Human development, social vulnerability and COVID-19 in Brazil: A study of the social determinants of health

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Abstract

Background: COVID-19 was confirmed in Brazil in February 2020. Since then, the disease has spread throughout the country, reaching the poorest areas. This study analyzes the relationship between COVID-19 and the population's living conditions. We aimed to identify social determinants related to the incidence, mortality, and case fatality rate of COVID-19 in Brazil, in 2020.

Methods: This is an ecological study evaluating the relationship between incidence, mortality, and case fatality rates and 49 social indicators of human development and social vulnerability. For the analysis, bivariate spatial correlation and multivariate and spatial regression models (spatial lag model and spatial error models) were used, considering a 95% confidence interval and a significance level of 5%.

Results: A total of 44.8% of municipalities registered confirmed cases of COVID-19 and 14.7% had deaths. We observed that 56.2% of municipalities with confirmed cases had very low human development (incidence: 59.00/100,000; mortality: 36.75/million), and 52.8% had very high vulnerability (incidence: 41.68/100,000; mortality: 27.46/million). The regression model showed 17 indicators associated with transmission of COVID-19 in Brazil.

Conclusions: Although COVID-19 first arrived in the most developed and least vulnerable municipalities in Brazil, it has already reached locations that are farther from large urban centers, whose populations are exposed to a context of intense social vulnerability. Based on these findings, it is necessary to adopt measures that take local social aspects into account in order to contain the pandemic.

Background

On December 31, 2019, China reported to the World Health Organization (WHO) an outbreak of pneumonia in the city of Wuhan, a metropolis of 11 million people in the Hubei province. Days later, the causative agent was identified, a new coronavirus called severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), causing coronavirus disease 2019 (COVID-19)[1]. On March 11, the WHO declared a pandemic[2].

As of April 11, 2020, there were more than 4.1 million cases and 284,000 deaths due to the disease worldwide. The countries with the highest number of cases are the USA (1.3 million), Spain (224,000), and the United Kingdom (224,000). In number of deaths, the USA (79,000), the United Kingdom (32,000), and Italy (30,000) have the highest numbers[3].

In Brazil, the first case of COVID-19 was confirmed on February 26, 2020, and the first death was confirmed on March 17, in São Paulo, the country's most populous metropolis, with approximately 12 million inhabitants[4]. The disease spread rapidly to other Brazilian states. On April 11, the country had 163,000 cases and 11,000 deaths[3].

In all countries, but especially in those of low and middle incomes, there is concern regarding the effects of the pandemic on the most impoverished populations[5,6]. These population groups have difficulties in adopting preventive measures (such as social isolation); they are exposed to a context of pragmatic vulnerability that increases the risk of contamination, and, if infection occurs, they have limited access to health services. This is a complex, dynamic context that requires special attention from governments.

All of these conditions in which people live and which express, to a greater or lesser extent, the risk of illness, are called social determinants of health (SDH)[7]. The identification of the SDH that influence the dynamics of COVID-19 in Brazil is of fundamental importance for dealing with the pandemic and its consequences, thus contributing to the definition of mitigating public policies.

In Brazil, the Human Development Atlas and the Social Vulnerability Atlas are two important sources for studying the SDH, as they help to understand the context of the population's living conditions and thus supporting decision making. These include the Municipal Human Development Index (MHDI) and the Social Vulnerability Index (SVI) with their respective dimensions. The MHDI considers development as "the capacity to expand the freedoms of individuals, in relation to their capacities and opportunities"[8]. Although advances have been observed, especially in the last three decades, the MHDI of 1/4 of Brazilian municipalities are considered low or very low. The SVI, on the other hand, measures "the access, absence, or insufficiency of some assets in areas of Brazilian territory, which should, in principle, be available to every citizen, due to the action of the State." About 1/3 of the Brazilian municipalities are classified as having high or very high vulnerability[9].

Based on this and on the need to understand the relationship between COVID-19 and the population's living conditions, this study aimed to identify the SDH related to the incidence, mortality, and case fatality rates of COVID-19 in Brazil, in 2020.

Methods

This is an ecological study involving all confirmed cases of COVID-19 in Brazil until May 6, 2020.

