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Estimation of nitrogen dioxide levels on streets from Fortaleza Brazil using passive sampling and multivariate analysis

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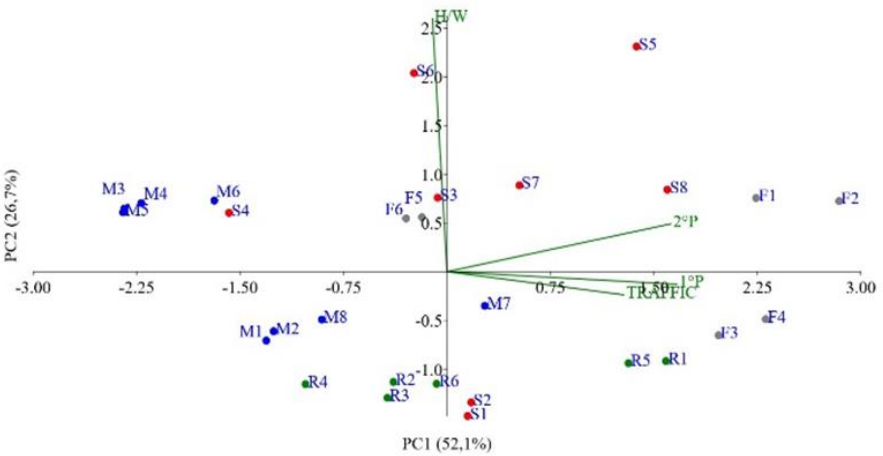
Abstract

The increase in the fleet of motor vehicles circulating in urban centers is one of the main generators of gaseous pollutants harmful to human health and the environment. Pollutants can be economically and effectively monitored through passive sampling. This study aims to estimate NO_2 levels on roads of Fortaleza city /CE using the passive sampling method. 12 campaigns covered the rainy (March-June) and the dry (July-November) seasons in 2019. The seasonal averages of NO_2 in the rainy season were higher than the dry one, and Almirante Rubim Street showed the greatest difference in the averages: 26.6 µg m^{-3} in the rainy and 19.3 µg m^{-3} in the dry season. The principal component analysis applied to the averages of NO_2 concentration in the rainy and dry seasons, vehicle traffic and Height of the road/width ratio indicated that components 1, 2 and 3 explain 94.4% of the studied cases. Passive sampling proved to be efficient, contributing to the production of unpublished data about NO_2 levels in streets of Fortaleza/Ceará/Brazil from mobile sources.



The PCA was used to group the sampling points that present similar behavior about the average NO_2 variables in the rainy and dry seasons, H/W ratio and vehicle traffic, through a two-dimensional graph.

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Highlights

- Passive sampling was efficient in indicating NO2 levels from mobile sources.
- Meteorological data and the H/W ratio of roads influence the NO2 levels.
- The PCA is a powerful and suitable statistical tool for interpreting NO2 levels.

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1. Introduction

Economic development in a region favors, among other factors, population growth, urbanization of green areas and the installation of diverse industries. This situation also contributes to the considerable increase in the emission of harmful compounds that in significant quantities reduce the air quality of the region and thus significantly affect the dynamics of the ecosystem and the health of the population (Baird and Cann, 2011; Ding *et al.*, 2022; Guo *et al.*, 2019; Lenzi and Favero, 2014; Zanetti and Melli, 1992). Nitrogen dioxide (NO_2) is one of these compounds and its main sources in urban areas are largely from industry and vehicle emissions from the burning of fossil fuels (Aránguez *et al.*, 1999; Biswal *et al.*, 2020; Januševičius and Grubliauskas, 2019; Lenzi and Favero, 2014; Richmond-Bryant *et al.*, 2017). At low altitude atmospheres, NO_2 is part of the photochemical smog that causes oxidation of any material it meets and at high altitudes, it causes the depletion of the ozone layer (Lenzi and Favero, 2014). Plants, by absorbing NO_2 through their leaf stomata, can oxidize this pollutant to nitrate through photochemical reactions, favoring the internal spaces of the leaf to become acidic, thus damaging them (Freedman, 1995; Rao *et al.*, 2014).

In the human population, NO_2 can cause eye irritation and when inhaled it favors inflammation of lung tissue, emphysema, and installation of respiratory infections, caused by changes in local immunity (Ghozilaki *et al.*, 2016; Negrisoli and Nascimento, 2013; Russo *et al.*, 2014), in addition to increase the susceptibility to bronchoconstrictor agents and respiratory infections caused by bacteria, especially in children (Shiraiwa *et al.*, 2012; Ugucione *et al.*, 2002) and positively increase the number of hospitalizations and mortality (Arbex *et al.*, 2012; Duan *et al.*, 2019; Hatzopoulou *et al.*, 2013; Martins *et al.*, 2002; Nascimento *et al.*, 2006; Pestana *et al.*, 2017). Between 2009 and 2018, about 115 thousand hospital admissions of people residing in Fortaleza were carried out because of asthma, bronchitis, influenza, and pneumonia. Of this total, more than 50% of cases are due to pneumonia. The number of deaths due to these diseases in the period from 2009 to 2017 was 29,292, with 89.5% being people aged 50 years or older (Datasus, 2019).

Emissions of atmospheric pollutants produced by vehicular sources are difficult to control, thus leading much research to studies that verify the reduction of car emissions using catalytic converters (Halim *et al.*, 2018; Mehta and Dey, 2020). In Fortaleza, until December 2018, about 1.1 million vehicles were registered, with more than 50% of this fleet being private cars and more than 13% being diesel vehicles (IBGE, 2019). To evaluate the number of atmospheric pollutants, as well as NO_2, several types of sampling were developed that can be classified according to the analysis methodology, among which passive sampling equipment stands out (Harner *et al.*, 2013; Miranda *et al.*, 2017) due to its low cost, easy handling and understanding, without any automatic systems, it does not require electricity, has easy labor logistics and can absorb pollutants of a gaseous nature or polluted vapors from the atmosphere through the process of diffusion and permeation by concentration difference (Cruz and Campos, 2008; Hauser *et al.*, 2015; Lacava *et al.*, 2002; Lisboa and Kawano, 2010; Masey *et al.*, 2017; Piceli and Lisboa, 2018; Souza *et al.*, 2017).

Considering these facts, in the city of Fortaleza there is no annual monitoring of the levels of all legislated inorganic compounds (SO_2, Total Suspended Particulates, CO, O_3, PM 2.5, PM 10 and even NO_2) on high-traffic roads. The absence of monitoring work on NO_2 and other parameters is due to the lack of financial incentives, the lack of qualified and trained human resources and the high costs of materials and equipment needed. This lack of information emerges as a very serious problem, which makes it difficult for health inspection and surveillance agencies to establish a mechanism for preventing and controlling atmospheric pollution.

Faced with this problem, the present study aims to estimate NO_2 levels using the passive sampling method in commercial streets in Fortaleza/CE.

2. Experimental

2.1. Study area

The city of Fortaleza has 2,473,614 inhabitants and a total area of 313.8 km^2 (**Fig. 1**). The city has an Aw' climate on the Koppen-Geiger scale, with an average annual temperature of 26.5 °C, an average wind speed of 12.7 km h^{-1} and an average annual rainfall of 1600 mm, with the highest occurrences between February and May featuring the city's rainy season (IBGE, 2019; M. Moura *et al.*, 2008; M. Moura, 2015).

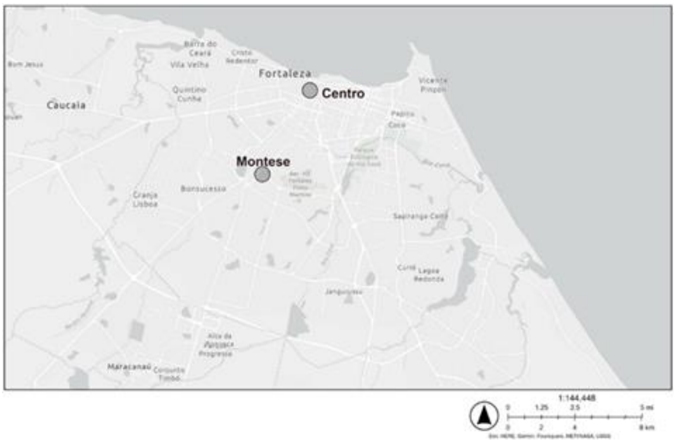

Figure 1. Map of the city of Fortaleza with the location of Montese and Centro.

Almirante Rubim (Street R) and Antônio Fiúza (Street F) streets, both in the Montese neighborhood and General Sampaio (Street S) and 24 de Maio (street M) Streets, both in the Centro neighborhood, were selected because they have two lanes and one-way traffic. Each road was divided into sectors and each sector has two sampling points, one on each side of the road. The chosen nomenclature and the georeferenced location of the sampling points were given as shown in **Table 1**.

