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The Impact of COVID-19 Partial Lockdown on Primary Pollutant Concentrations in the Atmosphere of Rio de Janeiro and São Paulo Megacities (Brazil)

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Abstract

As COVID-19 spread all over the world, most of the countries adopted some kind of restrictions to avoid the collapse of health systems. In Brazil, São Paulo and Rio the Janeiro, the two most populated cities in the country, were the first to determine social distancing. In this study, the impact of the social distancing measures on the concentrations of the three main primary air pollutants (PM_{10}, NO_2 and CO) was analyzed. CO levels showed the most significant reductions (up to 100%) since it is related to light-duty vehicular emissions. NO_2 also showed reductions (9.1%–41.8%) while PM_{10} levels were only reduced in the 1st lockdown week. The decrease of pollutants was not directly proportional to the vehicular flux reduction, because it depends on other factors such as the transport of air masses from industrial and rural areas. The differences observed can be explained considering the fleet characteristics in the two cities and the response of the population to the social distancing recommendations.

Keywords COVID-19 · Lockdown · Social distancing · Atmospheric pollutants · Brazil

On January 7, 2020, the identification of a new virus, named SARS-CoV-2, was announced by the World Health Organization (WHO 2020). The outbreak of the virus started in Wuhan, China, in the central Hubei Province, at the end of 2019. In a few weeks, the virus spread to dozens of other countries in Asia. On January 20, the first case was detected in the United States and, on January 24, the first cases were reported in Europe (Spain, France and Italy). The first case in Latin America was confirmed by the Brazilian Ministry of Health on February 25, 2020 (COVID 2020; Croda et al. 2020). Since then, the virus has spread in Africa, Asia, America, Europe and Oceania (Johns Hopkins 2020).

As the cases spread, most of the countries adopted some kind of restrictions to avoid the collapse of health systems (Wilder-Smith and Freedman 2020). In Brazil's two most populated cities, São Paulo and Rio the Janeiro, it was first determined, on March 16, that schools and universities should remain closed, theaters, cinemas and other public events should be cancelled, work at home should be implemented, when possible, and gatherings should be avoided. On March 23, bars, restaurants, beaches, shopping centers and all non-essential business were closed, and public transport was limited. Supermarkets, banks, pharmacies and pet-shops were allowed to remain open. Industrial activities and construction were not suspended, as well as all activities related to health and basic services. Initially, the partial lockdown led to the emptying of streets and public spaces and, according to the government, the circulation of people in São Paulo and Rio de Janeiro, was reduced 75%–80%. In April, part of the population went back to the streets and since then, approximately 50% have attended the recommendation of social distancing (Cyberlab 2020).

The containment measures had a huge impact in the daily life of the citizens and negative consequences for economy, education, culture and tourism, both in Brazil an all over the world (Muhammad et al. 2020). Similar measures have been implemented in other countries. With these societal changes, a positive impact on air quality had been observed in China, India and some European countries (Gautam 2020; Gautam and Hens 2020; Muhammad et al. 2020; Sharma

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et al. 2020). To our knowledge, the first reports of Latin America air quality, during the restrictions, were recently published by Dantas et al. (2020) and later by Nakada and Urban (2020).

From the point of view of public health, the containment measures were certainly important to reduce the spread of the virus, but the partial adherence of the population and the lack of a clear and coordinate response of the national government to attend the World Health Organization recommendations, led to a rapid increase in the number of cases and the collapse of the health care systems (The Lancet 2020). On May 24, Brazil became the country with the second most coronavirus cases worldwide. The country's health ministry reported 347,398 confirmed cases and more than 22,000 deaths (COVID 2020; Johns Hopkins 2020).

The main objectives of this study were to analyze and compare air quality data obtained in the cities of São Paulo and Rio de Janeiro, in order to assess the impact of the partial lockdown on the concentrations of the three main primary pollutants: coarse particulate matter, nitrogen dioxide and carbon monoxide.