In this study, the following three epidemiological indicators were adopted as dependent variables: i. incidence rate/100,000 inhabitants, ii. mortality rate/million inhabitants, and iii. case fatality rate (%). Data on cases and deaths were obtained from the CoVida network panel (https://painel.covid19br.org/), and population data were obtained from the Brazilian Institute of Geography and Statistics (IBGE, acronym in Portuguese) (https://www.ibge.gov. br /). The indicators were calculated, according to the following equations: (see Equations in the Supplementary Files)

The group of independent variables was composed of 49 indicators of human development and social vulnerability, obtained from the Municipal Human Development Atlas of MHDI (http://atlasbrasil.org.br/2013/) and the Social Vulnerability Atlas of SVI (http://ivs.ipea.gov.br/index.php/pt/).

The MHDI is composed of nine variables grouped into the following three categories:

a. *Longevity (01 variable):* i) life expectancy at birth;
b. *Education (07 variables*): i) sub-index of schooling, ii) % of individuals aged 18 years or over who have completed elementary school, iii) sub-index of school attendance, iv) % of individuals aged 5 to 6 years enrolled in school, v) % of individuals aged 11 to 13 years who are enrolled in the final years of elementary school or who have completed elementary school, vi) % of individuals aged 15 to 17 years who have completed elementary school, and vii) % of individuals aged 18 to 20 years who have completed high school;
c. *Income (01 variable):* i) per capita income.

The MHDI ranges from 0 to 1; the closer to 1, the greater the degree of human development in the municipality. Municipalities are classified into the following five development strata: very low (MHDI 0 to 0.499), low (MHDI 0.500 to 0.599), medium (MHDI 0.600 to 0.699), high (MHDI 0.700 to 0.799), and very high (MHDI 0.800 to 1).

The SVI is composed of 16 variables grouped into the following three categories:

a. *Urban infrastructure (03 variables)*: i) percentage of people in households with inadequate water supply and sewage, ii) percentage of the population living in urban households without garbage collection service, and iii) percentage of people who live in households with per capita income less than half the minimum wage and who spend more than one hour to reach their place of work out of the total number of employed, vulnerable people who return from work daily;
b. *Human Capital (08 variables):* i) mortality up to one year of age, ii) percentage of children from 0 to 5 years of age who do not attend school; iii) percentage of people aged 6 to 14 years who do not attend school; iv) percentage of women aged 10 to 17 who have children; v) percentage of mothers who are heads of household, without complete elementary school and with at least one child under the age of 15, out of the total number of mothers who are heads of household; vi) illiteracy rate of the population aged 15 years or over; vii) percentage of children living in households where none of the residents have completed elementary school; viii) percentage of people aged 15 to 24 years who do not study, do not work, and have a per capita household income equal to or less than half minimum wage (2010), out of the total population of this age group;
c. *Income and Work (05 variables):* i) proportion of people with per capita household income equal to or less than half minimum wage (2010); ii) unemployment rate of the population aged 18 or over; iii) percentage of people aged 18 or over without complete elementary education and holding informal occupation; iv) percentage of people in households with per capita income below half minimum wage (2010) and dependent on the elderly; and v) activity rate of people aged 10 to 14 years.

The SVI varies from 0 to 1; the closer to 1, the greater the degree of social vulnerability in the municipality. Municipalities are classified into the following five strata of vulnerability: very low (SVI 0 to 0.200), low (SVI 0.201 to 3.00), medium (SVI 0.301 to 0.400), high (SVI 0.401 to 0.500) and very High (SVI > 0.501).

In addition to these, the following 16 variables that make up the Social Vulnerability Atlas and that express the population's living conditions were included: i) illiteracy rate of people 18 years or older, ii) illiteracy rate of people 25 years or older, ii) income per capita of those vulnerable to poverty, iv) % of income from work, v) Gini Index, vi) % of employees 18 years or older with a formal contract, vi) % of employees 18 years or older without a formal contract, viii) % of public sector workers 18 years or older, ix) % of self-employed workers 18 years or older, x) % of employers 18 years or older, xi) degree of formality of the employed 18 years or older, xii) % of employed persons 18 years or older who have completed primary education, xii)% of employed persons 18 years or older who have completed secondary education, xiv) % of employed persons 18 years or older who have completed higher education, xv) average income of employed persons 18 years or older, and xvi) % of employed persons 18 years or older without income.

