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Vulnerability to severe forms of COVID-19: an intra-municipal analysis in the city of Rio de Janeiro, Brazil

Vulnerabilidade a formas graves de COVID-19: uma análise intramunicipal na cidade do Rio de Janeiro, Brasil

Vulnerabilidad socioespacial y formas graves de COVID-19: un análisis intramunicipal en la ciudad de Río de Janeiro, Brasil

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Abstract

Given the characteristics of the COVID-19 pandemic and the limited tools for orienting interventions in surveillance, control, and clinical care, the current article aims to identify areas with greater vulnerability to severe cases of the disease in Rio de Janeiro, Brazil, a city characterized by huge social and spatial heterogeneity. In order to identify these areas, the authors prepared an index of vulnerability to severe cases of COVID-19 based on the construction, weighting, and integration of three levels of information: mean number of residents per household and density of persons 60 years or older (both per census tract) and neighborhood tuberculosis incidence rate in the year 2018. The data on residents per household and density of persons 60 years or older were obtained from the 2010 Population Census, *and data on tuberculosis incidence were taken from the Brazilian Information System for Notificable Diseases (SINAN). Weighting of the indicators comprising the index used analytic hierarchy process (AHP), and the levels of information were integrated via weighted linear combination with map algebra. Spatialization of the index of vulnerability to severe COVID-19 in the city of Rio de Janeiro reveals the existence of more vulnerable areas in different parts of the city's territory, reflecting its urban complexity. The areas with greatest vulnerability are located in the North and West Zones of the city and in poor neighborhoods nested within upper-income parts of the South and West Zones. Understanding these conditions of vulnerability can facilitate the development of strategies to monitor the evolution of COVID-19 and orient measures for prevention and health promotion.*

COVID-19; Vulnerability; Population Surveillance; Epidemiological Monitoring

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Four months after the emergence and spread of the novel coronavirus (SARS-CoV-2) to numerous countries around the world, the impact from the number of confirmed cases (823,626) and deaths (40,598), alongside the enormous pressure on health systems due to the need for hospital care of severe cases, poses one of the most daunting global health challenges in recent decades [1,2].

On April 1st, 2020, the world reported more than 4,800 deaths from COVID-19. The death toll exceeded 5,000 by the following day [1,2]. The rapid rise in the number of deaths makes COVID-19 the deadliest infectious disease in the world, surpassing tuberculosis (TB), which killed approximately 4,000 people a day in 2018 according to the World Health Organization (WHO) [3].

Differential risk of COVID-19 distribution is suggested by the biological characteristics of SARS-CoV-2, with high infectivity [4] and occurrence of the infection in a completely susceptible population occupying extremely heterogenous territories in terms of living conditions. The groups at greatest risk of developing the severe form of COVID-19 are the elderly, individuals with pre-existing respiratory diseases and debilitated immune systems, and population groups living in crowded conditions [5].

In the city of Rio de Janeiro, Brazil, starting with the introduction of the virus until maintenance of the circulation of autochthonous cases, growing numbers of confirmed cases and deaths have been reported (1,110 cases and 47 deaths as of April 6, with an estimated 4.24% case-fatality rate (Painel Rio COVID-19. https://experience.arcgis.com/experience/38efc69787a346959c931568bd9e2cc4, accessed on 02/Apr/2020).

In addition to the epidemiological situation, the city of Rio de Janeiro presents sharp social inequalities in housing, income, and demographics [6], creating the urgent need for surveillance to identify areas with greater vulnerability to the severe form of COVID-19, with the aim of optimizing control of its spread and prevention of severe cases. Studies have pointed to the impact in population groups disproportionately exposed to the risk of respiratory diseases based on their living conditions and health status [7,8].

The current study thus aims to characterize the areas of the city of Rio de Janeiro according to their vulnerability to the severe form of COVID-19, as factors that increase transmission of the infection and the severity of cases.

