Sustainability in Environment
ISSN 2470-637X (Print) ISSN 2470-6388 (Online)
Vol. 8, No. 3, 2023
www.scholink.org/ojs/index.php/se

*Original Paper*

# Analysis of Strict Social Isolation (SSI-Lockdown) Measures Impacts on Atmospheric Pollutant Emissions and Health Risks on Roads with Intense Vehicle Flow in the City of Fortaleza-Ceara/Brazil

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Received: March 22, 2023 Accepted: May 16, 2023 Online Published: June 03, 2023
doi:10.22158/se.v8n3p1 URL: http://dx.doi.org/10.22158/se.v8n3p1

***Abstract***

*In early 2020, governments of many countries adopted strict social isolation (SSI) measures to contain the spread of the SARS-CoV-2 Disease (COVID-19). Thus, the present work aimed to evaluate the influence of those SSI measures on atmospheric pollutants emissions and their potential health risks in the city of Fortaleza - Ceará. To this end, static and dynamic analyses were carried out in order to investigate the levels of some atmospheric pollutants found in four main avenues during SSI and post-SSI periods. In addition, some health indicators were investigated by analyzing potential Particulate Matter (PM) deposition in the respiratory tract of populations exposed to those environments. Our results for both dynamic and static analyses show that all pollutant concentrations from those avenues displayed an increase between SSI and the post-SSI period. The total $PM_{2.5}$ dose deposited in the respiratory tract and potential total $PM_{10}$ respiratory deposition showed increases between the SSI and post-SSI periods. The inhaled-dose numbers also showed considerable increases for all avenues when comparing SSI and post-SSI periods. According to our results, SSI contributed to decreases in atmospheric pollutant emissions, in potential particulate matter respiratory tract deposition and, consequently, in the inhaled particulate matter dose.*

***Keywords***

*Atmospheric Pollution, Particulate Matter, COVID-19, Strict Social Isolation*

## 1. Introduction

Air pollution is currently one of the main problems for public health and the environment. Technological advances in modern society have significantly contributed to an increase in both the concentration and variety of pollutants released into the atmosphere. Abundance of these substances in the air can be harmful to the health, safety and well-being of living beings (Santos et al., 2014). Motor vehicles play a considerable role in the degradation of air quality, mainly through the use of petroleum-derived fuels such as gasoline and diesel.

The main pollution sources produced by automobiles are exhaust gases and volatile emissions, both originating from fuel evaporation (Mellios; Ntziachristos, 2013). These exhaust gases include carbon monoxide (CO), nitrogen oxides (NOx), non-methane hydrocarbons (NMHC), total aldehydes (RCHO) and sulfur dioxide ($SO_2$), in addition to particulate matter (PM). This group also includes greenhouse gases, such as carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) (CETESB, 2018). Among these pollutants, there are also tropospheric ozone precursors, a dangerous secondary pollutant resulting from the reaction between NOx, CO and volatile organic compounds (VOC) when under solar radiation (Alvim et al., 2011; Seinfeld; Pandis, 2006).

Studies indicate a relationship between high concentrations of atmospheric pollutants and increases in vehicular traffic (Goel & Guttikunda, 2015; Jedynska et al., 2014). In this sense, analyses of atmospheric pollutant concentrations on roads with intense vehicular flow in large urban centers are important, since these motorways frequently present, in addition to vehicular circulation, intense movement of pedestrians who are susceptible to inhalation of harmful pollutants, even in concentrations below those established by legislation (Santos et al., 2014).

In addition to exposure to atmospheric pollutants and the harms they cause to health, the population is also subject to respiratory diseases. In early 2020, governments of many countries adopted Strict Social Isolation (SSI) measures to contain the spread of SARS-CoV-2 Disease (COVID-19), a severe acute respiratory infection of high transmissibility and global distribution (Dong et al., 2020). These isolation measures affected the functioning of several social and economic sectors, causing reductions in automobile flow as well as in industry and services-related activities. (San Martin; San Martin, 2020).

As a local measure, the Ceará state government adopted SSI during the COVID-19 “first wave”, starting from March 16 2020 by means of Decree No. 33.510, the first to restrict social and economic activities in the state. Subsequently, after a period of decreasing cases, there was a new increase and “second wave” in 2021, causing the Ceará government to adopt SSI once more, by decree No. 33,965 of March 04 2021, motivated by the rise in cases and deaths related to COVID-19.

In this context, this work aimed to evaluate the influence of the Strict Social Isolation (SSI), specifically during the second wave (decree No. 33,965), on atmospheric pollutant emissions in the city of Fortaleza and their potential damage to health. Thus, static and dynamic analyses were performed in order to assess some atmospheric pollutants levels found in four roads with intense vehicular flow which give access to the central area of Fortaleza, both during SSI and post-SSI (after restrictions were suspended). In addition, some health indicators were analyzed through the assessment of PM deposition in the respiratory tract of people exposed to these specified environments.

## 2. Method

### *2.1 Analyses Zones*

Our study was based on dynamic and static analyses of atmospheric pollutants found along four avenues of intense vehicular flow (Mister Hull/Bezerra de Menezes - MH/BM, Heráclito Graça/Duque de Caxias - HG/DQ, Doutor Silas Munguba - DSM and Abolição - AB), which give access to the central area of the city of Fortaleza-Ceará (Figure 1).

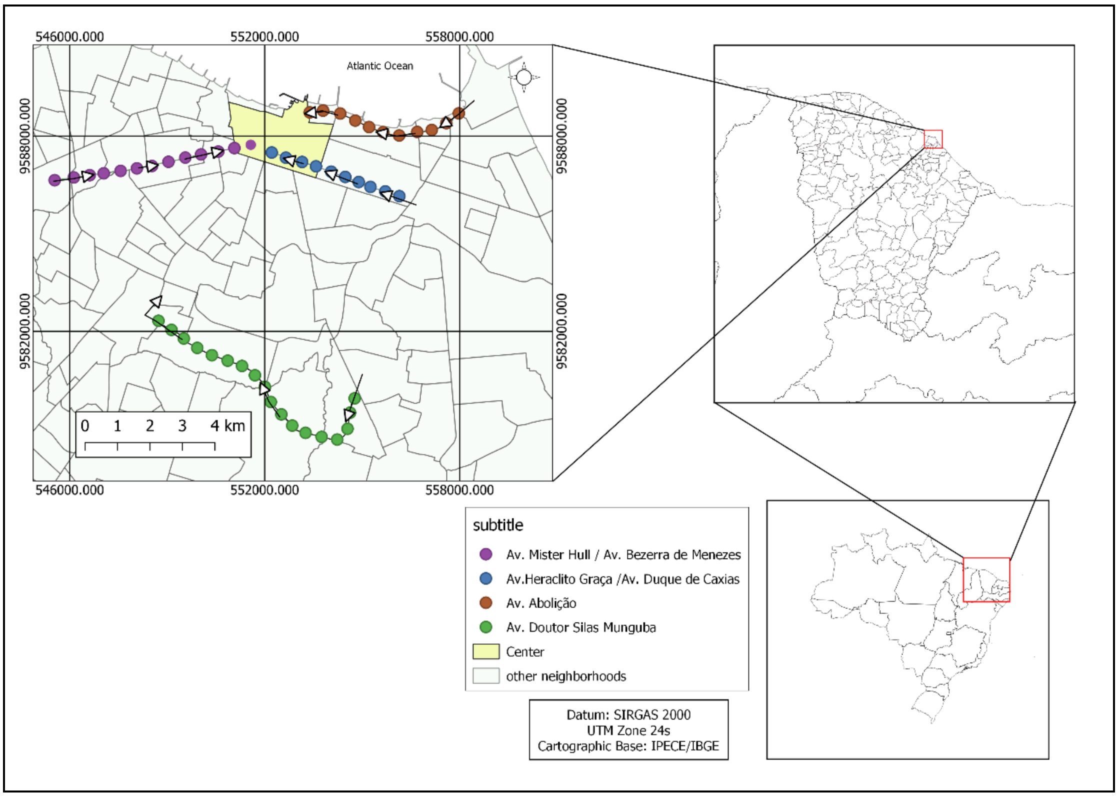


**Figure 1. Analyzed Avenues Location Map**

The analyses were carried out on these avenues both in March 2021, during the period in which strict social isolation measures were imposed (SSI period), and in September 2021, when all measures to restrict urban and social mobility were abolished (post-SSI period). Analyses in the SSI and post-SSI periods were performed in triplicate on consecutive days of the week (Tuesday, Wednesday and Thursday).