Materials and Methods

São Paulo and Rio de Janeiro are the two most populated cities of Brazil and also of South America. The city of São Paulo (SP) covers an area of 1521 km^2 and is a megacity with a population of 12.25 million, corresponding to more than 6% of the total population of the country. Moreover, the Metropolitan Area of São Paulo (MASP) has a total population of approximately 21.5 million. The city of Rio de Janeiro (RJ), with an area of 1200 km^2 has a population of 6.72 million and is part of the Metropolitan Region of Rio de Janeiro (MRRJ) with a population of approximately 12.3 million (IBGE 2020).

The MASP is characterized by local emissions of vehicular sources. According to the official emission inventory, road traffic accounts for 97.5%, 79%, 67.5% and 40% of CO, hydrocarbons (HC), nitrogen oxide (NO_x) and PM_{10} total emissions, respectively (Andrade et al. 2017). In the MRRJ, vehicular emissions account for 98%, 67.3%, 66.5% and 42.3% of total emissions of CO, HC, NO_x and PM_{10}, respectively (INEA 2016). According to the national inventory, when considering only vehicular emissions, 47% and 46% of CO and non-methane hydrocarbons (NMHC), respectively, are emitted by light-duty vehicles (LDV). Motorcycles also contribute with a high fraction (34% and 25% of CO and NMHC, respectively). Heavy-duty vehicles (trucks and buses), fueled by diesel, contribute 91% and 96% of NO_x and particulate matter, respectively (INE 2014).

The air quality monitoring network in Brazil is limited in terms of number of parameters monitored, territorial coverage and representativeness in measurements (Siciliano et al. 2019). Data available for the cities of Rio de Janeiro and São Paulo are obtained by the environmental agencies of the state of São Paulo (CETESB 2020), the state of Rio de Janeiro (INEA 2020) and the city of Rio de Janeiro (SMAC 2020), using standard methods and equipment according to Brazilian legislation (CONAMA 2018). Data were collected following international certificated methods, as described in the guides of the Brazilian Ministry for the Environment (MMA 2020). In this study, experimental data obtained by some representative urban monitoring stations, operated by CETESB (São Paulo) and SMAC (Rio de Janeiro), were compiled. The concentrations of NO_2, and CO were obtained at 10-min intervals and PM_{10} at 1-h intervals. The detection limits (LOD) were 0.01 $\mu g\ m^{-3}$, for PM_{10} and NO_2, and 0.01 ppm, for CO. The monitoring stations for the two cities are shown in the map (Fig. 1) and their main characteristics are presented in Table 1. The studied locations were Copacabana (C), Tijuca (T), Irajá (I), Bangu (B) and Campo Grande (CG), in Rio de Janeiro, and Cerqueira César (CC), Pinheiros (P), Parque Dom Pedro II (PP), Itaim Paulista (IP), Grajau (G), in São Paulo.

For each day, data were compiled following Brazilian air quality standards (CONAMA 2018): 24-h mean for PM_{10}, maximum 1-h mean for NO_2 and maximum 8-h mean for CO. Then, values were organized in four groups, as shown in Table 2. The period from 2/16/2020 to 3/15/2020 was used as reference. On 3/16/2020 schools and universities were closed, and public events were cancelled. On 3/23/2020 containment measures were adopted, such as limiting the mobility and close contact among people. These measures were called "quarantine" by the government and were indicated in this study as "partial lockdown". In March, the adherence to the social mobility restrictions was higher than 50% and, in some locations, reached 75%–80%. In April, the adherence to measures was dismissed by part of the population, despite the exceptional efforts by the state governors and city mayors, as a consequence of the response of the country's President and the growing uncertainty among the population about the health risks and economic impacts of the pandemic.

Results and Discussion

Results are shown in Figs. 2, 3, 4 for PM_{10}, NO_2 and CO, respectively, for all the monitoring stations listed in Table 1. Some data were not available, especially for Rio de Janeiro. The variability of the data is typical of these locations, as have been shown in previous studies (Tsuruta et al. 2017). As a general trend, concentrations varied with substantial differences among pollutants and also among the monitoring stations.

