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Effect of partial lockdown due to Covid-19 pandemic on PM_{10} concentration in Belo Horizonte, Brazil

Efeito da quarentena da Covid-19 na concentração de MP_{10} em Belo Horizonte, MG, Brasil

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ABSTRACT: Despite their proven effectiveness in combating the pandemic of COVID-19, measures of social isolation, quarantines, and *lockdowns* have drastic consequences in the social and economic spheres. This paper presents results from an ongoing study in Belo Horizonte, Brazil, to evaluate the effect of social isolation on MP10 concentration. The monitoring point was chosen in a wooded area within a university campus. Social isolation was analyzed in terms of vehicle movements recorded by speed cameras, during all phases following the partial lockdown (PL) instituted in the city. The social isolation index (SDI) showed a maximum isolation percentage of 49.5%, reached in the first week of the PL, with a subsequent continuous downward trend. The results showed a 65.2% reduction in PM_{10} due to the PL, when comparing the mean values monitored before (22.2 ± 3.0 µg m-3) and during (7.7 ± 4.2 µg m^{-3}) the PL. The relationship between vehicle movement and MP_{10} concentrations in the monitoring region was evidenced and found to be significant (r(XY) = 0.782, p-value = 0.000). Such reduction, observed in such a short term, but due to force majeure, certainly has beneficial effects on the population's health, reinforcing the reflection about the positive impacts that could come with policies that favor the reduction of vehicle movement in the cities.

Keywords: COVID-19; vehicular traffic; air pollution; PM_{10}; lockdown.

RESUMO: Apesar de comprovadamente eficientes no combate à pandemia da COVID-19, as medidas de isolamento social, quarentenas e *lockdowns* têm consequências drásticas nas esferas social e econômica. Entretanto efeitos positivos na esfera ambiental podem ser observados e já têm sido relatados em todo o mundo, como a redução da emissão de poluentes atmosféricos nas cidades. Este artigo apresenta resultados de um estudo em

andamento em Belo Horizonte, Brasil, com o intuito de avaliar o efeito do isolamento social na concentração do MP_{10}. O ponto de monitoramento foi escolhido em uma área arborizada dentro de um campus universitário. O isolamento social foi analisado em termos da movimentação de veículos registrada por radares de trânsito, durante todas as fases que sucederam o lockdown parcial (PL) instituído na cidade. O índice de isolamento social (SDI) apontou percentual máximo de isolamento da população de 49,5%, atingido na primeira semana do PL, com posterior tendência contínua de redução. Os resultados apontaram redução de 65,2% no MP_{10} devido ao PL, quando comparadas as médias dos valores monitorados antes (22,2 ± 3,0 μg m^{-3}) e durante (7,7 ± 4.2 μg m^{-3}) o PL. A relação entre a movimentação de veículos e as concentrações de MP10 na região de monitoramento foi evidenciada e considerada significativa (r(XY) = 0,782, p-valor = 0,000). Tal redução, observada em tão curto prazo, mas por ocasião de força maior, certamente tem efeitos benéficos à saúde da população, reforçando a reflexão sobre os impactos positivos que poderiam advir com políticas que favoreçam a redução da movimentação de veículos nas cidades.

Palavras-chave: COVID-19; movimentação veicular; poluição do ar; MP_{10}; quarentena.

1. Introduction

In December 2019, a new infectious disease, transmitted between humans, was identified in Wuhan, Hubei province, China. Named coronavirus disease 2019 (COVID-19) and caused by a new coronavirus, identified as SARS-CoV-2 (Chen *et al*., 2020a; Zheng, 2020; Zhou *et al*., 2020), it later turned out to be a pandemic. Countries around the world have adopted measures to halt the spread of the disease. In Brazil, the first official case was registered on February 26th, 2020, and the first records of community transmission occurred in mid-March, when the states started to adopt the first social isolation measures.