Dynamic analyses were carried out by monitoring emissions concentrations from the exhaust of a Ford Ranger 2017 (2.2 XLS-X4-6V-Diesel) automobile driven along each avenue route during SSI and post-SSI periods. These analyses started at 6 a.m. on Mister Hull/Bezerra de Menezes and Heráclito Graça/Duque de Caxias avenues, and at 11 a.m. on Doutor Silas Munguba and Abolição avenues.

To perform static analyses, the route along each avenue was divided into 500-meter intervals (Figure 1), with atmospheric pollutants analyses being carried out at each interval point for 5 minutes. Readings started at 7 am on Mister Hull/Bezerra de Menezes and Heráclito Graça/ Duque de Caxias avenues, and at 12 pm on Doutor Silas Munguba and Abolição avenues.

MH/BM Avenue is one of the main access roads from the western part of the metropolitan area of Fortaleza to the central area of the city. This avenue is characterized by its large variety of shops, schools, residences, a bus terminal and intense traffic flow. The total avenue length used for this analysis was 6.5 km, divided into 13 points for static analyses, starting from the point closest to Antônio Bezerra Bus Station (3°44’24.713"S, 38°35’37.769"W) to the end point of the avenue (3°43’50.563"S, 38°32’24.366"W).

DSM Avenue is one of the main access routes from the southwestern part of the metropolitan area of Fortaleza to the central area of the city. The avenue is characterized by a concentration of large commercial centers, research centers, the International Airport, the main football Stadium, residences, schools and intense vehicular traffic. The total avenue length used for this analysis was 8.5 km, divided into 18 points for static analyses, starting from the point next to BR-116 Highway (3°48’0.666"S, 38°30’24.323"W) until the end point next to the Parangaba Bus Terminal (3°46’43.316"S, 38°33’40.020"W).

HG/DC Avenue is one of the main access routes from the northeast of Fortaleza to the central area of the city. The avenue is characterized by its clinics, hospitals, universities, banks, shops and intense automobile traffic. The total avenue length used for this analysis was 4.5 km, divided into 10 points for static analyses, starting from the point near Tibúrcio Cavalcante Street (3°44’25.899"S, 38°30’15.156"W) to the end point near José Jatahy Street (3°43’39.144"S, 38°31’8.964"W).

AB Avenue is one of the main access roads from the east part of Fortaleza to the central area of the city. The avenue is distinguished for large real estate developments, hotel activities, residences, in addition to being one of the main access roads to Beira Mar Avenue, the most touristic area in the city of Fortaleza. The total avenue length used for this analysis was 5 km, divided into 11 points for static analyses, starting from the point closest to the Fortaleza Yacht Club (3°43’15.180"S, 38°28’40.089"W) to the final point near the end of Alberto Nepomuceno Avenue (3°43’14.533"S, 38°31’8.964"W).

*2.2 Pollutants Analyses*

To perform dynamic analyses, a gas analyzer (Seintro Chemist 900 Ecil®) was attached to the exhaust of a 2017 Ford Ranger vehicle (2.2 XLS-X4-6V-Diesel) to monitor the vehicle’s exhaust emitted along the dynamic route of the four avenues studied. During the dynamic analyses, concentrations of carbon monoxide (CO), nitrogen oxides ($No_x$) and carbon dioxide ($CO_2$) were monitored, as well as the oxygen ($O_2$) percentage and exhaust temperature, in addition to ambient temperature and relative air humidity.

To carry out the static analyses, an aerodispersoid detector (TEMTOP M2000) was used to evaluate particulate matter concentrations ($PM_{2.5}$, $PM_{10}$), carbon dioxide ($CO_2$) and formaldehyde (HCHO). In addition, ozone ($O_3$) concentrations were determined using a continuous ozone analyzer, model 202 (2B Technologies).

*2.3 Health Risk Assessments*

2.3.1. Respiratory Deposition Dose (RDD)

The concentrations of particles that deposited in the airways was estimated for three regions of the respiratory tract (upper, tracheobronchial and alveolar) of adults, considering the means of the different parameters for adult men and women (20 to 39 years-old). Equation 1 shows the estimated respiratory deposition dose ($RDD$) calculation (Sousa et al., 2021; Segalin et al., 2017; Azarmi; Kumar, 2016; Kumar; Goel, 2016):

$$RDD = (VC \cdot f) \cdot DF_{ij} \cdot PM_i \qquad (1)$$

where $VC$ is the respiratory tidal volume ($m^3$/cycle), $f$ is the respiratory rate (breaths per minute), $DF_{ij}$ is the deposition fraction for each specific diameter, and $PM_i$ is the measured concentration. Respiratory parameters $VC$ and $f$ for adults (men and women) were: $3.8 \cdot 10^{-4}$ $m^3$ per respiratory cycle and 14 breaths per minute, respectively (Parreira et al., 2010). $DF_{ij}$ was calculated based on the equations proposed by Hinds (1999).

2.3.2 Particulate Matter Inhalation Dose Calculation

The PM dose per body mass was estimated. For this calculation, two scenarios were determined. Scenario 1 simulates the PM amount inhaled by a driver inside a vehicle during a round trip in the four different avenues, exposure time being determined by the respective dynamic route of the avenue; scenario 2 simulates the PM amount inhaled by an individual who works in the vicinity of the four different avenues, with an exposure time determined as 44h/week or 176h/month. The determination of PM dose concentration was calculated based on equation 2 (Slezakova et al., 2018; Fonseca et al., 2014):

$$Dose\ (D) = (VM/m) \cdot C \cdot t \qquad (2)$$

where $VM$ is the minute volume ($L/min$); $m$ is the body mass (kg); $C$ is the PM concentration ($\mu g/L$) and $t$ is the exposure time in minutes. An average body mass of 67 kg and $VM$ of 5.15 kg $L/min$ was considered for both men and women (Parreira et al., 2010).

## 3. Results and Discussion

*3.1 Dynamic Analyses Evaluation*

Regarding dynamic analyses, Table 1 presents results referring to analyses of the variables for travel time, average speed, gas temperature, oxygen percentage, ambient temperature and relative humidity on each avenue in SSI and post-SSI periods.