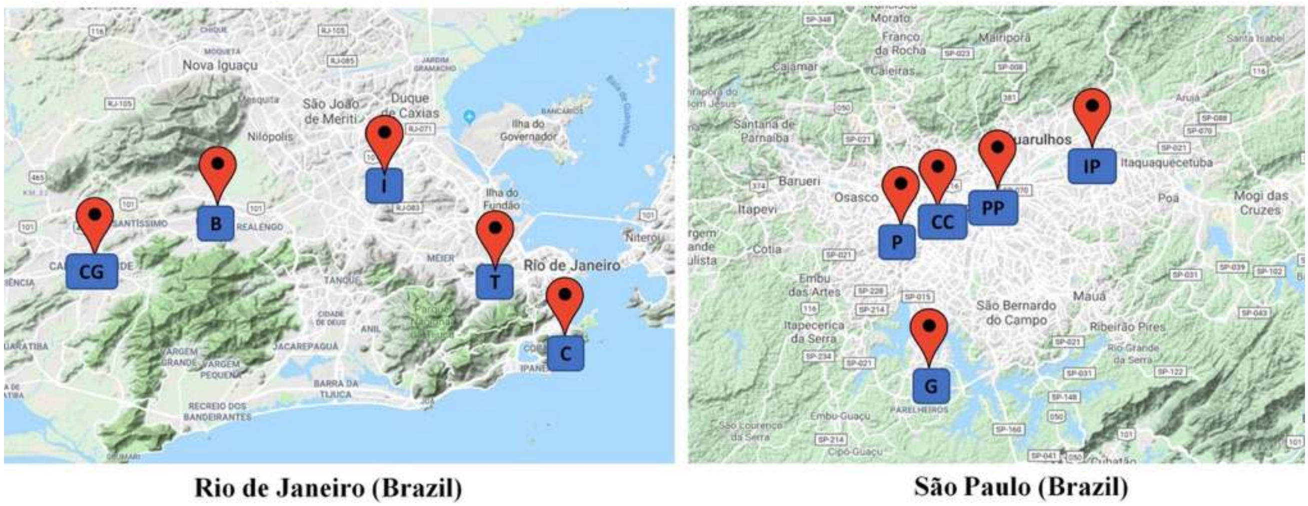

Fig. 1 Monitoring stations in Rio de Janeiro: Copacabana (C), Tijuca (T), Irajá (I), Bangu (B), Campo Grande (CG) and in São Paulo: Cerqueira Cesar (CC), Pinheiros (P), Parque Dom Pedro II (PP), Itaim Paulista (IP), Grajau (G)

Table 1 Monitored pollutants, main sources and developmental status of sampling locations in Rio de Janeiro (RJ) and São Paulo (SP), Brazil

Monitoring station	Monitored primary pollutants	Main emission sources	Economic and social development
Copacabana (C), RJ (SMAC)	PM_{10}, CO	Vehicular	Very high
Tijuca (T), RJ (SMAC)	PM_{10}, CO	Vehicular	High
Irajá(I), RJ (SMAC)	PM_{10}, NO_2	Vehicular, industrial	High
Bangu (B), RJ (SMAC)	PM_{10}, CO, NO_2	Vehicular, industrial	Medium
Campo Grande (CG), RJ (SMAC)	PM_{10}, CO	Vehicular, industrial	Medium
Cerqueira César (CC), SP (CETESB)	PM_{10}, CO, NO_2	Vehicular	Very high
Pinheiros (P), SP (CETESB)	PM_{10}, NO_2	Vehicular	Very high
Parque D. Pedro II (PP), SP (CETESB)	PM_{10}, NO_2	Vehicular	High
Itaim Paulista (IP), SP (CETESB)	PM_{10}, NO_2	Vehicular, industrial	Medium
Grajau (G), SP (CETESB)	PM_{10}, CO	Vehicular, industrial	Medium

Table 2 Characteristics of the studied periods

Group	Period	Characteristics
Reference period	2/16/2020–3/15/2020	Normal activities
A period with some restrictions	3/16/2020–3/22/2020	Schools and universities were closed, public events were cancelled
Partial lockdown (“quarantine”)	3/23/2020–4/3/2020	Bars, restaurants, beaches, shopping centers and all non-essential business were closed, and public transport was limited. More than 50% social mobility restrictions
“Relaxed” partial lockdown	4/4/2020–4/16/2020	Less than 50% social mobility restrictions

In general, primary pollutant concentrations showed a decrease in the first days of the partial lockdown (3/23/2020–4/3/2020). As expected, the decrease of pollutants was not directly proportional to the vehicular flux reduction, because it depends on other factors such as meteorological parameters, the transport of air masses and other emission sources.