Despite being extremely necessary and proven efficient in controlling the spread of the disease, social distancing and people working from home has unfortunately resulted in negative and dramatic consequences for the social and economic aspects of society. However, this measure also has positive effects on the environmental aspect, such as the reduction of atmospheric pollutant emission in cities, mainly from industrial activities and vehicular traffic. Satellite data from NASA (National Aeronautics and Space Administration) and ESA (European Space Agency) showed reductions in nitrogen dioxide (NO_2) and carbon dioxide (CO_2) levels of up to 30% after the lockdown at several COVID-19 epicenters around the world, such as China, Italy, India, Spain, France and the USA (ESA, 2020; NASA, 2020). In addition to gaseous pollutants, there are also reports of reduction of inhalable particulate matter in the air (PM_{10}). In Chinese cities it was 14-15% (Bao & Zhang, 2020; Chen *et al*., 2020b), up to 52% in several megacities in India (Jain & Sharma 2020), 30% reduction of average concentration in the city of Chittagong, Bangladesh (Masum & Pal, 2021) and between 28 and 31% in Barcelona, Spain (Tobías *et al*., 2020).

The partial lockdown measures also resulted in a reduction in levels of atmospheric pollutant in Brazil, recorded mainly in State capitals (R7, 2020). In the city of São Paulo, despite a significant reduction in carbon monoxide and nitrogen monoxide (CO and NO) and NO_2 levels recorded after a period of partial lockdown, no significant reduction in PM_{10} was observed (Nakada & Urban, 2020). The Environmental Protection Agency of Minas Gerais state (FEAM) reported a 10% reduction in PM_{10}

close to heavy traffic roads in the northeast region of Belo Horizonte and 31% in the downtown area (G1, 2020).

It is known that the inhalable fraction of the particulate matter in the air is very harmful to health and can cause asthma, cardiovascular and respiratory diseases, etc. (WHO, 2018). Several analyses have been pointing out a direct relationship between the concentration of PM_{10} in the air and the rate of mortality or hospitalization due to cardiovascular and respiratory diseases (Yi *et al*., 2010, Samoli *et al*., 2011; Araujo Pinheiro *et al*., 2014; among others).

The main objective of this study is to analyze and compare the concentrations of airborne particulate matter (air pollution by PM_{10}) before and during the partial lockdown due to the COVID-19 pandemic in Belo Horizonte, a metropolitan center in Brazil. This paper presents the first results of social distancing, after a period of partial lockdown (PL), in the PM_{10} content. The level of the social distancing was analyzed in terms of the evolution of the vehicular traffic recorded on traffic monitoring cameras during the different phases of the partial lockdown (PL) enforced by the municipal authorities. The monitoring point of PM_{10} was located on the campus of the Federal University of Minas Gerais (UFMG), in a green area located about 2 km from the main traffic avenues. It is a unique opportunity in the recent history of the world to gather primary data and contribute to the knowledge of the impacts of human activities on atmospheric pollution and the methods to mitigate theses impacts, improving the quality life.

2. Description of the study area

The study was carried out in Belo Horizonte, capital of the State of Minas Gerais, and one of the most populated metropolitan regions in Brazil with about 2.5 million inhabitants (IBGE, 2020). The number of vehicles in Belo Horizonte is the third largest in Brazil, approximately 2.3 million vehicles in April 2020 (DENATRAN, 2020).

The monitoring point for PM_{10} sampling is located within the limits of the Nuclear Technology Development Center (CDTN/CNEN), within the campus of the Federal University of Minas Gerais (UFMG). Of the 8.7 million square meters of the total campus area, only 7.3% is urbanized (UFMG, 2020). In the vicinity of the campus, almost all areas are urbanized, with important roads with intense daily traffic flow. More than 55,000 people commute around the UFMG campus every day. It is the second most crowded traffic area in Belo Horizonte (UFMG, 2020). Approximately 2 million vehicles pass through the avenue closest to the monitoring point (Avenida Antônio Carlos) every month. The heavy traffic may contribute to the city's atmospheric pollution. However, the monitoring point located inside the campus, in a green area, close to an environmental protection area, away from the main external traffic routes. This monitoring place was chosen in order to assess whether the partial lockdown would influence air quality in a green area close to the environmental protection area, even in large urban centers. Most UFMG activities have been interrupted since March 8, 2020, causing an important decrease in traffic the within Campus.