After data collection, the variables were grouped into 10 blocks for statistical treatment. This organization aimed to reduce multicollinearity, which could compromise the quality of the study results. Data analysis was subsequently divided into the following four stages:

Stage 1- Exploratory analysis of epidemiological indicators according to population size and human development and social vulnerability: In this stage, municipalities were grouped according to population size and strata of human development and social vulnerability. Epidemiological indicators were subsequently calculated for each stratum, and exploratory analysis of rates was carried out.

Step 2- Analysis of bivariate spatial correlation: Moran bivariate statistics and pseudo-significance test were used to assess the correlation between the incidence rate and the independent variables. The Moran index ranges from −1 to +1. Values close to zero indicating spatial randomness; positive values suggest positive spatial autocorrelation, and negative values suggest negative spatial autocorrelation[10]. Only variables with statistical significance ($p < 0.05$) in this stage were included in the next one. It should be noted that, in stages 2 and 3, only incidence rate was analyzed, given that only 821 municipalities (14.7%) had registered deaths on the date of collection.

Step 3- Multivariate analysis and spatial association: The association between the incidence rate and the independent variables was initially tested with the use of classical multivariate regression (ordinary least squares [OLS]). The model residues were submitted to spatial dependence analysis by global Moran statistics to assess the need to incorporate a spatial component of the regression model, according to the decision model proposed by Luc Anselin[11,12]. Once established, Lagrange multiplier tests were applied to define whether the most appropriate spatial model for the data set would be the spatial delay model (assigning an unknown value to the response variable Y) or the spatial error model (considering the spatial component as noise to be removed)[11]. Finally, residues from spatial models were subjected to Moran statistics again to verify spatial independence. In addition to this criterion, the following items were used to assess the quality of the final model: Akaike information criterion (AIC), Bayesian information criterion (BIC), log probability, and determination coefficient (R^2). Analyses were performed using GeoDa 1.10.0.8 software (University of Illinois at Urbana-Champaign, USA).

Because this study uses data in the public domain, Research Ethics Committee approval was waived.

Results

A total of 125,186 cases and 8,452 deaths from COVID-19 were included in the study. Cases were reported in 2,496 municipalities (44.8%), and deaths were reported in 821 municipalities (14.7%). Although the disease is present both in municipalities with large populations (> 100,000 inhabitants) and in those with small sizes (≤ 10,000), 81.3% of municipalities with up to 10,000 inhabitants have not yet registered cases of COVID-19. The two extremes have the highest incidence and mortality rates. Municipalities with populations over 100,000 inhabitants were the first affected, and, to date, they have an incidence of 88.95/100,000 and a mortality rate of 61.36/million inhabitants. In second place are municipalities with up to 10,000 inhabitants, with incidence rate of 45.89/100,000 and mortality rate of 27.26/million. It is noteworthy that the case fatality rate in municipalities with populations between 10,000 and 20,000 inhabitants is similar to that observed in large municipalities (6.81% and 6.90%, respectively) (Table 1).

Table 1
Incidence, mortality, and case fatality rate of COVID-19, according to population size, Municipal Human Development Index and Social Vulnerability Index. Brazil, 2020.

Population size	No. of municipalities	No. of cases	No. of deaths	Resident population	Incidence rate/100,000	Mortality rate/million	CFR (%)
≤ 10,000 inhabitants	482	1,296	77	2,824,212	45.89	27.26	5.94
10,001 to 20,000	580	2,568	175	8,549,277	30.04	20.47	6.81
20,001 to 50,000	783	7,075	390	24,491,464	28.89	15.92	5.51
50,001 to 100,000	328	6,988	411	22,642,923	30.86	18.15	5.88
> 100,000	323	107,259	7399	120,576,849	88.95	61.36	6.90
MHDI							
Very low (0-0.499)	18	289	9	489,795	59.00	36.75	3.11
Low (0.500-0.599)	588	4,031	301	13,623,241	29.59	22.01	7.47
Medium (0.600-0.699)	830	13,021	832	31,335,083	41.55	26.55	6.39
High (0.700-0.799)	1.016	72,544	4,891	100,556,389	72.14	48.63	6.74
Very high (0.800-1)	44	35,301	2,419	3,308,021 7	106.71	73.12	6.85
SVI							
Very low (0-0.200)	350	7,428	362	20,782,329	35.74	17.42	4.87
Low (0.200–0.300)	703	54,736	3,722	79,129,666	69.17	47.04	6.80