Points F3 and F4 are close to the corner of Street Antônio Fiúza and Street 15 de Novembro, the access road to Fortaleza airport. Points M7, and M8, from 24 de Maio and points S7 and S8, from General Sampaio, then fixed on the corner with Street Castro e Silva. In this block is located the bus terminal of Praça da Estação. On all 4 lanes, the odd-numbered points are located on the posts on the right side of the street and the even points are on the posts on the left side, as illustrated in **Fig. 2**.

Table 1. Nomenclature and georeferenced location of sampling points.

Street	Point	Latitude	Longitude	Street	Point	Latitude	Longitude
Street F	F1	3°46'07.7"S	38°33'06.3"W	**Street M**	M3	3°43'44.1"S	38°31'57.7"W
	F2	3°46'07.7"S	38°33'06.0"W		M4	3°43'44.1"S	38°31'57.4"W
	F3	3°46'12.3"S	38°33'08.2"W		M5	3°43'26.8"S	38°31'52.2"W
	F4	3°46'12.7"S	38°33'07.8"W		M6	3°43'26.3"S	38°31'51.6"W
	F5	3°46'17.8"S	38°33'10.0"W		M7	3°43'22.3"S	38°31'50.6"W
	F6	3°46'17.8"S	38°33'09.8"W		M8	3°43'22.3"S	38°31'50.3"W
Street R	R1	3°46'22.5"S	38°33'26.3"W	**Street S**	S1	3°43'57.5"S	38°31'56.7"W
	R2	3°46'22.5"S	38°33'26.8"W		S2	3°43'57.2"S	38°31'57.1"W
	R3	3°46'19.1"S	38°33'25.1"W		S3	3°43'47.1"S	38°31'53.6"W
	R4	3°46'18.4"S	38°33'25.4"W		S4	3°43'46.3"S	38°31'53.9"W
	R5	3°46'13.0"S	38°33'22.9"W		S5	3°43'29.4"S	38°31'48.6"W
	R6	3°46'12.7"S	38°33'23.3"W		S6	3°43'29.4"S	38°31'48.8"W
Street M	M1	3°43'56.4"S	38°32'01.7"W		S7	3°43'23.6"S	38°31'46.6"W
	M2	3°43'56.4"S	38°32'01.4"W		S8	3°43'23.4"S	38°31'47.1"W

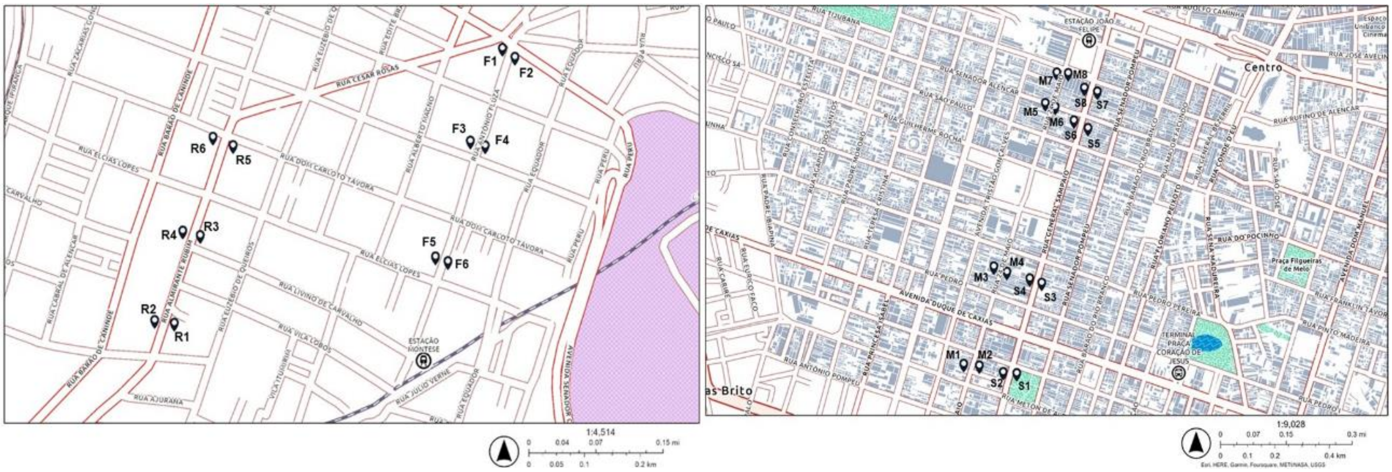

Figure 2. Schematic of the location of sampling points – (from left to right) – Str. F, Str. R, Str. M and Str. S.

2.2. Sampling period

The sampling period was carried out from March 10, 2019, to December 10, 2019, with a total of 12 campaigns (**Table 2**) comprising the rainy season, from March to May and the dry season, from June to November.

Table 2. Rainy and dry period of passive sampling of NO_2 filters.

Campaign	Period	Season
1º	10/03 – 31/03	Rainy
2º	31/03 – 21/04	Rainy
3º	21/04 – 05/05	Rainy
4º	05/05 – 26/05	Rainy
5º	26/05 – 16/06	Rainy
6º	16/06 – 07/07	Dry
7º	07/07 – 28/07	Dry
8º	28/07 – 18/08	Dry
9º	18/08 – 08/09	Dry
10º	08/09 – 29/09	Dry
11º	29/09 – 20/10	Dry
12º	20/10 – 10/11	Dry

Each campaign has a period of 21 days, except for the 3rd campaign which took place in 14 days due to strategic reasons. The change of samplers from one campaign to another took place on Sundays, due to the low flow of vehicles on the roads and consequently little emission of pollutants and for the safety of the sampling team. Overall, 360 filters were produced, with 30 filters per campaign (28 for sampling points and 2 for blanks).

2.3. Nitrogen dioxide methodology

Among the various methodologies for sampling NO_2, the methodology used in this work was based on the works of Saltzman (1954) where an absorber solution (0.5 M KI (Campinas, Brazil, Dinâmica) + 0.2 M KOH (Campinas, Brazil, Dinâmica) in Methanol (Suzano, Brazil, Neon)) was prepared, used to be added directly (impregnated) in cellulose filters to capture and adsorb NO_2 molecules present in the environment. Then, a reagent solution (0.5% w/v Sulfanilamide (Suzano, Brazil, Neon), 0.005% w/v N–1-Naphthyl-ethylenediamine (St. Louis, USA, Sigma-Aldrich) and 1% v/v Phosphoric Acid (St. Louis, USA, Sigma-Aldrich)) was used on the filters after the sampling period to the extraction of NO_2 present in the filters and converting it into nitrite ion $[NO_2]^-$. A stock solution (0.0203 g of Sodium Nitrite P.A in 1 L of water) was prepared to construct the UV-VIS (Barueri, Brazil, Shimadzu) calibration curve, where the levels of NO_2 present in the filters were determined (Dita and Dias, 2016; Lodge, 1988; Saltzman, 1954; Shaw, 1967).

2.4. Street morphology and traffic

Urban morphology can be considered one of the factors that contribute to the dispersion of a pollutant, along with the wind direction and speed on a road. The calculation of the morphology of a road is obtained through the ratio between the height of the road (H) and width (W) - distance between buildings (Aguiar *et al.*, 2017; Bender and Dziedzic, 2014; Muniz-Gäal *et al.*, 2018;

Nakata-Osaki *et al.*, 2016). The values of H and W were manually measured from the distance between the buildings and for the height of the road, consider that each building floor is 3 m high.

To quantify the number of vehicles that travel on the Streets where the sampling took place, a count of vehicles that pass-through a given reference point in the first 15 min of each hour was performed.

2.5. Principal component analysis (PCA)

The PCA was used to group the sampling points that present similar behavior about the average NO_2 variables in the rainy and dry seasons, H/W ratio and vehicle traffic, through a two-dimensional graph (Azevedo and Anzanello, 2015; Ghosh and Dubey, 2013; Honda *et al.*, 2010; Moori *et al.*, 2002; Stricker *et al.*, 2013; Xu *et al.*, 2015). To perform the calculation of these algorithms, PCA, the free software PAST (Hammer *et al.*, 2001), version 3.26b for Windows was used, in which it is possible to analyze scientific data, with functions for data manipulation, plotting, univariate and multivariate statistics. Before applying the data obtained in the software, they were pre-treated by self-scaling to minimize the influence of the dominant variable (Ferreira, 2015; Hongyu *et al.*, 2016; Karamizadeh *et al.*, 2013; Lyra *et al.*, 2010; Maia *et al.*, 2019).

