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Mobility restrictions and air quality under COVID-19 pandemic in São Paulo, Brazil

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Abstract

Social distancing policies put in place during COVID-19 epidemic in addition to helping to limit the spread of the disease also contributed to improving urban air quality. Here we show a decrease in air pollutant concentration as a consequence of mobility reduction in São Paulo during the containment measure which began on 22nd March 2020. When comparing to foregoing weeks to equivalent periods of 2019, the concentration of most air pollutants sharply decreased in the first days of mobility restriction, to then increase again after government officials downplayed the threat of the disease. This trend is also followed by a decrease in hospital admissions by SARS-influenza. Therefore, despite the great economic and social unrest caused by the pandemic, this unique situation shows that large-scale mobility reduction policy had a significant impact on air quality, benefiting, directly and indirectly, the public health system.

Introduction

Air pollution is connected to 4.24[1] to 8.8 million[2] global deaths in 2015, mainly due to cardiopulmonary diseases. The concentration of air pollutants has been strongly reduced as a consequence of strict lockdown procedures in many countries around the world in the first months of 2020. Examples of this had occurred notably in China (e. g. [3-7]), where European Space Agency (ESA) satellite data has shown a 10-30% decrease in nitrogen dioxide (NO_2), which is a pollutant emitted by vehicle engines, power plants, and many industrial processes, when comparing similar periods of 2020 and 2019[7]. Even higher reductions in NO_2 concentrations were observed over northern Italy and England after the lockdown started in these countries[8]. In addition, reductions on carbon monoxide (CO) concentrations, which is a good indicator of light-duty vehicular traffic intensity, had been observed over large cities. For instance, in 2020 New York City had a 50% reduction in CO concentrations and a 5-10% reduction in carbon dioxide (CO_2) as a consequence of a 35% reduction in traffic levels compared to 2019[7].

Social distancing although initially conceived as a sanitary measure to reduce the propagation of the coronavirus disease 2019 (COVID-19)[9], and in doing so mitigating its effects on the public health system, may potentially impact all respiratory and cardiovascular diseases that typically affect the densely populated, more polluted urban areas[10]. As COVID-19 affects the respiratory[11] and cardiovascular[12] systems, the outcomes are potentially more severe for people that live in polluted areas. As shown by Qu et al.[13] for China, the high levels of particulate matter (PM) concentration in urban areas could be a factor for the impairment of the immune response to the virus in infected individuals. This can also explain the age-related impact of the disease affecting more severely the elderly, who were exposed to longer periods of heavy air pollution[1, 13, 14] or to habits that affect the respiratory system such as smoking[15, 16]. A study involving 3,080 cities in the United States of America revealed that an increase of 1.0 μg m^{-3} in the exposure to $PM_{2.5}$ was associated with a 15% increase in mortality due to COVID-19[17]. Besides, there are indications that atmospheric particles can also help in spreading the new coronavirus[18], increasing the potential of contamination beyond closer contact with infected people or surfaces.

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In Brazil, social distancing has been encouraged as a way to slow down the spread of COVID-19. In the Metropolitan Area of São Paulo (MASP), isolation measures were imposed by local authorities from 20th March 2020[19]. These measures had high initial adherence but were later dismissed by part of the population after broadcasted presidential announcements[20] derided the danger of the disease in clear opposition to the World Health Organization (WHO) recommendations. This unique sequence of dramatic pivots (from zero quarantine, then to full restrictions, and finally reverting to a partial quarantine) in the MASP allows us to explore the role of social distancing on air pollutant concentrations and their consequences to public health. It is important to note that all containment measures adopted in Brazil aiming at protective measures for the general population, such as limiting mobility and the close contact among people, were epitomized under the term "quarantine" by the São Paulo state government and it will be used in this sense from here on in this paper.

In this paper, we used general mobility data, pollutant concentration measurements, and public health data to assess the impact of social distancing policies on the air-quality of the MASP and on respiratory and cardiovascular diseases. Air pollution data are provided by the São Paulo Environmental Agency (CETESB) automated air quality network[21]. First, we compared different periods of 2020, namely the weeks before the quarantine and the following weeks, including those after the president's first announcement encouraging the population to dismiss the social distancing policies. Then we compared the same intervals in 2019 and 2020. In order to take into account the dynamics of air pollution concentrations through time, the comparison between the datasets of the two years was adjusted to match the hours and also the day of the week. In doing so, we moved 2019 datasets forward 24 hours to match the same weekday of 2020. We also added 24 hours to March 1st, 2019 since 2020 is a leap year. As the calendar for 2019 was moved, it is still possible to compare holidays and working days between the years. General mobility trends were derived from the position of smartphones and other mobile devices with Global Position Systems (GPS) and public health data were obtained from public governmental statistics. We show a correlation between people's mobility and urban air pollution, and the decreasing of hospital admissions for other respiratory diseases. Therefore, we put in evidence positive feedbacks of limiting social mobility in further decreasing the pressure on hospitals besides the direct benefit of limiting the spread of COVID-19 infection.