Methodology

Study area

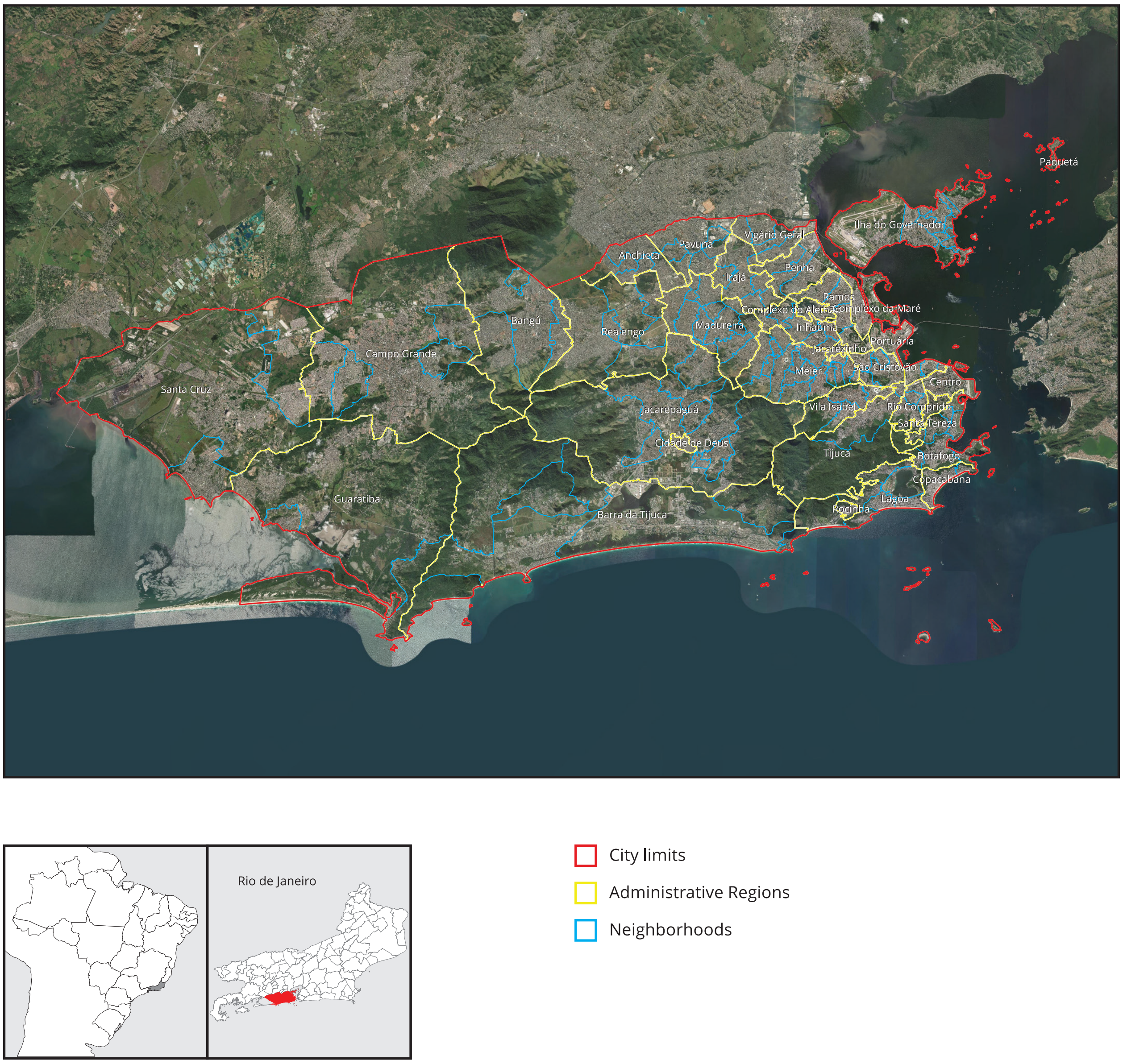
The city of Rio de Janeiro, capital of the state by the same name, is located in the Southeast region of Brazil. The city's area is approximately 1,197km², and the population was 6,320,446 in 2010. The city is divided into 10 Planning Areas, 33 Administrative Regions, and 160 neighborhoods. Rio displays enormous geographic complexity (topographic characteristics, peculiarities of the coastline, and spatial heterogeneity of land use and occupation), making this urban territory a mosaic of landscapes and social contrasts (Figure 1).

Vulnerability to the severe form of COVID-19 was measured by elaborating a composite index, calculated by cross-referencing three levels of information pertaining to indicators that increase the transmission and the severity of cases. Information was used on the mean number of residents per household per census tract, density of persons 60 years or older per km² per census tract, and TB incidence per 100,000 inhabitants per neighborhood. The TB incidence rate jointly expresses the presence of housing contexts favorable to the transmission of respiratory diseases and a risk factor for severe forms of COVID-19 [9,10]. Since the study aimed to develop an indicator for timely operationalization and rapid response in crisis situations, we opted to create a simplified model (with few variables) rather than a more complex model.

The mean number of residents per household used data from the *2010 Population Census* to calculate the resident population divided by the number of households [11]. Higher numbers of residents per household were considered a facilitating factor for COVID-19 transmission, considering exposure to the viral load between susceptible and infected individuals within the household.

Figure 1

Administrative division of the city of Rio de Janeiro, Brazil.



Source: Brazilian Institute of Geography and Statistics.

To build the indicator "density of persons 60 years or older per km²" in 2020, the database of the *2010 Population Census* was used to obtain the number of persons over 50 years of age, and this total was divided by the occupied residential area in each census tract [12]. Mapping the area actually occupied in the territory was done with "Supervised Classification" of the Landsat 8 satellite image from 2018 (https://landsat.gsfc.nasa.gov/landsat-data-continuity-mission/). The semiautomatic classification was refined by visual interpretation of the Pleiades satellite image (year 2018. https://eos.com/pleiades-1/), which consists of manual vectorization of the target classes. The density of persons over 60 years of age expresses greater density of a risk group for the development of the severe form of COVID-19 [13].