3. Results and discussion

The results of the 360 NO_2 samples analyzed in this study over 12 collection campaigns on the studied streets are shown in **Table 3**. The street with the lowest overall mean concentration was on 24 de Maio (Street M) with 19.2 µg m^{-3} with a variation between 1.6 and 33.6 µg m^{-3}. Antônio Fiúza (Street F) presented the highest average concentration with 25.3 µg m^{-3} with a variation between 1.5 and 55.7 µg m^{-3}. The other streets showed average concentrations of 22.4 µg m^{-3} in Almirante Rubim (Street R), 24.3 µg m^{-3} and General Sampaio (Street S).

Table 3. Average concentration of NO_2 during the 12 campaigns.

Campaign	Street F			Street R		
	$\bar{x}$	Conc. Min-Max	sd	$\bar{x}$	Conc. Min-Max	sd
1º	23.8	6.5–38.9	13.0	23.5	15.4–31.5	5.9
2º	32.7	21.3–44.3	9.2	24.7	18.8–31.5	5.2
3º	22.9	13.4–29.4	7.0	34.0	20.3–45.2	11.1
4º	26.5	17.0–35.7	8.5	27.9	23.1–34.3	4.3
5º	26.5	17.6–35.1	6.7	22.5	15.6–30.2	5.5
6º	25.0	19.2–32.0	5.3	23.4	17.4–32.7	6.1
7º	29.5	16.2–47.7	13.4	20.1	15.6–24.4	3.6
8º	24.4	18.6–27.5	4.3	23.2	17.8–30.7	5.3
9º	23.3	20.1–26.6	2.8	20.2	13.8–25.9	5.8
10º	30.0	19.4–55.7	17.2	16.1	10.7–21.9	4.8
11º	24.6	21.4–28.6	3.3	16.6	10.9–22.7	4.6
12º	21.3	6.5–38.9	13.0	16.1	13.5–20.6	2.8

Note: $\bar{x}$ is average; **sd** is standard derivation; **conc. min-max** is the minimum and maximum concentration.

The low average concentrations of NO_2 presented by M Street, as well as the higher average concentrations of NO_2 presented by F Street, may be related to the flow of vehicles, since M Street presented an average daily traffic of 5,402 vehicles, the lowest among the routes, while Street F had 12,406 daily vehicles, indicating that the levels of NO_2 present in the streets may come from vehicular sources and secondary chemical reactions from the reaction of NO with O_3 (Carslaw *et al.*, 2016; Lenzi and Favero, 2014).

None of the analyzed samples showed values above the current standards established by National Council for the Environment No. 491/2018 (CONAMA, 2018) which is 260 µg m^{-3} h^{-1} and by international bodies such as the World Health Organization (WHO, 2005) and the Environmental European Agency (EEA, 2018) that set a maximum limit of 200 µg m^{-3} per hour and the Environmental Protection Agency (EPA, 2018) that established a maximum limit of 188 µg m^{-3} per hour.

The concentration of NO_2 levels using passive sampling varies from one street to another according to the studied sites' local characteristics. Hien *et al.*, 2014, found a maximum concentration of 84 µg m^{-3} in the city of Hanoi, Vietnam, using passive sampling with an estimated annual variation between 45.2 and 79.7 µg m^{-3} for high-flow lanes and between 18, 7 to 41.2 µg m^{-3} for streets with access to industries. Grundström and Pleijel, 2014, analyzed NO_2 with passive samplers arranged inside and outside treetops located in regions close to the highway in the city of Gothenburg, Sweden, obtaining results ranging from 12.9 to 47.1 µg m^{-3}. Bari *et al.*, 2015, monitored NO_2 in Alberta province of Canada, between 2006 and 2010, obtaining data ranging from 0.4 to 34.0 µg m^{-3}, with a total average of 3.9 µg m^{-3}. Bozkurt *et al.*, 2018, obtained mean concentrations of NO_2 between 18.3 and 33.8 µg m^{-3}, in the city of Düzce, Turkey. In Brazil, Campos *et al.* (2010) found mean values ranging from 3.6 to 12 µg m^{-3} in Salvador city, BA and from 6.7 to 11.0 µg m^{-3} in residential areas of the city of Curitiba/PR.

3.1. Analysis by sampling point

Figure 3a shows NO_2 concentrations in µg m^{-3} at all sampling points located on Antônio Fiúza (Street F) during the 12 campaigns. In it, we observed that F5 and F6 were the points that presented the lowest concentrations both in the rainy and dry seasons and this may be related to the low circulation of vehicles, especially heavy vehicles such as buses and trucks, in addition to factors that may have corroborated a deviation that occurred during a city hall work on this road on the sampling days (Nakata-Osaki *et al.*, 2013). The averages for F5 and F6 in the rainy season were, respectively, 18.4 and 17.9 µg m^{-3} and in the dry season, the averages were 20.0 and 19.6 µg m^{-3}, respectively, according to presented in **Table 1**.

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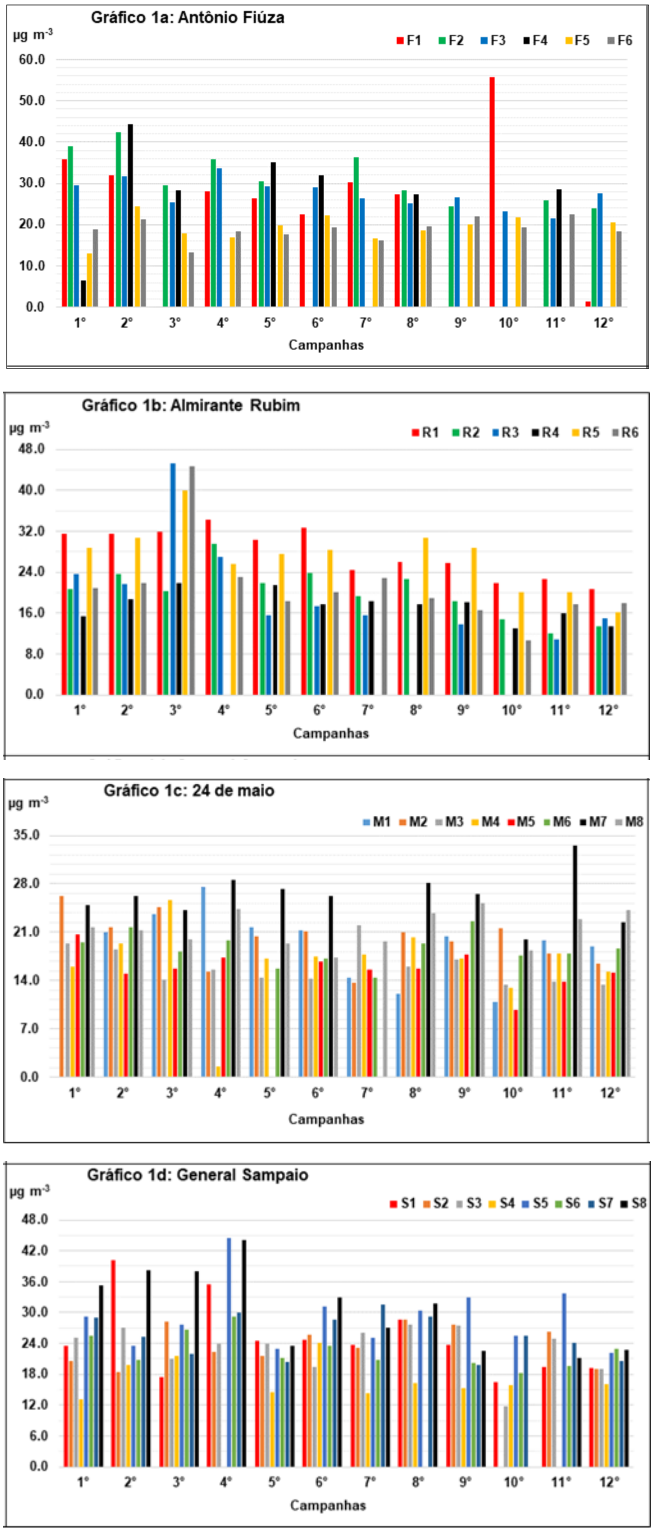

Figure 3. (a) NO_2 levels obtained at the points located at Antônio Fiúza; **(b)** at Almirante Rubim; **(c)** at 24 de Maio; **(d)** at General Sampaio.