Results

Mobility trends before and during the quarantine

General mobility trends derived from GPS position of smartphones and other mobile devices with GPS have been provided by Internet companies to the public. The Apple Mobility Reports (https://www.apple.com/covid19/mobility) for Brazil and São Paulo (Fig. 1) show driving, transit, and walking percentage change with reference to the baseline of January 13th, 2020. The mobility in all modes plummeted until March 23rd, followed by a slow increase with a peak on April 10th and then decreased again until April 12th, however, the last values of the series present a positive trend. Although both figures show similar behavior, we can see that São Paulo's mobility tendencies of increase after March 23rd were lower than the national curve, probably due to the strong advice and procedures taken by the São Paulo state government, following WHO recommendations.

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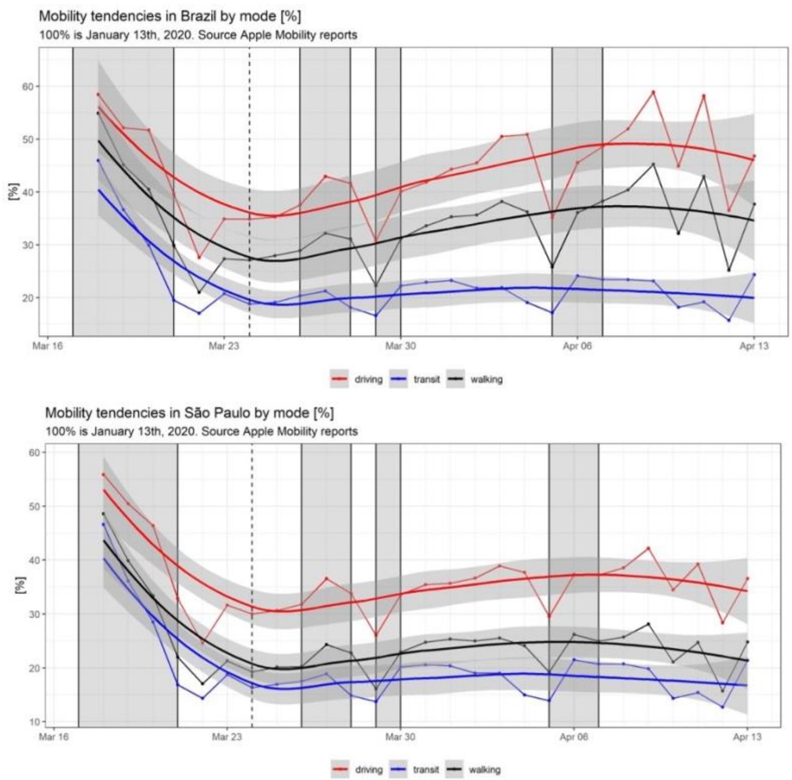

Fig.1: Mobility tendencies in Brazil by mode (%) between March 17th and April 13th for 2020 for Brazil (top) and São Paulo (bottom). Source: Apple Mobility reports.

Another tool to measure human activity is the "isolation index". To check the adherence to the quarantine the São Paulo state government developed a monitoring system that tracks the mobility trends and check the quarantine measures efficacy by informing the percentage of the population that left home each day estimated using the data from mobile phone companies (see Supplementary Note 1). After the Brazilian Ministry of Health declared a public health emergency[22], local authorities started to implement policies aiming at a 70% social mobility restriction to control COVID-19[23]. However, only a few small towns in São Paulo state have reached that goal.

Air pollutant concentrations before and during the quarantine

Over the state of São Paulo, a marked decrease of air pollutants can be observed after the beginning of the quarantine period on 22nd March 2020. For instance, NO_X concentrations are negatively correlated to the "isolation index" in São Paulo city and in neighboring cities as well (see Supplementary Fig. 1). At the scale of the MASP, the effects of stay-at-home and quarantine policies (physical distancing measures and movement restrictions) during the months of March and April 2020 can be seen in Fig. 2, where air quality stations are represented by colored dots (see also Supplementary Table 1). A clear decrease in most pollutant concentrations is observed after the beginning of the quarantine order with a reduction of around 25-75% in CO, nitrogen oxides (NO_X), PM_{10}, and $PM_{2.5}$ for most locations between the first week of quarantine (from 22nd to 28th, March 2020) and what we considered a normal week before it (from 15th to 21st, March 2020). For ozone (O_3), the reductions were lower and in some stations there was even an increase for the same period of analysis. After the first week, a continuous trend of progressive increase in air pollutants is observed following the trend of increased mobility. It is important to mention that meteorological conditions across these weeks do not explain this observed behavior (Fig. 2) and

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will be addressed in the next sections. Most likely, they resulted from a less effective quarantine, as indicated by the mobility indicators.