The TB incidence rate per 100,000 inhabitants according to neighborhoods in the year 2018 was calculated with data on new cases of pulmonary TB provided by the Brazilian Information System for Notificable Diseases (SINAN) and the population projections for each neighborhood (Secretaria Municipal de Saúde do Rio de Janeiro. TabNet Linux 2.6a: tuberculose – SINAN Net. http://tabnet.rio.rj.gov.br/cgi-bin/dh?sinan/definicoes/tuberc2007.def, accessed on 03/Apr/2020). This level of information jointly expresses the occurrence of spaces prone to transmission of respiratory etiological agents and more precarious socioeconomic conditions [9].

Having built and mapped the information levels, analytic hierarchy process (AHP) [14] was used to determine each level's relative contribution to the data integration and construction of the index. The levels' percentage contribution to vulnerability to severe COVID-19 was 40% for TB, 30% for density of persons 60 years or older, and 30% for mean residents per household. The information levels were standardized by the minimax method such that they varied from 0 to 1 in order for the different scales of magnitude not to interfere with construction of the index.

Based on this standardization and the definition of the relative contributions, thematic integration of the different levels of information was performed through weighted linear combination via map algebra [15].

After the thematic integration process, the map was obtained that expresses, in the territory, the index of vulnerability to the severe form of COVID-19 in the city of Rio de Janeiro on the census-tract scale, analyzed on different geographic scales such as Administrative Regions and neighborhoods. All the data processing and mapping were performed in ArcGis 10.5 (http://www.esri.com/software/arcgis/index.html).

Results

The mean number of residents per household displayed huge heterogeneity. The lowest intra-domiciliary density rates were observed in the census tracts in the Administrative Regions located in the South Zone (Copacabana: 2.20 residents/household, Botafogo: 2.35 residents/household, and Lagoa: 2.48 residents/household), Central Zone (Centro: 2.25 residents/household and Paquetá: 2.49 residents/household), and Grande Tijuca Zone (Tijuca: 2.68 residents/household and Vila Isabel: 2.77 residents/household). High household density was most frequent in large parts of the Administrative Regions comprising the North Zone (Jacarezinho: 3.29 residents/household, Complexo do Alemão: 3.24 residents/household, and Vigário Geral: 3.23 residents/household) and West Zone (Santa Cruz: 3.26 residents/household, Guaratiba: 3.24 residents/household, and Cidade de Deus: 3.22 residents/household) (Figure 2, Table 1).