Figure 3b shows the NO_2 concentrations in µg m^{-3} at all sampling points at Almirante Rubim (Street R) during the 12 campaigns. We can observe that R1 and R5 are the points that present the highest concentrations of this road, in most of the samples, except in campaign 3. This fact can be explained by the location of these points being close to the crossing of streets. Although R1 and R5 presented values above the others, they did not register levels above 40 µg m^{-3}. On the other hand, R3 and R6, in the 3rd campaign, when they reached the highest levels recorded in this street, being 45.2 and 44.8 µg m^{-3}, respectively. During this campaign, the sampling lasted 14 days, different from the rest of the campaigns, and presented an average temperature of 22.9 °C, the lowest recorded during the study, and the highest average daily amount of rain recorded, reaching 17.9 mm. Such factors may have contributed to the reduction in the flow of vehicles and, consequently, there was a higher concentration of NO_2 at these points of the road. It also shows the absence of samples R3 in the 8th and 10th campaigns; R4 in the 4th campaign; and R5 in the 10th campaign. Such samples were lost during the sampling period.

Figure 3c shows the NO_2 concentrations in µg m^{-3} at all sampling points on the 24th of May (Via M) during the 12 campaigns. In this one, we observed that all points had concentrations below 28.0 µg m^{-3}, except M7 in campaigns 4, 8 and 12. We also observed that all, except the 4th campaign of M4, had concentrations above 7.0 µg m^{-3}. Point M7 stands out among the other points for presenting the highest concentration in most campaigns and this can be explained by the fact that this point is located close to the bus terminal and a crossroads, contributing to the higher concentration of NO_2 in this region of the street (Carslaw *et al.*, 2016).

Figure 3d shows NO_2 concentrations in µg m^{-3}, at all sampling points, in General Sampaio Street (Street S) during the 12 campaigns. In it, we observed that the points, except for S1, S5 and S8 in the rainy season, do not reach concentrations above 30 µg m^{-3}, with S1 and S5 being located near bus stops and S8 being located at road crossings and close to a bus terminal. From the 7th campaign onwards, there was a drop in NO_2 levels in S8, as works began at that moment in the station square, reducing vehicle traffic on the road.

3.2. Influence of meteorological data and H/W ratio of roads

According to the data obtained from Instituto Nacional de Meteorologia (INMET, 2019) meteorological stations, the average temperature of the 12 campaigns was 26.72 °C, except in excess, a single campaign had an average of 22.9°C with winds blowing mostly from the southeast and east directions. Such meteorological parameters did not suffer sudden variations during the sampling campaigns (22.9–27.8 °C). However, humidity (%), wind speed (km h^{-1}) and precipitation (mm) in each campaign had notable variations and these values are shown in **Table 4**, together with the general average of NO_2 in µg m^{-3}, per campaign, in each studied route. As can be seen, the average humidity and precipitation gradually decreased over the sampling period, while the average wind speed increased, characterizing the rainy and dry periods in Fortaleza city. It is important to emphasize that the individual assessment of these parameters should not be related to the concentration since it can lead to misinterpretations.

Table 4. Mean values of humidity in (%), wind speed in (km h^{-1}), temperature (°C), precipitation (mm) and average at streets during the 12 campaigns.

Variable	Rainy Season						Dry Season							
	1°	2°	3°	4°	5°	$\bar{x}$	6°	7°	8°	9°	10°	11°	12°	$\bar{x}$
Moisture (%)	90.0	86.9	85.8	82.3	76.3	84.3	74.1	71.8	68.2	66.0	66.7	66.6	65.8	68.5
Wind Speed (km h^{-1})	4.4	4.6	5.9	6.5	7.4	5.8	8.0	9.2	10.7	11.8	12.2	12.0	11.1	10.6
Temperature (°C)	26.4	26.8	22.9	27.1	26.9	26.0	26.6	26.6	26.7	27.1	27.3	27.4	27.8	27.1
Precipitation (mm)	13.8	10.7	17.9	10.1	9.6	12.4	6.2	2.7	0.9	0.5	0.5	0.4	0.0	1.9
$\bar{x}$ of NO_2 St. F (µg m^{-3})	23.8	32.7	22.9	26.5	26.5	26.6	25.0	29.5	24.4	23.3	30.0	24.6	21.3	25.5
$\bar{x}$ of NO_2 St. R (µg m^{-3})	23.5	24.7	34.0	27.9	22.5	26.5	23.4	20.1	23.2	20.2	16.1	16.6	16.1	19.3
$\bar{x}$ of NO_2 St. M (µg m^{-3})	21.2	20,6	20.8	18.8	19.4	20.0	18.9	16.8	19.5	20.8	15.5	19.7	18.1	18.5
$\bar{x}$ of NO_2 St. S (µg m^{-3})	25.2	24.7	25.3	30.9	21.5	25.3	26.2	24.0	27.5	23.7	18.9	24.2	20.2	23.6

Note: **$\bar{x}$ of NO_2 St. F** is NO_2 average on Antônio Fiúza Street; **$\bar{x}$ of NO_2 St. R** is NO_2 average on Almirante Rubim Street; **$\bar{x}$ of NO_2 St. M** is NO_2 average on 24 de Maio Street; **$\bar{x}$ of NO_2 St. S** is NO_2 average on General Sampaio Street.

The results showed that, for the rainy season, the NO_2 levels are slightly higher than in the dry season. However, the R Street showed a greater difference from 26.5 µg m^{-3} to 19.3 µg m^{-3}. This small reduction of NO_2 for the dry season to the levels obtained in the rainy season may be consistent with a reduction in the speed of cars, high traffic jams and a decrease in secondary reactions (Arbex *et al.*, 2012; Moura *et al.*, 2015). Other parameters that may have influenced this reduction were meteorological conditions.

For this, a Pearson correlation matrix was elaborated to verify the influence of Relative Humidity (RH), Wind Speed (WS), Precipitation (PP) and Temperature (T) with the levels of NO_2 obtained in each route (**Table 5**). In it, we found that the correlation of RH and PP with NO_2 concentration was positive in all streets, especially the R Street. However, WS showed negative correlation with NO_2 levels, especially for the R Street. Concerning T, the correlation was negative in the streets, except for the F Street. From what was shown by the matrix, except for the F Street, the increase in the values of UR and PP together with the reduction of WS and T, favors a slight increase in NO_2 concentrations, especially in the R Street.

Table 5. Pearson's correlation matrix between Relative Humidity (RH), Wind Speed (WS), Precipitation (PP) and Temperature (T) with the average concentrations of NO_2 of the studied streets.

	RH	WS	PP	T	NO_2 Str F	NO_2 Str R	NO_2 Str M	NO_2 Str S
RH	1							
WS	−0.976	1						
PP	0.941	−0.917	1					
T	−0.519	0.461	−0.707	1				
NO_2 St. F	0.193	−0.206	0.030	0.169	1			
NO_2 St. R	0.753	−0.741	0.855	−0.807	−0.063	1		
NO_2 St. M	0.526	−0.504	0.533	−0.372	−0.370	0.522	1	
NO_2 St. S	0.437	−0.445	0.371	−0.228	−0.077	0.635	0.418	1

Note: **NO_2 St. F** is average concentrations of NO_2 on Antônio Fiúza Street; **NO_2 St. R** is average concentrations of NO_2 on Almirante Rubim Street; **NO_2 St. M** is average concentrations of NO_2 on 24 de Maio Street; **$\bar{x}$ of NO_2 St. S** is average concentrations of NO_2 on General Sampaio Street.

The literature reports that low relative humidity and wind speed favor the increase of NO_2 levels while the occurrence of precipitation and the increase of wind speed can favor the reduction of NO_2 levels (Drumm *et al.*, 2013; Kamińska, 2019; Monte *et al.*, 2016). The increase in temperature near the surface, especially during the summer, can increase the kinetics of gases and consequently improve vertical mixing, contributing to the reduction of NO_2 concentrations in the lower atmosphere (Gasmi *et al.*, 2017). In addition to meteorological conditions, the secondary chemical reactions of NO_2 with photochemical oxidants that occur in the atmospheric lower layers and the morphology of the pathway normally influence NO_2 concentrations (Gasmi *et al.*, 2017; Han *et al.*, 2011).

Compared with the results obtained in the literature, a study performed in Dhahran City, Saudi Arabia showed that NO_2 concentration is strongly affected by traffic emission and photochemistry. Ambient air temperature and wind speed had negative correlation coefficients with NO_2 concentrations while relative air humidity had a positive correlation coefficient (Gasmi *et al.*, 2017). In Mato Grosso do Sul, Brazil, a study found negative correlations between relative humidity and wind speed with NO_2 concentration and a positive correlation between temperature and NO_2 concentration (Souza and Santos, 2018).

Regarding the morphology of the street, the mean values of the H/W ratio for the F, R, M and S Streets were 0.45, 0.23, 0.50 and 0.55, respectively. According to the simplified classification of different urban forms, the H/W ratio with values between 0.2 and 0.6 and with an area occupied by buildings of 70 to 90% are highly developed streets, with low or medium urban density, with large low-rise buildings (Oke *et al.*, 2004). This description confirms the studied streets, as there are shopping centers, restaurants, and parking lots. The results also show that even with the winds blowing perpendicularly to the direction of the street, there were no discrepancies in concentration on one side of the street that was contrary to what was cited in the literature. It is important to report that the influence of meteorological parameters and morphology on NO_2 levels requires a more detailed study, using meteorological stations at the sampling site.