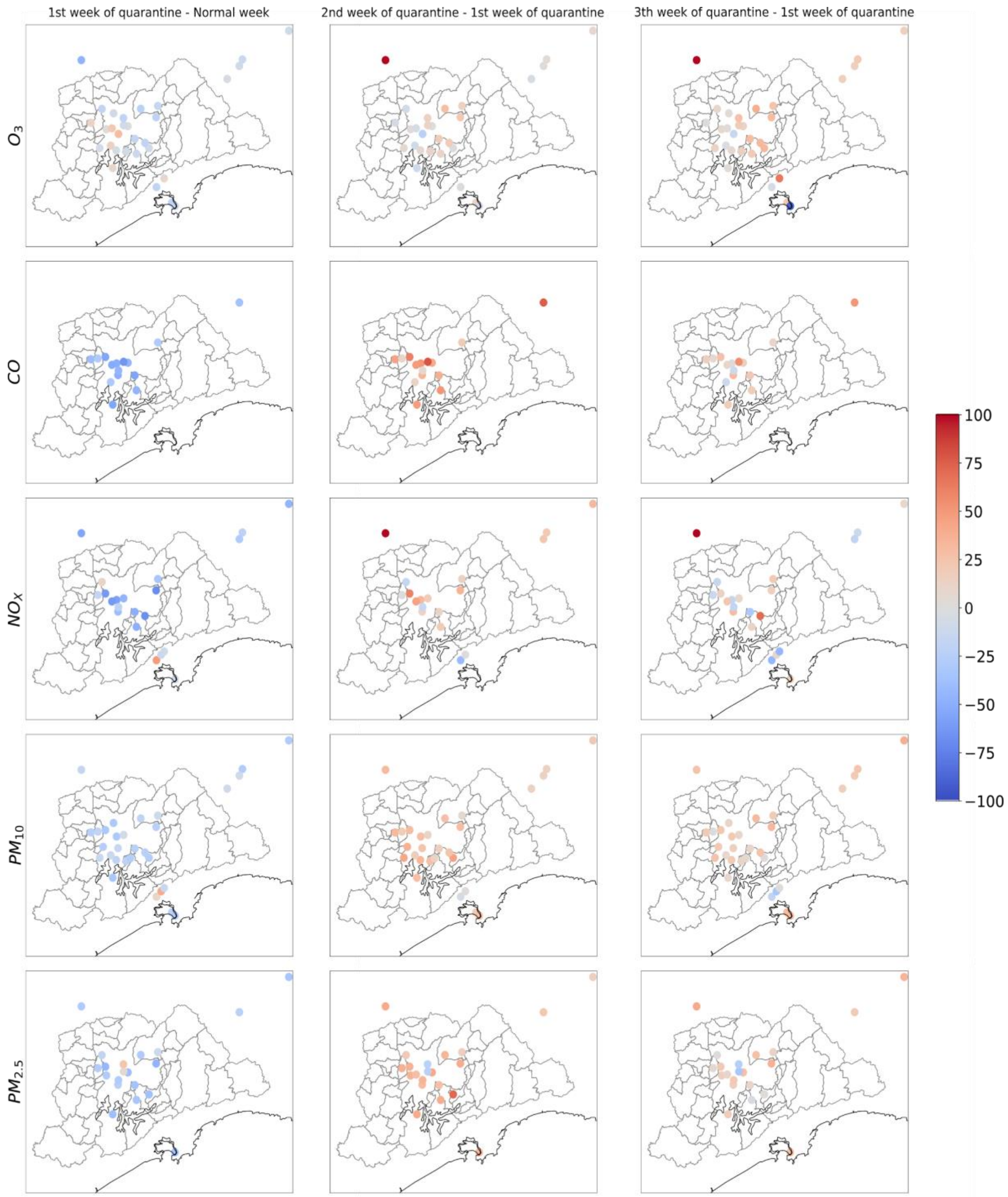

Fig. 2: Spatial comparison (%) between 1st week of quarantine – Previous week (left), 2nd week of quarantine – 1st week of quarantine (middle), and 3rd week of quarantine – 1st week of quarantine (right) for O_3, CO, NOx, PM_{10} and $PM_{2.5}$. The circles indicate monitoring stations from the São Paulo Environmental Agency (CETESB), and the map illustrate the Metropolitan Area of São Paulo, Southeast of the São Paulo state in Brazil.