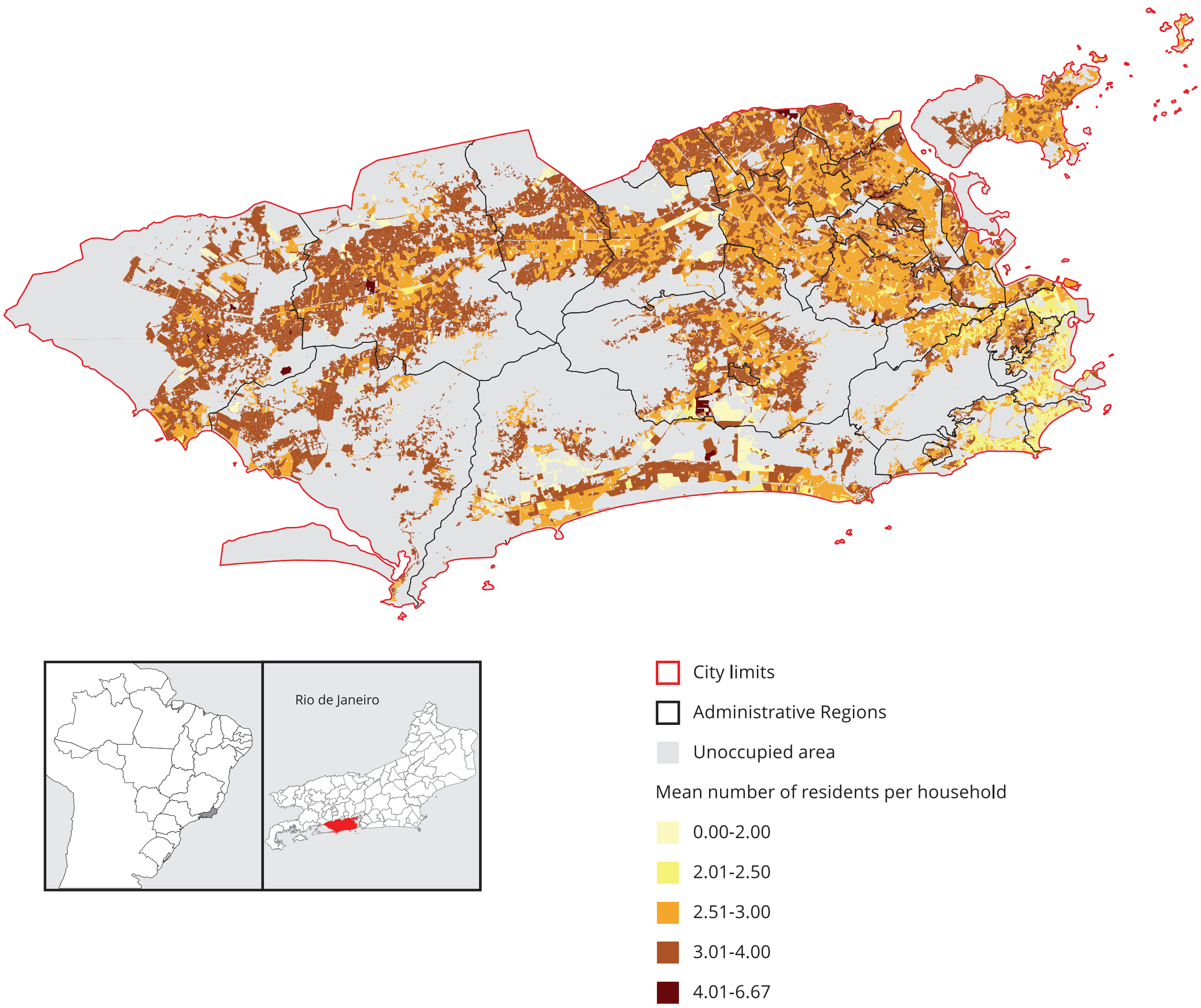
As for density of persons 60 years and older, the highest figures were seen in census tracts belonging to the Administrative Regions of Copacabana: 7,707 residents/km^2, Rocinha: 4,735 residents/km^2, Botafogo: 3,291 residents/km^2, Jacarezinho: 3,227 residents/km^2, Vila Isabel: 3,130 residents/km^2, Tijuca: 2,970 residents/km^2, Lagoa 2,395 residents/km^2, Cidade de Deus: 2,146 residents/km^2, and Complexo da Maré: 2,130 residents/km^2. The lowest density of elderly residents was seen in the Administrative Regions of Guaratiba: 302 residents/km^2, Santa Cruz: 474 residents/km^2, Portuária: 555 residents/km^2, and Barra da Tijuca: 584 residents/km^2 (Figure 3, Table 1).

Spatial distribution of TB shows very high incidence rates in a large share of the neighborhoods in the city of Rio de Janeiro, especially those comprising the Administrative Regions of Jacarezinho: 645/100,000, Cidade de Deus: 527/100,000, Inhaúma: 475/100,000, Portuária: 428/100,000, Complexo da Maré: 410/100,000, Complexo do Alemão: 396/100,000, Bangu: 364/100,000, Ramos: 316/100,000, and Rocinha: 313/100,000 (Figure 4, Table 1).

The characterization of vulnerability to severe COVID-19 stratified the municipality into five classes: (1) very low vulnerability, with 41.9% of the city's occupied area and 16.6% of the population; (2) low, with 13.4% of the occupied area and 20.5% of the population; (3) medium, with 17.4% of the occupied area and 21.1% of the population; (4) high, with 18.2% of the occupied area and 20.2% of

Figure 2

Spatial distribution of mean number of persons per household according to census tracts in the city of Rio de Janeiro, Brazil.



Source: Brazilian Institute of Geography and Statistics. Municipal Health Secretariat. Brazilian Information System for Notificable Diseases.

the population; and (5) very high, accounting for 8.9% of the city's occupied area and 21.3% of the population. The census tracts classified as having high and very high vulnerability are located in different Administrative Regions of the city, especially Bangu, Guaratiba, Cidade de Deus, Rocinha, Copacabana, Rio Comprido, São Cristóvão, Ramos, Inhaúma, Penha, and Vigário Geral (Figure 5).