The higher decrease in CO concentrations in comparison to NO_2 was due to the changes in vehicular fleet contributions. During the partial lockdown, trucks continued to run

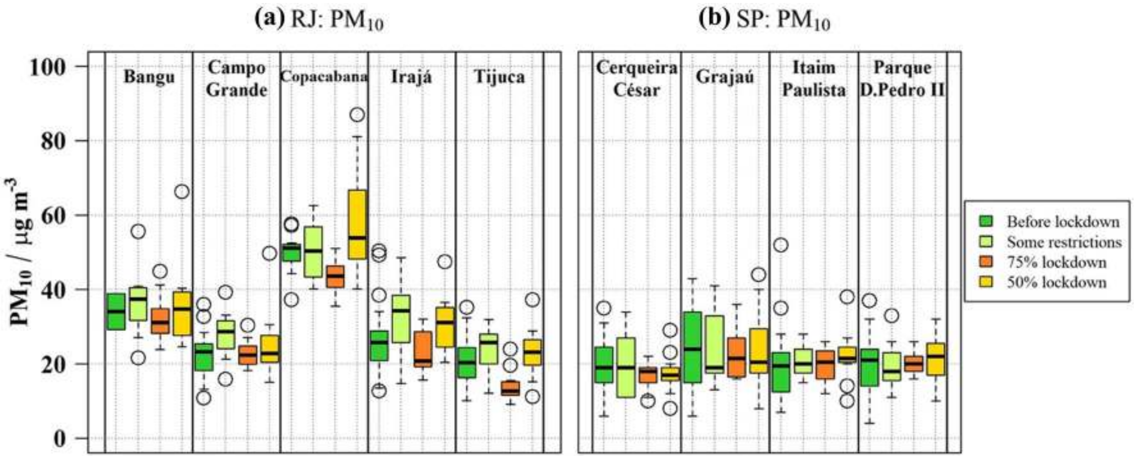

Fig. 2 Boxplots for PM_{10} concentrations calculated for (1) before the lockdown (2/16/2020–3/15/2020); (2) a period with some restrictions (3/16/2020–3/22/2020); (3) partial lockdown (3/23/2020–4/3/2020); (4) "relaxed" partial lockdown (4/4/2020–4/16/2020). **a** Monitoring stations in Rio de Janeiro; **b** monitoring stations in São Paulo

Fig. 3 Boxplots for NO_2 concentrations calculated for (1) before the lockdown (2/16/2020–3/15/2020); (2) a period with some restrictions (3/16/2020–3/22/2020); (3) partial lockdown (3/23/2020–4/3/2020); (4) "relaxed" partial lockdown (4/4/2020–4/16/2020). **a** Monitoring stations in Rio de Janeiro; **b** monitoring stations in São Paulo

