



The Effect of Urban Green Spaces on Reduction of Particulate Matter Concentration

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Abstract

In an urban scenario, one of the air pollutants most harmful to human health and environmental is the particulate matter (PM). Considering that urban green areas can contribute to mitigating the effects of PM, this work compares the concentration of PM_{2.5} in two closer locations in Rio de Janeiro, in order to verify how vegetation cover can actually improve air quality. One is the entrance to the Rebouças Tunnel (RT) and the other is the Rio de Janeiro Botanical Garden (RJBG). For this purpose, PM_{2.5} samples were taken from September 2017 to March 2018 using a Large Volume Sampler (LVS). The results reveal that RT has a higher concentration of PM_{2.5} in almost all samples. The RJBG obtains concentrations around 33% less than the other area, suggesting that the presence of urban green areas like the RJBG can reduce PM_{2.5} levels when compared to places with less vegetation cover, providing better air quality.

Keywords Botanical garden · Vehicular emissions · Atmospheric pollution · Human health · Urban pollution

It is well known that risks to human health and the environment have increased due to exposure to ambient air pollution, and especially to particulate material (PM) (Alemayehu et al. 2020; Manojkumar and Srimuruganandam 2021). PM is defined as a complex mixture of small particles and liquid droplets, which due to their size and mass can remain suspended in air, and may contain a variety of species harmful to human health, such as polycyclic aromatic compounds (PAHs) (Hu et al. 2017).

Depending on their size, the particles can be inhaled through the respiratory tract and reach the pulmonary alveoli, and, consequently, resulting in several implications for the system cardiorespiratory, both in the development of illnesses and in the aggravation of existing diseases, including increasing visits to hospitals, hospitalizations and mortality risks (WHO 2021).

PM exposure can induce stress associated with endothelial dysfunction and inflammatory reactions (Lotufo 2017; Kim et al. 2019), due to the presence of reactive oxygen species (ROS), which are unstable and extremely reactive molecules capable of transforming other molecules which they collide with, may have an occurrence linked to PM (Lee et al. 2016). During the process of aerobic respiration, oxygen must be reduced, which allows four electrons to enter the end of the electron transport chain within the mitochondria. If oxygen reduction occurs with fewer electrons, ROS will be produced, which can be easily balanced by antioxidants, but in excess of ROS or absence of antioxidants, caused by possible PM interference, oxidation caused by ROS occurs and interferes with transport of substances across plasma membranes and in the control of metabolic pathways, in addition to being able to damage DNA by modifying purine and pyrimidine bases (Souza et al. 2018; Ribeiro et al. 2020). High oxidative stress can also activate protein kinases as well as transcription factor-1 (AP-1) activating protein, which lead to the release of pro-inflammatory cytokines (Lee et al. 2016). The presence of PM can also be associated to other health problems. In Italy, during the COVID-19 pandemic, the experiments conducted by Setti et al. (2020) gave positive results for the presence of SARS-CoV-2 in the analyzed PM₁₀, which corroborates the idea that, if it's possible to find the RNA SARS-CoV-2 in external particles, it could

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create clumps with PM_{10} , reducing its diffusion coefficient and extending the permanence of the virus in the atmosphere. PM could create a suitable environment for transporting the virus at greater distances than those considered for close contact. Moreover, PM induces inflammation in lung cells and exposure to PM could increase the susceptibility and severity of the COVID-19 patient symptoms (Comunian et al. 2020).

The smaller its size, the greater its reach in the body, which may cause inactivation of microbiota bacteria in the lung tissue, changes in epithelial permeability, and decreased macrophage function, and may could act as immunosuppressants of pulmonary defense mechanisms. Thus, it is important to characterize the PM according to its size: (i) coarse (particles with a diameter between 2.5 and 10 μm); (ii) fine particles (with an aerodynamic diameter less than 2.5 μm); and, (iii) ultra-fine particles (with less than 0.1 μm in diameter) (Meschede al. 2019). Due its size, $PM_{2.5}$ can penetrate the respiratory system and be absorbed by the systemic circulation, thus reaching various organs of the human body (He et al. 2017), and because of that, has been considered one of the most critical urban air pollutants in most countries (Dantas et al. 2021).

