Spatial association between the incidence rate of COVID-19 and poverty in the São Paulo municipality, Brazil

Marcos César Ferreira

Institute of Geosciences, State University of Campinas, Brazil

Abstract

In this article, we investigated the spatial dependence of the incidence rate by COVID-19 in the São Paulo municipality, Brazil, including the association between the spatially smoothed incidence rate (INC_EBS) and the social determinants of poverty, the average Salary (SAL), the percentage of households located in slums (SLUMS) and the percentage of the population above 60 years of age (POP>60Y). We used data on the number notified cases accumulated per district by May 18, 2020. The spatial dependence of the spatially smoothed incidence rate was investigated through the analysis of univariate local spatial autocorrelation using Moran's *I*. To evaluate the spatial association between the INC_EBS and the determinants SAL, POP>60Y and SLUMS, we used the local bivariate Moran's *I*. The results showed that the spatially smoothed incidence rate for COVID-19 presented significant spatial autocorrelation (I = 0.333; P<0.05), indicating that the cases were concentrated in clusters of neighbouring districts. The INC_EBS showed a negative spatial association with SAL (I = -0.253, P<0.05) and POP>60Y (I = -0.398, P<0.05). We also found that the INC_EBS showed a positive spatial association with households located in the slums (I = 0.237, P<0.05). Our study concluded that the households where the population most vulnerable to COVID-19 resides were spatially distributed in the districts with lower salaries, higher percentages of slums and lower percentages of the population above 60 years of age.

Correspondence: Marcos César Ferreira, Institute of Geosciences, State University of Campinas, Rua Carlos Gomes, 250, Campinas, 13083-855 SP, Brazil.
E-mail: macferre@unicamp.br

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Introduction

The severe acute respiratory syndrome corona virus 2 (SARS-CoV-2), which causes COVID-19, was initially identified on December 31, 2019, in the city of Wuhan, which is located in Hubei Province, China (Sohrabi *et al*., 2020). The first reports on COVID-19 indicated the existence of a cluster located in the Huanan seafood market, located in Wuhan (Zhu *et al.,* 2020). Although the majority of patients diagnosed with this disease have mild symptoms, such as cough, secretions and fever, a large number of patients who progress to the fatal form, experiencing pulmonary oedema, severe pneumonia and other symptoms (Chen *et al*., 2020).

Studies have shown that in the initial phase of the epidemic, COVID-19 showed rapid transmissivity between humans, with an effective Reproductive number (R) that reached 2.7 (Shen *et al*., 2020), which is higher than SARS, for example, that showed R = 1.77 (Liu *et al*., 2020). For this reason, sixty days after the identification and description of the disease, COVID-19 had already spread to several countries, and on January 11, 2020, the World Health Organization (WHO) declared it a pandemic (Sohrabi *et al*., 2020). The literature reports that populations susceptible to COVID-19 are mainly made up of elderly people, people with a depressed immune response, people with various chronic co-morbidities and people with a previous history of surgery (Adhikari *et al*., 2020). In addition, other studies have found that social determinants of health, including poverty, the physical housing environment and ethnicity issues, are also associated with considerable effects on susceptibility, morbidity and incidence with respect to COVID-19 (Abrams and Szefler, 2020).

The poorest populations are those most susceptible to chronic diseases, and this places them in the high-risk group for COVID-19 infection. Life expectancy and disease incidence rates have historically been uneven among the wealthiest and poorest populations. (Ahmed *et al*., 2020). Workers in essential sectors, who are disproportionately of African origin, such as employees of commercial retail establishments, public transit employees, and caregivers, are at the forefront of the pandemic and are part of the segregated population who do not have the privilege of staying home (van Dorn *et al*., 2020). The impact of the virus on people living under low-income conditions may be more severe than others. Among the mechanisms that determine the impact of the virus, one can mention overpopulation in urban slums, inadequate sanitation and defective water supply conditions. In addition, severe cases often lead to death due to the interaction of the virus with highly prevalent co-morbidities. Malnutrition is another contributing factor to mortality in this connection (Dahab *et al.*, 2020). Low-paid workers, especially those employed in the service sector, such as at businesses providing food, cleaning and delivery services, need to use public transport to get to work, which increases their exposure to the COVID-19 (Bambra *et al*., 2020).

In India, the COVID-19 pandemic has made the precarious conditions of slums worse due to inefficiency of social distancing and physical separation between individuals due to the high population density (Wasdani and Prasad, 2020). The cited authors further argue that the poverty, in these slums and in their surroundings, has led its residents to make a difficult decision between following the government's recommendation to stay at home or to continue with their work activities; that is, they must decide between the virus and hunger (Wasdani and Prasad, 2020). On 26 February, 2020, the first case of COVID-19 in the municipality of São Paulo was confirmed in a patient who had returned from a trip to Italy the week earlier. As of this date, the incidence of COVID-19 has grown very rapidly across the country, especially in the municipality of São Paulo. According to the COVID-19 Daily Bulletin no. 64 from the Health Department of the Municipality of São Paulo (Secretaria Municipal da Saúde, 2020a), the municipality of São Paulo had accumulated a total of 185,082 suspected cases and 7,793 deaths by May 29, 2020.

Despite being the richest municipality in Brazil, São Paulo has great social and economic inequalities among its 96 districts. One % of the population owns 25% of all property in the municipality (Rede Nossa São Paulo, 2017), which makes it very difficult for the low-income population to gain access to housing, forcing families in this stratum living in makeshift homes and slums. São Paulo is located in the south-eastern region of Brazil (Figure 1), and it is the most populous municipality in South America, with 11,869,000 inhabitants in its urban area (SEADE, 2020).

The aim of this study was to investigate the spatial association between the incidence rate by COVID-19 in the municipality of São Paulo and social determinants, such as average salary, percentage of households located in the slums and percentage of the population >60 years old. The investigation was conducted using univariate local and bivariate local spatial autocorrelation analysis, using the district as the spatial aggregation level.

Materials and methods

Epidemiological data

We used data from the São Paulo Municipal Health Department covering 143,447 notified cases accumulated by May 18, 2020 (Secretaria Municipal da Saúde, 2020b). Data on the total resident population by district in 2017 were obtained from the Secretariat of Urban Development of São Paulo (Secretaria de Desenvolvimento Urbano, 2020).