**Table 1. Dynamic Analysis Variables, Variables Results for Dynamic Analyses Carried out on Mister Hull/Bezerra de Menezes (MH/BM), Doutor Silas Munguba (DSM), Heráclito Graça/Duque de Caxias (HG/DC) and Abolição (AB) Avenues in SSI and Post-SSI Periods**

| Variable / Avenue | | Travel Time (min) | Average Speed (Km/h) | Gas Temp (°C) | Oxygen% | Ambient Temp (°C) | Moisture (%) |
|---|---|---|---|---|---|---|---|
| MH/ BM | SSI | 14.88±0.30 | 26.20±0.53 | 118.77±0.62 | 14.49±0.04 | 26.40±1.20 | 83.67±2.31 |
| | Post-SSI | 18.91±1.89 | 20.74±2.35 | 117.75±0.86 | 14.33±0.14 | 26.37±0.51 | 84.33±1.53 |
| DSM | SSI | 20.65±2.02 | 24.85±2.30 | 117.17±1.00 | 15.78±0.15 | 26.50±1.10 | 86.00±2.65 |
| | Post-SSI | 25.12±1.36 | 20.42±1.11 | 118.16±0.42 | 15.47±0.20 | 28.93±0.76 | 82.00±2.00 |
| HG/ DC | SSI | 15.57±0.14 | 17.33±0.17 | 116.70±1.41 | 15.93±0.24 | 26.00±0.53 | 74.67±2.31 |
| | Post-SSI | 18.52±0.79 | 14.60±0.64 | 118.29±0.28 | 15.92±0.12 | 26.90±0.56 | 78.67±1.15 |
| AB | SSI | 19.42±0.12 | 15.45±0.09 | 116.00±1.62 | 14.45±0.54 | 27.07±0.64 | 76.00±2.65 |
| | Post-SSI | 24.27±2.15 | 12.42±1.07 | 116.69±1.79 | 14.99±0.88 | 28.13±0.31 | 77.33±2.31 |

These results show, in general, a higher average travel time and lower average speed on the avenues in the post-SSI period, in relation to the SSI period. This is due to the absence of restrictions on urban mobility in the post-SSI period, yielding greater vehicle traffic on the avenues. The temperatures and $O_2$ % in the exhaust gases did not show significant variations, due to the fact that these variables change according to the combustion temperature and, consequently, to the vehicle's engine. However, the vehicle's engine was preheated before initiating dynamic analyses, so that these variables would not present significant variations between the dynamic routes on the different avenues.

Ambient temperature and humidity values in the dynamic routes on the different avenues showed variations. This is possibly due to the different times of analyses: 6 am for MH/BM and HG/DC avenues, and 11 am for DSM and AB avenues.

Regarding the pollutants of the dynamic analyses, Figure 2 shows results of gas emission factors mean values for carbon monoxide (CO), nitrogen oxide ($NO_x$) and carbon dioxide ($CO_2$) in exhaust from the 2017 Ford Ranger vehicle (2.2 XLS-X4-6V- Diesel) on each avenue, during the SSI and post-SSI. CO and $NO_x$ emissions were compared to the regulatory limits established by the Brazilian norms from the Vehicle Emission Control Program (PROCONVE) in the L6 phase, applied to the exhaust emission from light motor vehicles and light commercial vehicles with a mass greater than 1700 kilograms (IBAMA, 2011). However, all analyzed values were below these legislation limits.

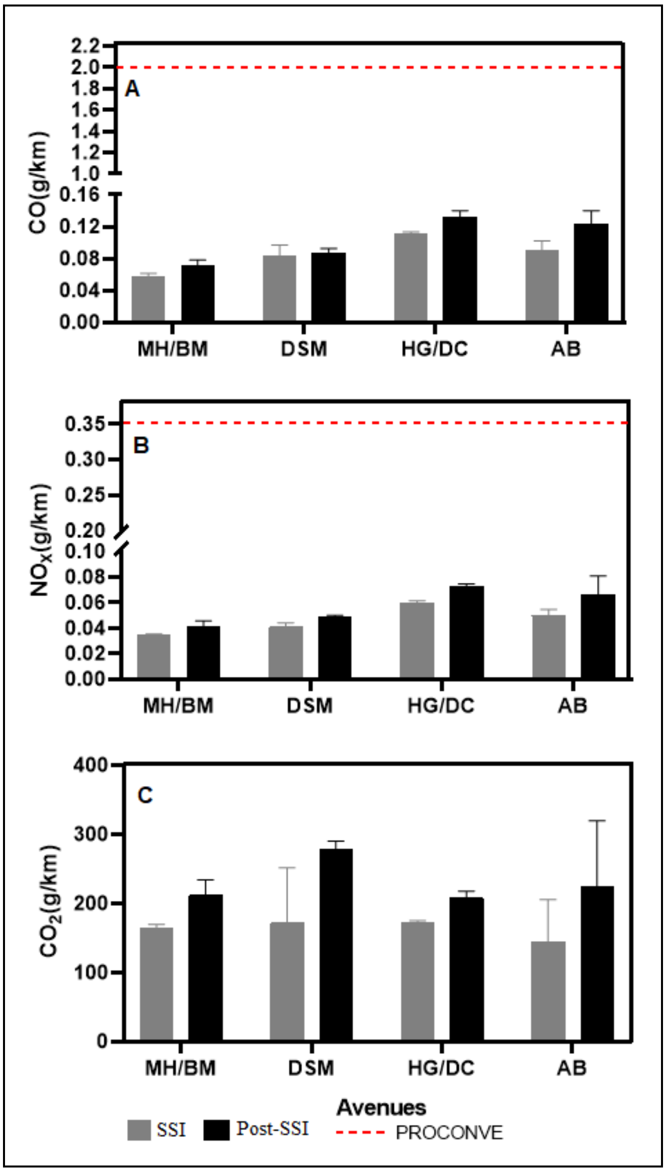


**Figure 2. Pollutants Dynamic Analysis**

CO, NO and $CO_2$ emissions results for the dynamic analyses carried out on Mister Hull/Bezerra de Menezes (MH/BM), Doutor Silas Munguba (DSM), Heráclito Graça/Duque de Caxias (HG/DC) and Abolição (AB) avenues in SSI and post-SSI periods.

In general, all average concentrations observed on the different avenues through the dynamic analyses exhibited an increase between the SSI and post-SSI periods. In terms of percentages, concentrations on MH/BM Avenue showed increases of 22.16%, 21.39% and 28.02%, for CO, $NO_x$ and $CO_2$ analyses, respectively. On DSM Avenue, the percentage increases were 5.06%, 19.65% and 62.50%, for CO, $NO_x$ and $CO_2$, respectively. HG/DC Avenue showed percentage increases of 19.57%, 22.21% and 20.24%, for CO, $NO_x$ and $CO_2$, respectively. On AB Avenue, the percentage increases were 37%, 31.85% and 54.18% in respective CO, $NO_x$ and $CO_2$ values.

Traffic jams in large cities influence air pollution increases, due to the constant stoppages of automobiles, as well causing increased health risks both for drivers and individuals who live or work around the roads (Zhang; Batterman, 2013; Habermann, 2012). Traffic congestion reduces average speeds, which increases travel time and decreases the dispersion of automobile-related pollutants, since vehicle-induced turbulence depends on speed (Benson, 1986). These characteristics may explain the higher values observed in the pollutants analyzed during the dynamic analyses in the post-SSI period, when vehicular flow was greater.

*3.2 Static Analyses Evaluation*

Regarding static analyses, the results of the averages for collections obtained over the course of three days on all avenues during SSI and Post-SSI are presented below. Most of the static collections were performed on the same day as the dynamic analyses, except for DSM Avenue in the post-SSI period; these were held on September 22, October 5 and October 7. In the analyses results and discussion, some individual values for each pollutant will be shown separately for further consideration. The remaining results for all avenues will be subsequently presented, along with the discussion.