3.3. Principal component analysis

The Principal Component Analysis of the 4-way sampling points related the average NO_2 concentration with the average estimate of vehicle traffic and the H/W ratio according to **Fig. 4**.

The variance of the 4 principal components (CP) analyzed CP1, CP2, CP3 and CP4 are 52.1, 25.6, 16.7 and 5.6%, respectively. These results show that two main components (CP1 and CP2) explain 77.7% of the cases studied. The CP1, represented by the X axis, indicates that the points in the positive direction of this axis have great influence on the variables Average of NO_2 in the rainy (1°P) and dry (2°P) periods, since both have Loading (weight) of 0.63 and 0.61, respectively, while the Loadings for altimetry and traffic are –0.04 and 0.48, respectively. CP2, represented by the Y axis, indicates that its positive axis has a great influence of the altimetry variable, with a Loading of 0.98.

In **Fig. 4**, the blue points belong to M Street, the red points belong to S Street, the grey are points of F Street and the green are those of R Street. Note that all points of the M Street, except M7, were on the negative axis of the principal component 1, indicating that they presented values of NO_2 below the general average in both periods, which were 24.3 μg m^{-3}, 21.5 μg m^{-3}, for 1°P and 2°P, respectively. It is also worth noting that all points on the R Street are on the negative axis of the principal component 2, indicating that the H/W ratio was below the general average that was 0.4. Most of the points on F Street, except for points F5 and F6, were on the positive axis of the main component 2, indicating that these points presented NO_2 levels in both periods and vehicle traffic above the general average. The S Street points did not show clusters in a specific region of the graph.

Applying PCA with PC1 and PC3, we obtain **Fig. 5**. In this graph, the percentage of the total variance (%) of the data of the two principal components (PC) is explained by 68.8% of the cases, PC1 being represented on the X axis and PC3 on the Y axis. Due to the high loading presented by the Traffic variable in PC3, which was 0.87, the points were grouped according to the average number of vehicles that travel on the street per day, with a general average of 8,535 vehicles. As a result, we can observe that, although the total variance of this graph is smaller than the previous one, all samples were separated by streets, with the F Street having the highest values and the M Street having the lowest traffic values. We also observed in this graph that the points F1, F2, F3, F4, R1, R5, S5, S8 and M7 are in the positive region of the average NO_2 variables in the rainy and dry periods, that is, they presented the highest values for these variables.

Applying PCA with PC2 and PC3, we obtain **Fig. 6**, in which the percentage of total variance of the data is explained by 42.3% of the cases, PC2 being represented by the Y axis and PC3 by the X axis. The highest Loading in CP2 was the H/W ratio and in CP3 was the vehicle traffic variable. From this graph, we can see that the points of lane F are all located on the positive axis of CP3, indicating that they presented a greater flow of vehicles among the studied streets, confirming what was described in **Fig. 6**, about CP2, F3 and F4 are on the negative axis, indicating the low H/W ratio. However, the other points of this street are on the positive axis of CP2.

The points of the R Street are grouped on the negative axis of CP2, indicating the low H/W ratio, as mentioned in **Fig. 4**. The points of the M Street are all located on the negative axis of CP3, indicating the lowest flow of vehicles among the lanes studied, as also shown by **Fig. 6**. Both in **Fig. 5** and **6**, the points belonging to the S Street are more dispersed among the streets, indicating that the points of this street do not present a similarity between the samples.

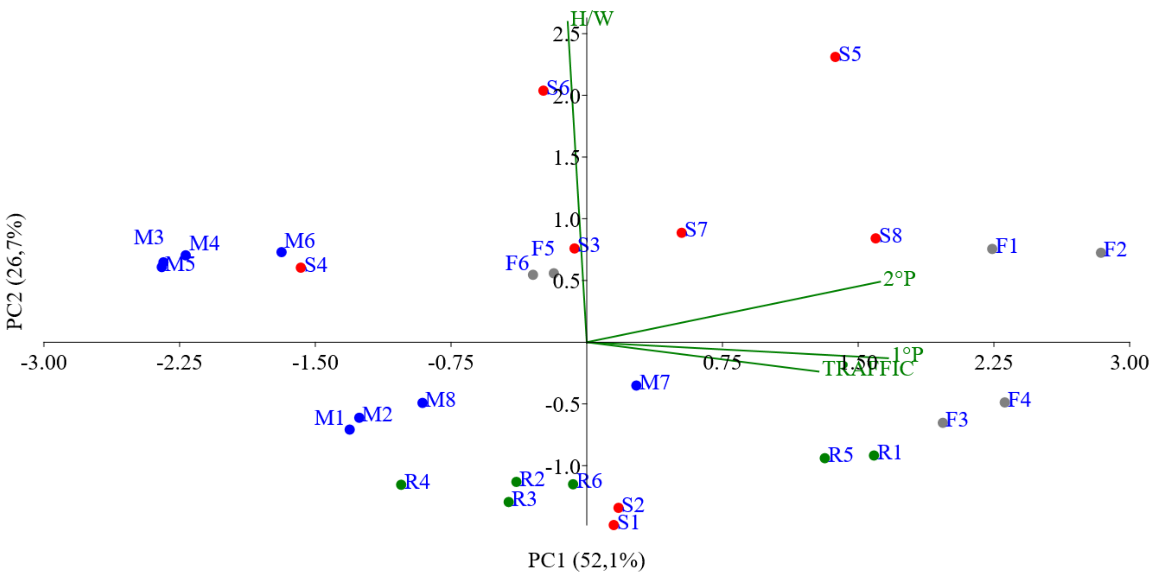

Figure 4. PCA with principal components 1 and 2 of the sampling points using the variables' general average of NO_2 in the rainy and dry seasons, altimetry (H/W) and vehicle traffic.

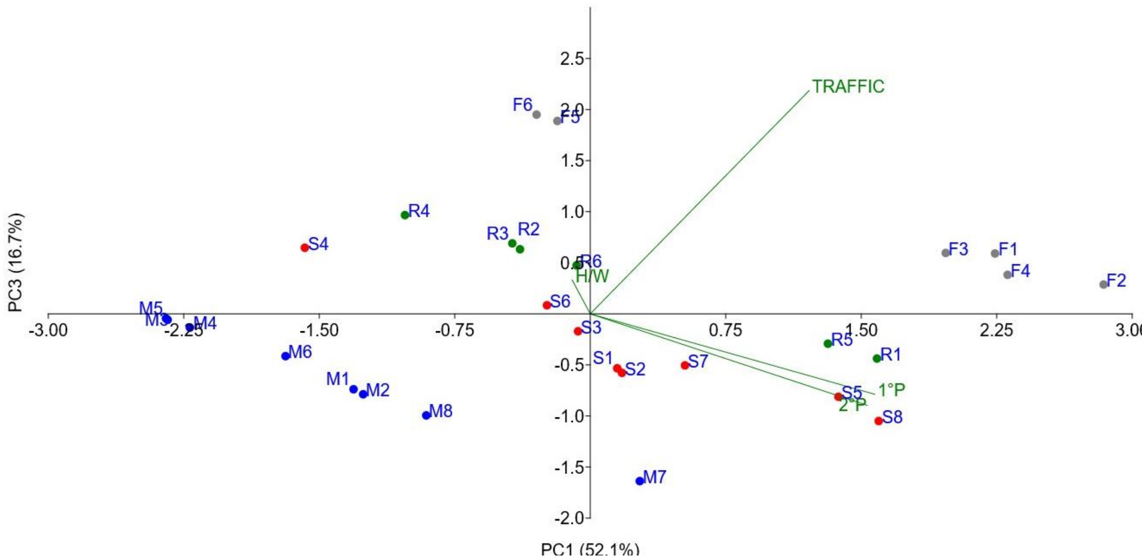

Figure 5. PCA with principal components 1 and 3 of the sampling points using the variables' general average of NO_2 in the rainy and dry seasons, altimetry (H/W) and vehicle traffic.