According to the World Health Organization (WHO), guidelines for $PM_{2.5}$ is 5 $\mu\text{g m}^{-3}$ for an annual mean and 15 $\mu\text{g m}^{-3}$ for a 24-h mean, due its several health effects of short- and long-term exposure (WHO 2021). In Brazil, $PM_{2.5}$ was included as a criteria pollutant only in 2018, and having proposed interim goals to be achieved in incremental steps until the standards recommended by the WHO are reached (CONAMA 2018). However, studies indicate that monitoring of this pollutant in Brazil is still incipient, and that only a few monitoring stations in a few cities carry out $PM_{2.5}$ monitoring (Siciliano et al. 2020).

Others impacts about the exposure to particulate matter, can be observed on vegetation, which may affect the morphological, biochemical and physiological attributes of plants. Previous studies have related plant exposure to particulate matter to variations in the size, shape and number of leaves, flowering, development and production of species. Other aspects have been observed, such as variations in the levels of chlorophyll, enzymes, nutrient water (Rai 2016).

In an urban environment, PM has different emission sources, such as the re-suspension of dust and mineral particles, marine aerosol, as well as road traffic and fuel combustion, which the latter two being the largest sources of fines particles emission (Mukherjee and Agrawal 2017). There are studies focusing on the positive effects of urban green spaces on air pollution mitigation, especially on PM concentrations, indicating the importance of the presence of green areas, such as parks, urban forests and others green structures in a city (Silva et al. 2017; Gourdjji 2018; Heo and Bell 2019; Srbinovska et al. 2021).

Rio de Janeiro is the second largest city in Brazil, and has about 30% of its territory covered by vegetation, especially the Tijuca Forest, which is considered the largest urban secondary forest in the world. The Rio de Janeiro Botanical Garden (RJBG) is located on the side facing the southern part of the Tijuca Forest, having been designated by UNESCO (1992) as a biosphere reserve and arousing interest in its importance in the quality of the regional air (da Silva et al. 2016; Moreira-Junior et al. 2017). The main objective of this study was to evaluate $PM_{2.5}$ levels in an urban vegetation cover area, such as the RJBG, compared to levels in another urban area, with the expectation of proposing possible mitigation effects on particulate material levels and their effects about human health.

Materials and Methods

Rio de Janeiro is a Brazilian coastal city, capital of the homonymous state, and is the second most populous city in Brazil, with territorial area of 1,200,329 km^2 with an estimated population of 6.7 million inhabitants (IBGE 2021). It is characterized by having about 70% of its territory urbanized, and with approximately 30% of vegetation cover with the Atlantic rainforest, known as Mata Atlântica, as its predominant biome distributed in urban parks and ecological reserves, with emphasis on the Tijuca Forest, with an area of about 40 km^2 , located in the Tijuca National Park, which is of great tourist interest and divides the city between the north and the south zone (Braga et al. 2019; IBGE 2021). According to Köppen's climate classification, the city has average temperatures ranging from a minimum of 18.4°C (in winter) to a maximum of 30.2°C (in summer), and the city's climate is considered tropical, Am type, with a rainy season in the summer and a dry season in the winter (Moreira-Junior et al. 2017).

With regard to air quality, the pollutants ozone and particulate matter are the most critical air pollutants found in the region (Siciliano et al. 2020; Dantas et al. 2021), and considering its interaction with the vegetation it seems appropriate to evaluate and compare $PM_{2.5}$ levels between an urban green area and an area with a little vegetation cover and a high vehicular flux. For this work, two sampling sites were selected: the Rio de Janeiro Botanical Garden (RJBG) and the Rebouças Tunnel (RT) in whose respective UTM grid coordinates: S. 7458939.4794197 m; E. 681618.51642434 m; Z. 23 and S. 7460004.7631074 m; E. 684083.4926675 m; Z. 23, as shown in Fig. 1.