Social determinants

Data from three social determinants were used: average remuneration of formal employment (average salary) in 2015 (SAL) (Rede Nossa São Paulo, 2017); percentage of households located in slums in 2016 (SLUMS) (Rede Nossa São Paulo, 2017); and the percentage of the population aged >60 in 2017 (POP>60Y (Secretaria de Desenvolvimento Urbano, 2020).

Cartographic data

The map of the municipal districts of São Paulo was obtained in vector file and in shapefile format from the Center for Metropolitan Studies (CEM, 2020). This file contains the territorial polygons of the São Paulo districts and their attributes.

Spatial analysis

Empirical Bayes Smoothing and choropleth maps

The spatial distribution of the values of SAL, SLUMS and POP>60Y by district of São Paulo was represented on choropleth maps using the quantile classification method including legends of five classes. This method proportionally distributes the number of spatial units (districts) by class on the map in ascending order of the value of the variable. From these maps, it was possible to compare the distribution of upper and lower quantiles of the social determinants.

The gross incidence rate by COVID-19 per district values was smoothed using the Empirical Bayes Smoothing (EBS) technique (Anselin *et al*., 2006). Then, the incidence rates were smoothed by district (INC_EBS) to construct the incidence risk map. The EBS technique removes the instability of variance of the demographic data that occurs in small areas by smoothing the already-calculated gross rates. When EBS is applied to small areas with small populations exposed to risk, the gross rates tend to be adjusted, while they change very little in larger area (Anselin *et al*., 2006).

The EBS technique was based on the weighted average between the gross incidence rate in each district and the average gross incidence rate in the municipality of São Paulo. This procedure used the 1st order *Queen* neighbourhood spatial weight. Subsequently, the values of INC_EBS were saved in the table of attributes of the shapefile. On the COVID-19 incidence risk map (INC_EBS), the districts with shades of blue were those with risk levels lower than the municipal average (<25% and 25-50%), while the districts in shades of brown were those of higher risk (50-75% and >75%).

Univariate and local bivariate spatial autocorrelation

Moran's local univariate spatial autocorrelation analysis, *i.e.* Local Moran's *I* with EB rate (Anselin *et al.,* 1995), was used to map the clusters and outliers in the districts that contributed to the spatial autocorrelation of the smoothed incidence rate and to analyze the local indicators of spatial association. Using the Local Indicators of Spatial Association (LISA) technique, we identified the local spatial heterogeneity of COVID-19 incidence, *i.e.* detecting districts with high incidence rate values surrounded by districts with high incidence rate values (H-H clusters) and districts with low incidence rates surrounded by districts with low incidence rates (L-L clusters).

We also used local bivariate autocorrelation analysis or Bivariate Local Moran's *I* (Anselin *et al*., 2010) to evaluate the spatial association between the smoothed incidence rate (INC_EBS) in district *i* and the mean values of the determinants SAL, SLUMS, POP>60Y calculated in a neighbouring districts *j*. The district neighbourhood was defined based on the *Queen* technique of weighting the spatial contiguity between polygons, where the first order contiguity option was selected. According to this technique, the vicinity of a polygon is formed by spatial units that share a vertex or edge of this polygon (Anselin *et al*., 2010).

In our study, the value of INC_EBS in district *i* was related to the values of SAL, POP>60Y and SLUMS measured in a neighbouring district *j* located in direct contact with district *i*. Through the analysis of local bivariate spatial autocorrelation, maps of clusters formed by districts with high values for the variable INC_EBS were produced, which were surrounded by districts with high values for the variables SAL, POP> 60 and SLUMS. These clusters were represented in the high-high (H-H) class. Moran's *I*s were also calculated, and the other low-low (L-L), low-high L-H) and high-low (H-L) clusters were mapped considering a P-value <0.05 significant. All stages of spatial analysis of this research were performed using the exploratory spatial data analysis software *GeoDa* v.1.14.07 (Anselin, 2019).

Results

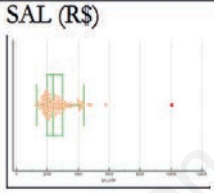
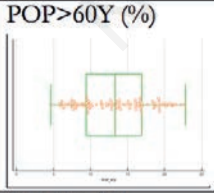
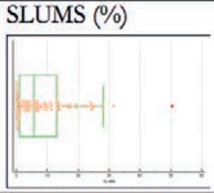
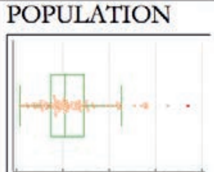
Appendix (online) presents the values of the determinants SLUMS, SAL, POP> 60Y, number of notified cases and the incidence rate smoothed (INC_EBS) by district of São Paulo. The *Code* column shows the district code, the location of which is shown on the map in Figure 2. The statistical summary of all variables used in this study is shown in Table 1. We can see in Table 1 that, according to the D values of the Kolmogorov-Smirnov test (Smirnov, 1939) normality was rejected for all variables (P<0.05) indicating that they are spatially dependent. By comparing the D values in Table 1 with the choropleth maps in Figure 3, one can observe the spatial dependence of the determinants SAL, SLUMS and POP>60Y. The values in the upper quantile of the SAL map (Figure 3A) are located in the central areas of the municipality and those in the lower quantile are distributed along the periphery, mainly in the eastern and southern zones.

Regarding SLUMS (Figure 3B), we observed the opposite because the upper quantiles were concentrated along the peripheries of the south-western, southern and northern zones, while the lower quantiles were located in the central areas. The POP> 60Y map (Figure 3C) shows that the upper quantiles were located in the central areas, and the lower quantiles at the peripheries of the eastern and southern zones.

COVID-19 incidence risk

Figure 3D shows the COVID-19 incidence risk map, which is represented by the spatially smoothed incidence rate (INC_EBS). Here, we can see that the districts presenting an incidence risk higher than the average for São Paulo were mainly located along the periphery of the municipality, in the eastern, south-western and southern zones. In the northern zone, we identified two districts,

Table 1. Statistical summary of all variables used in the study.

