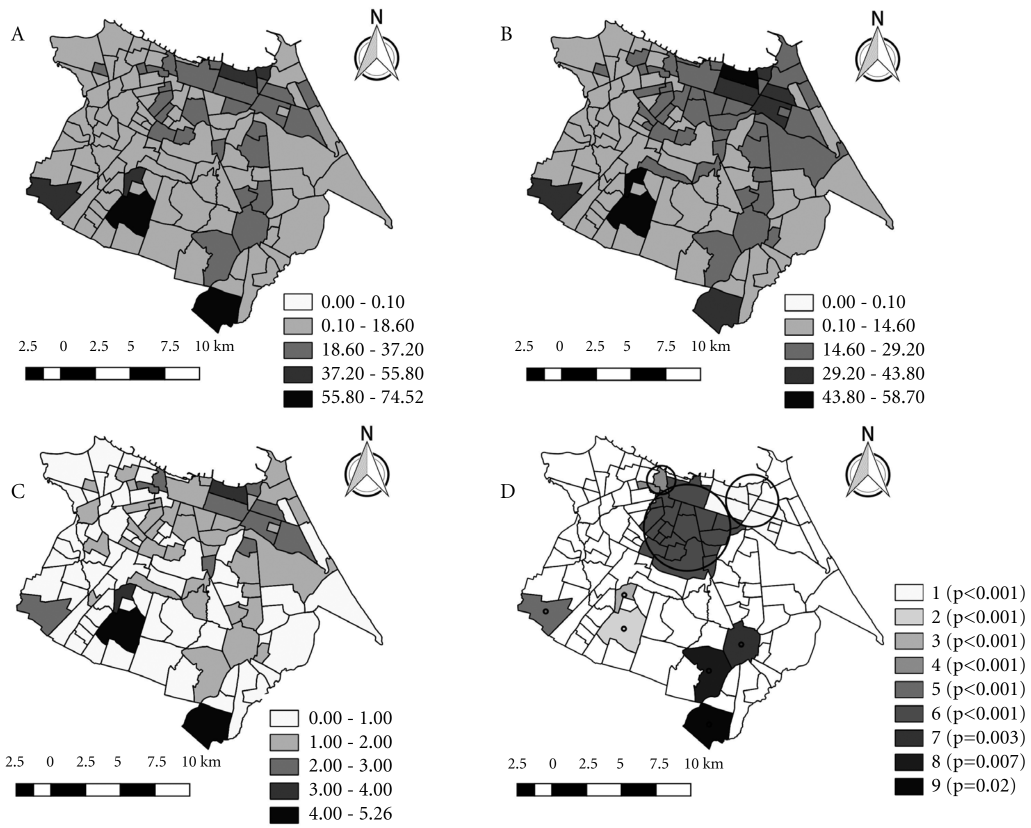

Figure 2. Crude and Bayesian incidence of COVID-19 in Fortaleza, risk of illness and probable clusters of infection.

Source: Elaborated by the author.

Table 2. Final model of OLS step forward and GWR regression for COVID-19 incidence.

Variables	OLS Regression		GWR Regression	Regressão GWR	
Social vulnerability indicators	**Coefficient**	**Standard Error**	**p-value**	**Coefficient**	**Standard Error**
Maximum per capita household income of the poorest fifth	.042	.010	<0.001	0.04	0.002
% of self-employed >18 years	1.36	.628	0.03	1.40	0.18
% of the population >18 years with complete elementary school	-.323	.16	0.04	-0.26	0.04
Demographic density	-.0002	.0001	0.04	-0.0002	0.0002
Constant	-1.22	16.15		-5.70	3.76

OLS Regression: $R^2=0.2399$; Adjusted $R^2=0.2137$; GWR Regression: $R^2=0.2816$; Adjusted $R^2=0.2165$.
Source: Elaborated by the author.