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Air pollutant concentrations in equivalent weeks of 2020 and 2019

Fig. 3 shows the hourly mean concentrations of $PM_{2.5}$, PM_{10}, NO_2, CO, and O_3 for the MASP in 2019 and 2020. The general trend since March 20th is of remarkably lower concentrations on working days between 2020 and 2019 (the normality of all samples analyzed was attested by the Shapiro test). $PM_{2.5}$ (µg m^{-3}) concentrations (Fig. 3a), whose main sources are the exhaust of diesel vehicles, soil resuspension, and biomass burning are on average 3.7 µg m^{-3} lower (CI95: -4.5 to -2.9 µg m^{-3}). Similarly, PM_{10} concentrations (Fig. 3b) are 4.6 µg m^{-3} lower on average (CI95: -6.0 to -3.3 µg m^{-3}) in 2020. NO_2 concentrations (Fig. 3c) follow the $PM_{2.5}$ since they originate mostly from the combustion of diesel from heavy-duty vehicles[24]. The general trend for NO_2 in 2020 is lower concentrations than 2019 of 10.2 µg m^{-3} on average (CI95: -11.7 to -8.8 µg m^{-3}), reflecting a probable reduction in heavy-duty emissions. CO concentrations (Fig. 3d), which is a good tracer for light-duty vehicles, especially passenger cars[24], have similar trends to $PM_{2.5}$ and NO_2, with 2020 mean values 0.17 ppm lower (CI95: -0.19 to -0.15 ppm) than 2019 ones. In the cases of CO, NO_2, and Toluene, concentration levels went to almost zero during the last weeks of March 2020 (Fig. 4), measured at Pinheiros station, which is a residential area located near to one of the main urban motorways of São Paulo city[24].

Despite a general trend of decrease, there are some periods in which 2020 concentrations of most air pollutants were higher than those observed in 2019 (marked as grey swathes in Fig. 3). For instance, the periods between March 18-21th, just after the social distancing measure was announced, March 26-27th and April 5-8th. Meteorological conditions for these periods are as follows. Average wind speed in April at 22:00 LT for 2020 was 7.4 m s^{-1} while in 2019 it was 5 m s^{-1}, indicating that the same period in 2020 had more favorable conditions for pollution dispersion than in 2019. On March 18-21st, 2020 and the 2019 equivalent period (March 20-23rd, 2019), the synoptic conditions were very similar, with a cold front crossing São Paulo and causing few and sparse precipitation in 2020 but more intense and generalized in 2019, according to infrared (10.35 µm) satellite images and ground stations over São Paulo city (not shown). These features possibly influenced the 2019 record compared to 2020. On March 27th, 2020 and the 2019 equivalent period (March 29th, 2019), there was a western branch of a high-pressure system influence over São Paulo state, which led to similar mean wind speed and direction patterns, and no cloud cover in São Paulo. Therefore, there was no clear evidence of synoptic influence on the difference in pollutant concentrations for the two years. On April 05-06th, 2020, stable conditions were present over São Paulo with the presence of the western branch of a high-pressure system centered over the Atlantic Ocean. During the equivalent period in 2019 (April 07-08th, 2019), a stationary front caused rainfall over São Paulo. On April 07-08th, 2020 a cold front crossed São Paulo with a cloud band associated without rainfall. For the equivalent period of 2019 (April 09-10th), a high-pressure system predominated over São Paulo. In sum for all periods, but April 05-06th, specific meteorological conditions may not be used to explain the higher concentrations observed in 2020. Instead, they seem to be related to small increases in mobility in these days for the year 2020, as shown in Fig. 1.

In contrast to the other pollutants, the O_3 concentrations (Fig. 3e) are higher on average for 2020 than 2019, with an increase of 8.2 µg m^{-3} (CI95: 5.11 to 11.24 µg m^{-3}) in the studied period. The difference for the period 21:00-03:00 LT was 11.5 µg m^{-3} (CI95: 9.33 to 13.64 µg m^{-3}), and the difference between 12:00 and 17:00 LT was not significant. Ozone is originated by complex reactions evolving NOx, Volatile Organic Compounds (VOC), and solar radiation[25]. It is a secondary pollutant with no linear relationship with its precursors. Therefore, the reduction of primary pollutants does not necessarily reduce O_3 concentrations[26]. As O_3 is a gas with deleterious effects on health[27], the increment of O_3 might trigger a more severe impact on patients infected

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with COVID-19[17]. Ozone can also be responsible for exacerbating respiratory and cardiovascular diseases[28]. For instance, hospital admissions due to circulatory and heart disturbances associated with ozone concentrations were identified by Wang and Kwok[29] and Ballester et al.[30]. The increase in O_3 in 2020 observed exclusively at night may be a response to the lack of NOx in MASP during this period. At night the concentrations that usually go near zero in normal days are kept around 30 µg m^{-3}, keeping nocturnal O_3 levels higher than normal. Similar behavior was observed over California, USA, where, despite NOx reductions of around 50% due to stay-at-home policies, night-time O_3 concentrations were more pronounced [31].