The RT is one of the main connection routes between the northern and southern parts of the municipality. With its 2840 m long, divided into two sections, one of 2040 m and the other of 800 m, the tunnel was inaugurated on October 16, 1967, and has an estimated daily volume of 190,000

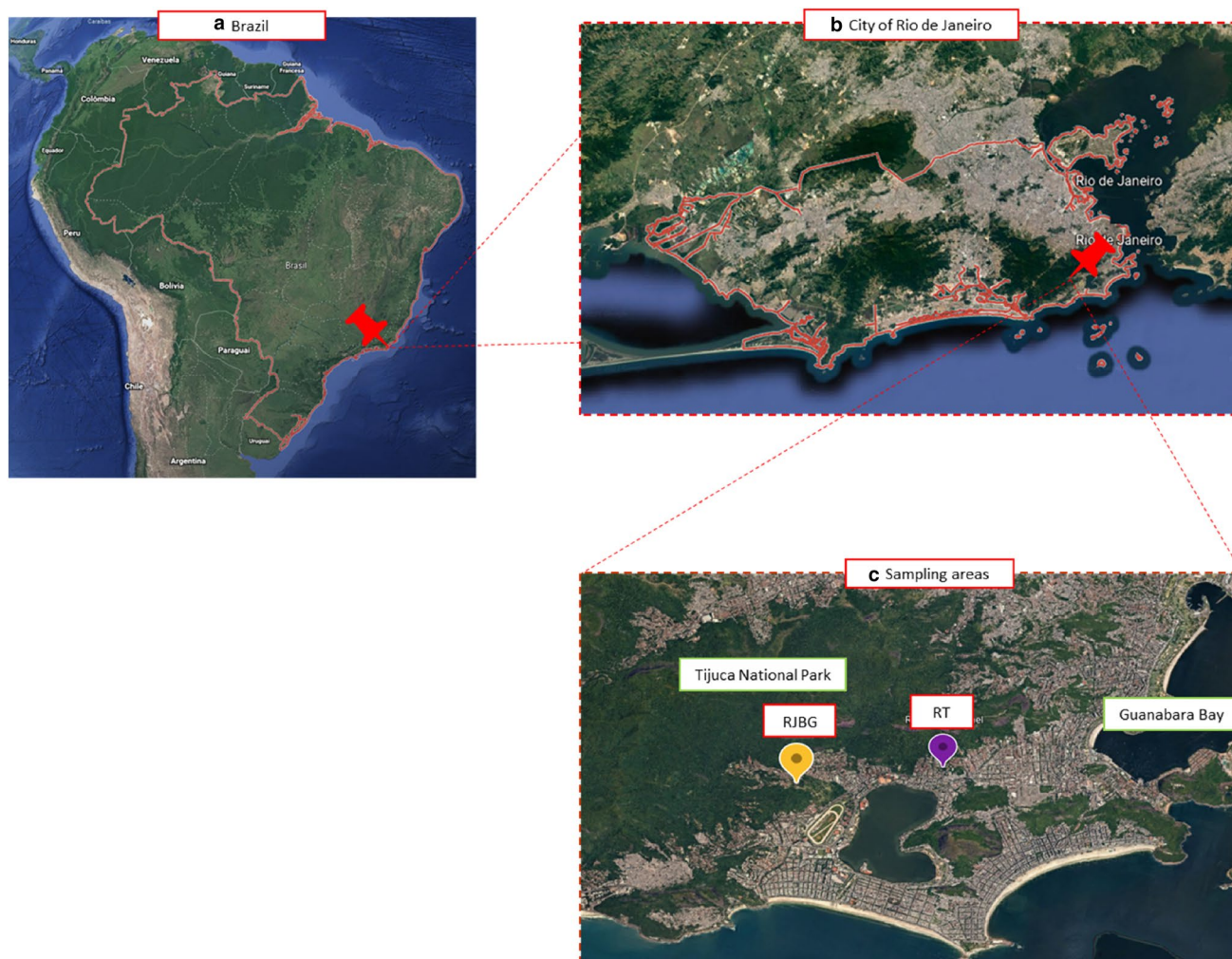


Fig. 1 Map of **a** Brazil, showing the **b** city of Rio de Janeiro (delimited in a red line) and the **c** sampling areas: Reboças Tunnel (RT) (pointed in purple) and Rio de Janeiro Botanical Garden (RJBG) (pointed in yellow), as well as the Tijuca National Park and Guanabara Bay