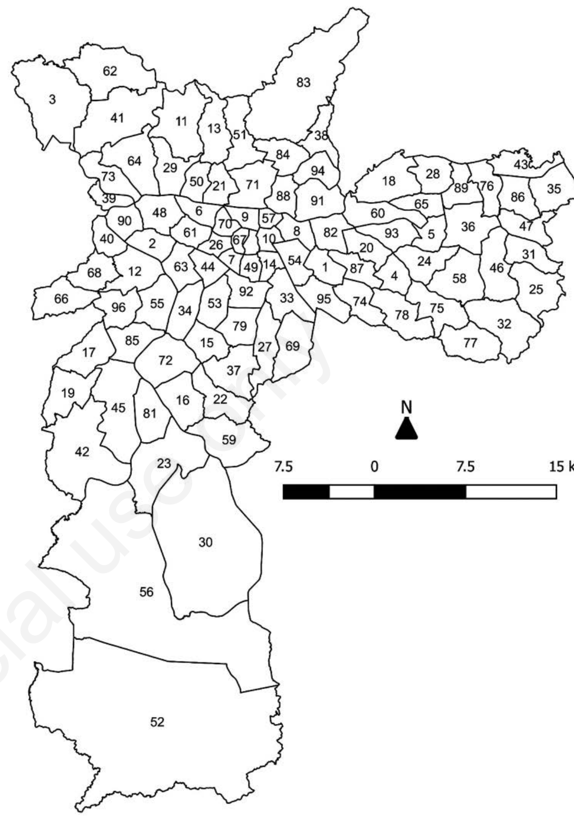
Variable	Minimum and maximum	Average	95% CI	Kolmogorov-Smirnov Test D
SAL (R$) 	1287.00 – 10079.00	2657.10	2424.91 – 2889.29	0.1640 (*p*<0.0001)
POP>60Y (%) 	4.66 – 22.76	13.37	12.405 – 14.339	0.1115 (*p*=0.0050)
SLUMS (%) 	0.00 – 50.45	8.145	6.28 – 9.99	0.1870 (*p*<0.0001)
POPULATION 	7934 – 370810	120878.83	106231.68 – 135525.98	0.1324 (*p*=0.0003)

Perus and Cachoeirinha, that showed outlier values in the upper quantile. Districts with incidence risks below the municipal average occurred in districts located in the central and north-eastern zones of the municipality.

Local univariate spatial autocorrelation analysis of the smoothed incidence rate

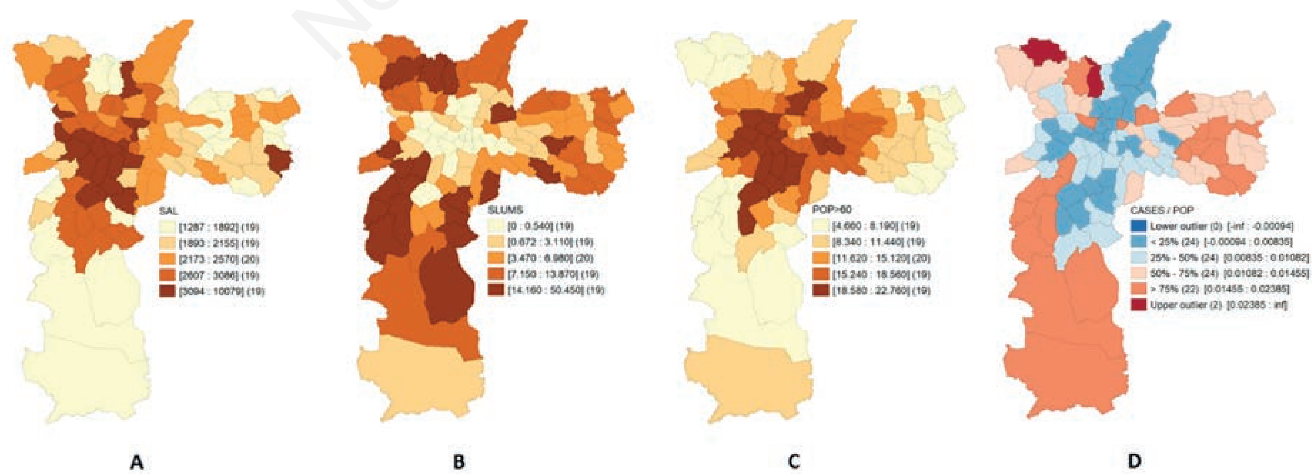
The map of the clusters and the Moran's *I* diagram of INC_EBS are shown in Figure 4. The analysis of local univariate spatial autocorrelation showed that INC_EBS presented positive and statistically significant autocorrelation (I=0.333; P<0.05). In the map to the left in Figure 4, we identified a H-H cluster located in the eastern zone that was formed by the following districts: Iguatemi, São Mateus, Parque do Carmo, José Bonifácio, Itaquera, Cidade Líder and Ponte Rasa. This cluster also included the districts of Marsilac in the far south and Anhanguera in the northwest.

Figure 1. Location of the municipality of São Paulo in Brazil and South America. Source: Google Maps (2020).



The numeric codes are associated with the district names in Table 1.

Figure 2. Map of the districts of the municipality of São Paulo.



A) average salary in Reais; B) percentage of households located in slums; C), percentage of the population aged >60 years; D) risk of COVID-19 incidence.

Figure 3. Maps of the geographical diversity of the social determinants investigated.

We also identified an L-L cluster formed by the districts Campo Belo, Campo Grande, Cidade Ademar, Saúde, Vila Mariana, Bela Vista, Liberdade, Jd. Paulista, Consolação, República, Sé and Santa Cecília. In the Northeast, this cluster also included the districts of Tremembé, Tucuruvi and Jaçanã.