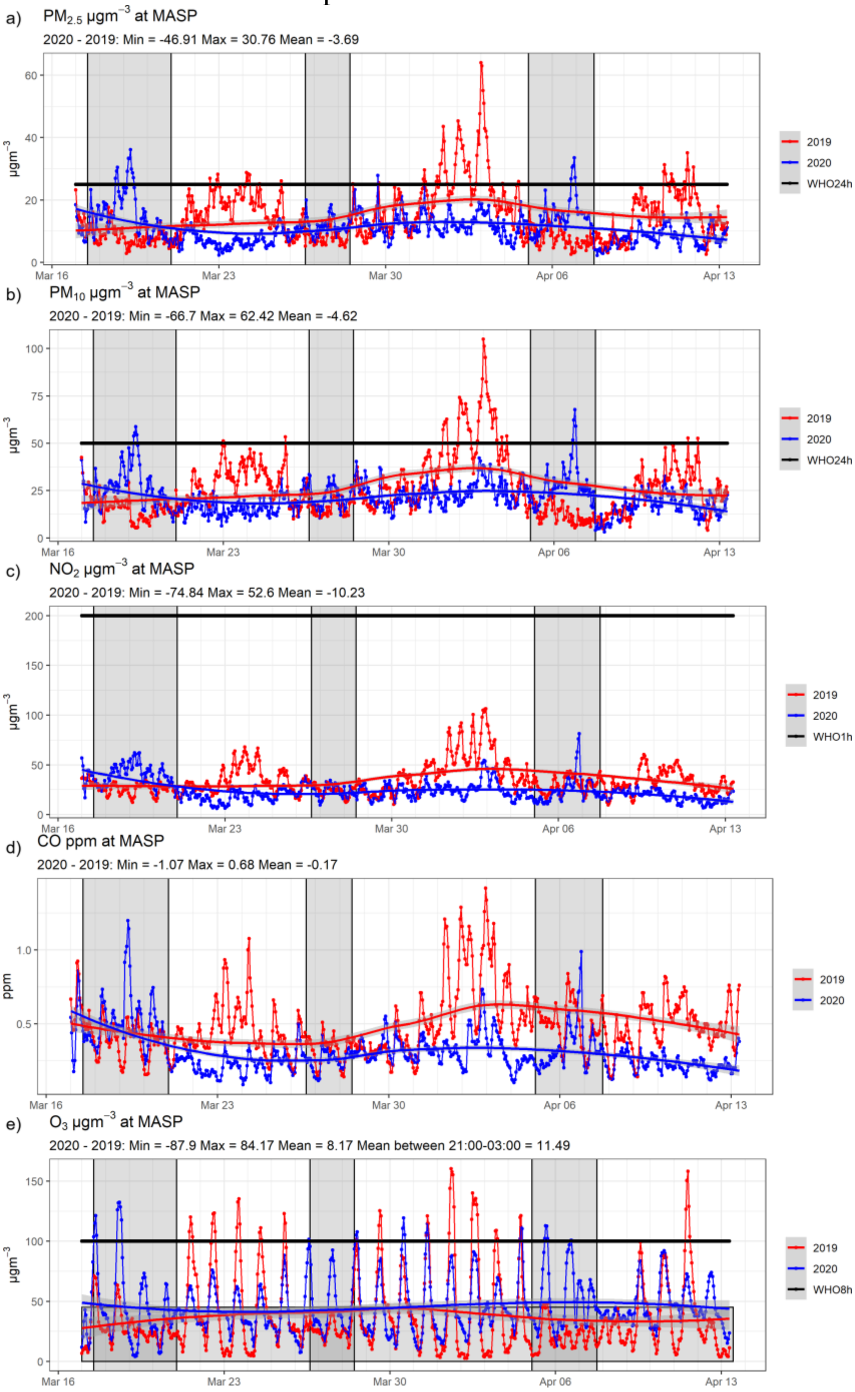

Fig. 3: Hourly means of $PM_{2.5}$ (a), PM_{10} (b), NO_2 (c), CO (d) and O_3 (e) for MASP in 2019 and 2020. Units are displayed in each panel. Black flat lines represent the WHO recommended limits for each pollutant. Grey swathes show where 2020 concentrations were higher than 2019.

Correlating air pollutant concentrations with mobility and "isolation index" is useful to see if they are potentially related to human activity. Correlations between the driving mode of Fig. 1 and the pollutants $PM_{2.5}$, PM_{10}, NO_2, O_3, and CO were all positive and significant and equal to 0.30, 0.29, 0.52, 0.33, and 0.67, respectively. An opposite behavior is observed regarding the "isolation index". Supplementary Fig. 1 presented the "isolation index" with an apparent negative correlation with air pollution. The correlations between this index and the concentrations for $PM_{2.5}$ (Fig. 3a), PM_{10} (Fig. 3b), NO_2 (Fig. 3c), CO (Fig. 3d), and O_3 (Fig. 3e) are -0.30, -0,20, -0.71, -0.64, and -0.11, respectively. Notoriously, the NO_2 and CO present good negative correlation values, being good tracers of human activity.