vehicles, with an average of approximately 5000 per hour with peaks in the morning and late afternoon flow, which positions it as a major contributor to the emission of air pollutants of vehicular origin (Almeida et al. 2020), such as fine particles ($PM_{2.5}$), since vehicular emissions are a significant source of PM, especially fine particles (Pacheco et al. 2017).

The RJBG is located in the south of the city, only 2.5 km away from RT, and is bordered by Jardim Botânico Street, which has a large circulation of motorcycles, cars and buses, and by Pacheco Leão Street, a residential area with less vehicular traffic. On the east side, it borders the Tijuca Rainforest slope of the Tijuca National Park and few houses. It is a park with a considerable human interaction, whether by pruning trees, transplanting specimens or cultivation in greenhouses, especially in the managed area—the arboretum—where visits take place. It is one of the largest green areas in the city of Rio de Janeiro, with a total area of 1.44 km², which 0.54 km² is of arboretum. Considering the

outdoor perimeter and in greenhouses, the park is also one of the most preserved wooded areas in the city, in which around 8200 species can be found—some of which are threatened with extinction. It is divided into different sectors, in order to facilitate botanical study and management, one of the most important is the one occupied by native species from the Atlantic Rainforest, an area well inside the park and significantly away from the main circulation road, Jardim Botânico street (Molinari and da Costa 2001). The PM sampling equipment was installed inside the park, next to the slope of the Tijuca National Park.

$PM_{2.5}$ samples were carried out from September 2017 to March 2018, and for both sampling sites $PM_{2.5}$ were collected using a large volume sampler up to 2.5 μ m (Fig. 2) which allows the determination of particles up to 2.5 μ m in suspension in ambient air. The equipment model used in this study works by inertial impaction, and is equipped with a set of 40 nozzles that accelerate the collection air into an



Fig. 2 PM_{2.5} sampler installed in RJBG

impaction chamber, where particles larger than 2.5 μm are retained in an oily layer. The air fraction with particulate material with a diameter of less than 2.5 μm (PM_{2.5}) is carried out of the chamber and directed to a fiberglass collection filter installed inside a shelter box, where the particles remained. The filters used are specific for a minimum efficiency of 99% for the collection of 0.3 μm Dioctyl Phthalate particles. The particles are collected in this filter, which is previously heated to 600°C for four hours, balanced at a temperature of 25°C in a desiccator, and then its mass is measured using a precision scale, before and after sampling, in order to determine the mass gain of the sample. The sampling period is 24 h and is controlled by a timer with an accuracy of at least 15 min in 24 h.

An important tool used in air quality management is the determination of the Air Quality Index (AQI), which provides information on the health effects of exposure to major air pollutants, correlating them with their respective concentration levels. For this work, the standards established by the United States Environmental Protection Agency (US EPA) were used, being divided into six intervals corresponding to a different level of air quality and health concern in relation to the concentration of pollutants. The first range corresponds to an AQI from 0 to 50, being considered good

Table 1 PM_{2.5} concentrations ($\mu\text{g m}^{-3}$) on Rebouças Tunnel (RT) and Rio de Janeiro Botanical Garden (RJBG)