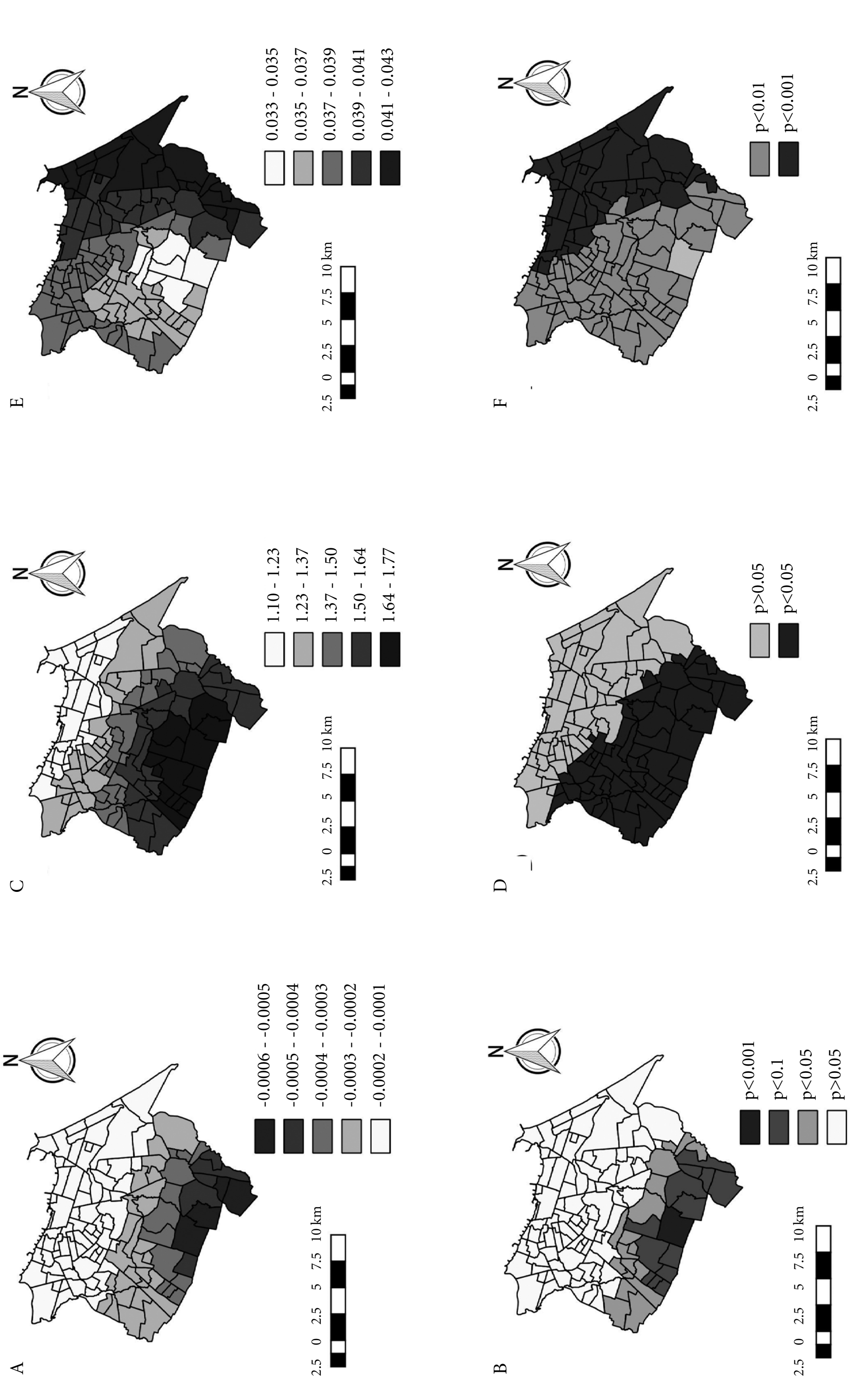

Figure 3. Coefficients and p-values of the GWR regression for COVID-19 vulnerability indicators in Fortaleza.

Note: Figure 3A: β value for demographic density. Figure 3B: p-value of demographic density. Figure 3C: β value for % of self-employed >18 years. 3D figure: p-value % of self-employed >18 years. Figure 3E: β value of the maximum per capita household income of the poorest fifth. Figure 3F: p-value of the maximum per capita household income of the poorest fifth.

weak employment ties. In turn, these situations favor vulnerability in health, a human condition characterized by the subject-social interaction, and this relationship produces unsafety when agency is not woven by the subject or collective in the context of health[18]. In this study, the entire neighborhood demographic density was used instead of the household's, as they are the only ones available by IBGE.

We could also observe that municipalities with high COVID-19 numbers are among the most populous, such as New York, in the United States (U.S)[21], and Mumbai, India[22]. In New York, the Coronavirus outbreak began in March 2020, reaching 100 cases in 5 days and 10,000 cases on March 22[21].

In the national context, some populous Brazilian cities such as São Paulo, Rio de Janeiro, and Fortaleza have reached high numbers of cases. The latter showed high, rapidly growing case rates and with two peaks recorded in May[23]. Associated with tourism and travel, this epidemic is initially characterized by spreading among the middle and upper classes, in which there was a large number of cases and incidence in more affluent geographic regions of the big capitals.

Although much research is under development, the causal relationship between COVID-19 and the territory has not yet been fully established. However, some inferences can be made since the profile of people with COVID-19 in this study is similar to that of other studies conducted in the State[7,8] and other Brazilian regions[9].

In this study, the most populous city in the state, with a mostly urban territory and high demographic density, Fortaleza had a high incidence of COVID-19, similar to that of Mumbai, a city in western India, with a high urban population density and representing 20% of cases in that country[22], and with other urban areas of greater epidemic intensity and high population density[24].

Furthermore, the spatial distribution was heterogeneous, with a disproportionate disease distribution between wealthy and suburban neighborhoods. The incidence was higher in northern neighborhoods with lower demographic density and lower in neighborhoods located in the extreme south of the municipality, with high demographic density. A spatial analysis study of COVID-19 carried out in the 24 administrative regions of Mumbai showed a distinct heterogeneous distribution, with fewer cases in less populated regions and a higher number of cases in more populated regions[22].