Figure 3 (A, B and E) shows $O_3$, $CO_2$ and HCHO mean concentrations collected during the SSI and post-SSI periods on the four avenues. The average $O_3$ concentrations were compared with those of limit standards established by the National Council for the Environment (CONAMA) through resolution 491/2018, and by the limits recommended by the World Health Organization (WHO), updated in 2021. Averages of external $CO_2$ concentrations were compared using the 500 ppm standard recommended by Normative Recommendation 02/2003 by the Brazilian Association of Refrigeration, Air Conditioning, Ventilation and Heating (ABRAVA). According to ABRAVA, this is a significant indicator for intense traffic in urban areas, proving the influence of great vehicular flow on $CO_2$ concentrations. Due to the lack of legislation for HCHO concentrations in external areas, its averages were compared using the limits established by the WHO for internal environments.

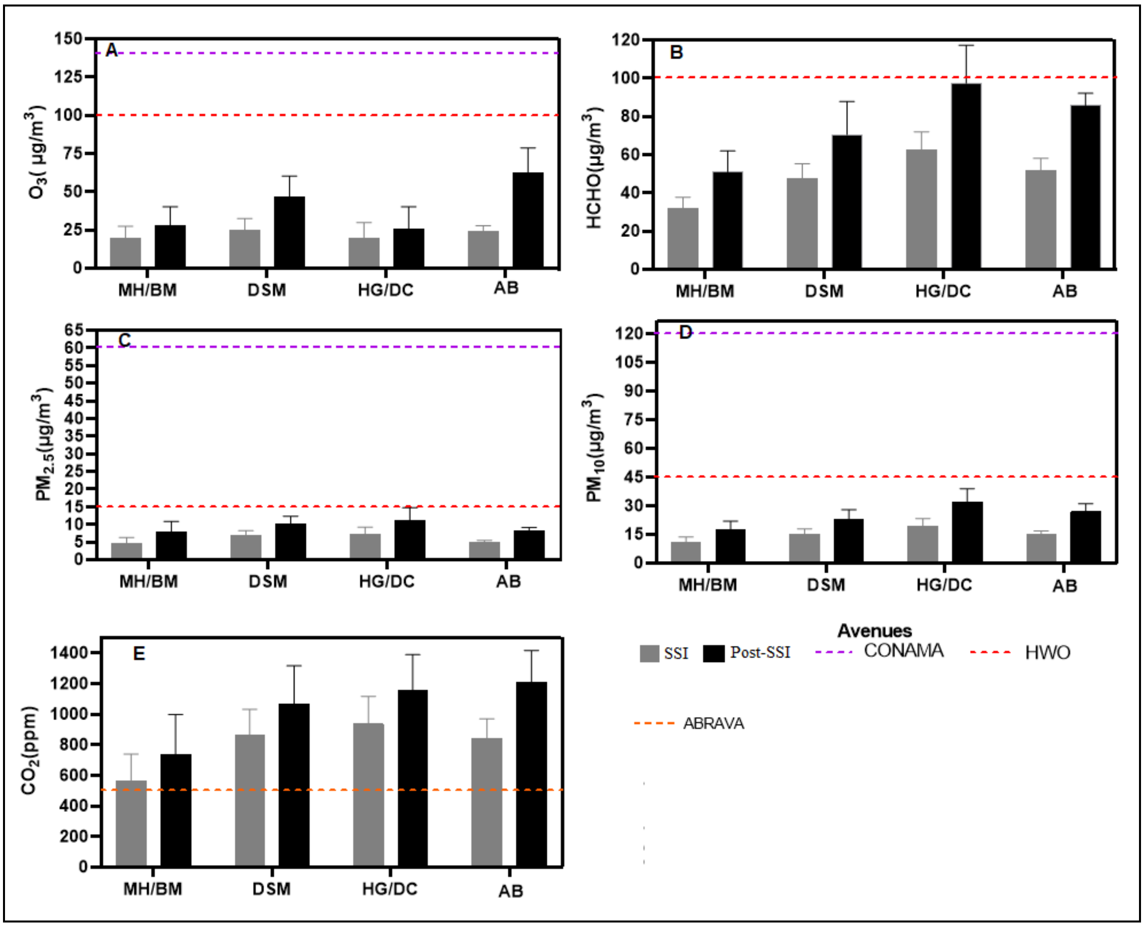


**Figure 3. Pollutants Static Analysis**

O3 (A), HCOH (B), PM2.5 (C), PM10 (D), and CO2 (E) emissions results in the static analyses carried out on Mister Hull/Bezerra de Menezes (MH/BM), Doutor Silas Munguba (DSM), Heráclito Graça/Duque de Caxias (HG/DC) and Abolição (AB) avenues in SSI and after SSI periods.

This Figure shows that $O_3$, $CO_2$ and HCHO had increased concentrations along the four avenues (MH/BM, DSM, HG/DC and AB) during the post-SSI period. Values for these avenues were, respectively, up to 41.55%, 86.51%, 33.09% and 160.65% for $O_3$; 31.19%, 23.97%, 23.16% and 43.17% for CO2; and 59.28%, 49.16%, 55.18% and 65.91% for HCHO. $O_3$ and HCHO concentrations remained below the legislated standards, whereas $CO_2$ exceeded the limits recommended by ABRAVA.

Figure 3 (C and D) shows the mean concentrations of $PM_{2.5}$ and $PM_{10}$ collected during the SSI and post-SSI periods. Their averages were compared with the limits established by the National Council for the Environment (CONAMA) resolution 491/2018 and with those recommended by the World Health Organization (WHO) in the 2021 update.

It is possible to observe that $PM_{2.5}$ had concentration increases of 66.24%, 48.42%, 53.64% and 63.67% on the four avenues (MH/BM, DSM, HG/DC and AB, respectively) during the post-SSI. $PM_{10}$ also exhibited mean concentration increases of 60.00%, 53.24%, 63.50% and 79.10% along the same routes during the post-SSI period. Both $PM_{2.5}$ and $PM_{10}$ maintained concentration values below the limits required by CONAMA and WHO.

Currently, many studies seek to analyze lockdown impacts on atmospheric emissions, with analyses arising from all continents, with the exception of Antarctica (DA SILVA, 2021). Pollutants such as NO, $NO_2$, CO, $PM_{10}$ and $PM_{2.5}$ had reduced emissions during lockdown, succeeded by increases during the reopening (Tudo et al., 2022; Sarra; Mülfarth, 2021; Liu et al., 2020). A decrease in pollutant emissions during lockdowns is expected, but the more important objective, however, is to quantify this decrease.

Regarding $O_3$ analyses, some studies show an increase in this pollutant (Aix; Petit; Bicout, 2022; Lian, *et al.,* 2020), while others show a decrease (Tavella et al., 2021). This usually occurs because tropospheric ozone is one of the atmosphere's most complex chemical species, being formed during the day by non-linear chemical processes at a rate that is determined by atmospheric concentrations of VOCs and nitrogen oxides (Tavella; da Silva Júnior, 2021).

In environments with very high levels of $NO_x$, $O_3$ is sequestered by NO to form $NO_2$. Increases in ozone concentrations, as opposed to decreases in other pollutants, are associated with reduced $NO_x$ emissions. Lockdown led to NO emissions decrease and lower consumption of $O_3$ during titration (i.e., $NO + O_3 = NO_2 + O_2$) (Li et al., 2020; Selvam et al., 2020).