*Data from May 6, 2020. CFR: Case Fatality Rate, MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Population size	No. of municipalities	No. of cases	No. of deaths	Resident population	Incidence rate/100,000	Mortality rate/million	CFR (%)
Medium (0.300–0.400)	485	49,528	3,413	49,839,712	99.37	68.48	6.89
High (0.400–0.500)	534	8,530	628	17,423,869	48.96	36.04	7.36
Very high (0.500-1)	424	4,964	327	11,909,149	41.68	27.46	6.59
Total	2,496	125,186	8,452	179,084,725	69.90	47.20	6.75

*Data from May 6, 2020. CFR: Case Fatality Rate, MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

In relation to human development, it was observed that all 44 municipalities with very high MHDI were affected by COVID-19. This group had the highest incidence rate (106.71/100,000) and mortality (73.12/million). In second place are municipalities with very low MHDI, 56.2% of which have already registered cases of the disease. Regarding incidence and mortality rate, the group with very low MHDI held third place (incidence rate: 59.00/100,000 and mortality rate: 36.75/million) (Tables 1 and 2).

Table 2
Proportion of municipalities affected by COVID-19, according to population size, Municipal Human Development Index, and Social Vulnerability Index. Brazil, 2020.

Population size	No. of municipalities	No. of municipalities with confirmed cases	% of municipalities with confirmed cases
≤ 10,000 inhabitants	2,452	482	19.7
10,001 to 20,000	1,344	580	43.2
20,001 to 50,000	1,101	783	71.1
50,001 to 100,000	349	328	94.0
> 100,000	324	323	99.7
MHDI			
Very low (0-0.499)	32	18	56.2
Low (0.500-0.599)	1,367	588	43.0
Medium (0.600-0.699)	2,233	830	37.2
High (0.700-0.799)	1,889	1,016	53.8
Very high (0.800-1)	44	44	100.0
SVI			
Very low (0-0.200)	627	350	55.8
Low (0.200–0.300)	1,699	703	41.4
Medium (0.300–0.400)	1,258	485	38.5
High (0.400–0.500)	1,178	534	45.3
Very high (0.500-1)	803	424	52.8

*Data from May 6, 2020. MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index. The difference observed in the number of municipalities according to population size (5,570) differs from the number of municipalities according to strata of MHDI and SVI (5,565). This is due to the date of creation of new municipalities, after 2010.

Regarding social vulnerability, 55.8% of the municipalities with very low SVI have already registered cases of COVID-19, followed by the municipalities with very high SVI (52.8%). Considering the incidence and mortality rates, municipalities with average SVI held first place (99.37 cases/100,000 and 68.48 deaths/million). It is also noteworthy that the municipalities with high SVI had higher case fatality rate (7.36%) (Tables 1 and 2).

Of the 49 variables analyzed, five showed no spatial correlation with the incidence rate of COVID-19 and were excluded from subsequent analyses. In the multivariate regression model, 21 variables were

associated with incidence rate. None of the variables in block 2 (domains of the SVI) showed significance. In all other blocks of variables, the residuals of the regression model were spatially dependent. Lagrange multiplier tests indicated the spatial error model for block 8 (domains of the MHDI education) and spatial lag model for the others (Table 3).