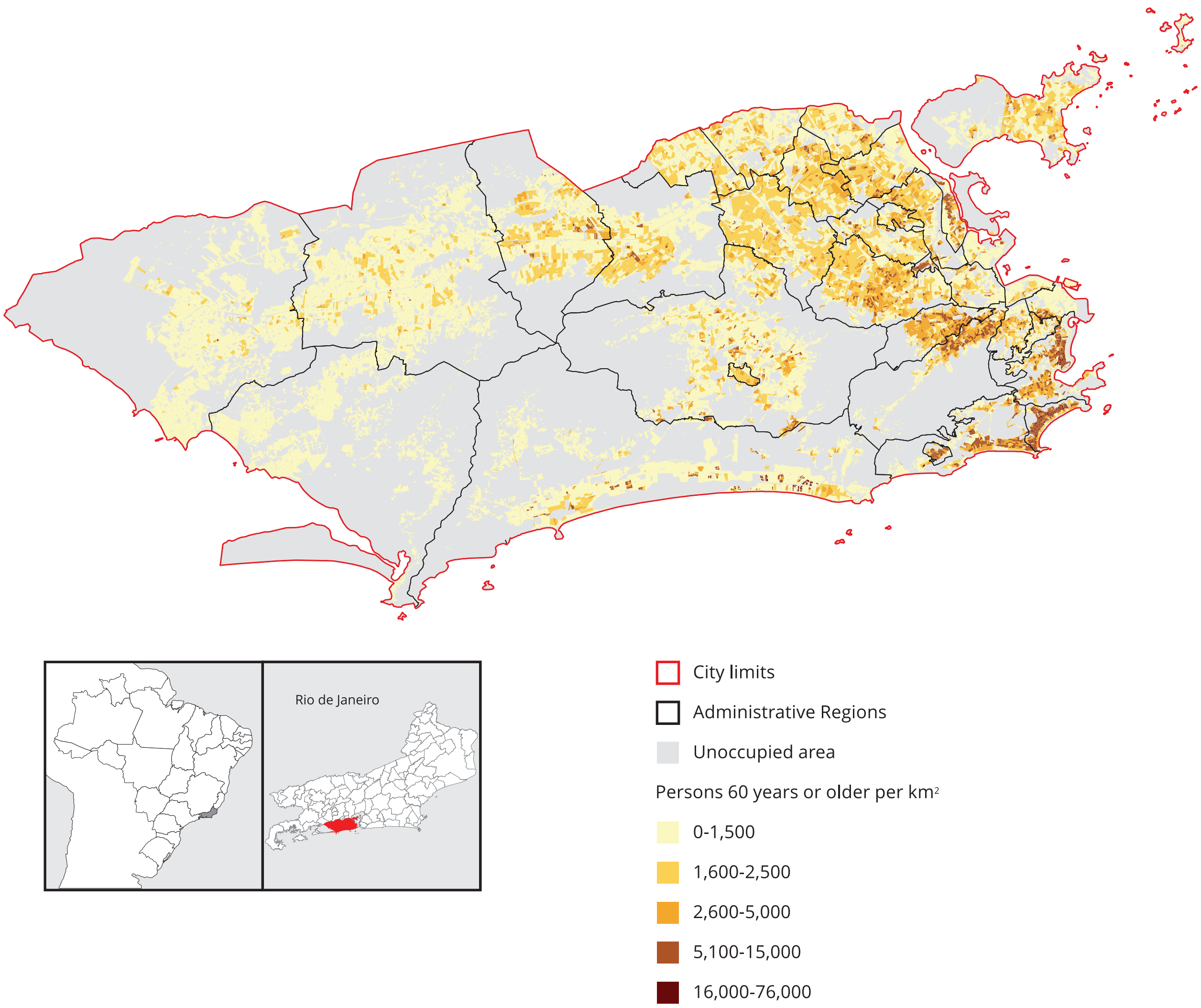
Table 1

Mean number of residents per household, density of persons 60 years and older, tuberculosis (TB) incidence, and classification of vulnerability to severe COVID-19 according to Administrative Regions of Rio de Janeiro, Brazil.

Administrative Regions	Mean number of residents per household	Persons 60 years or older per km²	TB incidence per 100,000 inhabitants in 2018
Anchieta	3.08	1,434.59	237.59
Bangu	3.12	1,394.63	364.99
Barra da Tijuca	2.83	584.69	105.94
Botafogo	2.35	3,291.12	135.67
Campo Grande	3.20	773.66	135.42
Centro	2.25	1,011.42	284.31
Cidade de Deus	3.22	2,146.10	527.30
Complexo da Maré	3.07	2,130.01	410.37
Complexo do Alemão	3.24	2,060.29	396.66
Copacabana	2.20	7,707.73	90.94
Guaratiba	3.24	302.41	261.92
Ilha do Governador	2.95	791.96	112.92
Inhaúma	2.97	1,545.91	475.00
Irajá	2.97	1,816.86	196.53
Jacarepaguá	3.01	1,060.84	123.33
Jacarezinho	3.29	3,227.60	645.04
Lagoa	2.48	2,395.71	170.38
Madureira	3.00	1,690.37	89.77
Meier	2.89	2,120.58	142.23
Paquetá	2.49	594.21	148.90
Pavuna	3.20	1,183.00	133.23
Penha	3.18	1,550.92	122.62
Portuária	3.07	555.53	428.57
Ramos	2.96	1,557.53	316.71
Realengo	3.05	925.82	62.92
Rio Comprido	3.07	1,861.74	267.62
Rocinha	2.95	4,735.97	313.05
Santa Cruz	3.26	474.40	80.12
Santa Tereza	2.89	1,873.77	174.80
São Cristóvão	3.06	1,143.03	203.60
Tijuca	2.68	2,970.36	102.45
Vigário Geral	3.23	1,281.32	111.44
Vila Isabel	2.77	3,130.45	67.26