On the effectiveness of social distancing policies tracked by air pollutants data

In detail, the Brazilian data also provides some insights into the influence of the governmental orientation (or lack of it) on the efficiency of social distancing policies. Although many efforts are in progress to avoid COVID-19 spread worldwide, there were negative reactions to lockdowns or stay-at-home initiatives, contradicting the WHO guidance. Examples of the negative actions are the suspension of environmental laws enforcement amid the coronavirus outbreak. As mentioned by Beitsch[32] US EPA has been under pressure from industries to suspend enforcement of a number of environmental regulations due to the coronavirus pandemic. Similarly, the Brazilian president has discouraged people to follow WHO recommendations, minimizing the risks of COVID-19 and asking them to end social distancing. Although most São Paulo state population kept to the stay-at-home policy, a clear increase in mobility is observed after the president started a campaign against the quarantine on 24th March 2020. The consequences of this action in terms of an increase in pollutant concentrations can be seen in Fig. 4.

The smoothed blue lines in this figure show a decrease of concentrations between April 18-23th followed by an increase in the following days, until April 7th. For each period we calculated slopes as simple regressions of the concentrations over time. The significant slope for NO_2 is -6.187e-05 (Pr(>|t|) = 0.000235) for the decreasing period and 7.669e-06 (Pr(>|t|) = 9.08e-14) for the increasing period. In the case of CO, only the increasing period resulted in a significative slope of 1.077e-07 (Pr(>|t|) = 3.34e-14). Toluene presented a negative slope of -1.452e-05 (Pr(>|t|) = 0.0386) and a positive slope of 1.269e-06 (Pr(>|t|) = 1.31e-07). Finally, the negative slope for $PM_{2.5}$ was -5.869e-05 (Pr(>|t|) = 0.000192) and the positive slope was 4.456e-06 (Pr(>|t|) = 2.50e-07). In the case of O_3 the slopes were non-significant. Therefore, the data suggest that the effort to adopt a reduction in the circulation of people, with the closure of activities in industry and commerce in Brazil, has been partially successful. While most local leaders, including mayors and governors abided by the recommendations of WHO, these actions were counter effected by the direct action of the Brazilian president that delayed government aid to unemployed and informal workers and systematically minimized the threat of the pandemic.

Assessing the impact on the public health system

In order to investigate the impact of the quarantine periods on respiratory diseases other than COVID-19, we investigated the hospital admissions rates across the period of quarantine and equivalent weeks in previous years. Around the world, the health system is under pressure and numbers of hospitalizations are not updated in a timely manner. Despite that, we analyzed the epidemiological weeks (1-15) for years 2017-2020 of hospital admissions by SARS-influenza in São Paulo state, with 2017 being a typical epidemiological year for hospital admissions by SARS-influenza (http://info.gripe.fiocruz.br/).

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The prevalence (number/100,000 inhabitants) of SARS-influenza (Fig. 5) shows a similar behavior between 2017 and 2020 until week 10, with a peak in week 11 and then an abrupt decrease after mobility restrictions were imposed on the population.