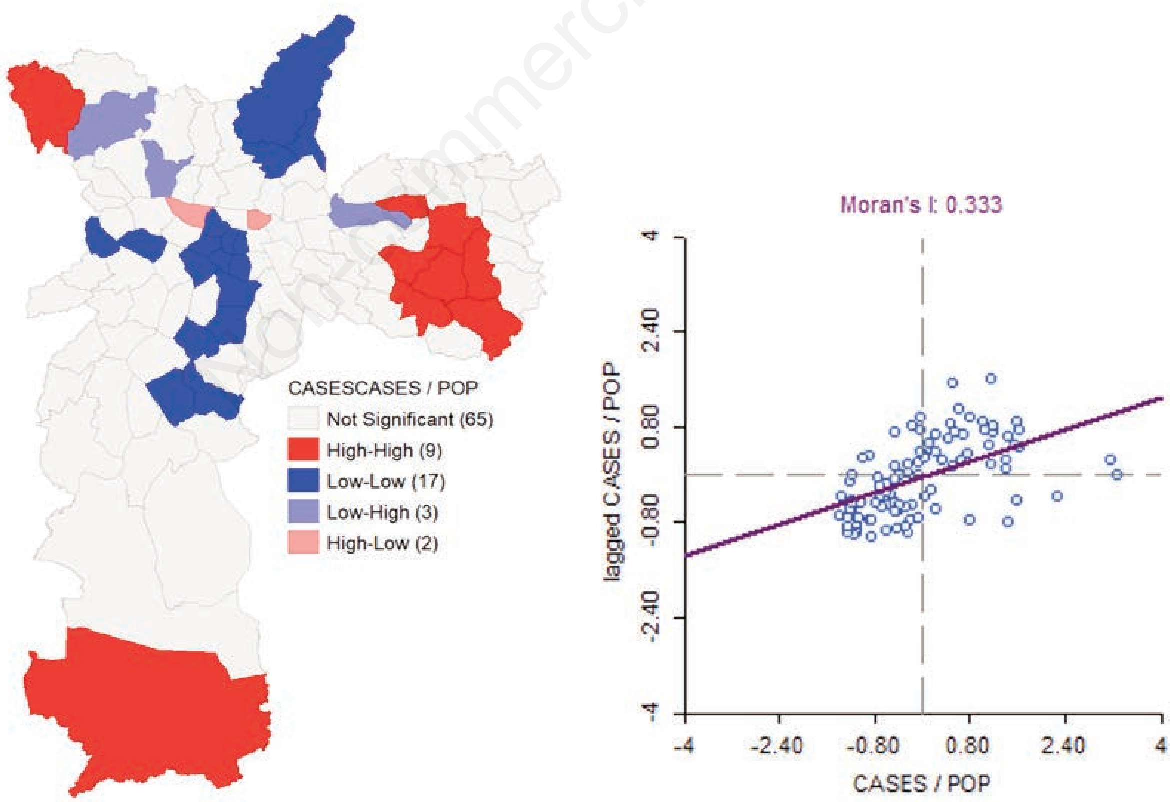
Local bivariate spatial autocorrelation analysis

Salary

Figure 5 shows the cluster map and Moran's *I* diagram resulting from the analysis of local bivariate autocorrelation between the spatially smoothed incidence rate (INC_SRS) and the average salary in the district (SAL). We found a negative and statistically significant spatial association between these two determinants (*I*=-0.253, P<0.05). In Figure 5, two important clusters associated with salary (L-H and H-L) can be observed. The L-H cluster (districts with a low incidence rate surrounded by districts with high salaries) was formed by the districts Pinheiros, Jd. Paulista, Itaim Bibi, Moema, Vila Mariana, Campo Belo, Saúde, Jabaquara, Santo Amaro and Cidade Ademar. Cluster H-L, which included districts that had high incidence rate and were surrounded by districts with low salaries, was found in the east zone and composed of the districts Sapopemba, São Mateus, Pq. do Carmo, Cidade Líder, Vila Matilde, Artur Alvim, Ponte Rasa, Ermelino Matarazzo São Miguel, Vila Curuçá and Itaim Paulista. The H-H cluster of a high incidence of cases associated with high salaries was formed by Morumbi and Vila Andrade, two isolated districts.

Percentage of households located in slums

Figure 6 shows the map of the spatial association clusters between INC_SRS and SLUMS and the respective Moran's *I* diagram. We identified a positive and statistically significant spatial association between these determinants (*I*=0.237, P<0.05). Figure 6 shows the map with an H-H cluster (districts with high incidence rates surrounded by districts with a high percentage of households located in slums) located in the south-western area of the municipality. This cluster was formed by the districts Jardim Ângela, Capão Redondo, Campo Limpo, Vila Andrade and Jardim São Luís. As seen in Figure 6, a large L-L-type cluster (districts with low incidence rates surrounded by districts with low percentages of households in slums) extends from the Paulista Avenue area to the centre of São Paulo. It was formed by the districts Moema, Vila Mariana, Jardim Paulista, Alto de Pinheiros, Perdizes, Consolação, Bela Vista, Liberdade, Cambuci, Mooca, Vila Prudente, Água Rasa, Belém, Brás, Sé, República, Santa Cecília, Bom Retiro and Santana.



The figure to the left shows the spatially associated clusters, and that to the right the spatial autocorrelation diagram obtained by Moran's local univariate analysis technique (LISA).

Figure 4. Map and spatial autocorrelation diagram referring to the district clusters in relation to the smoothed COVID-19 incidence rate.

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Percentage of the population aged >60 years