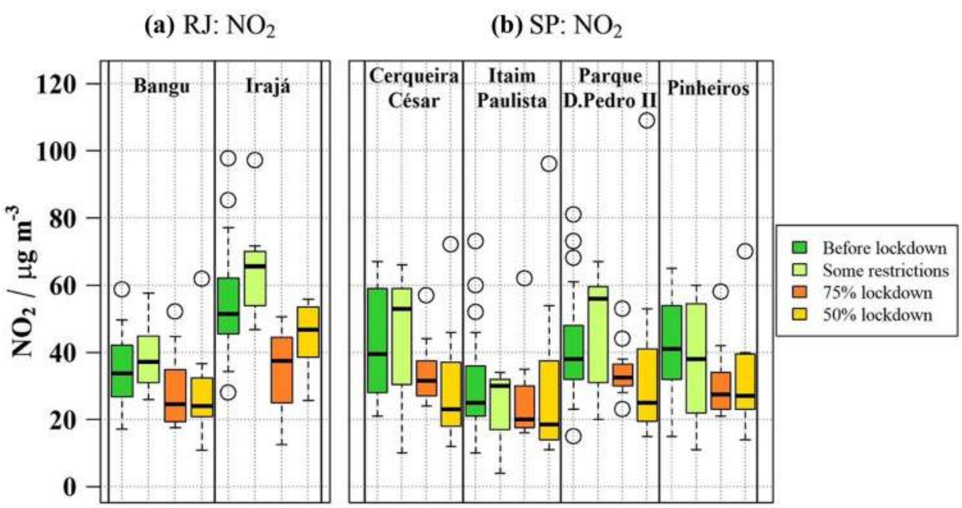

Fig. 4 Boxplots for CO concentrations calculated for (1) before the lockdown (2/16/2020–3/15/2020); (2) a period with some restrictions (3/16/2020–3/22/2020); (3) partial lockdown (3/23/2020–4/3/2020); (4) "relaxed" partial lockdown (4/4/2020–4/16/2020). **a** Monitoring stations in Rio de Janeiro; **b** monitoring stations in São Paulo. Values for Copacabana (RJ) were not plotted since most of the values were < LOQ

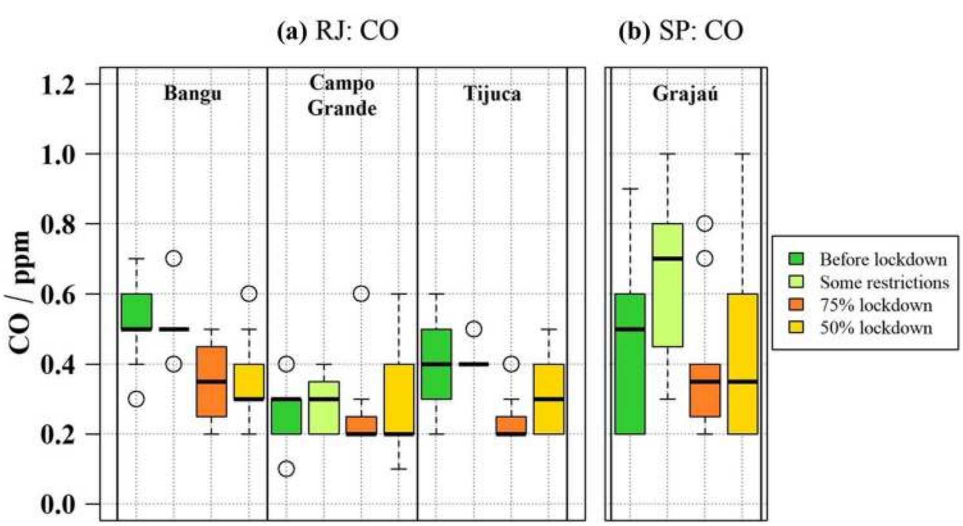

Table 3 Differences (%) between each period of time and the reference period (from 02/16/2020 to 03/15/2020)

Monitoring station	03/16/20–03/22/20*	03/23/20–04/03/20**	04/04/20–04/16/20***
PM_{10} (24-h mean) (industrial and natural emissions; buses and trucks: diesel)			
Copacabana (RJ)	− 1.6%	− 14.8%	+ 5.27%
Tijuca (RJ)	+ 25.6%	− 37.7%	+ 13.7%
Irajá (RJ)	+ 32.9%	− 19.2%	+ 20.7%
Campo Grande (RJ)	+ 23.4%	− 2.8%	− 1.9%
Cerqueira César (SP)	0%	− 5.3%	− 10.5%
Parque Dom Pedro II (SP)	− 14.3%	− 4.8%	+ 4.8%
Itaim Paulista (SP)	+ 2.6%	+ 5.1%	+ 10.3%
Grajau (SP)	− 20.8%	− 10.4%	− 14.6%
NO_2 (maximum value, 1-h mean) (industrial emissions; buses and trucks: diesel)			
Irajá (RJ)	+ 27.4%	− 27.4%	− 9.1%
Bangu (RJ)	+ 10.4%	− 27.3%	− 28.9%
Cerqueira César (SP)	+ 34.2%	− 20.3%	− 41.8%
Parque Dom Pedro II (SP)	+ 47.4%	− 14.5%	− 34.2%
Pinheiros (SP)	− 7.3%	− 32.9%	− 34.1%
Itaim Paulista (SP)	+ 20%	− 20%	− 26%
CO (maximum value, 8-h mean) (light-duty vehicles and motorcycles: gasoline, ethanol)			
Copacabana (RJ)	0%	− 100%	− 100%
Tijuca (RJ)	− 20%	− 60%	− 40%
Bangu (RJ)	0%	− 30%	− 40%
Campo Grande (RJ)	0%	− 33.3%	− 33.3%
Cerqueira César (SP)	0%	− 40%	− 50%
Parque Dom Pedro II (SP)	+ 33.3%	− 33.3%	− 50%
Pinheiros (SP)	+ 40%	− 40%	− 50%
Grajau (SP)	+ 40%	− 30%	− 30%