Table 3
Moran bivariate correlation, multivariate regression, and spatial regression between COVID-19 incidence rate and social determinants of health. Brazil, 2020.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
Block 1- synthetic indicators of social vulnerability and human development						
Social Vulnerability Index	0.076	0.002	157.70	< 0.001	85.992	< 0.001
Municipal Human Development Index	−0.022	0.002	297.64	< 0.001	184.08	< 0.001
Block 2- Domains of the Social Vulnerability Index						
SVI urban infrastructure	0.012	0.024	−0.015	0.664	–	–
SVI human Capital	0.041	0.002	−14.374	0.445	–	–
SVI income and work	0.029	0.005	−0.150	1.000	–	–
Block 3- Domains of the Municipal Human Development Index						
MHDI longevity	−0.004	0.050	49.268	0.339	−2.2737	0.960
MHDI education	−0.018	0.002	71.587	0.002	60.566	0.004

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
MHDI income	−0.028	0.001	−65.9104	0.052	−26.068	0.394
Block 4- SVI urban infrastructure domain						
% of people in households with inadequate water supply and sewage	0.111	0.002	0.298482	0.00323	0.0538755	0.55741
% of the population living in urban households without garbage collection service	0.105	0.002	−0.105842	0.40675	−0.0830367	0.47279
% of people who live in households with per capita income less than half minimum wage (2010) and who spend more than an hour to reach place of work	0.074	0.005	1.19532	0.00000	0.78499	0.00001
Block 5- SVI human capital domain						

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
Mortality up to 1 year old	−0.019	0.010	−0.0233645	0.94510	0.068086	0.82536
% of children aged 0 to 5 who do not attend school	0.026	0.002	−0.480704	0.0050	−0.370537	0.0733
% of people aged 6 to 14 who do not attend school	0.164	0.001	2.99476	0.00000	1.2672	0.00621
% of women aged 10 to 17 who had children	0.0899	0.002	2.0033	0.01684	1.28813	0.09273
% of mothers who are heads of household, without complete elementary school and with children under 15 years of age	0.0556	0.002	0.0249375	0.88425	−0.194968	0.21320
Illiteracy rate of the population aged 15 or over	−0.0456	0.004	−1.11608	0.00049	−0.66807	0.02257

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
% of children living in households where none of the residents have completed elementary school	−0.0175	0.002	−0.372317	0.05105	−0.235047	0.17791
% of people aged 15 to 24 who do not study, do not work and have a per capita household income equal to or less than half minimum wage (2010)	0.029	0.002	0.859119	0.00164	0.572682	0.02164
Block 6- SVI income and labor domain						
Proportion of people with per capita household income equal to or less than half minimum wage (2010)	0.0281	0.005	0.823252	0.00000	0.496891	0.00007

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
Unemployment rate of the population aged 18 or over	−0.0065	0.01	−0.643252	0.15191	−0.361881	0.37497
% of persons aged 18 or over with no complete elementary education and informally employed	0.0048	0.002	−1.64513	0.00000	−1.05841	0.00000
% of people in households with per capita income less than half the minimum wage (2010) and dependent on the elderly	−0.0031	0.198	–	–	–	–
Activity rate of persons aged 10 to 14 years of age	0.0943	0.005	1.31266	0.00000	0.586937	0.00466
Block 7 - MHDI longevity domain						
Life expectancy at birth	−0.0044	0.030	0.986428	0.02657	0.89851	0.02545

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
Block 8 - MHDI education domain						
Subindex education	0.0100	0.002	2728.69	0.52713	294.603	0.93733
% of individuals aged 18 or older who have completed elementary school	0.0100	0.002	−26.5486	0.53830	−2.21157	0.93733
School attendance index	−0.0430	0.002	74.3527	0.32880	−40.6921	0.56735
% of individuals aged 5 to 6 years in school	−0.0731	0.002	−0.55266	0.03744	−0.017439	0.94772
% of individuals aged 11 to 13 years old who are enrolled in the final years of elementary school or who have completed elementary school	−0.0775	0.005	−0.536377	0.08705	0.644394	0.03203
% individuals aged 15 to 17 years, with complete primary	−0.0226	0.002	−0.405591	0.21912	0.0235485	0.93707

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
% individuals aged 18 to 20 years who have graduated from secondary school	−0.005	0.382	–	–	–	–
Block 9 - MHDI income domain						
Per capita income	−0.0113	0.002	0.228899	0.00799	0.199184	0.01070
Block 10- Other vulnerability and development indicators						
Illiteracy rate (aged 18 years or over)	−0.037	0.062	–	–	–	–
Illiteracy rate (aged 25 years or over)	−0.035	0.064	–	–	–	–
Per capita income of those vulnerable to poverty	−0.060	0.002	−0.109244	0.00003	0.0038270 3	0.96425
% of income from income from work	0.074	0.001	0.869056	0.19392	0.309083	0.10397
Gini Index	0.049	0.170	–	–	–	–