Figure 1 presents an image (from Google Earth®) showing the monitoring point, near traffic

routes and the predominant wind direction. It also shows the land use and occupation in the surroundings, such as constructions and green areas.

CDTN operates a meteorological station located 300 m from the monitoring point (EMET/CDTN). According to the data from the last five years, east/southeast wind and unstable atmosphere are locally predominant more than 90% of the time, with average annual velocities between 1.8 and 2.0 m s^{-1}. The monitoring point is 1.6 kilometers from Antônio Carlos Ave., and the east/southeast wind direction is from the avenue towards the Campus.

3. Monitoring period

The levels of particulate matter in the air were monitored during the PL control phase, during the reopening phases, and after the termination of PL, when daily activities resumed. These values were compared to the values in the period before the PL (monitoring starting in September 2019). Before PL, the frequency of monitoring was monthly and, during PL, weekly to increase the number of observations.

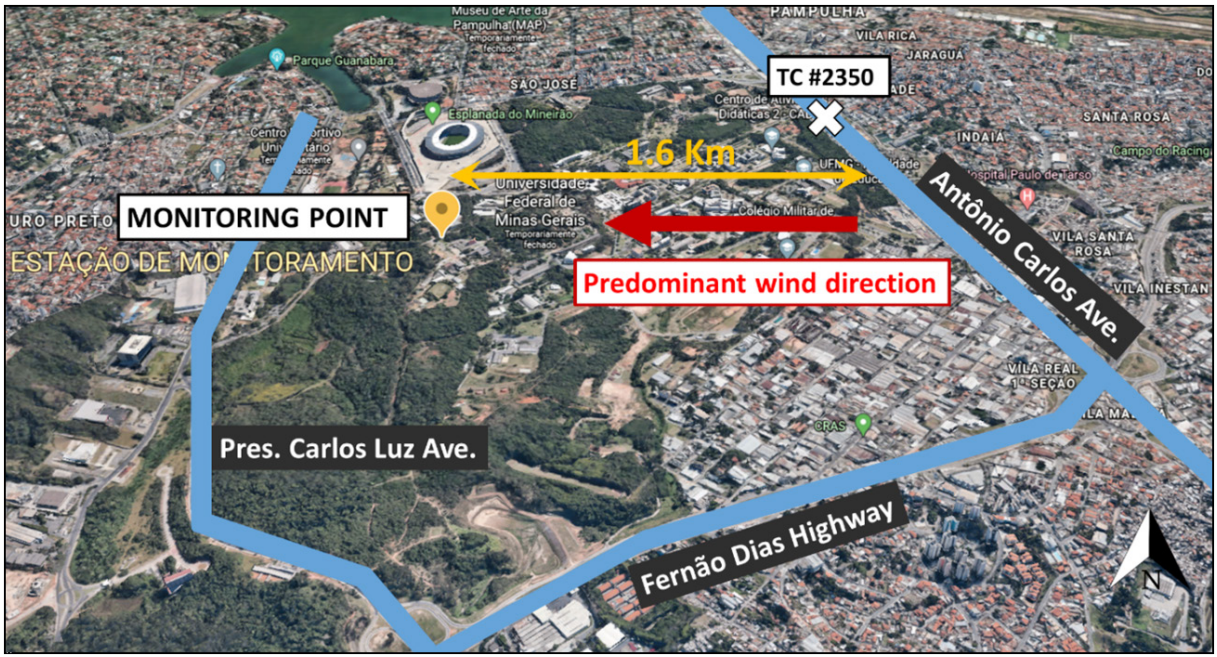

FIGURE 1 – Image with indication of the monitoring point (yellow marker), main traffic routes (in blue) and predominant wind direction (red arrow).