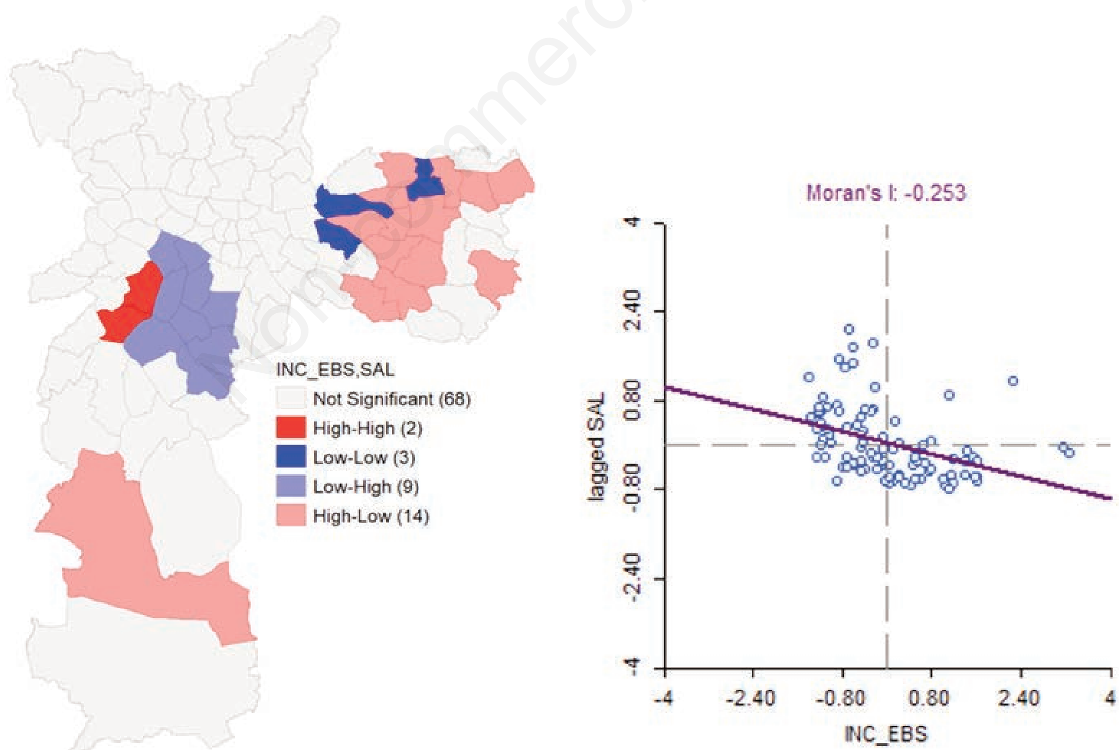
The map of the clusters and Moran's *I* diagram of the spatial association between INC_SRS and POP>60Y are shown in Figure 7. We found a negative and statistically significant spatial association between these determinants (I=-0.398, P<0.05). The H-L cluster (districts with high incidence rates surrounded by districts with low percentages of population over 60 years old) was distributed over the eastern and south-western zones of the municipality (Figure 7). The districts that belonged to the eastern zone cluster were Iguatemi, São Mateus, Parque do Carmo, Cidade Tiradentes, José Bonifácio, Guaianases, Itaquera, Lajeado, São Miguel, Vila Curuçá and Itaim Paulista. In the south-western zone, the H-L cluster included the districts of Campo Limpo, Capão Redondo, Jardim Ângela, Parelheiros and Grajaú. The north-eastern zone included the districts of Anhanguera and Perus.

The L-H cluster was formed by districts with low incidence rates surrounded by districts with high percentages of people >60 years and included the following districts: Vila Leopoldina, Lapa, Alto de Pinheiros, Perdizes, Pinheiros, Itaim Bibi, Jardim Paulista, Moema, Campo Belo, Saúde, Vila Mariana, Consolação and Santa Cecília. The map of Figure 7 also shows an H-H cluster with two districts with high incidence rates surrounding districts with high percentages of people over 60 years; this cluster included Morumbi and Barra Funda.

Discussion

In this study, we investigated the spatial distribution of the risk of incidence of COVID-19 by district in the municipality of São Paulo and the spatial association between the smoothed incidence rate and the social determinants: average salary, percentage of households located in slums and percentage of the population >60 years. The study used data accumulated by the end of May 2020 and reflects the moment when the curve of case numbers was growing rapidly in Brazil.

Our results show that the spatially smoothed incidence rate for COVID-19 during the pandemic in São Paulo presented a significant positive spatial autocorrelation indicating that the high incidence rates were not randomly distributed in space but instead clustered in districts located close together. The districts classified as having greater-than-average risk of incidence were located on the outskirts of the municipality in poor and populous neighbourhoods in the northern, eastern and southern zones, where infrastructure and urban equipment are inadequate. On the other hand, the districts that presented risk lower than the municipal average were located in high-income neighbourhoods, which extend from the central and western zones to the business and financial areas centred on the Paulista and Luís Carlos Berrini Avenues that are highly urbanized and display a high quality of life.



The figure to the left shows the spatially associated clusters between the smoothed incidence rate and the average salary, and that to the right the spatial autocorrelation diagram obtained by Moran's local bivariate analysis technique.

Figure 5. Map and spatial autocorrelation diagram referring to the spatially associated clusters between the smoothed COVID-19 incidence rate and the average salary.

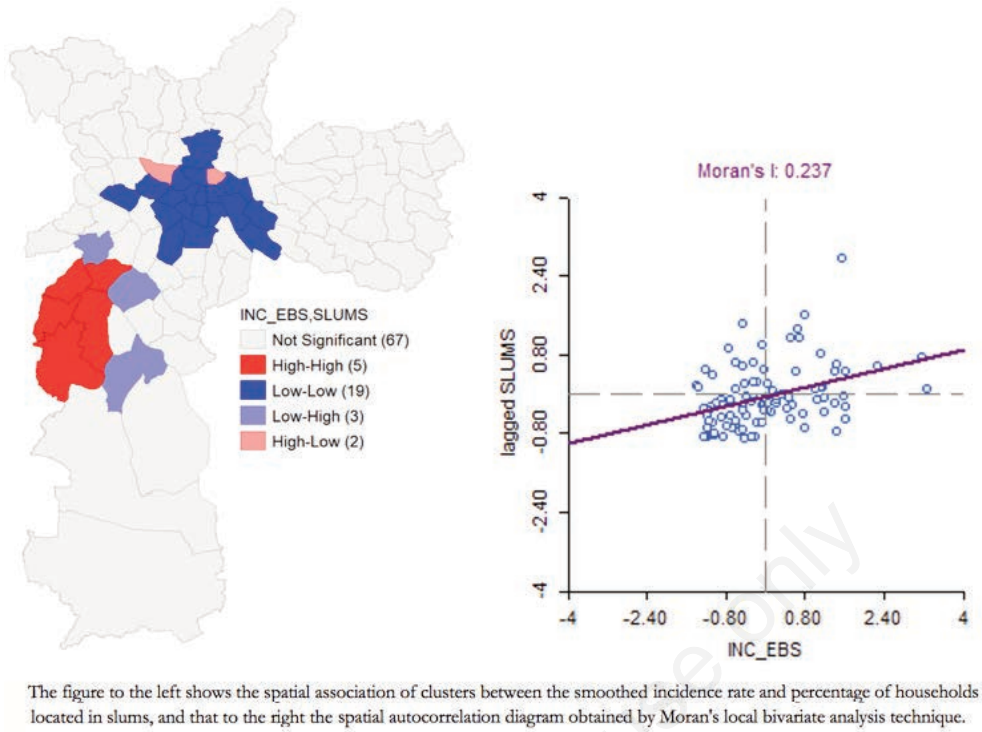


Figure 6. Map and spatial autocorrelation diagram referring to the spatial association clusters between the smoothed COVID-19 incidence rate and percentage of households located in slums.