*3.3 Particle Deposition Assessment in the Respiratory Tract*

Based on the $PM_{2.5}$ and $PM_{10}$ concentrations observed in SSI and post-SSI periods (Figure 4), particle depositions in the adult respiratory tract (upper, tracheobronchial and alveolar regions) were estimated (Figure 4). The highest concentrations of $PM_{2.5}$ and $PM_{10}$ deposition in the respiratory tract were obtained on HG/DC Avenue, for both periods (SSI and post-SSI). The lowest potential concentrations for $PM_{2.5}$ and $PM_{10}$ deposition in the respiratory tract were observed on MH/BM Avenue, for both periods (SSI and post-SSI).

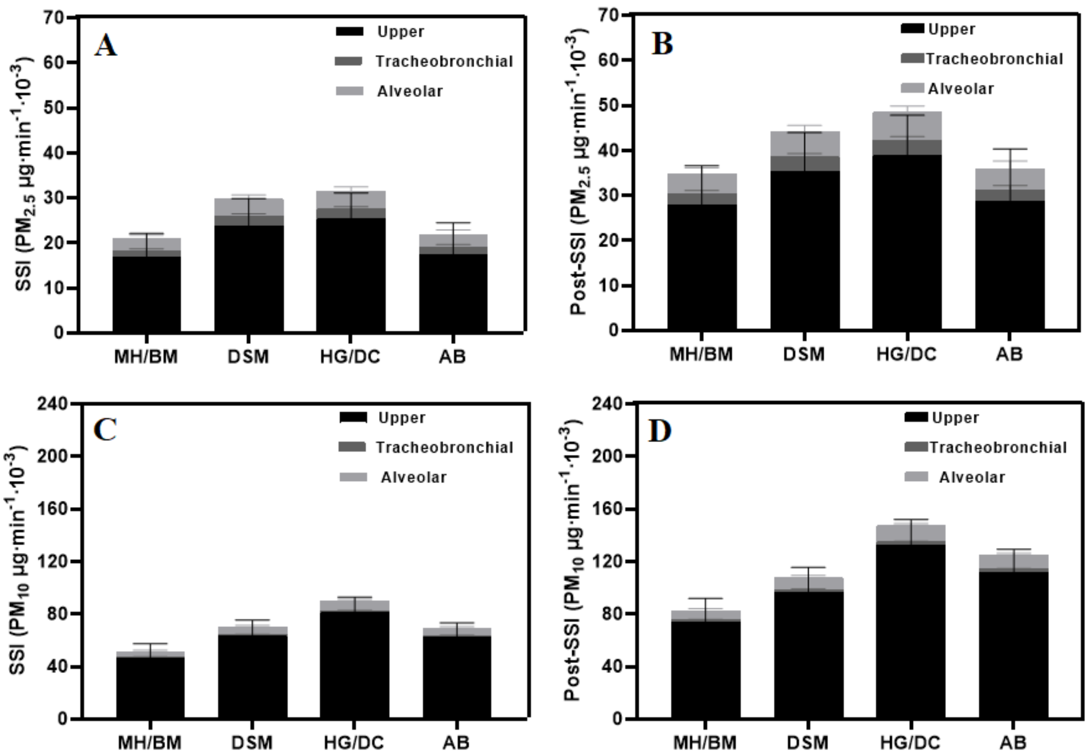


**Figure 4. Particles Deposition in the Respiratory Tract**

Particles deposition concentration estimated for three regions of the respiratory tract (Upper, tracheobronchial and alveolar) of adults on Mister Hull/Bezerra de Menezes (MH/BM), Doutor Silas Munguba (DSM), Heráclito Graça/Duque de Caxias (HG/DC) and Abolição (AB) avenues in ISS (A and C) and post-ISS (B and D) periods.

Regarding the total dose of $PM_{2.5}$ deposited in the respiratory tract (Figure 4 - A and B), the percent increases between SSI and post-SSI periods were 66.23%, 48.59%, 53.70% and 64.17% along MH/BM, DSM, HG/DC and AB avenues, respectively. For the total inhalable $PM_{10}$ (Figure 4 - C and D), percent increases between SSI and post-SSI periods were 60.07%, 53.24%, 63.35% and 79.25% for MH/ BM, DSM, HG/DC and AB avenues, respectively.

We also observed that, in general, the greatest amount of inhaled particulates ($PM_{2.5}$ and $PM_{10}$) would be deposited in the upper airway tract, with higher fractions of $PM_{10}$ deposition in this region. This can be explained by the fact that $PM_{2.5}$ has a smaller diameter, which allows it to penetrate more deeply into the pulmonary tract, reaching the alveoli in significant fractions (Haberzettl et al., 2014; Kelly; Fussel, 2012; Dockery, 2009).

Exposure to air pollutants is associated with respiratory disease development and intensification (Menezes et al., 2019; Nascimento et al., 2017; Patto et al., 2016; Xiong et al., 2015). Among its various components, particulate matter is one of the most harmful to health (WHO, 2016). Pollutants emitted by diesel combustion, such as particulate matter, carry several carcinogenic compounds with a high impact on human health and on ecosystems (Zin et al., 2011).

According to the International Energy Agency (IEA, 2020), a positive consequence of the SSI period was that the world ceased to emit one million tons of $CO_2$ per day, due to decreased combustion of fossil fuels. In addition, preliminary evidence confirms that atmospheric particles such as PM can carry SARS-CoV-2, since viruses are able to adhere to solid or liquid atmospheric particles, remaining in the atmosphere for hours, days or even weeks and being transported over long distances (Visbal; Pedraza, 2021; Setti et al., 2020; Tellier et al., 2019).

Additionally, atmospheric pollution contributes to the weakening of the body's immunity (Braga; Saldiva, 2001). This information leads to a need for greater attention regarding the pandemic context, since COVID-19 affects immunosuppressed individuals more severely (Suárez et al., 2021), causing greater mortality in this population (Vaid et al., 2021). Studies have also shown a relationship between exposure to air pollutants and the intensification of COVID-19 cases (Cole; Ozgen; Strobl, 2020; Zhu et al., 2020).

*3.4 Inhaled Dose Assessment*

To calculate the inhaled dose per body mass, respiratory parameters of men and women aged between 20 and 39 years-old were considered, using $PM_{2.5}$ and $PM_{10}$ concentrations measured on each of the avenues. As the inhaled dose is proportional to the exposure time, in the present work we used two exposure scenarios for evaluation.

Scenario 1 represents the daily dose inhaled by a person inside the vehicle driving, for example, to his/her work, in a round trip. Scenario 2 represents the dose inhaled in one month by a person (176h/month) working along each of the avenues, being constantly exposed to pollutants from this environment on a daily basis. Potential inhaled dose concentrations are shown in Figure 5.