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
% of employees with a formal contract (aged 18 years or over)	−0.055	0.002	−0.622194	0.19392	−0.533661	0.22342
% of employees without a formal contract (aged 18 years or over)	−0.039	0.4060	–	–	–	–
% of public sector workers (aged 18 years or over)	0.0286	0.002	0.457244	0.45981	0.566954	0.31684
% of self-employed workers (aged 18 years or over)	0.1020	0.001	0.386326	0.12980	−0.092865	0.69078
% of employers (aged 18 years or over)	−0.0292	0.005	−5.14761	0.00078	−4.63911	0.00094
Degree of formality of employed persons (aged 18 years or over)	−0.0424	0.005	0.102908	0.79265	−0.0738698	0.83667

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

Social determinants	Bivariate correlation		Multivariate regression		Spatial regression	
	I Moran	p value	Coefficient	*P* value	Coefficient	p value
% of employed persons with complete elementary education (aged 18 years or over)	−0.0039	0.005	0.99806	0.03399	0.889692	0.03927
% of employed persons with complete high school (aged 18 years or over)	−0.0074	0.002	0.71983	0.20002	0.189241	0.71284
% of employed persons with complete higher education (aged 18 years or over)	−0.0378	0.002	−2.44724	0.00030	−1.59828	0.00990
Average income of employed persons (aged 18 years or over)	−0.0036	0.002	0.0317216	0.00145	0.0317537	0.00050
% of employed persons without income (aged 18 years or over)	0.0422	0.001	0.890013	0.00021	0.373849	0.08911

MHDI: Municipal Human Development Index, SVI: Social Vulnerability Index.

The spatial regression model, finally, identified 17 indicators associated with incidence rate, 13 of which showed positive association, namely the following: SVI; MHDI; MHDI education; % of people who live in households with per capita income less than half minimum wage (2010) and who spend more than one hour to reach place of work; % of people aged 6 to 14 years who do not attend school; % of people aged 15 to 24 years who do not study, do not work, and have per capita household income equal to or less than half the minimum wage (2010); % of people with per capita household income equal to or less than half minimum wage (2010); activity rate of people aged 10 to 14 years; life expectancy at birth; % of individuals aged 11 to 13 who are enrolled in the final years of elementary school or who have completed elementary school; per capita income; % of employed persons aged 18 or over with complete elementary school; and average income of employed persons aged 18 or over. Four variables showed a negative association, namely, illiteracy rate of the population aged 15 years or over; % of employers aged 18 or over; % of people aged 18 or over without complete elementary education holding informal occupation; and % of employed people aged 18 or over with complete higher education (Table 3).

Discussion

COVID-19 currently represents the main global health, social, and economic challenge. In Brazil, the spread of the disease started in the most developed municipalities in the country, and it has spread throughout the Brazilian territory without delay, reaching smaller and more vulnerable areas whose populations are exposed to a chronic and historical context of social deprivation. This process of spatial dissemination justifies the complex influence of SDH on the spread of the virus across the country.

Considering that the virus is reaching the most vulnerable and least developed municipalities in the country after those with better living conditions, there is reason to believe that these municipalities will be more severely affected and will suffer incalculable consequences, if consistent support measures are not adopted urgently.

The first reason concerns the risk context of these populations and the difficulties in implementing and/or adopting preventive measures. Approximately 37 million Brazilian workers earn their income from activities related to the sale of products and the provision of services, constituting a population vulnerable to contamination[13]. In poorer municipalities, the percentage of these populations rises considerably[13]. Furthermore, in many cases, this is the only source of income for the family's subsistence, which makes adherence to voluntary social isolation difficult to maintain for a long period without the proper support of emergency public policies.