Date	PM _{2.5} concentration ($\mu\text{g m}^{-3}$)		Concentration in RJBG in relation to RT	
	RT	RJBG	$\mu\text{g m}^{-3}$	%
09/13/2017	16.94	9.15	- 7.79	- 46
09/21/2017	20.35	13.06	- 7.29	- 36
09/29/2017	19.31	14.64	- 4.67	- 25
10/07/2017	16.61	9.12	- 7.49	- 46
10/31/2017	11.18	11.95	+ 0.77	+ 7
11/17/2017	14.26	9.44	- 4.82	- 34
11/25/2017	17.00	11.29	- 5.71	- 34
12/13/2017	14.56	8.77	- 5.79	- 40
01/04/2018	12.15	7.16	- 4.99	- 42
01/13/2018	16.18	13.18	- 3.00	- 19
03/01/2018	13.37	12.05	- 1.32	- 10
03/07/2018	10.15	10.48	+ 0.33	+ 3

air quality and air pollution implies little or no risk to the population; the second interval corresponds to an AQI from 51 to 100, in which the air quality is considered moderate, being acceptable to the population and with risks to people with greater sensitivity to air pollution; the third range refers to an AQI of 101–150, where the air quality is unhealthy for sensitive groups such as the elderly and children; the fourth level corresponds to an AQI of 151–200, and the air quality is unhealthy for individuals in the general population, and with more severe effects on the health of more sensitive groups; the fifth range corresponds to an AQI from 201 to 300, and at this level the air quality is very harmful to health, and the risks of adverse health effects are increased for the entire population, this category is considered as an alert level; and, the sixth and last interval corresponds to an AQI above 301, classifying the air quality as dangerous to the health of the entire population, being considered a level of emergency conditions.

Results and Discussion

The results found at the entrance of the RT and the RJBG reveal, numerically, a greater gain in the mass of the filters used to collect samples in the RT, compared to the filters from the RJBG, which presented less weight after weighing. Considering that the volume of atmospheric fluid passing through the filter during the period of collection was constant, and equal to 1627.2 m³, there was a higher concentration of pollutants in the RT and a lower concentration in the RJBG, as shown in Table 1.

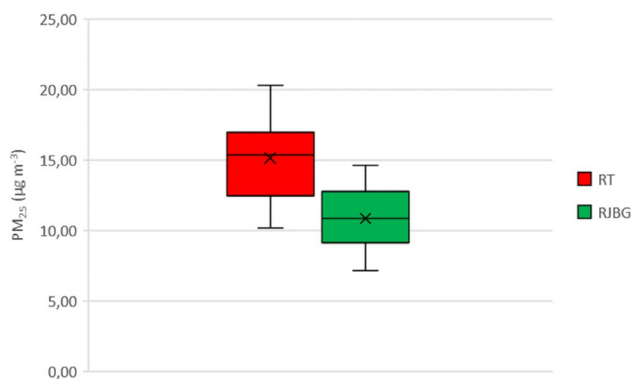


Fig. 3 Boxplots of $PM_{2.5}$ concentrations for the Rebouças Tunnel (RT) and Rio de Janeiro Botanical Garden (RJBG)

The median concentrations determined for both locations were $15.37 \pm 3.14 \mu\text{g m}^{-3}$ for RT and $10.88 \pm 2.21 \mu\text{g m}^{-3}$ for RJBG. Comparing both locals, the mass reduction median is about $3 \mu\text{g m}^{-3}$, and 33% less in a percentage analysis. Results suggest that RT has a mean 24-h value ($15.17 \mu\text{g m}^{-3}$) higher than those established by the WHO, $15 \mu\text{g m}^{-3}$. According to the WHO (2021), if the $PM_{2.5}$ levels were reduced and its interim targets were achieved, premature mortality could be reduced by 45–50 deaths per 100 000 people. Data were also analyzed by measures of dispersion, using boxplots graphics (Fig. 3).

Box plots (Fig. 3) emphasize that mean values for RJBG are lower than those for RT, it also can be noted that there is almost no overlap between the central values (50% of the data) of each dataset, and that the median value for the RT is greater than the maximum value determined for the RJBG. For this analysis it was not observed outlier values for neither sampling site. Values for RT show a greater data dispersion, which can be observed by a greater amplitude given by the difference between the maximum and minimum values (10.2 for RT and 5.87 for RJBG). Data for the RJBG have a more symmetrical distribution, with the median line closer to the center of the box, which may be related to the stability of conditions at the sampling site, suggesting a possible effect and contribution of the surrounding vegetation in this direction, especially considering the proximity between the two places studied.