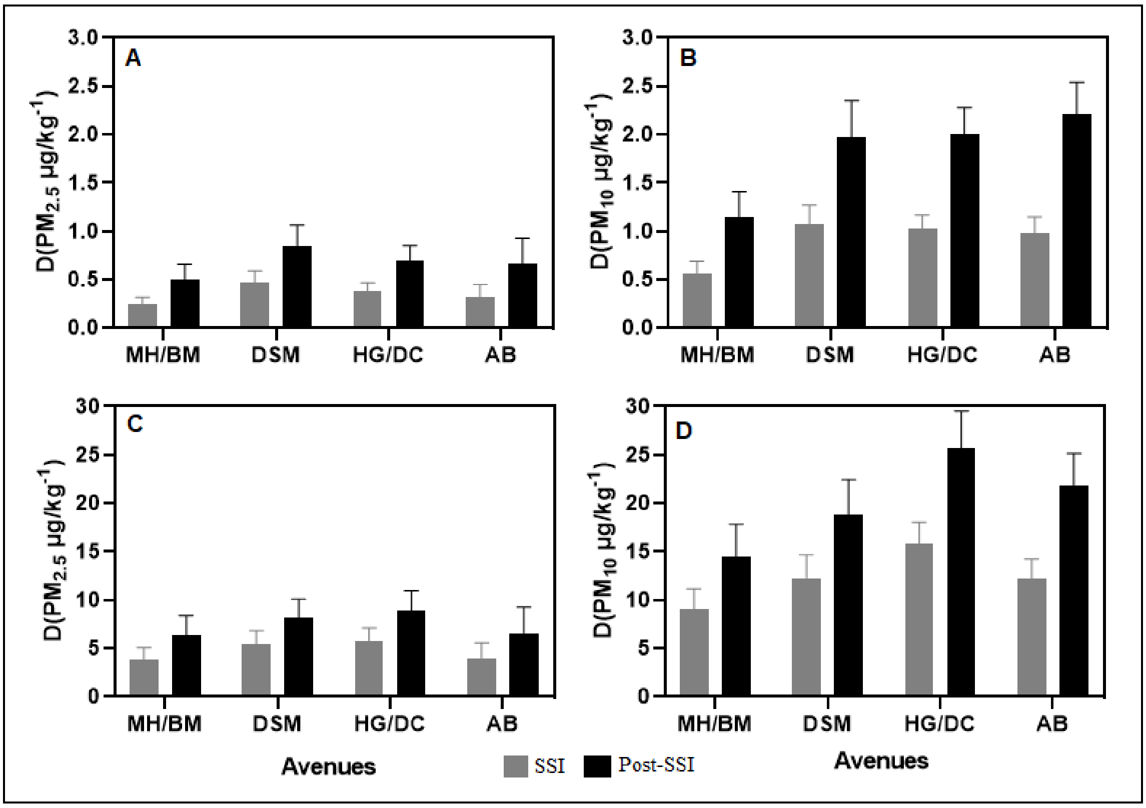


**Figure 5. Inhaled Particulate Matter Dose according to $PM_{2.5}$ and $PM_{10}$ Concentrations Found on Mister Hull/Bezerra de Menezes (MH/BM), Doutor Silas Munguba (DSM), Heráclito Graça/Duque de Caxias (HG/DC) and Abolição (AB) Avenues**

A- PM2.5 inhaled dose according to scenario 1 (Driver on the round trip); B- $PM_{10}$ inhaled dose according to scenario 1 (Driver on the round trip route); C- $PM_{2.5}$ inhaled dose according to scenario 2 (Workers in the region); D- PM10 inhaled dose according to scenario 2 (Workers in the surroundings).

Regarding the inhaled $PM_{2.5}$ dose in scenario 1 (Figure 5-A), percent increases between SSI and post-SSI periods were 108.33%, 80.85%, 81.58% and 106.25% for MH/BM, DSM, HG/DC and AB avenues, respectively. As for the inhaled $PM_{10}$ dose in scenario 1 (Figure 5-B), increases between SSI and post-SSI periods were 66.41%, 48.72%, 53.71% and 64.25% for MH/BM, DSM, HG/DC and AB avenues respectively.

Considering the inhaled $PM_{2.5}$ dose in scenario 2 (Figure 5-C), increases between SSI and post-SSI periods were 103.57%, 85.85%, 95.10% and 124.49% for MH/BM, DSM, HG/DC and AB avenues, respectively. Inhaled $PM_{10}$ dose increases in scenario 2 (Figure 5-D) between SSI and post-SSI periods were 60.04%, 53.26%, 63.37% and 79.26% within MH/BM, DSM, HG/ DC and AB avenues, respectively.

In scenarios 1 and 2, we observed a greater percent increase in the inhaled doses of $PM_{2.5}$ for MH/BM Avenue, and of $PM_{10}$ on AB Avenue. The lower concentrations of pollutants such as $PM_{2.5}$ and $PM_{10}$ during SSI were possibly due to the actions to minimize transmission of SARS-CoV-2.

Exposure to $PM_{2.5}$ is associated with an increased risk of mortality from a wide range of causes (Li et al., 2018), including increases in all-cause mortality risk and cardiovascular issues (Kim et al., 2020). Regarding exposure to $PM_{10}$, there is evidence of a positive association between exposure to this pollutant and the risk of lung cancer (Consonni et al., 2018).

Previous studies highlight the relationship between short-term exposure to $PM_{2.5}$ and COVID-19 cases and deaths (Zhou et al., 2021). Likewise, considering exposure to $PM_{2.5}$ and $PM_{10}$ is associated with COVID-19 cases and deaths, particulate matter may play a significant role in the COVID-19 outbreak (Bianconi et al., 2020).

## 4. Conclusion

According to our results--since it contributed to social and urban mobility reduction, resulting in a lower number of circulating vehicles--, SSI was also probably responsible for a decrease in atmospheric pollutant emissions (Figures 2 and 3). Thus, SSI directly contributes to a decrease in particulate matter deposition in the respiratory tract of individuals (Figure 4), as well as in the inhaled particulate matter dose (Figure 5). This phenomenon possibly helped to reduce the number of severe cases and deaths caused by COVID-19.

## Acknowledgement

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

## References

Aix, M. L., Petit, P., & Bicout, D. J. (2022). Air pollution and health impacts during the COVID-19 lockdowns in Grenoble. *France Poluição Ambiental*, *303*, 119-134. https://doi.org/10.1016/j.envpol.2022.119134

Alvim, D. S., Gatti, L. V., Santos, M. H. D., & Yamazaki, A. (2011). Studies on ozone precursors volatile organic compounds in the city of São Paulo. *Sanitary and Environmental Engineering*, *16*, 189-196. https://doi.org/10.1590/S1413-41522011000200013

Azarmi, F., & Kumar, P. (2016). Ambient exposure to coarse and fine particle emissions from building demolition. *Atmospheric Environment*, *137*, 62-79. https://doi.org/10.1016/j.atmosenv.2016.04.029

ABRAVA. (2003). *Normas e Recomendações: Recomendação normativa - nr Associação Brasileira de Refrigeração, Ar condicionado, Ventição e Aquecimento (Brazilian Association of Refrigeration, Air conditioning, Ventilation and Heating)*. 02. Retrieved from https://abrava.com.br/normalizacoes/

Benson, P. E. (1986). *CALINE4: A dispersion model for predicting air pollution concentrations near roadways—FHWA/CA/TL, 84/15*. Sacramento, USA: California Department of Transportation.

Bianconi, V., Bronzo, P., Banach, M., Sahebkar, A., Mannarino, M. R., & Pirro, M. (2020). Particulate matter pollution and the COVID-19 outbreak: Results from Italian regions and provinces. *Archives of Medical Science*, *16*(5), 985. https://doi.org/10.5114/aoms.2020.95336

Braga, A. L. F., & Saldiva, P. H. N. (2001). Pollution and health. Brazilian Journal of Pulmonology: II Congress of Pulmonology and Phthisiology of the Midwest. *I Journey of Respiratory Physiotherapy of the Midwest. Cuiabá*, 10-16.