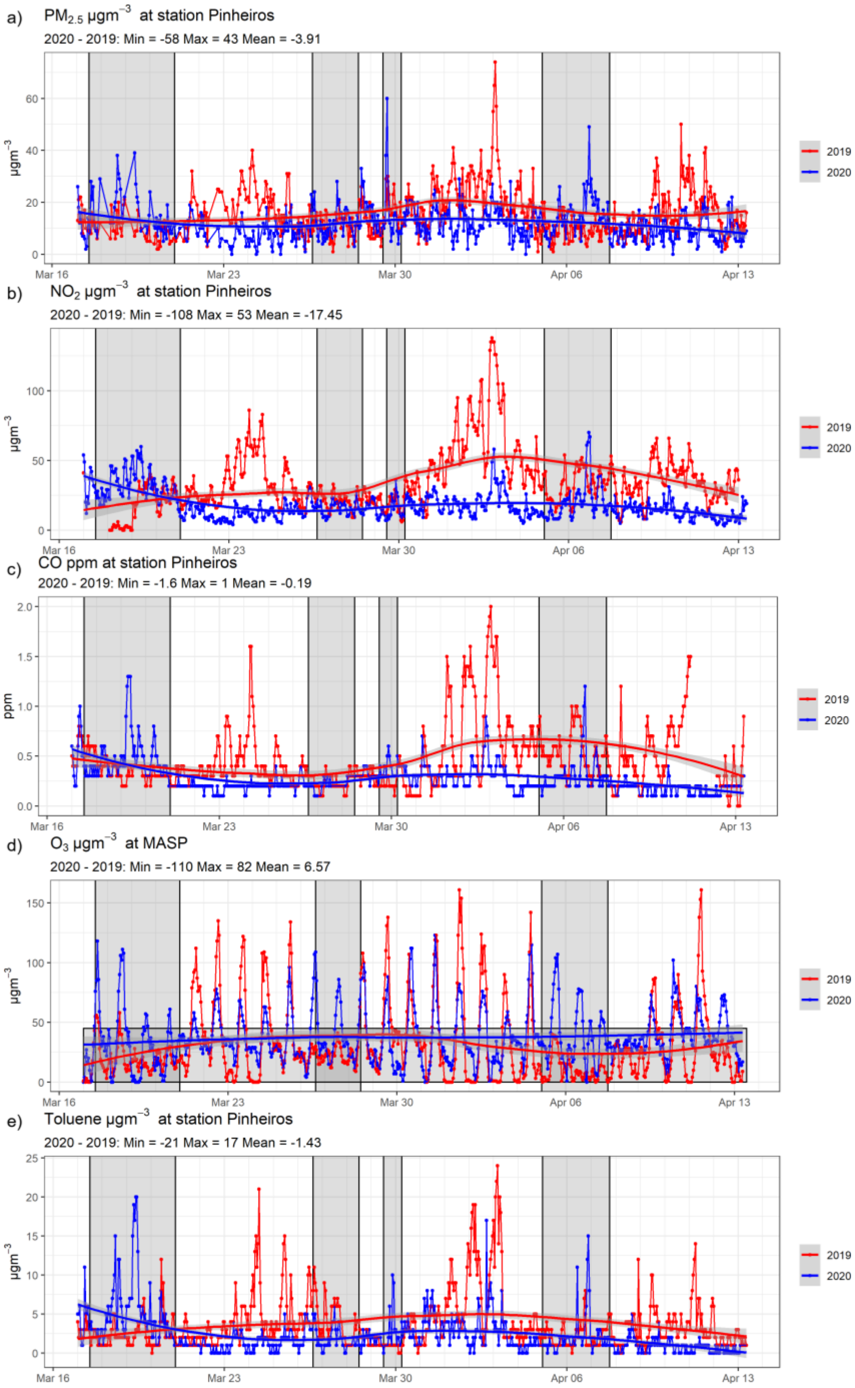

Fig. 4: Evolution of some pollutant concentrations at Pinheiros monitoring station in March and April 2020 in comparison with equivalent period in 2019. The t-Student test for the difference for NO_2 was -17.4 µg m^{-3} (CI95: -19.0 to -15.2 µg m^{-3}), for CO -0.19 ppm (CI95: -0.22 to -0.16 ppm), for Toluene -1.4 µg m^{-3} (CI95: -1.8 to -1.1 µg m^{-3}) and for $PM_{2.5}$ -3.91 µg m^{-3} (CI95: -4.83 to -2.98 µg m^{-3}). In 2020 O_3 concentrations are significantly higher than in 2019, with a mean difference of 6.57 µg m^{-3} (CI95: 3.51 to 9.68 µg m^{-3}). The difference for the period between 21:00-03:00 LT was 9.67 µg m^{-3} (CI95: 7.25 to 12.08 µg m^{-3}). However, the difference for the period 12:00-17:00 LT was only 1.96 µg m^{-3}, which was not significant.

We hypothesize that this decrease in hospital admissions is associated with social distancing and mobility reduction policies (Fig. 1), and also with the improvement in air quality (Figs. 2 and 3). It is likely that isolating the population, mainly the elderly, prevented the incidence of other respiratory diseases that are common in Brazil. In the past years, a high incidence of respiratory diseases was recorded in the transition from summer to winter months, which were largely spread due to a local culture of not staying at home during the onset of these illnesses. In addition, the use of facial masks is not common in Brazil. This result can show the importance of preventing the dissemination of other viruses, for instance, influenza.