Figure 3

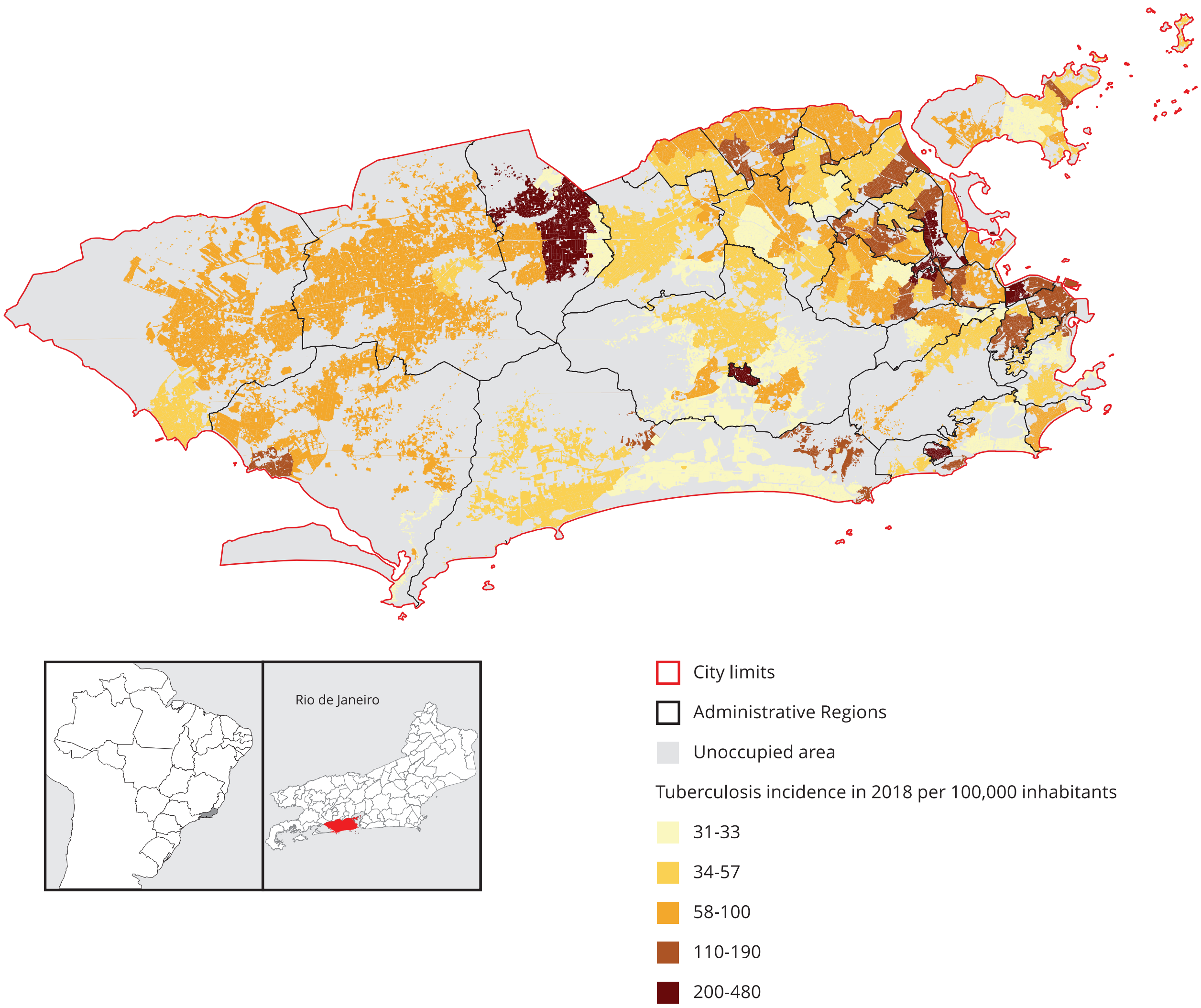
Spatial distribution of density of persons 60 years and older according to census tracts in the city of Rio de Janeiro, Brazil.



Source: Brazilian Institute of Geography and Statistics. Municipal Health Secretariat. Brazilian Information System for Notificable Diseases.