Cole, M. A., Ozgen, C., & Strobl, E. (2020). Air Pollution Exposure and Covid-19 in Dutch Municipalities. *Environmental and Resource Economics*, *76*, 581-610. http://dx.doi.org/10.1007/s10640-020-00491-4

CETESB. (2018). Relatório de emissões veiculares no Estado de São Paulo (Vehicle emissions report in the State of São Paulo). *Companhia Ambiental do Estado de São Paulo*. Retrieved from https://cetesb.sp.gov.br/veicular/wp-content/uploads/sites/6/2020/02/Relat%C3%B3rio-Emiss%C3%B5es-eiculares-no-Estado-de-S%C3%A3o-Paulo-2018.pdf

Consonni, D., Carugno, M., De Matteis, S., Nordio, F., Randi, G., Bazzano, M., & Landi, M. T. (2018). Outdoor particulate matter ($PM_{10}$) exposure and lung cancer risk in the EAGLE study. *PloS one*, *13*, e020353. https://doi.org/10.1371/journal.pone.0203539

da Silva, S. A. R. (2021). Lockdown impact of on air quality in Campinas city and region during COVID-19 pandemic through data analysis. *Technological Magazine of Fatec Americana*, *9*, 22-50.

Dockery, D. W. (2009). *Health effects of particulate air pollution. Annals of Epidemiology*, *19*, 257-263. https://doi.org/10.1016/j.annepidem.2009.01.018

Dong, E., Du, H., & Gardner, L. (2020). An interactive web-based dashboard to track COVID-19 in real time. *The Lancet Infectious Diseases*, *20*(5), 533-534. https://doi.org/10.1016/S1473-3099(20)30120-1

Fonseca, J., Slezakova, K., Morais, S., & Pereira, M. C. (2014). Assessment of ultrafine particles in Portuguese preschools: Levels and exposure doses. *Indoor Air*, *24*(6), 618-628. https://doi.org/10.1111/ina.12114

Goel, R., & Guttikunda, S. K. (2015). Evolution of on-road vehicle exhaust emissions in Delhi. *Atmospheric Environment*, *105*, 78-90. https://doi.org/10.1016/j.atmosenv.2015.01.045

Habermann, M. (2012). *Métodos de avaliação da exposição ambiental aos poluentes atmosféricos gerados por tráfego veicular (Methods for assessing environmental exposure to air pollutants generated by vehicular traffic)*. Doctoral thesis, Faculdade de Medicina da Universidade de São Paulo.

Haberzettl, P., Bhatnagar, A., & Conklin, D. J. (2014). Particulate Matter and Oxidative Stress-Pulmonary and Cardiovascular Targets and Consequences. In Laher I. (Ed.), *Systems Biology of Free Radicals and Antioxidants. Springer, Berlin, Heidelberg* (pp. 1557-1586). https://doi.org/10.1007/978-3-642-30018-9_120.



Published by SCHOLINK INC.

Hinds, W. C. (1999). Aerosol Technology: Properties, Behaviour and Measurement of Airborne Particles. second ed. *John Wiley & Sons, USA*, p. 483.

IEA – International Energy Agency. “Monthly OECD oil price statistics”. *IEA Website [2020]*. Retrieved from http://www.iea.org/reports/monthly-oecd-oil-price-statistics

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA). Programa de controle da poluição do ar por veículos automotores [Control program for vehicle-related air pollution] – Proconve/Promot/Ibama. 3 ed. Brasilia: Ibama/Diqua. 584 p. 2011.

Jedynska, A., Hoek, G., Eeftens, M., Cyrys, J., Keuken, M., Ampe, C., & Kooter, I, M. (2014). Spatial variations of PAH, hopanes/steranes and EC/OC concentrations within and between European study areas. *Atmospheric Environment*, *87*, 239-248. https://doi.org/10.1016/j.atmosenv.2014.01.026

Kelly, F. J., & Fussell, J. C. (2012). Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter. *Atmospheric Environmental*, *60*, 504-526. https://doi.org/10.1016/j.atmosenv.2012.06.039

Kim, I. S., Yang, P. S., Lee, J., Yu, H. T., Kim, T. H, Uhm, J. S., & Joung, B. (2020). Long-term fine particulate matter exposure and cardiovascular mortality in the general population: A nationwide cohort study. *Journal of Cardiology*, *75*(5), 549-558. https://doi.org/10.1016/j.jjcc.2019.11.004

Kumar, P., & Goel, A. (2016). Concentration dynamics of coarse and fine particulate matter at and around the signalised traffic intersections. *Environment Science Process Impacts*, *18*, 1220-1235. https://doi.org/10.1039/c6em00215c

Li, L., Li, Q., Huang, L., Wang, Q., Zhu, A., Xu, J., Liu, Z., L. I., Hongli, S., Liu, H., & LI, R. (2020). Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: An insight into the impact of human activity pattern changes on air pollution variation. *Science of the Total Environment*, 732, 139-282. https://doi.org/10.1016/j.scitotenv.2020.139282

Li, T., Yan, M., Sun, Q., & Andersson, G. B. (2018). Mortality risks from a spectrum of causes associated with wide-ranging exposure to fine particulate matter: A case-crossover study in Beijing, China. *Environment International*, *111*, 52-59. https://doi.org/10.1016/j.envint.2017.10.023

Lian, X., Huang, J., Huang, R., Liu, C., Wang, L., & Zhang, T. (2020). City lockdown impact on the air quality of the COVID-19-hit city of Wuhan. *Total Environmental Science*, *742*, 140556. https://doi.org/10.1016/j.scitotenv.2020.140556

Liu, Q., Harris, J. T., Chiu, L. S., Sun, D., Houser, P.R., Yu, M., Duffy, D. Q., Little, M. M., & Yang, C. (2021). Spatiotemporal impacts of COVID-19 on air pollution in California, USA. *Science of the Total Environment*, *750*, 141592. https://doi.org/10.1016/j.scitotenv.2020.141592

Mellios, G., & Ntziachristos, L. (2013). *EMEP/EEA emission inventory guidebook 2013 – Gasoline evaporation*.

Menezes, R. A. D. M., Pavanitto, D. R., & Nascimento, L. F. C. (2019). Exposure to air pollutants and respiratory disease in boys and girls. *Rev. paul. Pediatr*, *37*(2), 166-172. Retrieved from http://ref.scielo.org/9qpytg

Nascimento, A. P., Santos, J. M., Mill, J. G., Souza, J. B. D., Reis, N. C., & Reisen, V. A. (2017). Association between the concentration of fine particles in the atmosphere and acute respiratory diseases in children. *Revista de Saúde Pública*, *51*. http://dx.doi.org/10.1590/s1518-8787.2017051006523

Parreira, V. F., Bueno, C. J., França, D. C., Vieira, D. S., Pereira, D. R., & Britto, R. R. (2010). Breathing pattern and thoracoabdominal movement in healthy individuals: Influence of age and gender. *Revista Brasileira de Fisioterapia*, *14*(5) 411-416. https://doi.org/10.1590/S1413-35552010000500010

Patto, N. V., Nascimento, L. F. C., Mantovani, K. C. C., Vieira, L. C., & Moreira, D. S. (2016). Exposure to fine particulate matter and hospital admissions due to pneumonia: Effects on the number of hospital admissions and its costs. *Revista Da Associacao Medica Brasileira*, *62*(4), 342-346. http://dx.doi.org/10.1590/1806-9282.62.04.342.