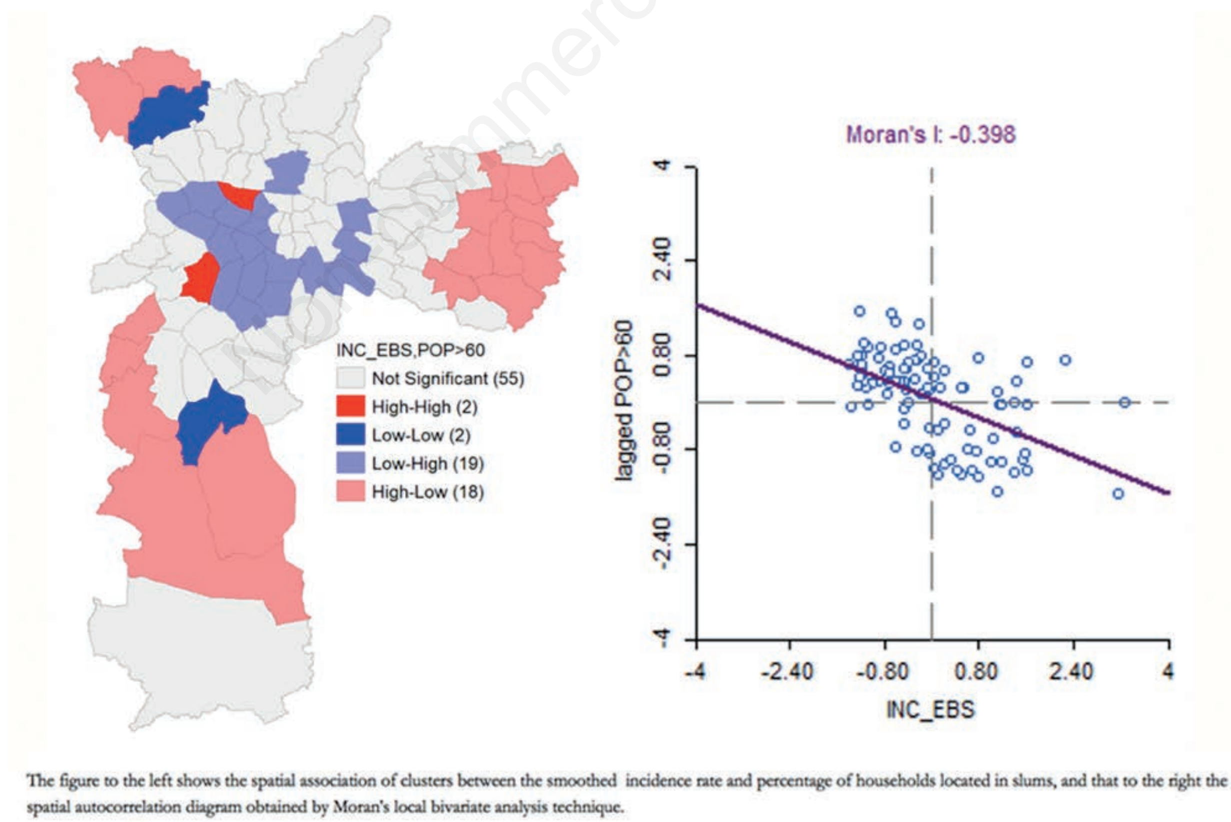


Figure 7. Map and spatial autocorrelation diagram referring to the spatial association clusters between the smoothed COVID-19 incidence rate and percentage of the population older than 60.

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We noted that the location of districts with high incidence rates was associated with location of districts with salaries below the municipal average. This spatial association was confirmed by the H-L type cluster with 14 districts, 13 of which located in the eastern zone of the municipality. The occurrence of this juxtaposition can be explained by the fact that low family income is an aggravating factor with respect to the incidence by COVID-19, as it limits adoption of the practice of social distance. Indeed, people at a socioeconomic disadvantage should be considered higher risk, as low salaries can lead families to live in private infrastructure neighbourhoods and in housing without adequate space, making them more susceptible to most of the risk factors for COVID-19 (Khalatbari-Soltani *et al*., 2020). A study in New York showed that the probability of tests for COVID-19 being positive is greater in poor neighbourhoods and in areas where large numbers of people live together (Borjas, 2020).

The eastern zone of São Paulo has a rate between 0 and 0.99 of formal jobs per inhabitant, one of the lowest in the city (Rede Nossa São Paulo, 2017). In addition, 49% of the population in the eastern zone has a monthly income of less than the minimum wage (CEM, 2020). A study in India shows that workers, such as housekeepers, waiting staff, urban cleaning professionals and motorcycle delivery drivers, among others, need to maintain their work to support their families, thus increasing social contact (Wasdani and Prasad, 2020). Most informal workers use their daily wages only for subsistence and presents co-morbidities that increase their vulnerability to COVID-19 (Corburn *et al*., 2020). The residents of the H-L cluster in the eastern zone live in places very far from where they work that are mainly located in the central and western zones of the municipality. This may have contributed to the greater rate of infection with COVID-19 and the higher incidence rate. These workers are forced to travel long distances in public transport that is always crowded and where the number of passengers travelling is often much larger than that recommended for the amount of space available. Surveys based on the source-destination research and gravitational models show that most districts in the eastern zone have very low accessibility to public transport, which often forces the local population to travel for more than two hours to their workplaces (CEM, 2020). Approximately one-third (34%) of the population residing in these districts in the eastern zone travels between 2 and 3 hours per day to go to work (Rede Nossa São Paulo, 2017). On these long journeys, there is a great possibility of contamination among passengers on buses and trains.