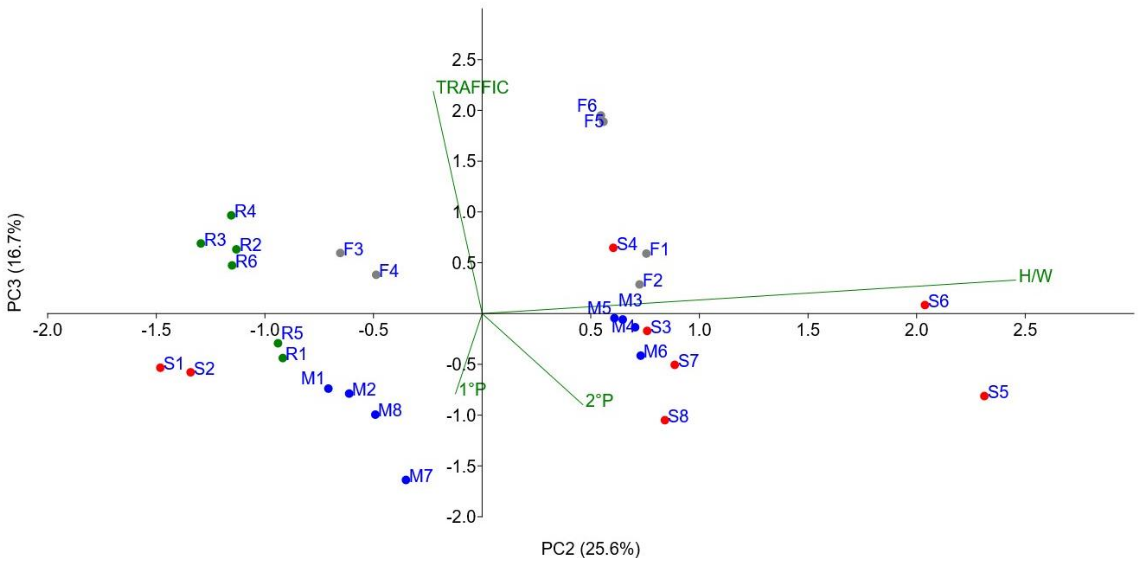

Figure 6. PCA with principal components 1 and 2 of the sampling points using the variables general average of NO_2 in the rainy and dry seasons, altimetry (H/W) and vehicle traffic.

4. Conclusions

Although difficult to compare, the results obtained showed that this pollutant did not exceed the limits established by current Brazilian legislation (CONAMA, 2018 – Resolution 491) and by international legislation (EEA, 2018; EPA, 2018; WHO, 2005) with levels like those previously mentioned in the literature using a methodology equivalent. This dataset also provided this work with a specific analysis of the pollutant behavior studied along a road using principal component analysis, in which it is possible to observe that NO_2 levels are dependent on the street profile, such as terrain and vehicle traffic. In front of the PCA graph, it was easy to visualize points that, although located in different ways, presented similar behavior of the analyzed variables. It is important to emphasize that the results observed throughout this research should be seen as indicative and not conclusive since a broader follow-up is necessary for the care to be elaborated.

Authors' contributions

Conceptualization: Sousa, F. W.; Bertoncini, B. V.; Nascimento, R. F.; Ribeiro, J. P.; **Data curation:** Maia, M. L.; Oliveira, C. S.; R. F.; Ribeiro, J. P.; **Formal Analysis:** Maia, M. L.; Oliveira, C. S.; Quintanilha, W. F. L.; Cassiano, D. R.; **Funding acquisition:** Not applicable; **Investigation:** Maia, M. L.; Sousa, F. W.; Quintanilha, W. F. L.; Cassiano, D. R.; Ribeiro, J. P.; Bertoncini, B. V.; Oliveira, C. S.; **Methodology:** Maia, M. L.; Sousa, F. W.; Quintanilha, W. F. L.; Nascimento, R. F.; Ribeiro, J. P.; Bertoncini, B. V.; Oliveira, C. S.; Cassiano, D. R.; **Project administration:** Sousa, F. W.; **Resources:** Sousa, F. W.; Maia, M. L.; **Software:** Quintanilha, W. F. L.; Cassiano, D. R.; **Supervision:** Sousa, F. W.; Bertoncini, B. V.; **Validation:** Maia, M. L.; Sousa, F. W.; Quintanilha, W. F. L.; **Visualization:** Sousa, F. W.; Maia, M. L.; **Writing – original draft**: Maia, M. L.; Sousa, F. W.; Bertoncini, B. V.; Nascimento, R. F.; Ribeiro, J. P.; **Writing – review & editing:** Maia, M. L.; Sousa, F. W.; Bertoncini, B. V.; Nascimento, R. F.; Ribeiro, J. P.

Data availability statement

All data sets were generated or analyzed in the current study.

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References

Aguiar, L. F. M. C.; Silva, M. V. C.; Gandu, A. W.; Rocha, C. A.; Cavalcante, R. M. Caracterização de Cânions Urbanos e seus Efeitos Climáticos em Área com Intenso Processo de Verticalização na Cidade de Fortaleza, Ceará. *Revista Brasileira de Geografia Física*. **2017**, *10* (4), 1046–1058. https://doi.org/10.26848/rbgf.v10.4.p1046-1058

Aránguez, E.; Ordóñes, J. M.; Serrano, J.; Aragonés, N.; Fernández-Partier, R.; Gandarillas, A.; Galán, I. Contaminantes Atmosféricos y su Vigilancia. *Revista Española de Salud Pública*. **1999**, *73* (2), 123–132. https://doi.org/10.1590/S1135-57271999000200003

Arbex, M. A.; Santos, U. P.; Martins, L. C., Saldiva, P. H. N.; Pereira, L. A. A.; Braga, A. L. F. Air pollution and the respiratory system. *Jornal Brasileiro de Pneumologia*. **2012**, *38* (5), 643–655. https://doi.org/10.1590/S1806-37132012000500015

Azevedo, B. B.; Anzanello, M. J. Agrupamento de trabalhadores com perfis semelhantes de aprendizado apoiado em Análise de Componentes Principais. *Gestão & Produção*. **2015**, *22* (1), 35–52. https://doi.org/10.1590/0104-530X1094

Baird, C.; Cann, M. *Química Ambiental*; Bookman, 2011.

Bari, A.; Curran, R. L. T.; Kindzierski, W. B. Field performance evaluation of Maxxam passive samplers for regional monitoring of ambient SO_2, NO_2 and O_3 concentrations in Alberta, Canada. *Atmospheric Environment*. **2015**, *114*, 39–47. https://doi.org/10.1016/j.atmosenv.2015.05.031

Bender, A. P.; Dziedzic, M. Dispersão de poluentes nos eixos estruturais em Curitiba (PR), Brasil. *Engenharia Sanitária e Ambiental*. **2014**, *19* (spe), 31–42. https://doi.org/10.1590/S1413-41522014019010000364

Biswal, A.; Singh, T.; Singh, V.; Ravindra, K.; Mor, S. COVID–19 lockdown and its impact on tropospheric NO_2 concentrations over India using satellite-based data. *Helion*. **2020**, *6* (9), E04764. https://doi.org/10.1016/j.heliyon.2020.e04764

Bozkurt, Z.; Üzmez, Ö. Ö.; Döğeroğlu, T.; Artun, G.; Gaga, E. O. Atmospheric concentrations of SO_2, NO_2, ozone and VOCs in Düzce, Turkey using passive air samplers: Sources, spatial and seasonal variations and health risk estimation. *Atmospheric Pollution Research*. **2018**, *9* (6), 1146–1156. https://doi.org/10.1016/j.apr.2018.05.001

Campos, V.; Passos, L.; Godoi, R. H. M.; Godoi, A. F. L.; Tavares, T. M. Development and validation of passive samplers for atmospheric monitoring of SO_2, NO_2, O_3 and H_2S in tropical áreas. *Microchemical Journal*. **2010**, *96* (1), 132–138. https://doi.org/10.1016/j.microc.2010.02.015

Carslaw, D. C.; Murrells, T. P.; Anderssonc, J.; Keenanc, M. Have vehicle emissions of primary NO_2 peaked? *Faraday Discussions*. **2016**, *189*, 439–454. https://doi.org/10.1039/C5FD00162E

Conselho Nacional do Meio Ambiente (CONAMA). Resolução nº 491, de 19 de novembro de 2018. *Dispõe sobre padrões de qualidade do ar*; Ministério do Meio Ambiente, 2018. 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 (accessed 2018-12-08).

Cruz, L. P. S.; Campos, V. Métodos de amostragem e análise para compostos reduzidos de enxofre atmosférico. *Química Nova*. **2008**, *31* (5), 1180–1189. https://doi.org/10.1590/S0100-40422008000500047

Datasus. Ministério da Saúde. Sistema de Informações sobre Internações Causadas por Doenças no Sistema Respiratório; Datasus, 2019. http://tabnet.datasus.gov.br/cgi/tabcgi.exe?sih/cnv/niuf.def (accessed 2019-11-17).