The discrepancy between Fortaleza and Mumbai may be related to socioeconomic aspects since Fortaleza's northern zone has a high HDI and is where the first cases of the disease were reported, unlike the southern suburban region, which has a low HDI, which directly affects the lower purchasing power of this population, hindering travel and tourism to countries with confirmed cases of the disease at the time[25].

Therefore, it became evident that the higher the percentage of employed people ≥18 years, the higher the disease incidence in a significant portion of Fortaleza's neighborhoods. This is an expected result, given that this population has greater difficulty maintaining social distancing due to its employment and income features, and because these people use public transport more frequently, have more residents per household, and have less access to basic sanitation and health. Thus, they are more likely to become infected and spread the disease. In this setting, the subject-social relationship is weakened, and, worse still, the appearance of these subjects is denied by employers and the State.

Given the above, Brazil is marked by inequalities and inequities in access to and ownership of goods, services, and wealth resulting from accumulated generational group work and unevenly distributed[4]. Health inequalities generate different possibilities to take advantage of technological advances and differ in the likelihood of exposure to factors that determine health, disease, and death[3]. Thus, the number of cases and mortality have been rapidly and consubstantially growing in the suburbs and slowly internalizing[14].

Also, while the number of cases is concentrated in the suburbs, there is talk of relaxing distancing measures. However, the break in isolation and social distancing has led to increased disease transmission, leading to higher hospitalization rates and severe cases[5,6]. In this area, unequal access to health services impacts the disease's clinical outcome, reaffirming the relevance of control measures. Furthermore, it reflects insufficient public policies and disregard for social vulnerability indicators.

This study shows, mainly, how the disease manifested itself at the onset of the pandemic, when, in most cases, people with higher income were tested, given that the diagnosis at that time was based on the molecular test (RT-PCR) performed on a larger scale by people with higher income and accessibility to health services.

For this reason, inequality has been observed in the underreporting rates of COVID-19 in the

Ciência & Saúde Coletiva, 26(3):1023-1033, 2021

various federative states, with the first seven spots occupied by states in the North and Northeast regions. Therefore, expanding the disease's testing and diagnosis is a challenge imposed on Brazilian society and the Unified Health System[2].

The relationship between pandemic and social vulnerability has been found in other historical moments, such as the Spanish, swine (H1N1), and SARS flu, confirming that social inequalities are determinant for the transmission severity of these diseases[1].

Based on the premise that health vulnerability occurs in an appearance scene that is a space for recognition by the other, we should reflect on how suburban life should be considered in a country with massive social inequality. However, how does one recognize own vulnerability? Never so pertinent and current question has been asked in this pandemic that has claimed the lives of thousands. In the face of the problem, it is vital to analyze the repercussions of COVID-19 on vulnerable individuals to curb the spread of the epidemic with targeted actions in order to support government policies.

Finally, it is worth noting that, besides demographic and spatial variables of social vulnerability as the COVID-19 pandemic evolves, countries consider policies to protect those most at risk of serious illnesses. Individuals with greater vulnerability are carriers of serious chronic diseases, older adults, males, cardiovascular diseases, and diabetes, and these factors have been associated with increased risk of severe COVID-19 and death[26].

It is complicated to define who is vulnerable, which transcends sociodemographic and geographic factors. Therefore, we must consider those individuals at risk of serious illness. The evidence shows that the proportion of people with this type of vulnerability can make up to 30% of the population in some regions. In this sense, special efforts to protect them are essential, implementing multifaceted strategies directed to the profile of the population[27].

This work has some limitations, such as few previous references that have helped select social vulnerability indicators to COVID-19 and that public data available for analysis in the study may be impacted by underreporting due to the low rate of tests per million inhabitants. We have also observed a significant delay in reporting test results during the first few weeks of the COVID-19 outbreak. Moreover, all suspected cases were tested, including those that were in contact with a confirmed case. However, the low availability of RT-PCR (reverse transcription-polymerase chain reaction) tests forced the Ministry of Health to recommend the test only for severe cases. This approach has also been extended to those in high-risk groups (for example, healthcare professionals).

As for the vulnerability indicators, it is essential to note that even following the IBGE criteria, the data used refer to the 2010 census and may have undergone changes in the last 10 years. New data would be collected in 2020 for more accurate production. However, the very pandemic studied prevented a new census.

Conclusion

The influence of vulnerability indicators on the incidence showed that the higher the level of education, the lower the risk of illness due to COVID-19, besides the fact that the working-age population is the most vulnerable to being exposed to infection.

Thus, knowing the social vulnerability indicators in the pandemic context allows identifying and prioritizing highly vulnerable groups and guiding and adapting interventions targeted to this population. There is an urgent need to reallocate public resources and reinforce health promotion actions and preventive measures in places of greater social vulnerability to favor the formulation of new socioeconomic stabilization policies and programs for these clients, curbing social inequalities.

Collaborations

VRF Cestari, RS Florêncio, RJB Sousa and TS Garces acted in the conception, analysis, and interpretation of the data. RR Castro, LI Cordeiro and LLV Damasceno contributed substantially to the writing of this paper. TA Maranhão, VLMP Pessoa, MLD Pereira, and TMM Moreira supervised and critically reviewed all the study stages. All authors participated in the approval of the final version to be published.

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