Figure 4

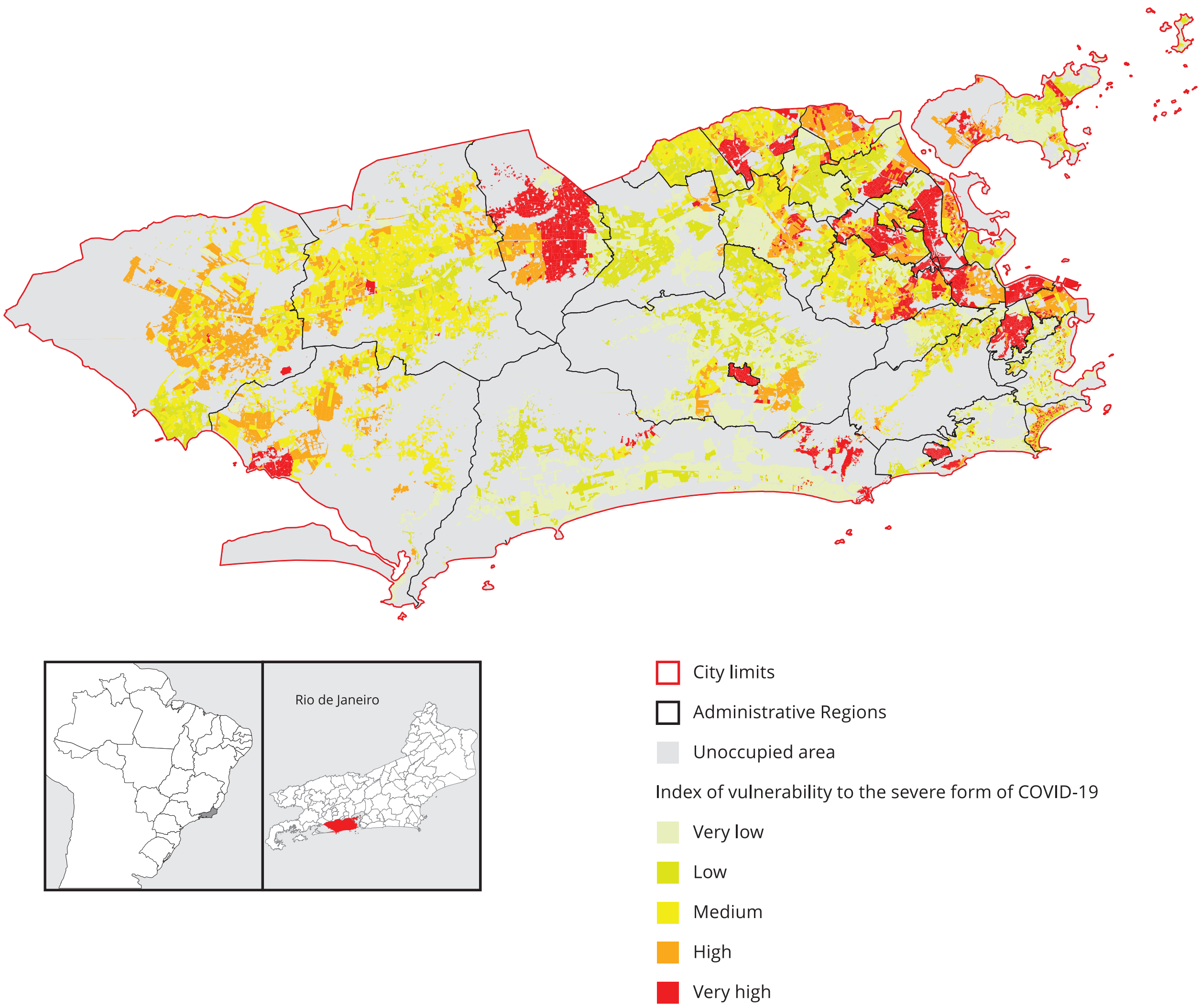
Spatial distribution of tuberculosis (TB) incidence by neighborhood in Rio de Janeiro, Brazil, 2018.



Source: Brazilian Institute of Geography and Statistics. Municipal Health Secretariat. Brazilian Information System for Notificable Diseases.

Figure 5

Spatial distribution of vulnerability to the severe form of COVID-19 according to Administrative Regions in Rio de Janeiro, Brazil.



Source: Brazilian Institute of Geography and Statistics. Municipal Health Secretariat. Brazilian Information System for Notificable Diseases.

Discussion

The findings reveal a highly heterogeneous spatial pattern in terms of vulnerability to the severe form of COVID-19 in Rio de Janeiro, with more vulnerable areas spread across the entire territory and reflecting its urban complexity. However, the results also show that the areas with greatest vulnerability are located in the North Zone and the non-coastal part of the West Zone and poor communities nested within wealthy areas (the coastal parts of the South Zone and West Zone), such as Rocinha and Cidade de Deus, respectively.

The elaboration of the vulnerability index used a simplified number of information levels that could express processes associated with higher possibility of transmission as well as living and demographic conditions related to the severe form of COVID-19.

One limitation to the study was the spatial modeling based on data from the *2010 Population Census*. Despite the time lag, this is the principal source of information on territorial scales with the smallest level of aggregation. In order to minimize the time lag effect, we defined as the population 60 years and older in 2020 the persons who were 50 years or older at the time of the *2010 Population Census*. The magnitude of household density may vary over time, but its differential pattern tends to be maintained. As for TB incidence, the decision to use data from 2018 was due to the time needed to consolidate the data in the information system.