Differences were calculated using median values

*Schools and universities were closed; gatherings were prohibited; **partial lockdown; ***partial lockdown was relaxed

since industrial and construction activities were maintained, as well as the transport of food and cargo in general. The fleet of buses (which highly contribute to NO_2 emissions) was partially reduced (approximately 50%) while passenger car activity had a 70%–80% decrease in the 1st partial lockdown week (03/23–03/29) and then increased to approximately 50% (Fiocruz 2020). Then, CO (emitted mainly by LDV) exhibited the largest decreases with the lockdowns. In particular, in Copacabana (RJ), CO concentrations were < 0.01 ppm during approximately 90% of the period considered as lockdown.

The lower decrease for particulate matter levels in comparison to NO_2 is probably due to the high contribution of trucks (HDV), which continue circulating within the city. Other sources such as construction activities, industrial emissions, dust resuspension and transport from the vegetated areas could also contribute to particulate matter emission. Recently, Tobias et al. (2020) reported similar results for the city of Barcelona (Spain).

The relative differences between each period of the partial lockdown and the reference period (from 02/16/2020 to 03/15/2020) are presented in Table 3. The main emission sources of each pollutant are also indicated in the table. The differences observed, between the stations and cities, can be explained considering the local fleet characteristics and topographical and meteorological differences.

As a general trend, during the second period of time (with some restrictions), reductions in PM_{10} levels in São Paulo were higher than in Rio de Janeiro, and during the third period of time (partial lockdown) the opposite situation was observed. Those results are probably due to favorable pollutant dispersion conditions in São Paulo from 3/16/2020 to 3/22/2020 (CETESB 2020) and transport of particulate matter from the industrial and vegetated areas in Rio de Janeiro. CO levels were in general lower in Rio de Janeiro (and with higher reductions), an expected result considering that the number of LDV in São Paulo is approximately three times larger than in Rio de Janeiro (IBGE 2020).

The partial adherence to social mobility restrictions, reduction of road traffic and economic activity led to an improvement in air quality, mainly regarding NO_2 and CO, with variations within locations due to the different responses of population to the lockdown recommendations and also to different local characteristics. Districts with the highest economic and social development, also showed the highest CO reductions due to decreased LDV activity. During the partial lockdown, NO_2 levels were reduced approximately 10%–40% while PM_{10} levels had a lower reduction, and also increased in some locations, probably due to the contribution of trucks, some buses and regional-background origin.

In general, emission inventories for urban areas in Brazil consider that vehicular sources account for approximately 40% of total PM_{10} emissions (Andrade et al. 2017; INEA 2016). The lower decrease in particulate matter levels, observed in this study, confirmed that other sources, such as transport from industrial and rural areas, are important and should be considered when analyzing future strategies to improve air quality.

It should be stressed that decrease in primary pollutant concentrations was positive for the environment and public health but was a local and short-time consequence of lockdown measures. By contrast, secondary pollutants, mainly ozone, which were not discussed in this study, showed high levels during the partial lockdown. This fact indicated that air quality was only partially improved. Other long-term effects of the pandemic, such as the worsening of social, economic and health conditions could lead to negative environmental consequences in Brazil, as well as in other countries in the future. Due to the developing economic crisis, many projects and investments in clean energy and basic infrastructure may be compromised in a near future.

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