As previously discussed, the PM levels determined for the RJBG were substantially lower ($\sim 33\%$) compared to those determined for the RT, in agreement with other studies that suggest the presence of green areas for the control and mitigation of the effects caused by emissions atmospheric, especially PM (Heo and Bell 2019; Gao et al. 2020; Srbinovska et al. 2021), since the reduction of these and other pollutants could result in an improvement in the region's air quality.

The Air Quality Index (AQI) was applied, and the AQI classification, considering the concentrations determined in this study, are shown in Table 2.

For the concentration data obtained in this work, the AQI levels determined for the RT were mostly classified as moderate, while for the RJBG they were mostly classified as good. An AQI rated as moderate suggests acceptable air quality for the general population, but individuals who are exceptionally sensitive to air pollution should consider certain exposure precautions and prolonged activities and efforts. An AQI rated as good suggests air quality without greater risk to the population. It is noteworthy that for both levels, individuals with respiratory or cardiac diseases, the elderly and children are groups at higher risk, even considering good air quality.

Data observed in Table 2 indicate, as expected, that areas with greater vegetation coverage influence the decrease in levels of air pollutants, and, consequently, in the classification of air quality, providing benefits to the environment and human health. In addition, green areas also play other important roles in urban centers, such as excellent climate regulators, mitigating the effects of noise and air pollution, influencing the regional water balance, sheltering biodiversity, in addition to contributing to the economy and tourism activities and leisure.

A low percentage of vegetation cover causes a rise in temperature and a greater amount of PM suspended in the atmosphere. In areas with less green space, there is even a greater association between PM and hospitalization for cardiovascular and respiratory diseases (Heo and Bell 2019). Therefore, it would be appropriate if there were plans for cities to include or increase green areas in their space, aiming improving the quality of life of the population itself (Douglas and Scott 2017). Anguluri and Narayanan (2017) also

Table 2 The Air Quality Index (AQI) at Rebouças Tunnel (RT) and Rio de Janeiro Botanical Garden (RJBG)

Date	AQI	
	RT	RJBG
09/13/2017	Moderate- 61	Good-38
09/21/2017	Moderate- 68	Moderate- 53
09/29/2017	Moderate- 66	Moderate- 56
10/07/2017	Moderate- 60	Good-38
10/31/2017	Good-46	Good-50
11/17/2017	Moderate- 55	Good-39
11/25/2017	Moderate- 61	Good-47
12/13/2017	Moderate- 56	Good-36
01/04/2018	Moderate- 51	Good-30
01/13/2018	Moderate- 59	Moderate- 53
03/01/2018	Moderate- 54	Good-50
03/07/2018	Good-42	Good-43

suggest a greater role for green areas in the development of smart city plans, with the application, for example, of the green index. The results of their research show scope, including, for alternative green cover, where ever the green index is low.

In a city like Rio de Janeiro, the historical role of urban green areas such as the RJBG in improving air quality should be more valued, especially because the presence of air pollutants such as PM also contributes to the proliferation of cases of contamination from viruses such as SARS-CoV-2. Yao et al. (2020) found positive associations between PM pollution and COVID-19 case fatality rate in cities closer to Hubei Province. According to Venter et al. (2020) research, the increase of outdoor activities suggests that green spaces also facilitated social distancing and indirectly mitigated the spread of COVID-19.

Huang et al. (2021) collected PM_{2.5} samples from residential, commercial, plaza and public green spaces in Lin'an, Hangzhou – China. They concluded that public green space had the most ecological benefits and should be fully utilized to improve public health in urban spaces.

As previous studies have already indicated the influence green areas have on the reduction of other atmospheric compounds, such as volatile organic compounds and greenhouse gases, this study also corroborates to the discussion about the relevance of the RJBG and its role and contribution to the region's air quality. This is the type of protagonism that makes the RJBG an important green area in the city, and locations with similar phytophysionomies or belonging to other biomes, should be taken more into account by authorities with regard to conservation and urban planning, as well as the reduction in vehicle traffic should be encouraged by the improvement of public transport services, since vehicular source are the most contributors to the PM_{2.5} emissions.

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