COVID-19, therefore, has a double effect on the most vulnerable populations, to the extent that itit both perpetuates poverty and is perpetuated by poverty itself. It is perpetuating in the sense that, for each percentage point reduction in the global economy, it is estimated that an additional 10 million people will be placed in poverty [5]. In Brazil, the pandemic could increase by 6.5 percentage points in the poverty index, going from the current 16.2–23.2%, thus affecting almost one quarter of the Brazilian population [14]. It would furthermore increase inequality in income distribution (6.5% increase in the Gini Index) [14]. In

the states of the North and Northeast Regions, these effects of pandemics can be even more pronounced, given that they are the least developed regions with the most vulnerable populations.

It is perpetuated by poverty, because this vulnerable population, having no financial reserves and depending on emergency government assistance, will scarcely be able to adhere to non-pharmacological preventive measures, such as social isolation, wearing masks, and hand hygiene. In this regard, living conditions are able to maintain the COVID-19 transmission chain active. In our study, there was a higher incidence rate in municipalities with greater social vulnerability; higher proportion of people who live in households with per capita income less than half minimum wage and who spend more than one hour to reach place of work; higher proportion of children aged 6 to 14 years who do not attend school; and higher proportion of people aged 15 to 24 years who do not study, do not work and have a per capita income of less than half minimum wage. These populations are more likely not to follow government recommendations [15].

The lack of home structure and the lack of access to minimum resources, such as water and basic sanitation, both on the outskirts of large cities and in municipalities in the interior of the country, can increase the risk of illness due to COVID-19, as observed with other respiratory diseases [16]. In Brazil, four million families do not have a bathroom at home; 35 million do not yet have access to treated water, and 100 million do not have a sewage network [17]. Therefore, it is possible to state that the degree of suffering generated by the pandemic depends on the area where individuals live and the social conditions to which they are subjected [18].

In addition, mortality caused by the disease, especially in household providers, can increase the poverty of families. In this investigation, municipalities with small population sizes, as well as those with low MHDI and high SVI already show high mortality rates. The situation tends to become more critical when all municipalities are affected, which will not take long to happen. Even with the set of actions implemented by the Brazilian government, through “Brazil’s response policy to COVID-19” [19], it is likely that after this pandemic, Brazil will face a second crisis related to poverty and the diseases associated therewith.

The second reason refers to the capacity of municipalities to face the contamination of their population and to offer conditions for detection and treatment of patients. If we consider that 7% of those infected will need hospitalization and that 2% will require intensive care [20], the group of municipalities with very high vulnerability (which recorded 4,964 cases of COVID-19) would need 347 hospital beds and 99 intensive care unit (ICU) beds.

Several factors make this scenario even more worrying. First, these small and more vulnerable municipalities do not have a hospital structure or ICU beds to meet the demand imposed by the pandemic [21]. In general, these beds are concentrated in municipalities that are regional health centers that serve the municipalities through agreements between managers. Second, because the disease first arrived in the larger municipalities with higher human development, these beds are already occupied. Third, these

populations depend exclusively on beds in the public Unified Health System (SUS, acronym in Portuguese). About 94.4% of the individuals who constitute poorest 20% of the population are dependent on the SUS [21].

Even with all the precautions adopted, this study has some limitations, among which the following stand out: i. the underreporting of COVID-19 cases due to the limited availability of tests and the capacity of local surveillance services, ii. deficiencies in investigating deaths due to the disease, with significant underreporting, and iii. use of secondary data that are subject to constant variation.

Conclusions

Concerns with the advance of the COVID-19 pandemic in the country's smallest, most vulnerable, and least developed municipalities raise the alert for Brazilian political authorities. It is necessary to do the following: i. delay the arrival of the disease in these locations by adopting effective prevention mechanisms that consider the collective risk of illness, the social context experienced by these populations, and the best existing scientific evidence; ii. expand and prepare the health network with urgent investments in the SUS at all levels of care [22]; and iii. guarantee social protection for the vulnerable population.

Declarations

Ethics approval and consent to participate

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Consent for publication

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Availability of data and materials

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Competing interests

The authors declare that they have no competing interests

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Authors' contributions

CDFS, RFC, MFM reviewed and edited. were responsible for data management, analysis and quality control. The author(s) read and approved the final manuscript.

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