The first official announcement of the beginning of PL in Belo Horizonte was made on March 17, 2020 through a municipal decree declaring a public health emergency. This was followed by restrictions on commercial and industrial operations and only essential activities were authorized to remain open (control phase). The gradual return of economic sectors started on May 25, 2020, with the first of four planned reopening phases. Later, the second reopening phase was cancelled by the municipality, back to the activities of the control phase due to a resurgence of COVID-19 cases. The reopening phases were restarted on August 6, 2020.

Figure 2 shows a timeline of these periods. The monitoring included the periods before PL; the PL phases; and the reopening phases as defined by the municipality.

4. Vehicular traffic and social distancing index (SDI)

The evaluation of the degree of engagement of the population of Belo Horizonte, the social distancing index (SDI), was done by analysis of vehicle traffic on weekdays based on automated records of traffic cameras (TC) in the city. Provided by the transport and traffic company of Belo Horizonte (BHTRANS), the raw data for each TC consisted of hourly records of vehicle traffic density by automobile category (cars, motorcycles, and heavy vehicles – buses and trucks) and by lane, per day. To better represent the traffic flow in the city, 32 TCs were selected based on the location (including major routes in the city) and the data accuracy (only TC with less than 1% of data errors).

The TC #2350, located on Antônio Carlos Ave. (TC #2350 has been highlighted with an "X" in Figure 1), was selected as the most representative of vehicle traffic in the monitoring region and, consequently, with the potential to more directly influence air quality at the monitoring point. For this selection, the proximity of the monitoring point and the wind direction (upwind relative to the wind direction) were used as criteria. In a research about vehicular emissions on heavy traffic routes, Cesar (2018) performed a statistical analysis of the consistency and representativeness of the TC data on this same avenue. TC #2350 was also considered representative of the route traffic by the author.

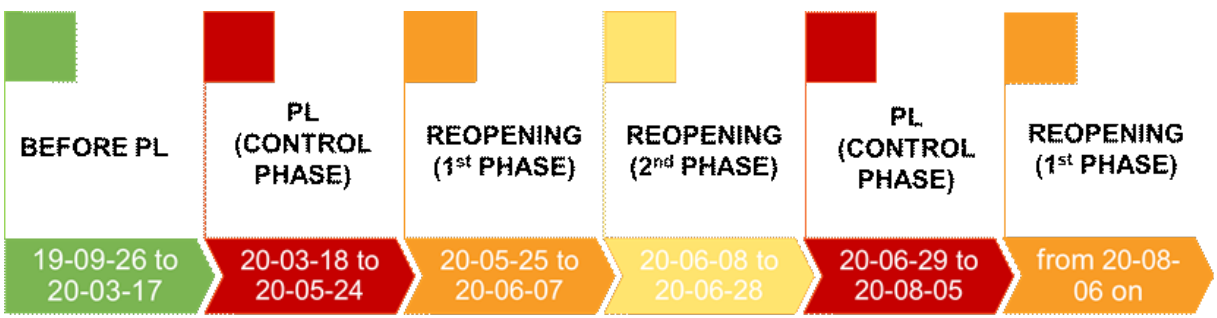

FIGURE 2 – Timeline of the monitoring periods according municipality decrees.

In order to represent a percentage of people "at home", the SDI was estimated, after the start of the PL, for each day at 100% minus the percentage of current vehicle traffic related to the average daily value for the period immediately before PL (between March 3 and March 17, 2020).

5. PM_{10} monitoring and data analysis

The PM_{10} concentration was measured using a high-volume sampler, with PM_{10} inertial separator (± 5 %), at 1.13 $m^3\ h^{-1}$ (AGV, ENERGÉTICA®, Brazil). Fiberglass filters (Whatman GF/A®, UK) were used to collect particulate matter. The methods for monitoring, calibration and operation of the equipment, as well as the filter preparation and gravimetric measurements in the laboratory, were done according to the United States Environmental Protection Agency (US EPA) guidelines (USEPA, 1999) and manufacturer's specifications.

For each PM_{10} monitoring event, the corresponding vehicle traffic was obtained, defined as the mean value for the two-day monitoring period between the beginning of the monitoring and the sampling. The Statistica 8.0® and Microsoft Excel 2010® software were used for statistical analysis (descriptive, tests of hypothesis and correlations).