We identified an L-H cluster (districts with incidence rates below the municipal average surrounded by districts with higher than average salaries) in the central region. This lower incidence may be related to the fact that the number of hospitalizations for influenza decreases with the increase in the number of people with university degrees who have health insurance and are employed (Sloan *et al*., 2015). This cluster extended from the financial centre of Paulista Avenue to the Eng. Luís Carlos Berrini Avenue including the neighbourhoods of Jardins, Moema, Itaim Bibi, Pinheiros, Vila Olímpia, and Campo Belo, among others. This cluster had a rate of 6 formal jobs per inhabitant. Furthermore, this cluster includes the Campo Belo district that, at R$ 10,079.98, has the highest average salary in the municipality of São Paulo, (Rede Nossa São Paulo, 2017). In these clusters, there are several headquarters of companies in the tertiary sector, and there is also extensive infrastructure for urban equipment due to agreements between public officials and the private sector (Frúgoli Jr., 1998). Data on source-destination surveys and gravitational models have shown that most districts located here have a high accessibility to public and private transport, and the population only needs between 30 and 45 minutes to travel to their place of work (CEM, 2020).

We observed a positive spatial association between the incidence rate of COVID-19 and the percentage of households located in slums. In the south-western zone, we identified an H-H cluster covering five districts with incidence rates higher than the municipal average, which were surrounded by districts with percentages of households located in slums that were also higher than the average. The high COVID-19 incidence rates in this cluster can be explained by the fact that this kind of slum (favelas) in Brazil have a high demographic density. They display aggregations of socioeconomically vulnerable people with precarious basic sanitation and with restricted access to health services (Pereira *et al*., 2020). factors that predispose its inhabitants to the risk of contracting COVID-19. In these types of households, social distancing is impossible, as residents in quarantine need to live in spaces insufficient to shelter everyone at the same time (Pereira *et al*., 2020). The population that inhabits slums and improvised homes is highly susceptible to COVID-19 infection, as they are restricted with regard to access to basic necessities such as water, bathrooms, sewage, garbage collection as well as safe and adequate housing (Corburn *et al*., 2020). We believe that these factors may have contributed to the high incidence rates found in these clusters. Gibson and Rush (2020) selected the following risk factors that can be considered impediments to achieving basic hygiene and social distancing: crowded living conditions, shared water and sanitation services, dependence on public health services, limited access to electronic communication tools and dependence on public transport. On the other hand, we identified a large L-L-type cluster that included 19 districts located in an area that extends from the region of Jardins and Paulista Avenue to the central area of São Paulo. This cluster had districts with incidence rates lower than the municipal average surrounded by districts that had lower than average percentages of households in the slums. Our study showed a negative spatial association between the incidence rate and the percentage of the population above 60 years of age in São Paulo. This association was confirmed by the H-L cluster (districts with high incidence rates surrounded by districts with low percentages of people >60 years). This cluster was composed of districts located at the edges of the eastern, south-western and southern zones of the municipality. This spatial association demonstrated that COVID-19 mainly infected the youngest and poorest population. In addition, this H-L cluster was formed by low-salary households located in slums and poor districts. Most people living in poor neighbourhoods are young day-labourers who participate in the informal labour market, implying that if they do not work, they will not be able to eat (Wasdani and Prasad, 2020). The impossibility of practicing social distancing and an inefficient government policy of financial aid to these workers may have contributed to the high incidence rate of COVID-19 in neighbourhoods with younger populations in São Paulo. An additional factor is that these poor neighbourhoods have tenements (small, unhealthy rooms of 30 m^2) often also house elderly people with chronic diseases who do not have access to hand sanitizers or masks for protection (Souza, 2020).

Our study reflects a time when the number of deaths and incidence curve of COVID-19 were growing rapidly in São Paulo. New studies should be carried out after this period to detect whether there were changes in the spatial association between the variables analyzed here. We suggest that further research be carried out to test a greater number of social determinants of poverty.

Conclusions

Our study concluded that the highest incidence rates of COVID-19 were located in clusters of contiguous districts with strong spatial dependence. The high-risk districts are located in the peripheral zones of São Paulo, in poor and populous neighbourhoods in the eastern, southern and northern zones, which are strongly socially vulnerable. Low-risk districts, on the other hand, were found to be located in wealthy and central neighbourhoods near the business and financial centres characterized by low social vulnerability.

It was found that the high incidence rate was spatially associated with districts with low salaries, especially those located in the eastern zone. We also observed a positive spatial association between high incidence rates and high percentages of households located in the slums, mainly in districts located in the south-western and northern zones. Our study also found a negative spatial association between the incidence rates and the percentages of the population over the age of 60 residing in the district; these areas were mainly situated in the eastern and south-western zones.

Our study results lead to an understanding that the highest incidence of COVID-19 in the first three months of the pandemic in São Paulo occurred in districts with low salaries, a high percentage of people living in slums and with low percentages of people over 60. We recommend that this study be expanded to include epidemiological data collected after the period used in this research to assess whether the spatial associations found here will be further confirmed and maintained in the São Paulo municipality throughout the pandemic.

References

Abrams EM, Szefler SJ, 2020. COVID-19 and the impacts of social determinants of health. Lancet Respir Med 8:659-61. doi:10.1016/S2213-2600(20)30234-4

Adhikari SP, Meng S, Wu YJ, Mao YP, Ye RX, 2020. Epidemiology, causes, clinical manifestation and diagnosis, prevention and control of coronavirus disease (COVID-19) during the early outbreak period: a scoping review. Infect Dis Poverty 9:29. doi:10.1186/s40249-020-00646-x

Ahmed F, Ahmed N, Pissarides C, Stiglitz J, 2020. Why inequality could spread COVID-19. Lancet Public Health 5:e240. Epub 2020 Apr 2. doi:10.1016/S2468-2667(20)30085-2

Anselin L, 1995. Local indicators of spatial association – LISA. Geogr Anal 27:93-115. doi:10.1111/j.1538-4632.1995.tb00338.x

Anselin L, Lozano-Gracia N, Koschinky J, 2006. Rate Transformations and Smoothing. Spatial Analysis Laboratory, Department of Geography, University of Illinois. Available from: https://www.researchgate.net/publication/249913160_Rate_Transformations_and_Smoothing

Anselin L, Syabri I, Smirnov O, 2010. Visualizing multivariate spatial correlation with dynamically linked windows. In: New Tools for Spatial Data Analysis: Proceedings of the Specialist Meeting, edited by Luc Anselin and Sergio Rey. University of California, Santa Barbara: Center for Spatially Integrated Social Science (CSISS).