Considering the current moment in the pandemic, the proposal for a simplified indicator for vulnerability to the severe form of COVID-19 is justified by the urgent need to develop surveillance and clinical care strategies that take into account the spatial distribution of specific aspects the occurrence of COVID-19 in each territory. Specifically, in terms of clinical care, the indicator can help orient activities in prevention and patient care by the Family Health Program, based on community needs identified with the indicator [16].

Finally, it is important to emphasize the simplified format of the proposed indicator and the need to develop an enhanced vulnerability index with the inclusion of such variables as distribution of hospital beds (ICU and intermediate units) [17], the population's income profile from formal and informal work [18], and other comorbidities such as hypertension and diabetes [19], so that in more normal health times, vulnerability can be mapped and analyzed more effectively.

Contributors

All the authors contributed to the study's conception and planning, data collection, analysis, and interpretation, and writing and critical revision of the manuscript.

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Resumo

Diante da pandemia de COVID-19 e da escassez de ferramentas para orientar as ações de vigilância, controle e assistência de pessoas infectadas, o presente artigo tem por objetivo evidenciar áreas de maior vulnerabilidade aos casos graves da doença na cidade do Rio de Janeiro, Brasil, caracterizada por grande heterogeneidade socioespacial. Para o estabelecimento dessas áreas foi elaborado um índice de vulnerabilidade aos casos graves de COVID-19 com base na construção, ponderação e integração de três planos de informação: a densidade intradomiciliar média, a densidade de pessoas com 60 anos ou mais (ambas por setor censitário) e a incidência de tuberculose por bairros no ano de 2018. Os dados referentes à densidade intradomiciliar e de pessoas com 60 anos ou mais provêm do Censo Demográfico de 2010 *e os de incidência de tuberculose do Sistema de Informação de Agravos de Notificação (SINAN). A ponderação dos indicadores que compuseram o índice foi realizada por meio da Análise Hierárquica de Processos (AHP), e os planos de informação foram integrados pela Combinação Linear Ponderada por álgebra de mapas. A espacialização do índice de vulnerabilidade aos casos graves na cidade do Rio de Janeiro evidencia a existência de áreas mais vulneráveis em diferentes porções do território, refletindo a sua complexidade urbana. Contudo, é possível observar que as áreas de maior vulnerabilidade estão nas regiões Norte e Oeste da cidade e em comunidades carentes encrustadas nas áreas nobres como as zonas Sul e Oeste. A compreensão dessas condições de vulnerabilidade pode auxiliar no desenvolvimento de estratégias de monitoramento da evolução da doença, bem como para o direcionamento das ações de prevenção e promoção da saúde.*

COVID-19; Vulnerabilidade; Vigilância da População; Monitoramento Epidemiológico

Resumen

Ante la pandemia de COVID-19, y la escasez de instrumentos para orientar las acciones de vigilancia, control y asistencia a las personas infectadas, el objetivo de este artículo persigue resaltar las áreas de mayor vulnerabilidad, donde se producen los casos graves de la enfermedad en la ciudad de Río de Janeiro, Brasil, caracterizada por una gran heterogeneidad socioespacial. Para el establecimiento de esas áreas se elaboró un índice de vulnerabilidad con los casos graves de COVID-19, a partir de la creación, ponderación e integración de tres planos de información: el de densidad intradomiciliaria media, el de densidad de personas con 60 años o más (ambas por sector de censo), y la incidencia de tuberculosis por barrios en el año 2018. Los datos referentes a la densidad intradomiciliaria y de personas con 60 años o más proceden del Censo Demográfico de 2010 *y los de incidencia de tuberculosis del Sistema de Información para Enfermedades de Notificación (SINAN). La ponderación de los indicadores que formaron parte del índice se realizó mediante el Proceso Analítico Jerárquico (AHP por sus siglas en inglés) y los planos de información se integraron a través de la "Combinación Lineal Ponderada" por álgebra de mapas. La espacialización del índice de vulnerabilidad en lo que se refiere a los casos graves, en la ciudad de Río de Janeiro, pone en evidencia la existencia de áreas más vulnerables en diferentes áreas del territorio, reflejando su complejidad urbana. Por ello, es posible observar que las áreas de mayor vulnerabilidad se encuentran en las Regiones Norte y Oeste de la ciudad, así como en comunidades sin recursos insertadas en áreas pudientes como las Zonas Sur y Oeste. La comprensión de estas condiciones de vulnerabilidad puede apoyar el desarrollo de estrategias de supervisión de la evolución de la enfermedad, así como la dirección de acciones de prevención y promoción de la salud.*

COVID-19; Vulnerabilidad; Vigilancia de la Población; Monitoreo Epidemiológico

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