6. Results and Discussion

6.1. Vehicular traffic and social distancing index (SDI)

The vehicular traffic recorded by the traffic monitoring cameras (total number of vehicles in circulation and classified by vehicle type) on the main avenues of the city during the analyzed periods (before the PL, during the PL, and in the reopening phases) is presented in Figure 3(a). A sharp and continuous reduction of vehicular traffic in the city can be observed, starting the day before of the official announcement of the PL by the municipality on March 18, 2020, but this first reduction lasted only one week. Since then, a continuous increase in overall vehicular traffic has been observed, even during the first control phase of the PL (from March 18 to May, 24 2020). After the end of the 1st reopening phase, the movement becomes stable and even the return to the PL control phase on June 29 did not produce any further reduction in vehicular traffic. The same behavior was reproduced for all vehicle types, with a tendency to increase the fraction of cars over the other types. The records from TC #2350 followed the same trend. The peak of social distancing was 49.5% in the first week of PL; on August 14, 2020, the index was only 5.7%. Figure 3(b) presents the evolution of the SDI since the start of the PL.

6.2. PL effect on PM_{10} concentration

Table 1 presents the PM_{10} concentration data in each monitoring period and the date of the monitoring events. The data were classified into three monitoring periods (pre-lockdown period; partial lockdown period; reopening phases). Since the second PL phase (from June 20 to August 5, 2020) occurred between the reopening phases and did not result in any further reduction in vehicular traffic (Figure 2), the data for this phase were considered to be from the reopening phases as well.