Anselin L, 2019. GeoDa v. 1.14.07. University of Chicago, Center for Spatial Data Science. Available from: https://geodacenter.github.io/index.html

Bambra C, Riordan R, Ford J, Matthews F, 2020. The COVID-19 pandemic and health inequalities. J Epidemiol Community Health 2020 Jun 12. doi:10.1136/jech-2020-214401

Borjas GJ, 2020. IZA DP No. 13115: Demographic determinants of testing incidence and COVID-19 infections in New York City Neighborhoods. Institute of Labor Economics. Available from: https://www.iza.org/publications/dp/13115/demographic-determinants-of-testing-incidence-and-covid-19-infections-in-new-york-city-neighborhoods

CEM, 2020. Centro de Estudos da Metrópole. ReSolution. Available from: http://centrodametropole.fflch.usp.br/pt-br. Acessed: 10 June 2020.

Chen N, Zhou M, Dong X, Qu J, Gong F, et al., 2020. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. Lancet 395:507-13. doi:10.1016/S0140-6736(20)30211-7

Dahab M, van Zandvoort K, Flasche S, Warsame A, Spiegel PB, et al., 2020. COVID-19 control in low-income settings and displaced populations: what can realistically be done?. Conflict and Health 14:54. doi:10.1186/s13031-020-00296-8

Corburn J, Vlahov, D, Mberu B, Riley L, Caiaffa W, et al., 2020. Slum health: arresting COVID-19 and improving well-being in urban informal settlements. J Urban Health 97:348-57. doi:10.1007/s11524-020-00438-6

van Dorn A, Cooney RE, Sabin ML, 2020. COVID-19 exacerbating inequalities in the US. Lancet 395:1243-4. doi:10.1016/S0140-6736(20)30893-X

Frúgoli Jr H, 1998. [O Centro, a avenida Paulista e a avenida Luiz Carlos Berrini na perspectiva de suas associações: centralidade urbana e exclusão social.] PhD thesis, University of São Paulo, São Paulo, 305pp. [Article in Portuguese]. Available from: https://repositorio.usp.br/item/000984520

Gibson L, Rush D, 2020. Novel coronavirus in Cape Town informal settlements: feasibility of using informal dwelling outlines to identify high risk areas for COVID-19 transmission from a social distancing perspective. JMIR Public Health Surveill 6:e18844. doi:10.2196/18844

Khalatbari-Soltani S, Cumming RG, Delpierre C, Kelly-Irving M, 2020. Importance of collecting data on socioeconomic determinants from the early stage of the COVID-19 outbreak onwards. J Epidemiol Community Health 74:620-3. doi:10.1136/jech-2020-214297

Liu T, Hu J, Kang M, Lin L, Zhong H, et al., 2020. Transmission dynamics of 2019 novel coronavirus (2019-nCoV). bioRxiv 919787. doi:10.1101/2020.01.25.919787

Pereira RJ, Nascimento GNL, Gratão LHA, Pimenta RS, 2020. The risk of COVID-19 transmission in favelas and slums in Brazil. Public Health 183:42-3. doi:10.1016/j.puhe.2020.04.042.

Rede Nossa São Paulo, 2017. [Mapa da Desigualdade 2017.] Available from: https://nossasaopaulo.org.br/portal/mapa_2017_completo.pdf. [Article in Portuguese].

SEADE, 2020. [Sistema Estadual de Análise de Dados.] Available from: https://www.seade.gov.br/. Acessed:10 April 2020. [Article in Portuguese].

Secretaria de Desenvolvimento Urbano, 2020. [Prefeitura Municipal de São Paulo.] Available from: www.prefeitura.sp.gov. br/cidade/secretarias/urbanismo. Acessed:10 April 2020. [Article in Portuguese].

Secretaria Municipal da Saúde, 2020a. [Boletim diário COVID-19

- 64.] Available from: www.prefeitura.sp.gov.br/cidade/secretarias/saude/vigilancia_em_saude. Acessed: 04 June 2020. [Article in Portuguese].
Secretaria Municipal da Saúde, 2020b. [COVID-19 Relatório Situacional.] Available from: www.prefeitura.sp.gov.br/cidade/secretarias/saude/vigilancia_em_saude. Acessed: 04 June 2020. [Article in Portuguese].
Shen M, Peng Z, Xiao Y, Zhang L, 2020. Modelling the epidemic trend of the 2019 novel coronavirus outbreak in China, 2020. The Innovation. doi:10.1016/j.xinn.2020.100048
Sloan C, Chandrasekhar R, Mitchel EF, Schaffner W, Lindegren ML, 2015. Socioeconomic disparities and influenza hospitalizations, Tennessee, USA. Emerg Infect Dis 21:1602-10. doi:10.3201/eid2109.141861
Smirnov NV, 1939. On the estimation of the discrepancy between empirical curves of distribution for two independent samples. Bull Math l'Univ Moscow 2:3-14.
Sohrabi C, Alsafib Z, O'Neill N, Khanb, M, Kerwanc A, et al., 2020. World Health Organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19). Int J Surg 76:71-6. doi: 10.1016/j.ijsu.2020.02.034
Souza MD, 2020. [Em SP, bairros com maior incidência por COVID-19 estão no centro "pobre". Brasil de Fato]. Released on May 28, 2020. Available from: https://www.brasildefato.com.br/2020/05/28/em-sp-bairros-com-maior-mortalidade-por-covid-19-estao-no-centro-pobre [Article in Portuguese].
Wasdani KP, Prasad A, 2020. The impossibility of social distancing among the urban poor: the case of an Indian slum in the times of COVID-19. Local Environ 25:414-8. doi:10.1080/13549839.2020.1754375
Zhu N, Zhang D, Wang W, Li X, Yang B, et al., 2020. A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med 382:727-33. doi:10.1056/NEJMoa2001017.