San Martin, M. C., & San Martin, M. C. (2020). Initial impacts of COVID-19 in the state of Rio Grande do Sul. *Boletim de Conjuntura (BOCA)*, *2*(4), 60-71. https://doi.org/10.5281/zenodo.3749844.

Santos, V. D. P., Medeiros, A. P. P. D., Lima, T. A. C. D., & Nascimento, L. F. C. (2014). Air pollutants role on birth weight in a medium-sized city in the State of São Paulo. *Revista Paulista de Pediatria*, *32*, 306-312. http://dx.doi.org/10.1016/j.rpped.2014.06.003.

Sarra, S. R., & Mülfarth, R. C. K. (2021). The impacts of new Coronavirus Epidemic on the levels of pollutants in the city of Sao Paulo. *Brazilian Journal of Development*, *7*(4), 40415-40438.

Segalin, B., Kumar, P., Micadei, K., Fornaro, A., & Gonçalves, F. L. (2017). Size–segregated particulate matter inside residences of elderly in the Metropolitan Area of São Paulo, Brazil. *Atmospheric Environment*, *148*, 139-151. https://doi.org/10.1016/j.atmosenv.2016.10.004.

Seinfeld, J. H., & Pandis, S. N. (2006). *Atmospheric Chemistry and Physics - From Air Pollution to Climate Change* (2 ed., p. 1203). Nova Iorque: John Wiley & Sons.

Selvam, S., Muthukumar, P., Venkatramanan, S., Roy, P. D., Bharath, K. M., & e Jesuraja, K. (2020). SARS-CoV-2 pandemic lockdown: Effects on air quality in the industrialized Gujarat state of India. *Science of The Total Environment*, *737*, 140391. https://doi.org/10.1016/j.scitotenv.2020.140391

Setti, L., Passarini, F., De Gennaro, G., Barbieri, P., Pallavicini, A., Ruscio, M., & Miani, A. (2020). Searching for SARS-COV-2 on Particulate Matter: A Possible Early Indicator of COVID-19 Epidemic Recurrence. *International Journal of Environmental Research and Public Health*, *17*(9), 2986. https://doi.org/10.3390/ijerph17092986.

Slezakova, K., Peixoto, C., Oliveira, M., Delerue-Matos, C., do Carmo Pereira, M., & Morais, S. (2018). Indoor particulate pollution in fitness centres with emphasis on ultrafine particles. *Environmental Pollution*, *233*, 180-193, https://doi.org/10.1016/j.envpol.2017.10.050

Sousa, N. A, Segalin, B., Busse, A. L., Wilson, F. J., Fornaro, A., & Gonçalves, F. L. (2021). Indoor/outdoor particulate matter and health risk in a nursing community home in São Paulo. Brazil. *Atmospheric Pollution Research*, *12*(10), 101188. https://doi.org/10.1016/j.apr.2021.101188.

Suárez-García, I., Perales-Fraile, I., González-García, A., Muñoz-Blanco, A., Manzano, L., Fabregate, M., & SEMI-COVID-19 Network. (2021). In-hospital mortality among immunosuppressed patients with COVID-19: Analysis from a national cohort in Spain. *PLOS ONE*, *16*(8), e0255524. http://dx.doi.org/10.1371/journal.pone.0255524.

Tavella, R. A., da Silva Salimene, L., Ulguim, S. M., Gabriel, R. R., & da Silva Júnior, F. M. R. (2021). Air pollutants behavior during and after lockdown in a medium-sized city. *VITTALLE - Revista de Ciências da Saúde*, *33*(3), 62-67. https://doi.org/10.14295/vittalle.v33i3.13663

Tavella, R. A., & da Silva Júnior, F. M. R. (2021). Watch out for trends: did ozone increased or decreased during the COVID-19 pandemic? *Environmental Science and Pollution Research*, *28*(47), 67880-67885. https://doi.org/10.1007/s11356-021-17142-w.

Tellier, R., Li, Y., Cowling, B. J., & Tang, J. W. (2019). Recognition of aerosol transmission of infectious agents: A commentary. *BMC Infectious Diseases*, *19*(1), 1-9. https://doi.org/10.1186/s12879-019-3707-y

Tudu, P., Gaine, T., Mahanty, S., Mitra, S., Bhattacharyya, S., & Chaudhuri, P. (2022). Impact of COVID-19 lockdown on the elemental profile of $PM_{10}$ present in the ambient aerosol of an educational institute in Kolkata, India. *Environmental Quality Management*.

Vaid, N., Ardissino, M., Reed, T.A, Goodall, J., Utting, P., Miscampbell, M., & Cohen, D. L. (2021). Clinical characteristics and outcomes of immunosuppressed patients hospitalized with COVID-19: experience from London. *Journal of Internal Medicine*, *289*(3), 385-394. https://doi.org/10.1111/joim.13172

Visbal, J. H. W., & Pedraza, M. C. C. (2021). Physical principles and mitigation measures associated with aerosol transmission of SARS-COV-2. *Revista Cubana de Medicina General Integral*, *37*. Retreived from http://revmgi.sld.cu/index.php/mgi/article/view/1908

WORLD HEALTH ORGANIZATION. (2002). *Formaldehyde: Concise international Chemical*, assessment document 40.

WORLD HEALTH ORGANIZATION. (2016). *Health topics Air pollution*.

___CONSELHO NACIONAL DO MEIO AMBIENTE - CONAMA. (2018). *CONAMA RESOLUTION*. Retreived from https://www.in.gov.br/web/guest/materia//asset_publisher/Kujrw0TZC2Mb/content/id/51058895/do1-2018-11 -21-resolucao-n-491-de-19-de-novembro-de-2018-51058603

___ Publications. WHO global air quality guidelines: Particulate matter (PM2:5 and PM10). ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. *World Health Organization*, 2021. xxi, 273 p. p. Retreived from https://apps.who.int/iris/handle/10665/345329

Xiong, Q., Zhao, W., Gong, Z., Zhao, W., & Tang, T. (2015). Fine Particulate Matter Pollution and Hospital Admissions for Respiratory Diseases in Beijing, China. *International Journal of Environmental Research and Public Health*, *12*(9), 11880-11892. http://dx.doi.org/10.3390/ijerph120911880.

Zhang, K., & Batterman, S. (2013). Air pollution and health risks due to vehicle traffic. *Science of The Total Environment*, *450*, 307-316, https://doi.org/10.1016/j.scitotenv.2013.01.074

Zhou, X., Josey, K., Kamareddine, L., Caine, M. C., Liu, T., Mickley, L. J., & Dominici, F. (2021). Excess of COVID-19 cases and deaths due to fine particulate matter exposure during the 2020 wildfires in the United States. *Science Advances*, *7*(33) eabi8789. https://doi.org/10.1126/sciadv.abi8789

Zhu, Y., Xie, J., Huang, F., & Cao, L. (2020). Association between short-term exposure to air pollution and COVID-19 infection: evidence from china. *Science of the Total Environment*, *727*, 138704. http://dx.doi.org/10.1016/j.scitotenv.2020.138704

Zin, W. A., Silva, A. G., Magalhães, C. B., Carvalho, G. M., Riva, D. R., Lima, C. C., & Faffe, D. S. (2012). Eugenol attenuates pulmonary damage induced by diesel exhaust particles. *Journal of Applied Physiology*, *112*(5), 911-917. http://dx.doi.org/10.1152/japplphysiol.00764.2011.