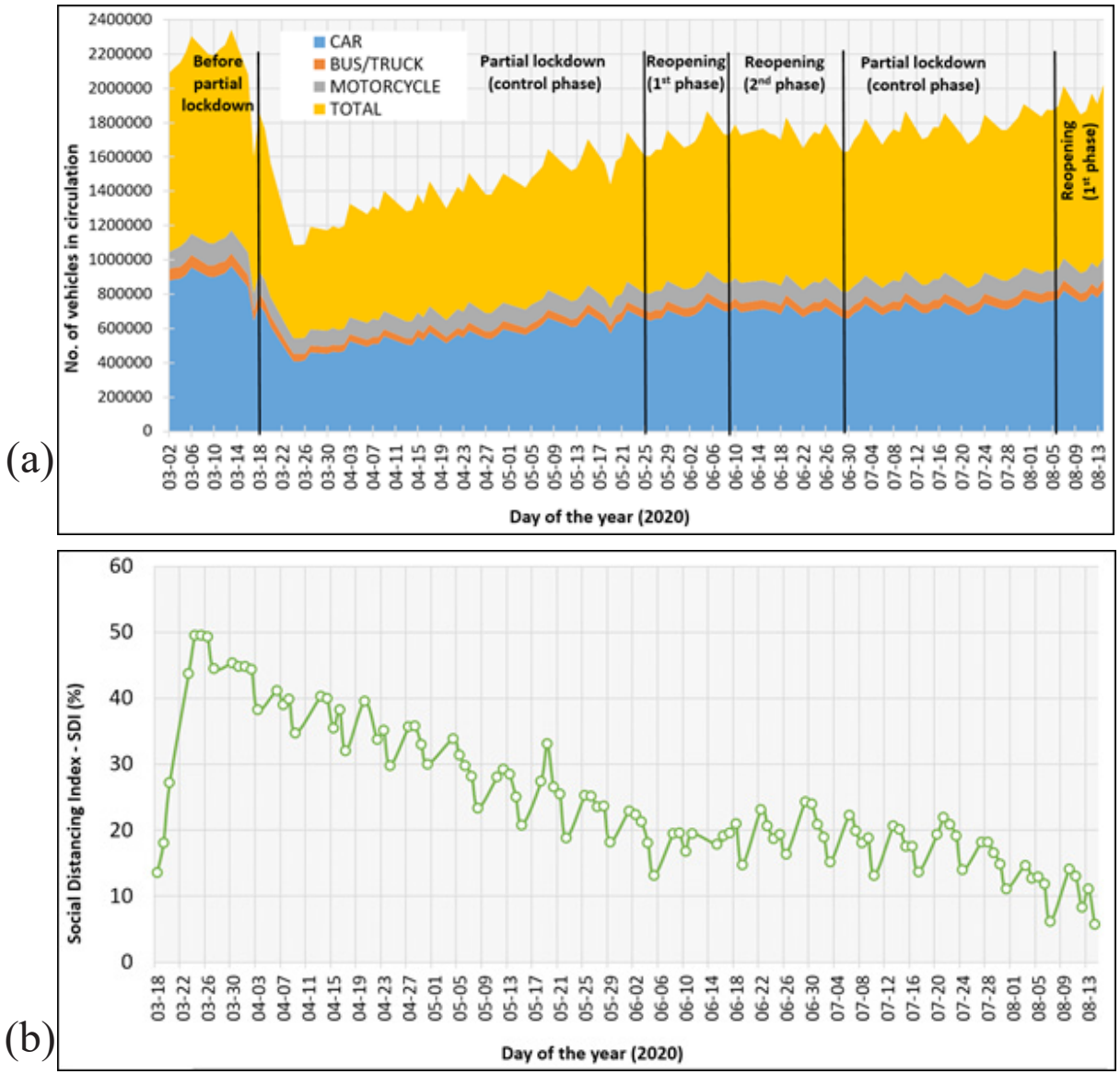

FIGURE 3 – (a) Vehicular traffic (total and classified by type) in the main avenues in Belo Horizonte, Brazil, along the analyzed periods (before partial lockdown, during partial lockdown (PL), and reopening phases) and (b) Evolution of the Social Distancing Index (SDI) since the start of the PL.

The results of PM_{10} concentration during the PL phase were (mean ± standard deviation, unless specified otherwise) 7.7 ± 4.2 μg m^{-3} (n = 9). When compared to the pre-lockdown period concentration value for PM_{10} (22.2 ± 3.0 μg m^{-3}, n = 7), this value was 65.2% lower. Considering the median values (5.5 and 21.6 μg m^{-3}, during and before PL, respectively), the reduction was 74.6%. The reopening phases caused a significant increase in PM_{10} air pollution (14.8 ± 4.3 μg m^{-3}, n = 7), although they did not reach the pre-lockdown mean value (66.6%). The *Shapiro-Wilk* statistical test showed that the PM_{10} concentration values follow the normal distribution with a significance level for $\alpha = 0.05$ ($W = 0.946$; *p-value* = 0.246, n = 23). As expected, the t-student test indicated a statistically significant difference in the mean concentration values during the monitoring phases (maximum *p-value* of 0.005, $< \alpha$ for all comparisons).

The mean reduction of 14.5 μg m^{-3} in PM_{10} concentration (or 65.2%) with the implementation of the PL can be considered significant, especially when considering that it took place in a more protected area, located more than one kilometer from possible sources. This result suggests that a higher impact could also occur in more urbanized regions located closer to heavier vehicles routes. Comparing the data achieved in this study with other values recorded in Brazil, the PM_{10} values obtained are higher than those of the study conducted by the Environmental Protection Agency of the State of Minas Gerais, FEAM, which obtained a 30% reduction in a peripheral area of Belo Horizonte, close to heavy traffic routes, and a 10% reduction in the downtown area, considering March and April 2020, compared to February (G1, 2020). According to Nakada & Urban (2020), the Environmental Protection Agency of São Paulo (CETESB) observed a reduction of 22.8% in PM_{10} and 29.8% reduction in $PM_{2.5}$ on an urban road after the ordered partial lockdown in the city on March 24, 2020, considering the four weeks during the partial lockdown vs five-year monthly mean for April. In São Paulo, social distancing varied from 54% (March 24), reaching a minimum

TABLE 1 – Timeline of the monitoring periods according municipality decrees.