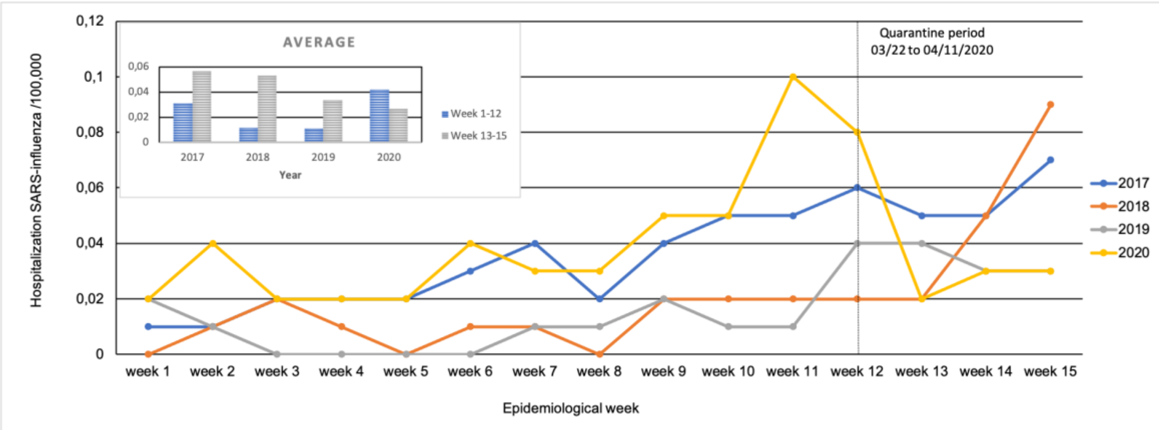

Fig 5: Prevalence (hospitalization/100,000) of SARS by influenza in the epidemiological weeks 1 to 15 in the years of 2017-2020 for the São Paulo state. Source: http://info.gripe.fiocruz.br/

Discussion

The world is facing its greatest challenge since the Second World War and there is a worry concerning how to overcome the economic difficulties imposed by social distancing policies. Yet, one aspect of the social distancing policies is the resulting decrease in the level of pollutants concentration all over the world. We believe this can be considered as a counterbalance for the externalities of air pollution, due to mortality and morbidity. As the São Paulo population is continuously exposed to heavy traffic emission, which is the main source of pollutants particularly to those who commute long distances every day, the extreme situation provided by the COVID-19 pandemics reinforces the need to reduce the traffic on the streets to improve the air quality. Our results show that mobility reduction has a direct impact on air pollution, but also an indirect impact on the spread of other common infectious diseases. This would, in turn, impact the hospitals' admissions and DALYS (Disability-Adjusted Life Year) by reducing the burden of diseases. During the events of quarantine and social distancing, it was possible to notice that the reduction was not the same for all the pollutants nor for all the air quality stations. More central stations showed more adherence to the isolation than the peripheric air quality stations, where the workers from essential activities live. We also observed that the degree of air pollutants reduction was strongly influenced by the attitude of government officials. While most of the Brazilian governors and mayors followed the social distancing recommendations of WHO, the daily opposition of the Brazilian president significantly counteracted these policies. A path to end the stay-at-home policy seems to imply massive testing and intermittent release of the population so that controlled small outbreaks are generated[33]. The São Paulo case reported here confirms that even partial mobility policies, together with other sanitation measures can contribute to decreasing diseases other than COVID-19 and should be recommended for the population when sick with transmissive respiratory diseases.

Methods

Pollutant concentrations used in this study were provided by São Paulo Environmental Agency (CETESB) automated air quality network, freely available under subscription in the QUALAR platform[21]. A list of the CETESB stations and the pollutants that each of them measures is available on Table 1 of Supplementary Material. As air pollution presented different patterns for each day of the week, the comparison between 2019 and 2020 was set matching the hours and also the day of the week. For instance, the first day of 2020 was Wednesday, but the first day of 2019 was Tuesday. Therefore, the data for 2019 was moved forward 24 hours to start also on Wednesday. Additional 24 hours were added after March 1st since 2020 is a leap year. Besides comparisons between 2019 and 2020, we also compared different weeks of 2020, namely, before the implementation of quarantine and the following weeks, after Brazilian president's pronouncement, encouraging the public not to follow stay-at-home or quarantine procedures, in order to save jobs and the Brazilian economy.

Comparison of observations of air pollutant and meteorology parameters for 2020 and 2019, hour and type of day were statistically made by means of the Shapiro test for normality and average values were compared with a t-Student test using R programming language[34] for the whole period. We also calculated the correlations and linear associations between observations and two sets of data with isolation index and mobility index from Apple Mobility Reports (https://www.apple.com/covid19/mobility) over the whole country and São Paulo city.

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Data availability

All the data used in this study are freely available on the internet. Air quality data can be obtained through CETESB/QUALAR website (https://qualar.cetesb.sp.gov.br/qualar/conDadosHorariosPorParametro.do?method=gerarRelatorio)

"Isolation index" is available at São Paulo State Government web site (https://www.saopaulo.sp.gov.br/sala-de-imprensa/release/isolamento-social-em-sao-paulo-e-de-50-aponta-sistema-de-monitoramento-inteligente-4)

Number of hospitalizations due to SARS by influenza can be verified at http://info.gripe.fiocruz.br/

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Code availability

In order to make data visualization easier, an automated visualization system was created and it is available at https://ibarraespinosa.github.io/coronavirus/. The system shows an interactive real-time comparison of air pollutant concentrations of O_3, NO_2, $PM_{2.5}$, and PM_{10} for the MASP comparing 2019 and 2020 equivalent periods. The website also shows the WHO recommendations for air quality[35] and also, some tags indicating when measurements for social isolation (announced on March 17th) and quarantine (announced on March 22nd) were taken.

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Contributions

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Ethics declarations

Competing interests

The authors declare no competing interests.