Ding, J.; Ronald van der A.; Mijling, B.; Laat, J.; Eskes, H.; Boersma, K. F. NO_x emissions in India derived from OMI satellite observations. *Atmospheric Environment: X*. **2022**, *14*, 100174. https://doi.org/10.1016/j.aeaoa.2022.100174

Dita, P. A.; Dias. J. W. C. *Método do Arsenito de Sódio para a Determinação de Dióxido de Nitrogênio na Atmosfera*; Energética, 2016.

Drumm, F. C.; Gerhardt, A. E.; Fernandes, G. D.; Chagas, P.; Sucolotti, M. S.; Kemerich, P. D. C. Air Pollution from the Burning of Fuels Derived from Petroleum in Motor Vehicles. *Revista Eletronica em Gestão, Educação e Tecnologia Ambiental*. **2013**, *18* (1), 66–78. https://doi.org/10.5902/2236117010537

Duan, Y.; Liao, Y.; Li, H.; Yan, S.; Zhao, Z.; Yu, S.; Fu, Y.; Wang, Z.; Yin, P.; Cheng, J.; Jiang, H. Effect of changes in season and temperature on cardiovascular mortality associated with nitrogen dioxide air pollution in Shenzhen, China. *Science of the Total Environment*. **2019**, *697*, 134051. https://doi.org/10.1016/j.scitotenv.2019.134051

European Environment Agency (EEA). *The European Union (EU) has developed an extensive body of legislation which establishes standards and objectives for a number of pollutants in air*; EEA, 2018 (Last updated on 2023-11-23). https://www.eea.europa.eu/themes/air/air-quality-concentrations/air-quality-standards (accessed 2018-04-07).

United States Environmental Protection Agency (EPA). *NAAQS Table*; EPA, 2018 (Last updated on 2024-02-07). https://www.epa.gov/criteria-air-pollutants/naaqs-table (accessed 2018-04-07).

Ferreira, M. M. C. *Quimiometria:* Conceitos. Métodos e Aplicações; Editora Unicamp, 2015. https://doi.org/10.7476/9788526814714

Freedman, B. The Ecological Effects of Pollution, Disturbance and Other Stresses. In *Environmental Ecology*; Academic Press, 1995.

Gasmi, K.; Aljalal, A.; Al-Basheer, W.; Abdulahi, M. Analysis of NO_x, NO and NO_2 ambient levels in Dhahran, Saudi Arabia. *Urban Climate*. **2017**, *21*, 232–242. https://doi.org/10.1016/j.uclim.2017.07.002

Ghosh, S.; Dubey, S. K. Comparative Analysis of K-Means and Fuzzy CMeans Algorithms. *International Journal of Advanced Computer Science and Applications*. **2013**, *4* (4), 35–39. https://doi.org/10.14569/IJACSA.2013.040406

Ghozilaki, M. G.; Heibati, B.; Naddafi, K.; Kloog, I.; Conti, G. O.; Polosa, R.; Ferrante, M. Evaluation of Chronic Obstructive Pulmonary Disease (COPD) attributed to atmospheric O_3, NO_2, and SO_2 using Air Q Model

(2011–2012 year). *Environmental Research*. **2016**, *144* (A), 99–105. https://doi.org/10.1016/j.envres.2015.10.030

Grundström, M.; Pleijel, H. Limited effect of urban tree vegetation on NO_2 and O_3 concentrations near a traffic Route. *Environmental Pollution*. **2014**, *189*, 73–76. https://doi.org/10.1016/j.envpol.2014.02.026

Guo, P.; Miao, H.; Chen, Y.; Fu, Y.; Zhao, Q.; Li, B. Maternal exposure to gaseous ambient air pollutants increases the risk of preterm birth in the Pearl River Delta, China 2014–2017. *Science of The Total Environment*. **2019**, *671*, 959–970. https://doi.org/10.1016/j.scitotenv.2019.03.375

Halim, N. D. A.; Latif, M. T.; Ahamad, F; Dominick, D.; Chung, J. X.; Juneng, L.; Khan, F. The long-term assessment of air quality on an island in Malaysia. *Helion*, **2018**, *4* (12), e01054. https://doi.org/10.1016/j.heliyon.2018.e01054

Hammer, Ø.; Harper, D. A. T.; Ryan, P. D. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*. **2001**, *4* (1), 9.

Han, S.; Bian, H.; Feng, Y.; Liu, A.; Li, X.; Zeng, F.; Zhang, X. Analysis of the Relationship between O_3, NO and NO_2 in Tianjin, China. *Aerosol and Air Quality Research*. **2011**, *11* (2), 128–139. https://doi.org/10.4209/aaqr.2010.07.0055

Harner, T.; Su, K.; Genualdi, S.; Karpowicz, J.; Ahrens, L.; Mihele, C.; Schuster, J.; Charland, J. P.; Narayan, J. Calibration and application of PUF disk passive air samplers for tracking polycyclic aromatic compounds (PACs). *Atmospheric Environment*. **2013**, *75*, 123–128. https://doi.org/10.1016/j.atmosenv.2013.04.012.

Hatzopoulou, M.; Weichenthal, S.; Dugum, H.; Pickett, G.; Miranda-Moreno, L.; Kulka, R.; Andersen, R.; Goldberg, M. The impact of traffic volume, composition, and road geometry on personal air pollution exposures among cyclists in Montreal, Canada. *Journal of Exposure Science and Environmental Epidemiology*. **2013**, *23*, 46–51. https://doi.org/10.1038/jes.2012.85

Hauser, C. D.; Buckey, A.; Porter, J. Passive samplers and community science in regional air quality measurement, education and communication. *Environmental Pollution*. **2015**, *203*, 243–249. https://doi.org/10.1016/j.envpol.2014.12.028

Hien, P. D.; Hangartner, M.; Fabian, S.; Tan, P. M. Concentrations of NO_2, SO_2, and benzene across Hanoi measured by passive diffusion samplers. *Atmospheric Environment*. **2014**, *88*, 66–73. https://doi.org/10.1016/j.atmosenv.2014.01.036

Honda, K.; Notsu, A.; Ichihashi, H. Fuzzy PCA-Guided Robust k-Means Clustering. *IEEE Transactions on Fuzzy Systems*. **2010**, *18* (1), 67–79. https://doi.org/10.1109/TFUZZ.2009.2036603

Hongyu, K.; Sandanielo, V. L. M.; Oliveira Junior, G. J. Análise de Componentes Principais: Resumo Teórico, Aplicação e Interpretação. *Engineering and Science*. **2016**, *5* (1), 83–90. https://doi.org/10.18607/ES201653398

Instituto Nacional de Meteorologia (INMET). Banco de dados meteorológicos (BDMEP); INMET, 2019. https://bdmep.inmet.gov.br/ (accessed 2019-11-07).

Instituto Brasileiro de Geografia e Estatistica (IBGE). Frota de Veículos; IBGE, 2019. https://cidades.ibge.gov.br/brasil/ce/fortaleza/pesquisa/22/28120 (accessed 2019-11-03).

Januševičius, T.; Grubliauskas, R. The effect of speed bumps and humps on the concentrations of CO, NO and NO_2 in ambient air. *Air Quality, Atmosphere & Health*. **2019**, *12*, 635–642. https://doi.org/10.1007/s11869-019-00683-y

Kamińska, J. A. A random forest partition model for predicting NO2 concentrations from traffic flow and meteorological conditions. *Science of the Total Environment*. **2019**, *651* (1), 475–483. https://doi.org/10.1016/j.scitotenv.2018.09.196

Karamizadeh, S.; Abdullah, S. M.; Manaf, A. A.; Zamani, M.; Hooman, A. An Overview of Principal Component Analysis. *Journal of Signal and Information Processing*. **2013**, *4* (3B), 173–175. https://doi.org/10.4236/jsip.2013.43B031

Lacava, C. I. V.; Alvares Junior, O. M.; Fernandes, P. S. *Emissões Atmosféricas*; SENAI, 2002.

Lenzi, E.; Favero, L. O. B. *Introdução à Química da Atmosfera*: Ciência. Vida e Sobrevivência; LTC, 2014.

Lisboa, H.; Kawano, M. *Monitoramento de poluentes atmosféricos*. Controle da Poluição Atmosférica; ENS-UFSC, 2010.

Lodge, J. P. *Methods of Air Sampling and Analysis*; Lewis Publishers, 1988.