Date	[PM_{10}] (μg m^{-3})
Pre-lockdown period	
Sept 26, 2019	25.46
Oct 22, 2019	27.04
Nov 19, 2019	18.93
Dec 17, 2019	19.70
Dec 18, 2019	22.05
Mar 3, 2020	20.56
Mar 4, 2020	21.60
Partial lockdown period	
Apr 8, 2020	3.21
Apr 13, 2020	5.20
Apr 16, 2020	13.18
Apr 20, 2020	4.86
Apr 23, 2020	8.68
Apr 27, 2020	5.49
May 5, 2020	15.48
May 11, 2020	8.45
May 19, 2020	4.93
*Reopening phases**	
May 27, 2020	15.79
Jun 2, 2020	20.86
Jun 9, 2020	14.56
Jun 24, 2020	8.66
Jul 9, 2020	19.48
Jul 15, 2020	12.35
Aug 3, 2020	11.87

* Second PL phase was considered to be also from the reopening phases

of 47% (April 9) and a maximum of 59%, with an average of 54% (Nakada & Urban, 2020).

It is important to mention that there were no rainy days. The temperature, wind speed and relative humidity records showed less marked fluctuations in the analyzed period. The daily values of these parameters during the monitoring period were tested considering the mean values for the pre-lockdown period and the PL period and showed no significant differences. The Shapiro-Wilk statistical test showed that the three variables follow the normal distribution (*p-value* = 0.428, 0.133, and 0.355, respectively). The t-student test showed no difference between mean relative humidity (*p-value* = 0.813) and wind speed (*p-value* = 0.708) for both periods ($\alpha = 0.05$). The mean air temperature showed to be significantly different between the two periods (22.7° C before and 20.2° C during the PL, *p-value* = 0.040), however, with a p-value very close to the α value used and without a significant correlation between these variables according to the Pearson's correlation test (r(XY) = 0.36, *p-value* = 0.114). Furthermore, the correlation between PM_{10} concentration and the air temperature may vary, and can also be negative (Czernecki *et al*. 2017; Hernandez *et al*. 2017). Thus, the results suggest that the observed reduction in PM_{10} during the partial lockdown period was not greatly determined by changes in meteorological conditions.

It is known that traffic is one of the sources of PM_{10}, being a coexisting factor with other possible sources. However, considering the wind conditions at the location and that there were no significant pollution sources operating in the monitoring region (example: industries), it is possible to consider that vehicular traffic represents a large part of this contribution to PM_{10}. Estimates regarding this relationship can be seen in the following section.

6.3. Vehicular traffic versus PM_{10} concentration

The *Shapiro-Wilk* statistical test showed that the vehicular traffic data also follow the normal distribution (W = 0.941; *p-value* = 0.209, n = 22), at $\alpha = 0.05$ significance level. TC #2350 traffic data also follow the normal distribution (W = 0.977; *p-value* = 0.852, n = 23) and were considered linearly correlated with all selected traffic cameras of the city (*Pearson's* correlation test, with r(XY) = 0.890, $R^2 = 0.792$, *p-value* = 0.000 < α). Therefore, the TC #2350 can be considered as representative of the overall city traffic. The correlation between the observed PM_{10} concentration and the TC #2350 data was considered statistically significant (*Pearson's* correlation test, with r(XY) = 0.782, *p-value* = 0.000 < α). Figure 4 presents the linear correlation graph between these variables ($R^2 = 0.611$). The colors in the figure represent the monitoring phases: in green, the pre-lockdown phase; in blue, the PL control phase; in orange, the reopening phases and second PL phase.

The linear regression equation presented in Figure 4 suggests a reduction or increase of 12 μg m^{-3} for each reduction or increase of 10,000 vehicles in circulation within the monitoring region. It must be emphasized that this estimate is strictly mathematical in nature, valid only for the monitoring region and ranges of the variables, with no predictable effect.

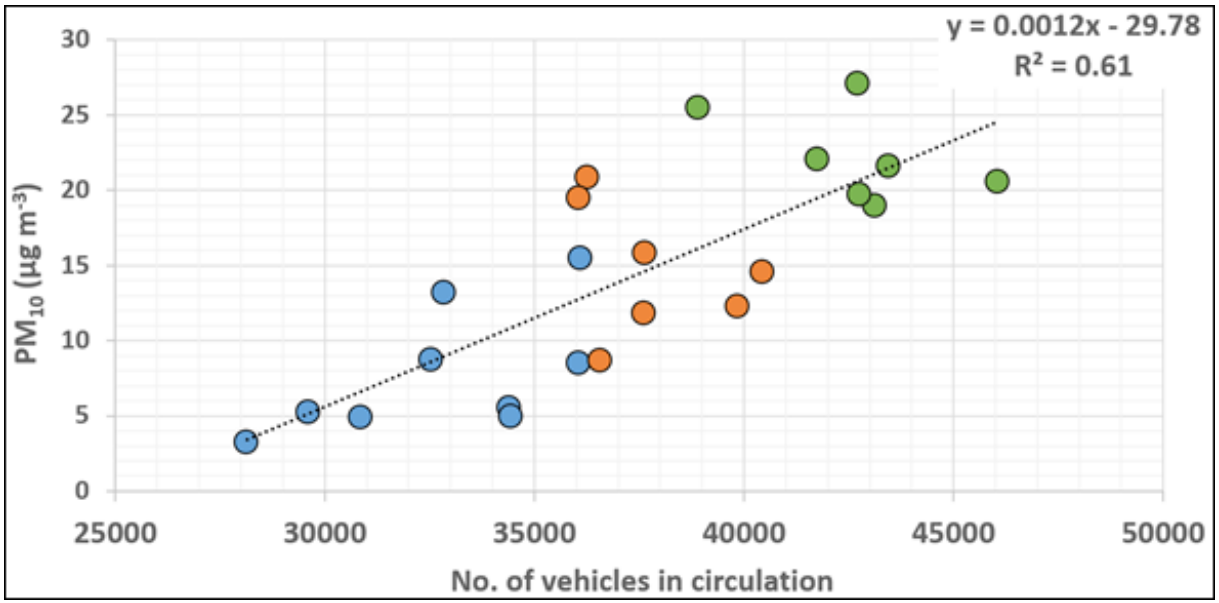

FIGURE 4 – Dispersion graphic with linear correlation between PM10 concentration and vehicular traffic (registered by traffic camera #2350) in the pre-lockdown phase (green); partial lockdown control phase (blue); and after reopening phases (orange).

7. Conclusion

In this study, a significant reduction in inhalable particulate matter, PM_{10}, air pollution associated with vehicular traffic was observed in a field monitoring performed before and during the partial lockdown due to COVID-19 in Belo Horizonte, Brazil. The PM_{10} concentration results during the partial lockdown were 65.2% lower compared to the pre-lockdown period (mean values). It is one of the few positive effects of a pandemic that has caused major negative effects on social and economic aspects around the world. In this case, statistical analysis and land use and land occupancy in the region suggested that vehicular traffic represented a large portion of this influence on PM_{10}.

Despite the short-term monitoring of the observed reduction in PM_{10} concentration, this has *certainly been positive for the health of the population* and can result in lower number of hospitalizations and deaths from respiratory and cardiovascular diseases, reinforcing the positive impacts of policies to the reduce the vehicular traffic in the cities, such as public transport encouragement, "odd-even" car rationing, and remote forms of working (the latter in vogue during this pandemic period). Future work can be developed to complement the results of this research and cover these aspects.

For the next stages of this work, elemental, ionic, and isotopic analysis of the air particles retained in the filters are being planned for all periods monitored, as well as the use the data in receptor models for source apportionment. These analyses

will allow further comparisons between periods, as well as reveal pollutant sources that tend to be masked due to prevailing vehicular pollution under normal and pre-pandemic conditions. Since March 2020, after partial lockdown, several laboratories at CDTN are not operating, so samples are being preserved for complementary analysis.

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