Lyra, W. S.; Silva, E. C.; Araújo, M. C. U.; Fragoso, W. D. Classificação Periódica: Um Exemplo Didático Para Ensinar Análise de Componentes Principais. *Química Nova*. **2010**. *33* (7), 1594–1597. https://doi.org/10.1590/S0100-40422010000700030

Maia, K. P.; Silva, G. A.; Libânio, M. Aplicação de análise multivariada no estudo da frequência de amostragem e do número de estações de monitoramento de qualidade da água. *Engenharia Sanitária e Ambiental*. **2019**, *24* (5), 1013–1025. https://doi.org/10.1590/S1413-41522019175743

Martins, L. C.; Latorre, M. R. D. O.; Cardoso, M. R. A.; Gonçanves, F. L. T.; Saldiva, P. H. N.; Braga, A. L. F. Poluição atmosférica e atendimentos por pneumonia e gripe em São Paulo, Brasil. *Revista de Saúde Pública*. **2002**, *36* (1), 88–94. https://doi.org/10.1590/S0034-89102002000100014

Masey, N.; Gillespie, J.; Heal, M. R.; Hamilton, S.; Beverland. I. J. Influence of wind-speed on short-duration NO_2 measurements using Palmes and Ogawa passive diffusion samplers. *Atmospheric Environment*. **2017**, *160*, 70–76. https://doi.org/10.1016/j.atmosenv.2017.04.008

Mehta, N. S.; Dey, S. Automobile pollution control using catalysis. *Resources, Environment and Sustainability*. **2020**, *2*, 100006. https://doi.org/10.1016/j.resenv.2020.100006

Miranda, D. C.; Ferreira, G. C.; Barbosa, L. D.; Pereira, N. L. A.; Ribeiro, T. C.; Maloncy, M. L.; Batista, M. S. Análise dos Poluentes Atmosféricos NO_2 E O_3 Via Amostradores Passivos de Baixo Custo. *E-Xacta*. **2017**, *10* (1), 29–35. https://doi.org/10.18674/exacta.v10i1.1960

Monte, E. Z.; Albuquerque, T. T. A.; Reisen, V. A. Impactos das Variáveis Meteorológicas na Qualidade do Ar da Região da Grande Vitória, Espírito Santo, Brasil. *Revista Brasileira de Meteorologia*. **2016**, *31* (4 suppl 1), 546–554. https://doi.org/10.1590/0102-7786312314b20150100

Moori, R. G.; Marcondes, R. C.; Ávila, R. T. A Análise de Agrupamentos como Instrumento de Apoio à Melhoria da Qualidade dos Serviços aos Clientes. *Revista de Administração Contemporânea*. **2002**, *6* (1), 63–84. https://doi.org/10.1590/S1415-65552002000100005

Moura, I. S. M.; Santos, D. F.; Pinheiro, F. G. M.; Oliveira, C. J. Characterization of Dry and Wet Periods of Fortaleza City (CE). *Ciência e Natura*. **2015**, *37*, 3–7. https://doi.org/10.5902/2179460X16206

Moura, M. O.; Zanella, M. E.; Sales, M. C. L. Ilhas Térmicas na Cidade de Fortaleza/CE.; *Boletim Goiano de Geografia*. **2008**, *28* (2), 33–44. https://doi.org/10.5216/bgg.v28i2.5718

Moura, M. O. Anomalias das temperaturas extremas do ar em Fortaleza, Ceará, Brasil. *Revista Brasileira de Geografia Física*. **2015**, *8* (6), 1588–1600. https://doi.org/10.5935/1984-2295.20150089

Muniz-Gäal, L. P.; Pezzuto, C. C.; Carvalho, M. F. H.; Mota, L. T. M. Parâmetros urbanísticos e o conforto térmico de cânions urbanos: o exemplo de Campinas, SP. *Ambiente Construído*. **2018**, *18* (2), 177–196. https://doi.org/10.1590/s1678-86212018000200249

Nakata-Osaki, C. M.; Souza, L. C. L.; Rodrigues, D. S. Impacto da geometria do cânion urbano na intensidade de ilha de calor noturna: análise através de um modelo simplificado adaptado a um SIG. *Ambiente Construído*. **2016**, *16* (3), 73–87. https://doi.org/10.1590/s1678-86212016000300093

Nascimento, L. F. C.; Braga, A. L. F.; Modolo, M. C. C. Effects of air pollution on children's health in a city in Southeastern Brazil. *Revista de Saúde pública*. **2006**, *40* (1), 77–82. https://doi.org/10.1590/S0034-89102006000100013

Negrisoli, J.; Nascimento, L. F. C. Atmospheric pollutants and hospital admissions due to pneumonia in children. *Revista Paulista de Pediatria*. **2013**, *31* (4), 501–506. https://doi.org/10.1590/S0103-05822013000400013

Oke, T. R.; *Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites*; World Meteorological Organization, 2004.

Pestana, P. R. S.; Braga, A. L. F.; Ramos, E. M. C.; Oliveira, A. F.; Osadnik, C. R.; Ferreira, A. D.; Ramos, D. Effects of air pollution caused by sugarcane burning in Western São Paulo on the cardiovascular system. *Revista de Saúde Pública*. **2017**, *51*, 13. https://doi.org/10.1590/s1518-8787.2017051006495

Piceli, P. C.; Lisboa, H. M. Quantificação de benzeno, tolueno, etilbenzeno e xilenos no ar de ambientes internos. *Engenharia Sanitária e Ambiental*. **2018**, *23* (3), 527–534. https://doi.org/10.1590/S1413-41522018119310

Rao, M.; George, L. A.; Rosenstiel, T. N.; Shandas, V.; Dinno, A. Assessing the relationship among urban trees, nitrogen dioxide, and respiratory health. *Environmental Pollution*. **2014**, *194*. 96–104. https://doi.org/10.1016/j.envpol.2014.07.011

Richmond-Bryant, J.; R. Chris Owen, R. C.; Graham, S.; Snyder, M.; Mcdow1, S.; Oakes, M.; Kimbrough, S. Estimation of on-road NO_2 concentrations, NO_2/NO_X ratios, and related roadway gradients from near-road monitoring data. *Air Quality, Atmosphere & Health*. **2017**, *10*, 611–625. https://doi.org/10.1007/s11869-016-0455-7

Russo, A.; Trigo, R. M.; Martins, H.; Mendes, M. T. NO_2, PM10 and O_3 urban concentrations and its association with circulation weather types in Portugal. *Atmospheric Environment*. **2014**, *89*, 768–785. https://doi.org/10.1016/j.atmosenv.2014.02.010

Saltzman, B. E. Colorimetric Microdetermination of Nitrogen Dioxide in Atmosphere. *Analytical Chemistry*. **1954**, *26* (12), 1949–1955. https://doi.org/10.1021/ac60096a025

Shaw, J. T. The measurement of nitrogen dioxide in the air. *Atmospheric Environment*. **1967**, *1* (2), 81–85. https://doi.org/10.1016/0004-6981(67)90036-4

Shiraiwa, M.; Selzle, K.; Pöschl, U. Hazardous components and health effects of atmospheric aerosol particles: reactive oxygen species, soot, polycyclic aromatic compounds and allergenic proteins. *Free Radical Research*. **2012**, *46* (8), 927–939. https://doi.org/10.3109/10715762.2012.663084

Souza, A.; Santos, D. A. S. Análise das Componentes Principais no Processo de Monitoramento Ambiental. *Nativa*. **2018**, *6* (6), 639–647. https://doi.org/10.31413/nativa.v6i6.6453

Souza, P. A. F.; Cardoso, A. A.; Karen, F. C. A. Desenvolvimento de Amostrador Passivo Sensível para Monitoramento de Poluição Atmosférica por Dióxido de Nitrogênio. *Quimica Nova*. **2017**, *40*, 1233. https://doi.org/10.21577/0100-4042.20170117

Stricker, M. D.; Onland-Moret, N. C.; Boer, J. M. A.; Van Der Schouw, Y. T.; Verschuren, W. M. M.; May, A. M.; Peeters, P. H. M.; Beulens, J. W. J. Dietary patterns derived from principal component- and k-means cluster analysis: Long-term association with coronary heart disease and stroke. *Nutrition. Metabolism & Cardiovascular Diseases*. **2013**, *23* (3), 250–256. https://doi.org/10.1016/j.numecd.2012.02.006

Ugucione, C.; Gomes Neto, J. A.; Cardoso, A. A. Método Colorimétrico para Determinação de Dióxido de Nitrogênio Atmosférico com Preconcentração em Coluna de C–18; *Química Nova*. **2002**, *25* (3), 353–357. https://doi.org/10.1590/S0100-40422002000300003

World Health Organization (WHO). *Air Quality Guideline for Particulate matter, Ozone, nitrogen dioxide and sulfur dioxide*. Global update 2005. https://iris.who.int/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf?sequence=1 (accessed 2018-04-20).

Xu, Q.; Ding, C.; Liu, J.; Luo, B. PCA-guided search for K-means. *Pattern Recognition Letters*. **2015**, *54* (1), 50–55. https://doi.org/10.1016/j.patrec.2014.11.017

Zanetti, P.; Melli, P.; *Environmental Modelling*; WIT Press, 1992.